Keele UNIVERSITY

Urban Metabolism: An integrated approach to exploring the challenges of resource management for urban sustainability in developing countries

Yesmeen Abdelkawi Khalifa

A thesis submitted for the degree of Doctor of Philosophy

in Environment and Sustainability

June 2021

Keele University

Acknowledgements

First, I would like to express my deepest appreciation to my inspiring supervisor Dr Sharon George for giving me the opportunity to conduct this research under her supervision. I am extremely grateful for her encouragement, continuous support, academic and professional guidance throughout this study. I would also like to thank Dr Sharon for encouraging and providing me the opportunity to gain practical experience and present my work in different occasions.

I would like to extend my sincere gratitude and appreciation to Dr Philip Catney for his insightful comments and suggestions, immense knowledge, and widening my understanding of research aspects, developing my research skills, encouraging and challenging myself to become a better researcher.

Special thanks to the representatives of the public authorities in Egypt who kindly participated in the interviews for sharing their knowledge, experience and time.

Finally, I would like to thank my husband, daughters and parents. I am extremely grateful for their patience, encouragement and unconditional support all through my PhD journey.

Abstract

Driven by climate change and scarcity of resources, resource management has become crucial for urban sustainability worldwide. There is an increasing interest in urban metabolism as a concept as it enables researchers to identify environment-related deficiencies in urban systems. The existing literature on urban metabolism studies shows a huge gap for such studies in the Global South. This gap is addressed in this thesis by employing the urban metabolism framework to better understand complex issues regarding the resource management system of Cairo Governorate (Egypt), an example of a rapidly urbanizing city in the Global South. This research was guided by a mixed methods approach to gain an in depth understanding of the barriers and drivers of resource management of the case study and to overcome the lack of reliable data. The findings of this study show that the flow of resources of Cairo Governorate are primarily linear flows. Cairo Governorate mainly relies on primary resources (inputs of cities: such as fossil fuels and fresh drinking water) and secondary resources (outputs of cities: such as solid waste and wastewater) are not used efficiently to feed them back into the city and develop circular flows. Sludge-to-energy and waste-to-energy projects, and the utilization of greywater present a huge potential for Cairo’s urban sustainability. The nature of urban form, the existing infrastructure, lack of an integrated sustainable waste management system, subsidies of primary resources, informal settlements and illegal connections, public behaviour, and the technical, financial and institutional capacities have a huge impact on the quality and the losses of the flow of resources of Cairo Governorate and the expansion of renewable energy projects. The outcome of this study indicates that the key challenge of resource management in developing countries is the lack of a comprehensive understanding of the interplay and interdependencies between resources and various flows. This study confirms the importance of understanding the flow of resources, the existing urban carrying capacity of cities and the limits of urban development to create robust sustainable strategies.

Table of Contents

List of Figures

List of Tables

1 Chapter One: Introduction

1.1 Urbanization and resource management

In 1950, more than 70% of the world's population lived in rural areas and the rest of the population lived in urban areas (United Nations, 2019). The industrial revolution had a major impact on the distribution of the world's population (Goudie, 2019). Technological developments and mass production at that time freed many families from farming and occupations shifted increasingly to the industrial sector (David et al., 2010). The development of transportation improved the movement of people, resources, and products from one place to another (Cuddihy et al., 2005). Economic and social growth, specifically in developed nations, improved the quality of life in urban areas. Many families since have continued to move to urban settlements seeking better job opportunities and social services.

For the first time in history, the percentage of the urban population exceeded the rural population in 2007 (United Nations, 2014). The United Nations (2016d) report shows that the urban population will continue to grow and is projected to reach seventy per cent within the next thirty years which presents a significant challenge. Yet the urbanization process is spread in highly uneven ways, being particularly concentrated in the Global South and in particular city-regions. The number of megacities will reach 41 by 2030, of which 27 will be located in the Global South (United Nations, 2016d). The continuous growth of urbanization will add more pressure on cities specifically the ones located in the Global South as the natural growth rate and the average annual urbanization growth rate are much higher than the Global North.

Although cities occupy only 2% of the world's land, they generate 70% of the world's GDP, but they also consume 60% of the global energy, produce 70% greenhouse gas emissions and 70% of the global waste (United Nations, 2016a). Cities consume most of the world's resources and cause massive environmental impacts that extend beyond their boundaries. 'Cities can make a significant contribution to the global sustainability challenges if they were managed and developed in a way that grew in harmony with nature' (United Nations, 2016a). This requires an understanding of the particular characteristics of cities, how they grow and interact with their local and surrounding environment, and the impacts they have. Driven by the global concern to mitigate climate change, greenhouse gas emissions, and pollution levels, resource management is vital to building sustainable societies worldwide especially in developing countries. Developing countries[1] should not follow the same approach of developed nations in managing and developing their countries. Cities should 'avoid a one-size-fits-all approach' (United Nations, 2016a).

Middle and low-income countries in Africa and Asia are experiencing rapid and uncontrolled growth of urban populations and land use without parallel social and economic growth, hampering the ability of these cities to absorb these growth pressures (United Nations, 2014). Additionally, developing countries are building their own economies in the era of resources scarcity and climate change. Both

---

[1] *"Developing country"* and *"Global South"* are used in this study interchangeably. These terms refer to the less developed countries that are located in the southern hemisphere.

present considerable challenges for urban sustainability in the Global South. A huge amount of resources are required for expanding existing cities and building new cities with sufficient infrastructure. In parallel, greenhouse gas emissions, wastewater and all types of waste are rapidly increasing causing massive environmental impacts.

Resource management is crucial for these countries to reduce the use of primary resources (such as fossil fuels) and environmental impacts, and maximize the use of renewable energy and secondary resources (such as solid waste and wastewater). Resource management requires quantifying, assessing, and controlling the flow of materials and energy resources (Kennedy and Hoornweg, 2012). The major challenges of such studies in the Global South's cities are the difficulty of tracking the flow of materials due to the uncontrolled growth of cities, the lack of reliable data at the city level, and the methods of data collection are inconsistent (Currie and Musango, 2017).

1.2 Case study: Cairo, Egypt

The focus of this study is how to develop strategies to improve resource management in Cairo Governorate, as an example of a rapidly urbanizing Global South city and to understand the potential limits to the uptake of these strategies arising from governance issues. Egypt has the highest population in North Africa and the Middle East (see Figure 1-1). Cairo Governorate is the largest Governorate in Egypt, with a population of 10 million inhabitants. It is located at the heart of Greater Cairo Region of more than 20 million inhabitants (CAPMAS, 2019), which represents almost a quarter of Egypt's population of 98 million inhabitants and almost half of the country's urban population (see Figures 1-2 and 1-3). The Greater Cairo Region is the world's sixth-largest megacity and is projected to be the fifth by 2030 (United Nations, 2018).

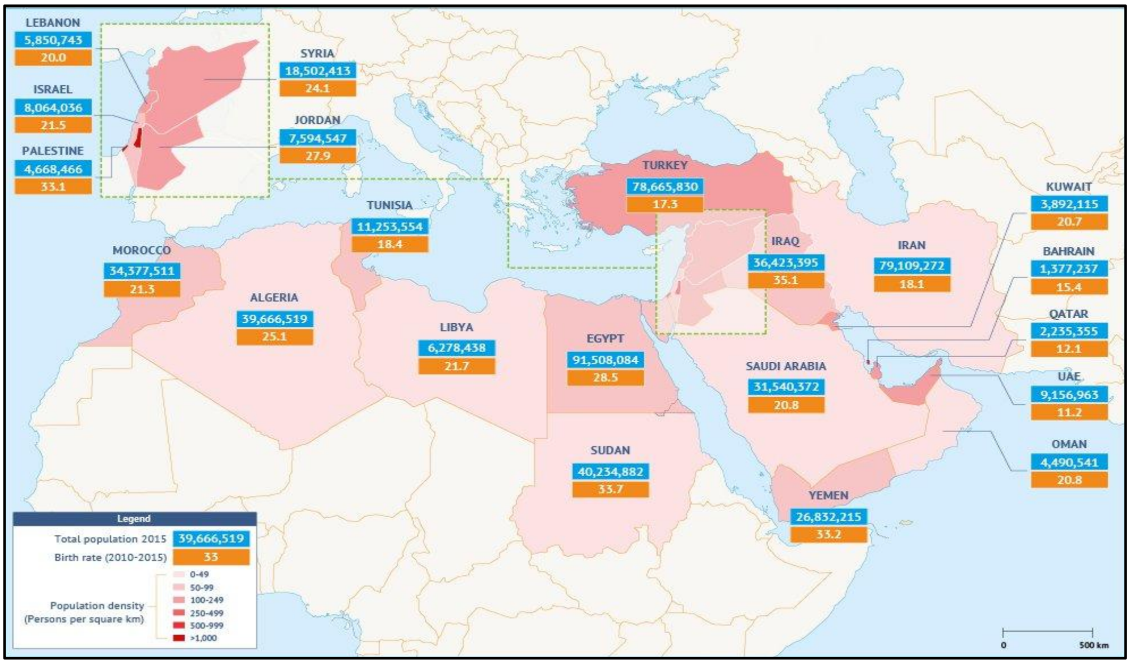


Figure 1-1: Population growth in MENA region (United Nations, 2015c).

Figure 1-2: Map of Egypt (United Nations, Department of Field Support Cartographic Section, 2012).

Figure 1-3: Map of Cairo Governorate (Google Maps, 2019).

As a developing country, Egypt is facing massive challenges due to the rapid population growth and the reduction of agricultural production. The growth of urbanization and industrialization have proceeded largely without environmental controls, creating severe pollution problems (Abdel Wahaab, 2003; Kanakidou et al., 2011). National and local authorities in Egypt face complex challenges in providing basic and adequate services (United Cities and Local Governments (UCLG), 2014).

There is a wide range of different types of buildings in Cairo Governorate, including large blocks and multi-storey, many of which are unregulated and unplanned. These are difficult to monitor in terms of future growth and municipal services. One critical issue is the lack of accurate data on consumption and efficiency of resources in these settlements despite this section being so large. This is a major challenge in Cairo Governorate, and forms a significant focus in this study and is discussed later.

The consequences of the uncontrolled growth of urbanization have been a persistent shortage of housing, the growth of informal settlements, increased waste production and use of resources. These pressures taken together have added considerable pressure on the country's fragile infrastructure, exacerbated social inequalities, and further degraded environmental quality leading to unsustainable development.

> Informal areas are residential areas where 1) inhabitants have no security of tenure vis-à-vis the land or dwellings they inhabit (they do not own the land), with modalities ranging from squatting to informal rental housing, 2) the neighbourhoods usually lack, or are cut off from, basic services and city infrastructure and 3) the housing may not comply with current planning and building regulations, and is often situated in geographically and environmentally hazardous areas[2] (UN-Habitat, 2015, p.1).

The Egyptian government redefined informal settlements in Egypt as unsafe areas and unplanned areas (Khalifa, 2011). This attempt was to identify informal settlements that require immediate actions for the unsafe areas and medium and long-term strategies for the unplanned areas as the living conditions in the unsafe

---

[2] Derived from UN-Habitat (2003), The Challenge of Slums; UN-Habitat (2013), The State of the World Cities Report 2012/13. Refer to Issue Paper No. 9 on Land for 'security of tenure' definition (UN-Habitat, 2015, p.1).

areas could be life-threatening while the unplanned areas do not comply with the planning and building regulations (Khalifa, 2011).

A shortage of water is one of Egypt’s most serious challenges. The annual share of renewable water per capita reached 1000m^3 in 1997, and this is the baseline of the water scarcity according to the Falkenmark Water Stress Indicator (NWRP, 2017). In 2015, the annual share of renewable water per capita dropped to 658m^3 due to the rapid population growth and the scarcity of water resources (NWRP, 2017). The River Nile is the main source of renewable surface water in Egypt. The share of Egypt is 55.5 billion m^{3}y^{-1}, this share has been fixed since 1959 when the High Dam was constructed (Wahba et al., 2018). It is predicted that the impacts of climate change will be drastic on the Nile Basin (UNDP, 2020). The gap between the supply and demand of water resources is increasing; the population is rapidly increasing and the water supply is threatened by impacts of climate change (UNDP, 2020; Ahmadi et al., 2020). By 2037, the annual share of renewable water per capita is expected to fall by 35% compared to 2015 (NWRP, 2017).

The energy profile of Egypt shows that it depends on two types of conventional energy resources, natural gas and oil. Despite the potential of renewable energy resources, their share does not exceed 8% of which 7% is hydropower and 1% is all other renewables (CAPMAS, 2017). The consumption of natural gas and oil is increasing, transforming Egypt from a net export to a net import country (Ibrahim, 2012). This transformation will affect the flow of foreign currency in the future, which is necessary for importing other essential materials (EIA, 2015). Recent reports have indicated that the production of natural gas started to increase once more due to new discoveries. However, energy production should not depend on one source of energy to guarantee sustainable growth (Mandelli et al., 2014). Egypt, like the majority of African countries, depends on fossil fuels with minimal exploitation of renewable energy resources. This is despite the huge potential of renewable energy resources in most of African countries (Mandelli et al., 2014).

The government is facing another problem as the electricity generation increased by 500% between 1981 and 2005 due to urbanization, industrial development and the increasing demand for housing and construction (Ibrahim, 2012). Additionally, electricity blackouts are common in Egypt because of its ageing infrastructure and the growing gap between supply and demand (BMI, 2015).

Egypt generates more than 57,000 tonnes of municipal solid waste every day (Zaki et al., 2013). The collection coverage in rural areas varies from 0-30% and 50-65% in urban areas (SWEEP-Net, 2014). Most of the generated waste is openly dumped (80-88%), only 10-15% is recycled and the rest is composted or landfilled (Zaki et al., 2013). Cairo Governorate generates more than 15,000 tonnes of solid waste every day and the average collection coverage is approximately 70% (Zaki et al., 2013). The high proportion of openly dumped waste is an issue of concern for public health and the amount of resources wasted. It follows that without intervention this is only set to increase with further unchecked population growth and a finite area of land.

The collection coverage in Cairo Governorate is higher than other parts of the country but uncollected solid waste is still thrown in the streets without treatment. Municipal solid waste is managed by formal (NGOs, international companies, and private companies) and informal sectors (such as Cairo's informal garbage collectors El-Zabbaleen). The overall performance of both formal and informal sectors is inefficient due to the absence of various essential elements: accurate data for measuring municipal solid waste (MSW) composition; source separation; public awareness; and a clear policy and a legal framework for waste management (SWEEP-Net, 2014). The lack of a proper waste management system is causing serious environmental and health problems in Cairo and the whole country.

Like many other countries in the Global South, resource management is considered a massive challenge for the sustainable urban development of Egypt. Better understanding of complex issues in resource management, and the characteristics of individual cities, countries or regions is necessary:

- to create robust urban sustainability strategies,
- to reduce the environmental impacts of urbanization,
- and to achieve the Sustainable Development Goals (SDGs).

1.3 Research aim, objectives and questions

1.3.1 Research aim

This study aims to explore the challenges of resource management for urban sustainability in the Global South. Cairo Governorate, an example of a rapidly urbanizing Global South city, was selected as a case study, to better understand complex issues in resource management. The rapid growth of population, urbanization and economic growth associated with the increasing demand for energy and water resources, and the generation of solid waste present considerable challenges for urban sustainability in Cairo Governorate.

1.3.2 Research objectives

The following objectives were identified to fulfil the aim of this research:

- The first objective: to outline the potential for measuring the flow of materials for the creation of robust urban sustainability strategies for a fast-growing city, Cairo Governorate, the capital of Egypt.
- The second objective: to test the suitability and applicability of an existing tool to understand the unique characteristics of Cairo Governorate, drivers and barriers to sustainable resource management.

1.3.3 Research questions

- RQ 1: What are the main characteristics of Cairo Governorate (case study) that affect the flow of materials (energy, electricity, water, solid waste, and wastewater)?
- RQ 2: Does the "multi-layered indicator set" that was developed by Kennedy et al. (2014) work in the context of Cairo Governorate?
- RQ 3: How is the flow of materials (energy, electricity, water, solid waste, and wastewater) in Cairo Governorate related to its sustainability performance?
- RQ 4: What institutional, economic, and social factors explain the nature and quality of Cairo's sustainability performance?

The first question aims to identify the unique characteristics of Cairo Governorate that have a great impact on the flow of resources (energy, electricity, water, solid waste, and wastewater). The second question aims to test the applicability of an existing urban metabolism tool that was developed by Kennedy et al. (2014) to assess the flow of materials of the world's megacities in the context of Cairo Governorate. This is important because Cairo Governorate includes informal areas which were absent from Kennedy et al.'s study (2014). This makes such studies more complicated due to the difficulty of measuring and tracking the flow of resources (this is further explained in Chapter 2). The third question aims to reveal the effect of the flow of resources on the performance of Cairo Governorate towards sustainable development and achieving the Sustainable Development Goals (SDGs). The fourth question aims to identify the institutional, economic, and social factors that determine the nature and quality of the progress of Cairo towards sustainable development.

1.4 Thesis overview

This thesis consists of nine chapters. Chapter 1 explains urbanization and the importance of resource management for urban sustainability in the Global South. The major challenges of resource management in Egypt and the case study Cairo Governorate are introduced. The research aims, objectives and questions for this study are presented.

Chapter 2 is divided into two sections. The first section introduces the background of the study by explaining urbanization and the growth of cities and megacities, and comparing the trends of urbanization in the Global North and the Global South. The second section reviews the existing literature to explore sustainability concepts, specifically the ones focusing on resource management.

Chapter 3 presents the research design and approach. The existing multi-layered indicator set (developed Kennedy et al., 2014) that is customized to fit in the informal context of the urban settlements in developing countries is described. The research used two principal data gathering methods: 1) a quantitative data collection to fill the customized multi-layered indicator set; and 2) qualitative interviews with representatives from public authorities to explore the drivers and barriers to resource management and site visits to study the physical environment that affects and results from the flow of materials in Cairo.

Chapter 4 presents the first two layers of the multi-layered indicator set that includes the population and the biophysical characteristics of Cairo Governorate, Giza, Qalyubia and Egypt. It includes the results and analysis of the primary data (semi-structured interviews and site visits) and secondary data (from official statistics, published reports and previous studies).

Chapters 5, 6, and 7 present the layers of information that are relevant to the energy sector in Chapter 5, water and wastewater sectors in Chapter 6 and the solid waste sector in Chapter 7. The structure of these three chapters is similar. They include the numerical data that was collected for the multi-layered indicator set, merged and analysed with the primary data of the semi-structured interviews with representatives from each sector and the site visits. This structure was chosen to gain a better in-depth understanding of each sector.

Chapter 8 presents the key findings of the study and how the research objectives and questions are addressed. It evaluates the potential and limitations of employing the urban metabolism framework to gain a better understanding of the characteristics of cities in developing countries and the drivers, and barriers to sustainable resource management.

Chapter 9 includes the conclusion of the study and recommendations for future studies.

2 Chapter Two: Background and literature review

2.1 Introduction

This chapter is divided into two sections. The first section introduces the background of the study by explaining urbanization and the growth of cities and megacities, and comparing the trends of urbanization in the Global North and the Global South. Additionally, the environmental impacts of rapidly urbanizing cities and the inefficient use of resources are explained for cities in the Global South. The second section reviews the existing literature to explore sustainability concepts, specifically the ones focusing on resource management. Previous urban metabolism and urban harvest studies are critically reviewed to determine the methods and tools that have been developed to quantify and assess the flow of materials, and how the lack of reliable data is addressed. Previous studies are classified according to the location of the case studies (international studies, developed nations, developing countries, Africa, and Egypt). The purpose of this classification is to identify the gap in the literature that this study attempts to address. Reviewing the existing literature on urban metabolism and material flow analysis indicated that most of the case studies are of cities in the Global North and China, and very few cases are explored in the Global South, specifically in Africa. This study attempts to address this gap by using the urban metabolism framework and an existing tool to better understand complex issues in resource management for the selected case study of Cairo Governorate.

2.2 Background

2.2.1 Urbanization and growth of cities and megacities

'By 2050 the urban population will reach 70%, making urbanization one of the 21st century's most transformative trends, intensifying its social, economic, political, cultural, environmental challenges and opportunities' (United Nations, 2016a, p.3). Despite this overall growth, the urbanization process is spread in highly uneven ways, being particularly concentrated in the Global South and in particular city-regions. Hence, the number of megacities is expected to reach 41 by 2030, of which 27 will be in developing countries (United Nations, 2014) (see Figure 2-1).

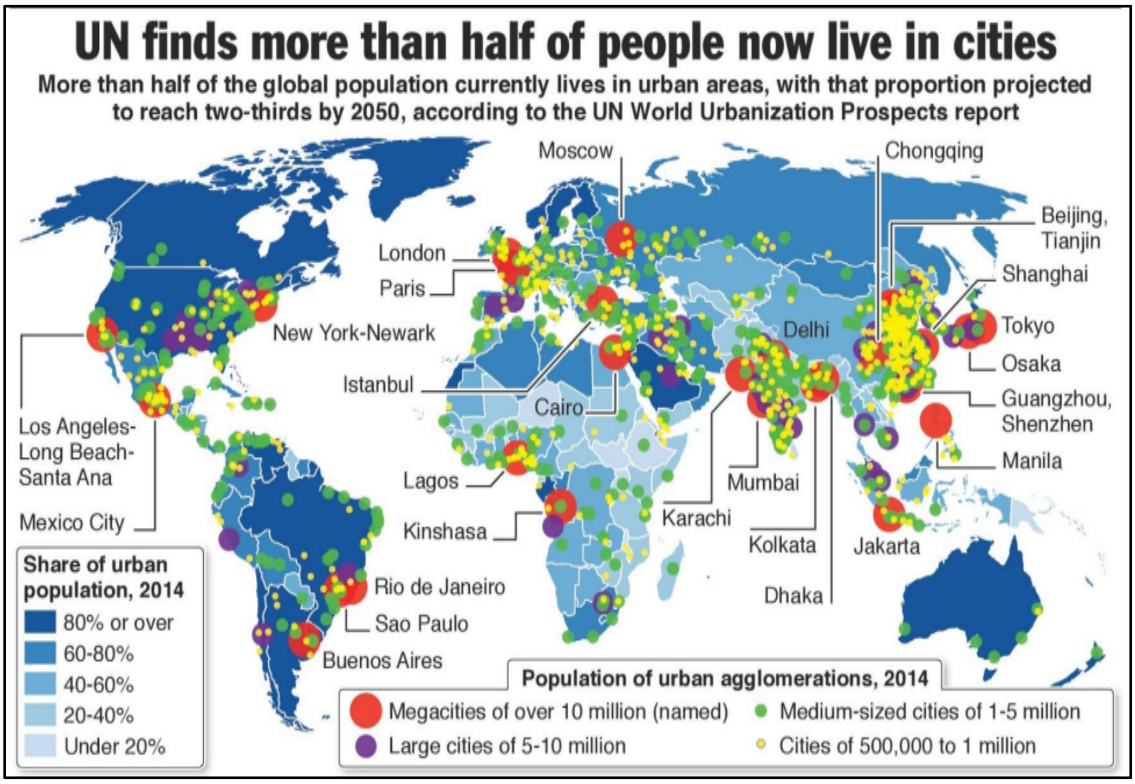


Figure 2-1: United Nations Urbanization Prospects, the 2014 Revision (United Nations, 2014).

Global urbanization is driven by the growth of all types of cities including large cities (5 to 10 million inhabitants), medium-sized cities (1 to 5 million), cities of 500,000 to 1 million and urban areas less than 500,000 inhabitants (United Nations, 2014) as shown in Figure 2-2.

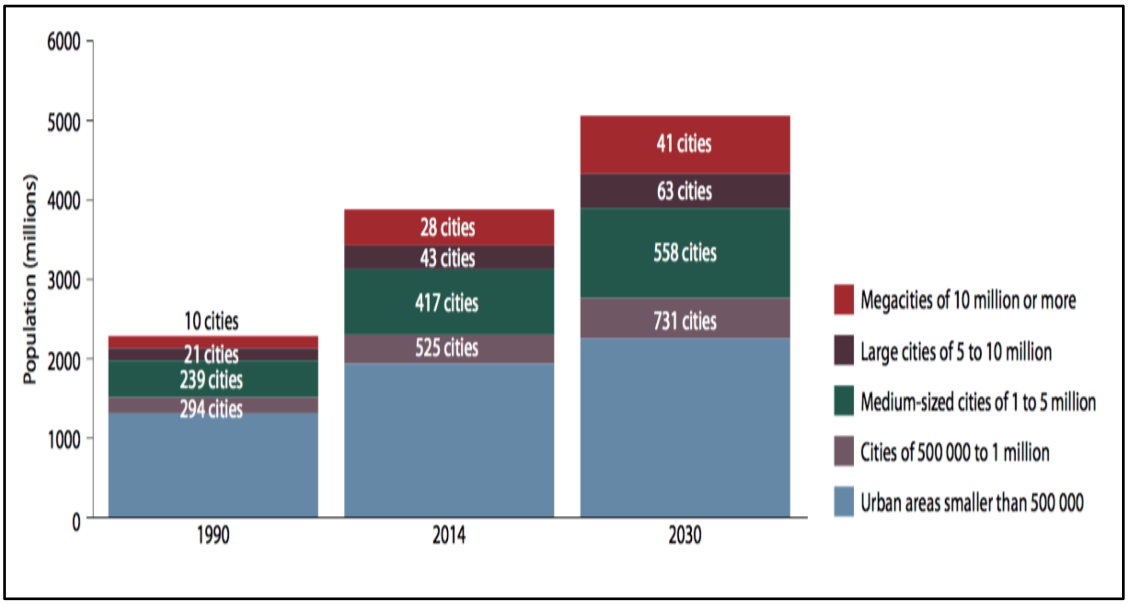


Figure 2-2: Global urban population growth is driven by the growth of cities of all sizes (United Nations, 2014).

Although cities occupy only 2% of the world's land, they generate more than 80% of the world's GDP (United Nations, 2016a). Alongside this wealth creation, is also pollution generation with cities generating considerably greater pollution and resource consumption than other types of human settlements (Mavropoulos, 2010). The effective management of the growth of such urban areas is hence an important corollary for achieving global sustainability. The current response to the various social and political challenges associated with such growth pressures is to double down on economic growth strategies, exacerbating urban unsustainability and worsening the quality for people living in such places, or to ignore the needs of people living on the edge of such settlements. Political turbulence in North Africa and the Middle East in 2011 was in part a consequence of such inequalities. The need to develop pathways to sustainability that are socially inclusive needs to be an essential part of urban sustainable development strategies.

While cities in the Global North developed in the context of industrial society, their counterparts in the Global South cannot follow a similar path.[3] However, what path they should follow is not easily identified. The recent United Nations' Urban Agenda states that cities should avoid a one-size-fits-all approach to achieve urban sustainability (United Nations, 2016a). While there are significant macro-economic and political elements, which will be necessary pillars of successful urban sustainability, the focus here is on the technological aspects of urban sustainability, as well as the socio-cultural acceptability of potential innovations. The latter is important, as while many advanced technologies, projects and management systems have been transferred from developed nations to developing countries, and have been successful, significant cultural and social barriers have hampered the expansion and success of such projects.

2.2.2 Trends of urbanization in developed nations and the Global South

Historically most of the urban population was concentrated in areas associated with rapid economic development and social transformations (United Nations, 2014). This economic growth enabled these areas to expand their capacity to provide job opportunities, housing, health, education, infrastructure, and social services. Since 1950, the rate of growth of cities in the Global North has slowed. Rapid urban population growth is nowadays located in middle and low-income

[3] Although the trade-off between growth now and sustainability for future generations is not easily resolved (see Catney and Doyle, 2011).

countries in Africa and Asia, though without the necessary economic growth to absorb such pressures (see Figure 2-3). This has created considerable 'growing pains' with developing countries struggling to cope with the pressures that are particularly located on major city-regions.

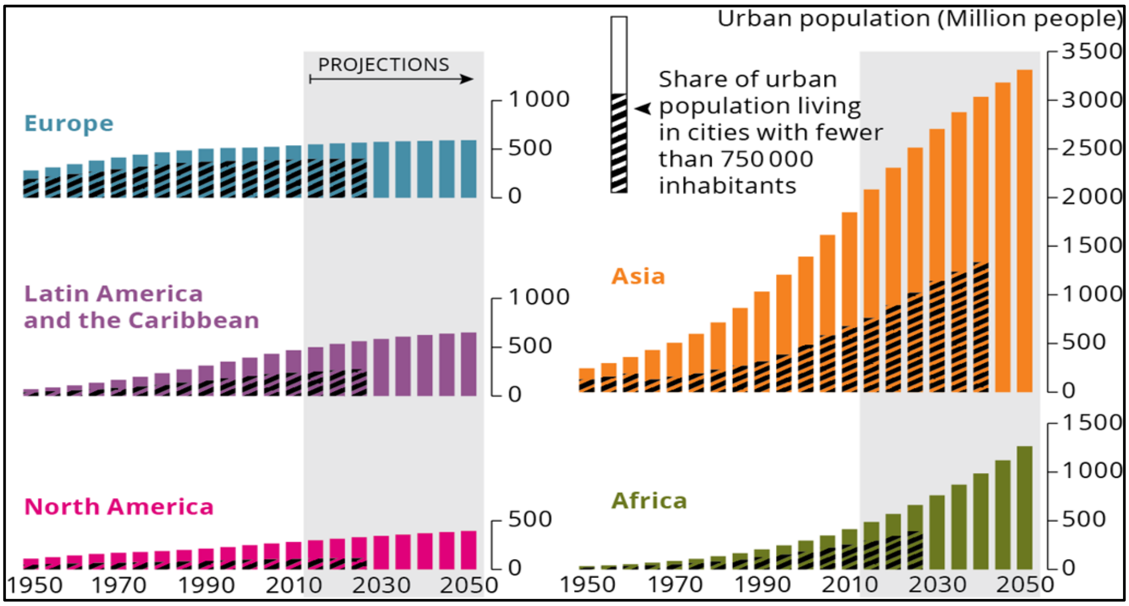


Figure 2-3: Urban trends by world regions 1950-2050 (United Nations, 2013b).

The world's megacities in 2014 are presented in Table 2-1. This table includes the ranking of the world's megacities in 2014 and the projected ranking in 2030 based on population size. This comparison shows that the ranking of the world's megacities is rapidly changing and that most of the world's megacities will be located in the Global South. This is due to the high average annual rates of change (per cent) of the megacities that are located in the Global South compared to the low average annual rates of change (per cent) of the megacities that are located in the Global North (Table 2-1).

Table 2-1: Population size and ranking of urban agglomerations with more than 5 million inhabitants (United Nations, 2014).

		Population (thousands)			Rank			Average annual rate of change (per cent)
Urban Agglomeration	Country or area	1990	2014	2030	1990	2014	2030	2010–2015
Tokyo	Japan	32 530	37 833	37 190	1	1	1	0.6
Delhi	India	9 726	24 953	36 060	12	2	2	3.2
Shanghai	China	7 823	22 991	30 751	20	3	3	3.4
Ciudad de México (Mexico City)	Mexico	15 642	20 843	23 865	4	4	10	0.8
São Paulo	Brazil	14 776	20 831	23 444	5	5	11	1.4
Mumbai (Bombay)	India	12 436	20 741	27 797	6	6	4	1.6
Kinki M.M.A. (Osaka)	Japan	18 389	20 123	19 976	2	7	13	0.8
Beijing	China	6 788	19 520	27 706	23	8	5	4.6
New York-Newark	United States of America	16 086	18 591	19 885	3	9	14	0.2
Al-Qahirah (Cairo)	Egypt	9 892	18 419	24 502	11	10	8	2.1
Dhaka	Bangladesh	6 621	16 982	27 374	24	11	6	3.6
Karachi	Pakistan	7 147	16 126	24 838	22	12	7	3.3
Buenos Aires	Argentina	10 513	15 024	16 956	10	13	18	1.3
Kolkata (Calcutta)	India	10 890	14 766	19 092	7	14	15	0.8
Istanbul	Turkey	6 552	13 954	16 694	25	15	20	2.2
Chongqing	China	4 011	12 916	17 380	43	16	17	3.4
Rio de Janeiro	Brazil	9 697	12 825	14 174	13	17	23	0.8
Manila	Philippines	7 973	12 764	16 756	19	18	19	1.7
Lagos	Nigeria	4 764	12 614	24 239	33	19	9	3.9
Los Angeles-Long Beach-Santa Ana	United States of America	10 883	12 308	13 257	8	20	26	0.2
Moskva (Moscow)	Russian Federation	8 987	12 063	12 200	15	21	31	1.2
Guangzhou, Guangdong	China	3 072	11 843	17 574	63	22	16	5.2
Kinshasa	Democratic Republic of the Congo	3 683	11 116	19 996	50	23	12	4.2
Tianjin	China	4 558	10 860	14 655	37	24	22	3.4
Paris	France	9 330	10 764	11 803	14	25	33	0.7
Shenzhen	China	875	10 680	12 673	308	26	29	1.0
London	United Kingdom	8 054	10 189	11 467	18	27	36	1.2
Jakarta	Indonesia	8 175	10 176	13 812	17	28	25	1.4

The United Nations report “The World’s Cities” identified the world’s megacities in 2016 and the expected megacities by 2030 (see Table 2-2) (United Nations, 2016d). This table shows that the number of megacities reached 31 in 2016 and that the ranking of the world’s megacities is also changing rapidly compared to the ranking of 2014. The ranking of the megacities that are located in the Global South are moving towards the top of the ranking and the ranking of the megacities that are located in the Global North are falling back.

Table 2-2: The world’s megacities in 2016 and projected ones by 2030 (United Nations, 2016d).

Rank	City, Country	Population in 2016 (thousands)	City, Country	Population in 2030 (thousands)
1	Tokyo, Japan	38 140	Tokyo, Japan	37 190
2	Delhi, India	26 454	Delhi, India	36 060
3	Shanghai, China	24 484	Shanghai, China	30 751
4	Mumbai (Bombay), India	21 357	Mumbai (Bombay), India	27 797
5	São Paulo, Brazil	21 297	Beijing, China	27 706
6	Beijing, China	21 240	Dhaka, Bangladesh	27 374
7	Ciudad de México (Mexico City), Mexico	21 157	Karachi, Pakistan	24 838
8	Kinki M.M.A. (Osaka), Japan	20 337	Al-Qahirah (Cairo), Egypt	24 502
9	Al-Qahirah (Cairo), Egypt	19 128	Lagos, Nigeria	24 239
10	New York-Newark, USA	18 604	Ciudad de México (Mexico City), Mexico	23 865
11	Dhaka, Bangladesh	18 237	São Paulo, Brazil	23 444
12	Karachi, Pakistan	17 121	Kinshasa, Democratic Republic of the Congo	19 996
13	Buenos Aires, Argentina	15 334	Kinki M.M.A. (Osaka), Japan	19 976
14	Kolkata (Calcutta), India	14 980	New York-Newark, USA	19 885
15	Istanbul, Turkey	14 365	Kolkata (Calcutta), India	19 092
16	Chongqing, China	13 744	Guangzhou, Guangdong, China	17 574
17	Lagos, Nigeria	13 661	Chongqing, China	17 380
18	Manila, Philippines	13 131	Buenos Aires, Argentina	16 956
19	Guangzhou, Guangdong, China	13 070	Manila, Philippines	16 756
20	Rio de Janeiro, Brazil	12 981	Istanbul, Turkey	16 694
21	Los Angeles-Long Beach-Santa Ana, USA	12 317	Bangalore, India	14 762
22	Moskva (Moscow), Russian Federation	12 260	Tianjin, China	14 655
23	Kinshasa, Democratic Republic of the Congo	12 071	Rio de Janeiro, Brazil	14 174
24	Tianjin, China	11 558	Chennai (Madras), India	13 921
25	Paris, France	10 925	Jakarta, Indonesia	13 812
26	Shenzhen, China	10 828	Los Angeles-Long Beach-Santa Ana, USA	13 257
27	Jakarta, Indonesia	10 483	Lahore, Pakistan	13 033
28	Bangalore, India	10 456	Hyderabad, India	12 774
29	London, United Kingdom	10 434	Shenzhen, China	12 673
30	Chennai (Madras), India	10 163	Lima, Peru	12 221
31	Lima, Peru	10 072	Moskva (Moscow), Russian Federation	12 200
32			Bogotá, Colombia	11 966
33			Paris, France	11 803
34			Johannesburg, South Africa	11 573
35			Krung Thep (Bangkok), Thailand	11 528
36			London, United Kingdom	11 467
37			Dar es Salaam, United Republic of Tanzania	10 760
38			Ahmadabad, India	10 527
39			Luanda, Angola	10 429
40			Thành Pho Ho Chí Minh (Ho Chi Minh City), Viet Nam	10 200
41			Chengdu, China	10 104

2.2.3 Challenges of urbanization in the Global South

The rapid growth of urbanization is usually associated with a massive growth of waste. At present, the world's cities produce 1.3 billion tonnes of municipal solid waste (MSW) and by 2025 it is expected that the waste products of the world's cities will reach 2.2 billion tonnes (Hoornweg and Bhada-Tata, 2012). Most of the waste generation increase will be in lower-middle-income countries where most of the megacities will be located in the future (Figures 2-4 and 2-5).

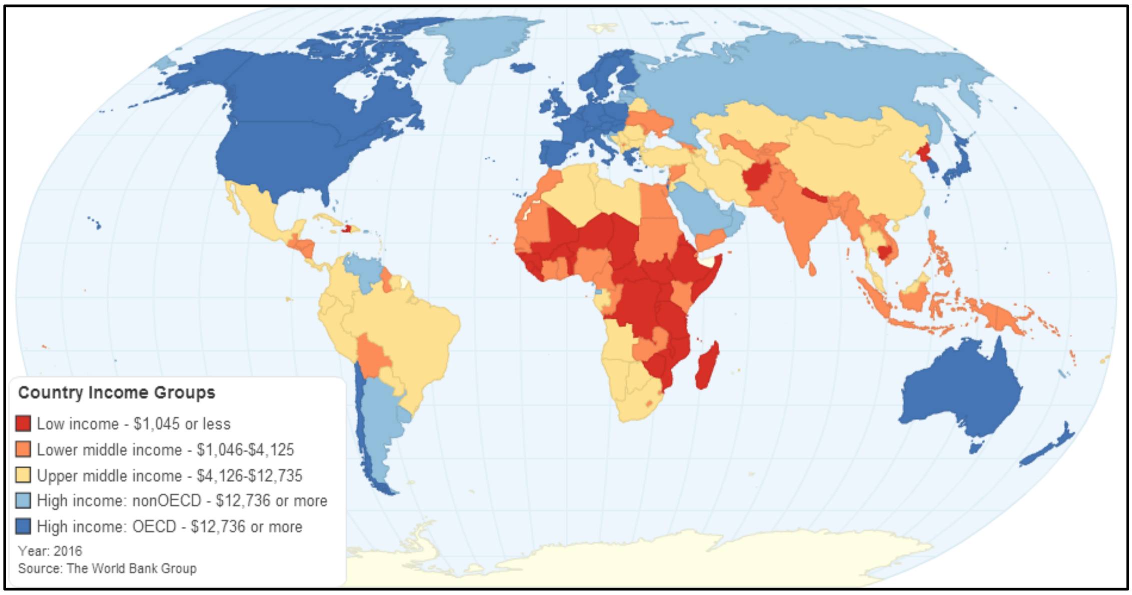


Figure 2-4: Country income groups, World Bank classification (The World Bank Group, 2016a).

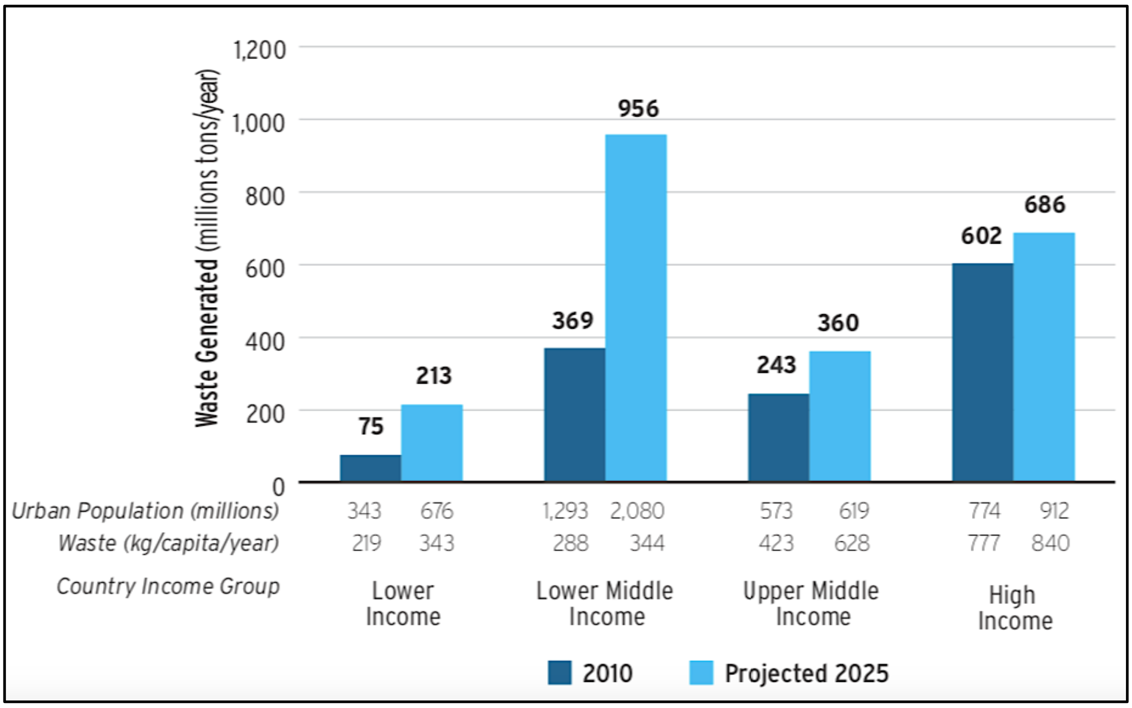


Figure 2-5: Urban waste generation by income level and year (Hoornweg and Bhada-Tata, 2012).

Municipalities in the Global South are facing tremendous challenges to manage the growth of waste and they usually fail to have appropriate waste management systems. They also experience difficulties in obtaining reliable data (Wilson et al., 2013). The average municipal solid waste collection in lower and lower-middle-income countries is 55% while in high-income countries it reaches 100% (Wilson et al., 2013). The municipal solid waste composition differs from one country to another based on the income level as shown in Figure 2-6. Organic waste represents 65% of total municipal solid waste in low-income countries and 30% in high-income countries. A successful waste management system should consider waste composition to provide the most suitable equipment and treatment. For example, Wilson et al. (2013) shed light on the potential of upgrading organic waste by anaerobic digestion to produce biogas in low-income countries. However, solid waste must be split into at least two categories: wet (organic waste) and dry (such as glass, metal and cardboard) for the treatment of organic waste in developing countries. In addition to the physical and technical aspects, the governance, socio-cultural, economic and environmental aspects need to be considered in order to provide tailored integrated sustainable waste management systems that fit in the place where they are being developed (Wilson et al., 2013). Failure to account for the governance context in part explains the failure of many waste management projects in developing countries that transplanted models from Global North to the Global South countries without sufficiently taking contextual factors into consideration.

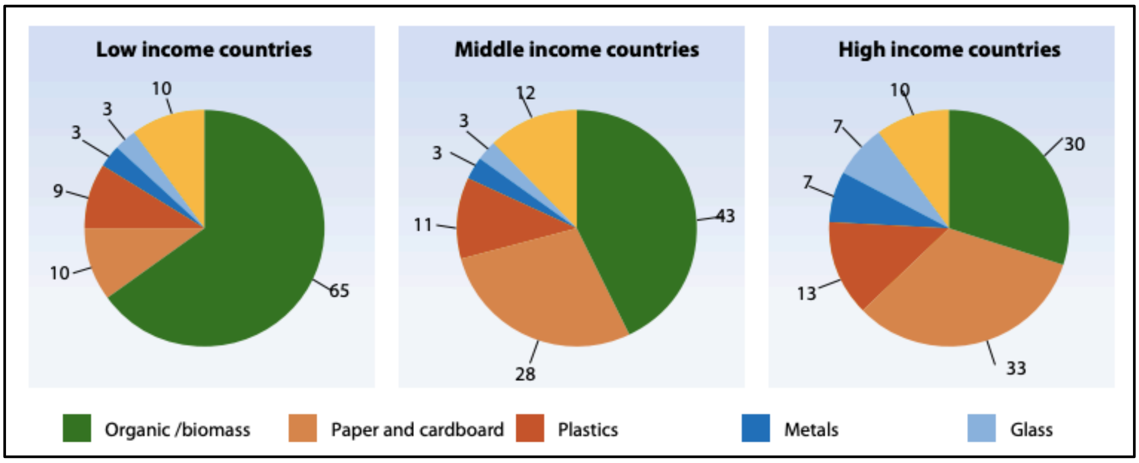


Figure 2-6: Composition of municipal solid waste (MSW) by national income (UNEP, 2011).

Megacities emit massive amounts of pollution, which is evident in densely populated cities; these emissions have a local effect and can transfer thousands of kilometres away from the source (Baklanov et al., 2016). Emissions of megacities are variable; for example, in developed countries emissions are mainly released from road use and transportation while in developing countries from residential (cooking and heating) and biomass burning.

Baklanov et al. (2016) outlined some of the mitigation strategies that were developed to reduce the emissions of megacities in developed nations. For example, developed nations shifted many of their industrial activities to developing countries, implemented air quality management programmes and used advanced technologies to monitor and reduce emissions. For developing countries, Baklanov et al. (2016) outlined the successful improvements of air quality in Mexico by developing and implementing air quality management programmes such as capturing biogas, waste management projects, improving public transportation and sustainable housing projects. Altogether these reduced the amount of emissions. The mitigation strategies that were developed in Mexico to reduce its environmental impacts set a good example for other cities in the Global South that face similar challenges.

Facchini et al. (2017) used a multi-layered perspective to assess and compare the resource consumption (including energy and water consumption) and waste generation of the world's 27 megacities. Figure 2-7 shows the share of metabolic flows as a percentage of the total resources consumed in the 27 megacities. The outcome of this comparison shows that cities with equal GDP do not have equal resource consumption and cities with high population and low GDP do not have the highest resource consumption. The energy consumption of megacities in developing countries (including Delhi and Cairo) is less than the energy consumption of megacities in developed nations (Facchini et al., 2017). The electricity generation mix in developed cities usually includes different types of energy resources (renewable and non-renewable) while in developing countries it usually consists of one or two types of energy (Facchini et al., 2017). Despite the significant potential of renewable energy resources in most developing countries, they mainly rely on fossil fuels for their energy needs, most of which is used in the residential sector (Khoury et al., 2016). The lack of finances, poor regulations, clear policies and legal frameworks, and corruption in some governments prevent the development of renewable energy projects (Khoury et al., 2016). It is important to note here that the energy mix of Egypt consists of two types of non-renewable energy resources: natural gas and oil with a small share of renewable energy.

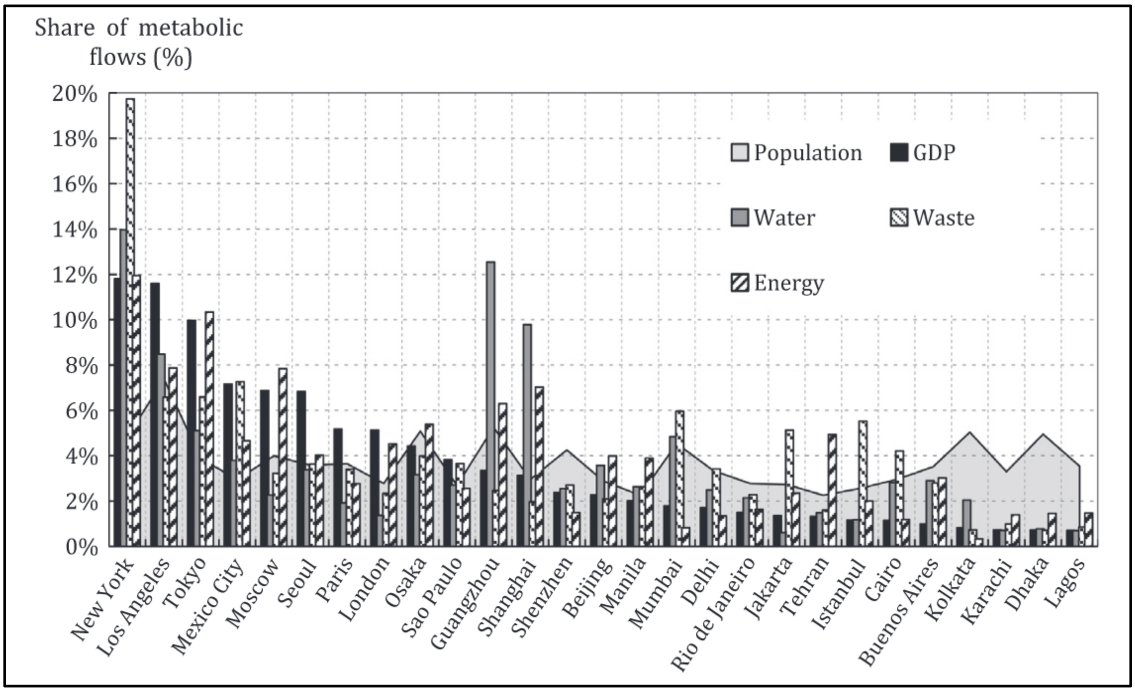


Figure 2-7: Overview of the metabolic flows of megacities ranked by descending GDP share[4] (Facchini et al., 2017, p.89).

Facchini et al. (2017) showed that the inefficient use of resources in developing countries is causing high levels of pollution and that these are expected to increase in the future due to urbanization and the increased generation of solid waste. Additionally, more resources will be required to increase the capacity of

[4] The shaded area in background reflects the share of population (Facchini et al., 2017, p.89).

existing cities and to build new cities to absorb the projected urbanization in developing countries. Driven by the scarcity of resources and climate change, resource management became a global concern to ensure sustainable growth of cities worldwide and specifically in the Global South where most urbanization will take place in the future.

2.3 Literature review

This section provides an introduction to the field of sustainability science and explains why this thesis contributes to this emerging field. This is followed by an overview of the most recent studies on the urban carrying capacity of cities and sustainable resource management. A wide range of existing literature was reviewed to identify resource management concepts and the methods developed and used to quantify and assess the flow of materials at different scales (local, city, country or region). Moreover, challenges and limitations for conducting such studies were explored.

2.3.1 Sustainability and urbanization

Sustainability is the “end goal” of sustainable development while sustainable development is the road or pathways to achieve it (Hector et al., 2014). The Brundtland Commission (WCED 1987) defined sustainable development as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development WCED, and Brundtland, 1987, p.8). The WCED gained worldwide support for its argument that development must ensure the coexistence of economy and the environment by comprising environmental, economic and social pillars, however, this concept is subject to criticism on many grounds, especially for its ambiguity and the lack of tangible operationalisation (Jerneck et al., 2010; Komiyama and Takeuchi, 2006). The United Nations introduced the 2030 Agenda "Transforming our World: the 2030 Agenda for Sustainable Development" including the Sustainable Development Goals (17 goals and 169 targets) in 2015 to address challenges of sustainable development that have emerged since the adoption of the Millennium Development Goals (MDGs) in 2000 (United Nations, 2016a; United Nations, 2015b). Although the MDGs were based on the United Nations Agenda 21 that emphasized on the interlinkages of the social, economic and environmental dimensions of sustainable development, the implementation process of the agenda and goals, arguably did not occur in the integrated way that was anticipated (United Nations, 2013a). The MDGs have achieved some improvements in the quality of lives for millions but failed to address other emerging challenges such as environmental degradation, increased poverty and inequalities (United Nations, 2016b). The United Nations developed the SDGs to address these gaps. Despite that the SDGs are meant to be integrated, invisible and balance the three dimensions of sustainable development and provide means of implementation among some of its targets. Stafford-Smith et al. (2017) argue that these implementation targets are extremely vague about interlinkages and interdependencies among goals. They suggest that further attention to these interlinkages should be made by focusing on three areas: across sectors (such as energy, transport, agriculture and technology); across societal actors (such as local authorities, government agencies, private sectors and civil societies); and finally between low, middle, and high-income countries. Despite the arguments around the SDGs and means of implementation, the SDGs encouraged many governments to find ways to evaluate or measure cities' performance and improvements towards sustainable development (Papaioannou, 2013). However, cities are still facing tremendous challenges and struggling to achieve sustainability.

> Populations, economic activities, social and cultural interactions, as well as environmental and humanitarian impacts, are increasingly concentrated in cities, and this poses massive sustainability challenges in terms of housing, infrastructure, basic services, food security, health, education, decent jobs, safety and natural resources, among others (United Nations, 2016a, p.3).

Despite the fact that urban areas provide better access to basic services, job opportunities, education, production of knowledge and wealth, they are also a source of high levels of pollution, carbon emissions, resources depletion, social exclusion and environmental degradation (Seto et al., 2017). Unplanned urbanization ruins these benefits and causes major threats for sustainability such as biodiversity loss, resource and energy-intensive consumption patterns, and high levels of pollution and carbon emissions (UN-Habitat, 2020). Conversely, well-planned urbanization provides opportunities to address these challenges and contribute to environmental value through energy innovation, sustainable settlement patterns, changes in human behaviour and lifestyles, environment-related improvements to health and wellbeing, and resource efficiencies (UN-Habitat, 2020). This shows that 'urbanization and cities will be either key components to the transition to sustainability or major threats to sustainability' (Seto et al., 2017, p.8935). Addressing sustainability challenges arising from unplanned urbanization and unsustainable cities is fundamental for transforming them into powerful tools for local and global sustainable development including developed and developing countries. Sustainability challenges are often known as:

> wicked problems because they are the result of interdependencies between societal, economic, environmental and cultural drivers that lead to dynamic and mutual reinforcement with causes and effects at many geographic and temporal scales (UNESDOC, 2017, p.1).

Understanding the causes of these problems and identifying suitable solutions are difficult due to complex interdependencies, knowledge is often incomplete, contradictory, and rapidly changing (Jerneck et al., 2010; UNESDOC, 2017). Addressing one of these wicked problems could end up creating more complex problems or could worsen existing ones (Jerneck et al., 2010; UNESDOC, 2017). Sustainability challenges are complex, deeply interconnected and require holistic approaches and integrated solutions across scales and domains (Jerneck et al., 2010; Kates et al., 2001).

Komiyama and Takeuchi (2006) point out two main problems that hamper the ability to deal with sustainability issues: First, the complex nature of sustainability challenges that are caused by multiple factors arising from the interaction of the human, social and global systems (see Figure 2-8); Secondly, the field of study that seeks to address these wicked problems. There is no single discipline that could identify the causes of such complex problems and provide integrated solutions to address them (Jerneck et al., 2010; Komiyama and Takeuchi, 2006). Sustainability science is an emerging field of study that is based on the concept of sustainable development and it is:

> usually defined as a discipline that points the way toward a sustainable society' as it 'adopts a comprehensive, holistic approach to the identification of problems and perspectives involving the sustainability of the global, social, and human systems (Komiyama and Takeuchi, 2006, p.3).

The main aim of sustainability science is to protect and improve the sustainability of the social, human and global systems by understanding the interactions and relationships among these systems and providing comprehensive solutions for sustainability challenges (Komiyama and Takeuchi, 2006). Sustainability science 'seeks to understand the fundamental character of interactions between nature and society to meet the needs of society whilst protecting the life support systems of the planet' (Kates et al., 2001, p.641).

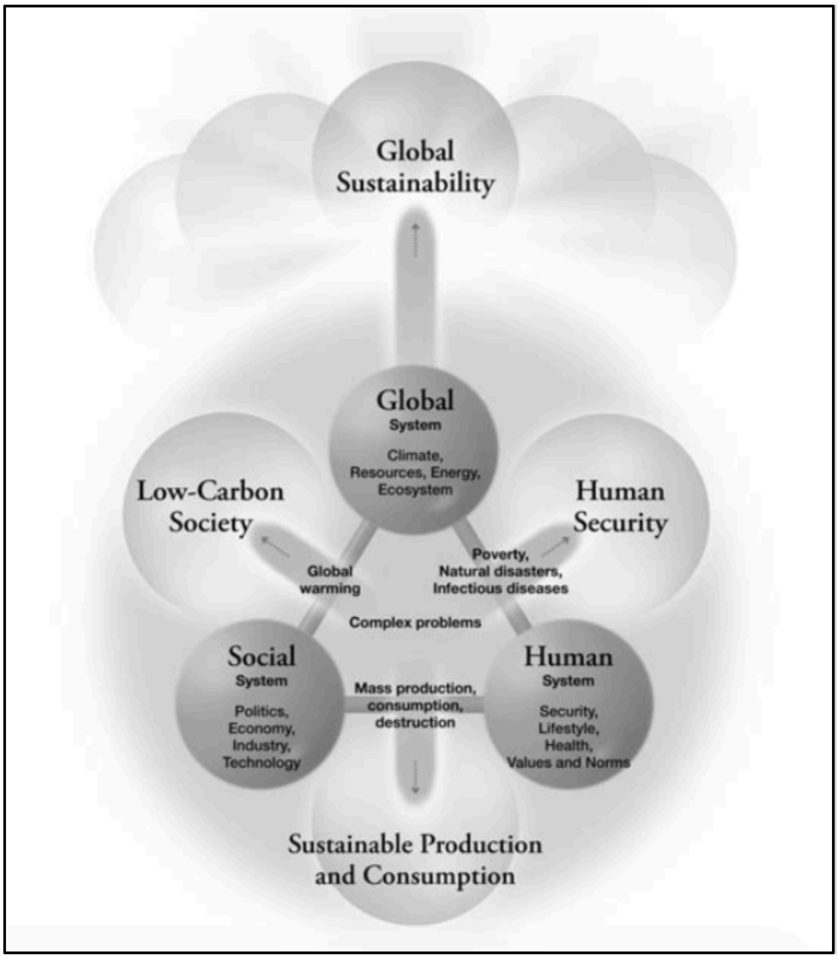


Figure 2-8: Addressing sustainability science through the lens of three systems, and the linkages among them (Komiyama and Takeuchi, 2006).

Sustainability science includes different systems (human, social and global) in its specialization and addresses problems that involve different elements from science and technology, politics and human behaviour (Komiyama and Takeuchi, 2006). For these reasons, sustainability science bridges the natural and social sciences to fill the gap in knowledge of existing disciplines in order to create solutions for complex sustainability challenges (Jerneck et al., 2010; Komiyama and Takeuchi, 2006). In sustainability science, interdisciplinary groups of researchers engage in transdisciplinary processes in order to construct frameworks where individual researchers from different disciplines will add indicators and measurable standards related to sustainability and conduct problem-solving research to shift research from problem identification to problem-solving (Jerneck et al., 2010; Komiyama and Takeuchi, 2006). Understanding the conditions that created sustainability challenges is also important as a first step in problem-solving research (Jerneck et al., 2010). Organizing and integrating knowledge of diverse disciplines strengthens the development of policies and strategies that are required for achieving sustainability transitions.

For knowledge structuring, Jerneck et al. (2010) proposed a three-dimensional matrix to approach sustainability challenges. The matrix includes three sections: a set of sustainability challenges that need to be addressed (this section could include any set of sustainability challenges such as water scarcity, biodiversity loss, land-use change and climate change); three core themes (scientific understanding of social-ecological systems, sustainability goals, and sustainability strategies, pathways and implementation); and two overarching approaches: problem-solving and critical research approaches (Jerneck et al., 2010). Four research theories have been developed to understand social-ecological systems: 1) earth system analysis deals with the natural world from a natural scientific perspective, 2) the world system dynamics metaphor of unequal exchange deals with the world system from a sociological perspective, both theories aim to explain and describe global processes, 3) resilience of coupled social-ecological systems, 4) material flow analysis of various cycles, both theories operate within well-defined systems (ibid). Among all these theories, the ecological footprint and material flow analysis are critically important to the topic of sustainability (ibid). Ecological footprint assessment ‘uses yields of primary products (from cropland, forest, grazing land, and fisheries) to calculate the area necessary to support a given activity’ (Ferrão and Fernández, 2013, p.12) or ‘it converts a population's resource consumption into a single indicator of how much land area is needed to sustain that population indefinitely' (Musango et al., 2017, p.10). Material flow analysis is 'used to characterize the material flows that enter, accumulate, and leave a given economy during a period of time, it quantifies resource flows by physical weight or volume' (Ferrão and Fernández, 2013, p.12; Musango et al., 2017, p.9). Although, there are many other theories and approaches (each has its advantages and disadvantages) that are emerging from different disciplines (such as industrial ecology, resilience theory, transition theory and world-system analysis) to bridge the gap between the natural and social sciences, yet variations in ontology and epistemology is challenging for the integration of knowledge among scientific disciplines (Feyerabend, 1991; Jerneck et al., 2010). Methodology is important in sustainability science, as many methods are strongly linked to specific methodologies, while techniques or tools are more flexible and could assist researchers in developing conceptual frameworks with high scientific standards (Jerneck et al., 2010; Ness et al. 2010). Furthermore, Miller et al. (2013b) revealed that the socio-technical change is not yet investigated in sustainability science, although it is crucial for sustainability transitions as transition management and governance explore policies and procedures that could assist in guiding emerging transitions towards more sustainable pathways.

This thesis uses the lens of sustainability science by employing a holistic framework and customizes an existing tool to identify complex issues regarding resource management in Cairo Governorate and their causes to provide solutions for policy and decision-makers that could assist in addressing sustainability challenges.

2.3.2 Sustainable urban development and the urban carrying capacity

Developing countries are struggling to cope with the consequences of rapid urbanization. Urbanization is exceeding the urban carrying capacity of cities in developing countries and is impeding cities from achieving sustainability goals. There is limited literature that describes the concept of urban carrying capacity (UCC). It provides an important guide and indicator for sustainable urban development (Wei et al., 2015).

> Urban carrying capacity in general consists of two parts; the natural system and man-made components of a given urban area, which should adequately meet the human demands and retain within a limit for urban development, beyond which instability, degradation, or irreversible damage may result (Wei et al., 2015, p.65; Godschalk and Parker, 1975; Joardar, 1996; Oh et al., 2005).

Wei et al. (2015, p.65) defined urban carrying capacity as ‘the limit of urban development from environmental impacts and natural resources, infrastructure and urban services, public perception, institution setting, and society supporting capacity.’ Equation (1) describes the relationship between the urban carrying capacity (UCC) and its components (Wei et al., 2015) (see Figure 2-9). The value of UCC is not fixed; it differs from one place to another because it depends on the interaction between its elements as shown in Figure 2-9. The components of the UCC are variable for example: the environmental impact is changeable because it is based on the nature of human activities and waste production in a particular place; the availability and types of natural resources are different; and capacity of infrastructure varies from one place to another.

Equation 1:

UCC = f (Environmental impacts and natural resources, Infrastructure and urban services, Public Perception, Institution Setting, Society Supporting Capacity)

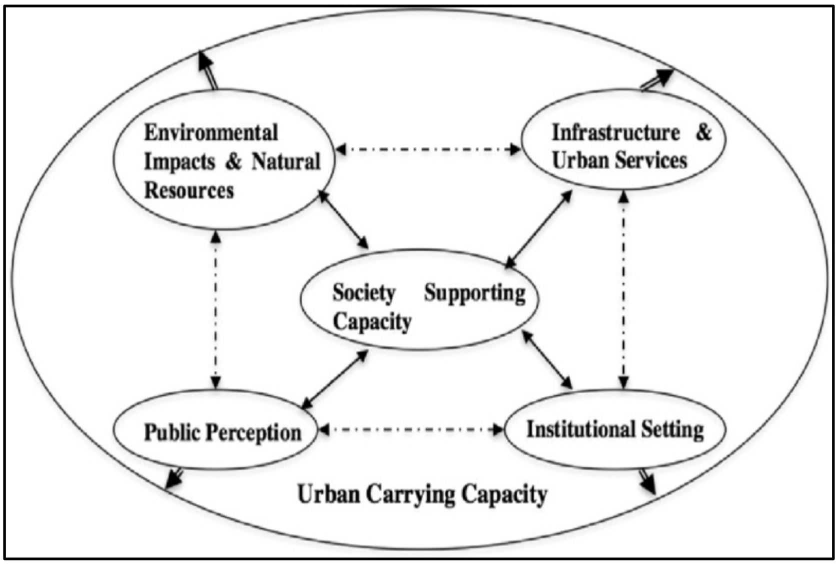


Figure 2-9: The components of UCC and their relationship (Wei et al., 2015).

Cities can improve and increase their capacities in different ways. This could be achieved by mitigating their environmental footprints (impacts), reducing levels of pollution, reducing the use of natural resources, providing adequate infrastructure and developing rural settlements to reduce internal migration. UCC is an important indicator to measure and evaluate the urban capacity of an area. It provides guidance to maintain and enhance the capacities of urban settlements to absorb the rapid population growth (Wei et al., 2015).

Urban problems (such as shortage of housing, growth of informal settlements, depletion of natural resources, demands exceed supply, air and water pollution, low percentages of access to basic services, social conflicts and ecosystem degradation) are indicators of over-carrying capacity of urban areas (Abernethy, 2001; Oh et al., 2005; Wei et al., 2015; Wong et al., 2006). Wei et al.

2015 summarized these urban problems as four areas of unsustainability: inadequate urban services, environmental degradation, natural resources shortage and social conflicts.

Wei et al. 2015 suggests that cities could enhance their UCC by pricing urban services to maintain the supply-demand balance. The pricing policies for urban services affect the spatial distribution of residence and the supply-demand balance (Sullivan, 1985). An average-cost pricing scheme does not consider spatial variation in marginal production costs, so in some locations the average-cost will be higher than the marginal cost and in others it will be lower (ibid). Therefore, locations where the price of urban services is lower than the marginal cost will attract more households causing high-density settlements and, in some cases, this could increase urban sprawl (Sullivan, 1985). Additionally, an average-cost pricing scheme provides inaccurate urban service demands because the price is not equivalent to the marginal cost, accordingly, the equilibrium quantity demanded is not equal to the optimum quantity (Sullivan, 1985). Replacing average-cost with marginal-cost based pricing schemes that vary depending on place is another key solution in maintaining supply-demand balance (ibid).

Furthermore, decentralization policies and strategies are necessary to reduce the massive demands for urban infrastructures and services that can be achieved by distributing functions from the national level to the local level (Wei et al., 2015). UNDP (1997, p.4) defines decentralization, or decentralizing governance, as:

> the restructuring or reorganization of authority so that there is a system of co-responsibility between institutions of governance at the central, regional and local levels according to the principle of subsidiarity, thus increasing the overall quality and effectiveness of the system of governance, while increasing the authority and capacities of sub-national levels.… Decentralization could also be expected to contribute to key elements of good governance, such as increasing people's opportunities for participation in economic, social and political decisions; assisting in developing people's capacities; and enhancing government responsiveness, transparency and accountability.

Decentralization makes government more responsive to local needs by ‘tailoring levels of consumption to the preferences of smaller, more homogeneous groups’ and enables municipalities to manage their resources and deliver public services more efficiently (Balaguer-Coll et al., 2010; Ibrahim, 2011; Shah, 1999; UNDP, 1993; Wallis and Oates 1988, p.5; World Bank, 1994). ‘Decentralization being seen as not an end in itself but a response to the requirements of the 21st Century, a means towards achieving sustainable development and improving the quality and delivery of services’ (UNDP and INP, 2004).

Local governments in developing countries have been facing immense challenges to improve and increase their managerial capacities to cope with urbanization; decentralization was a key tool to address these challenges (Ibrahim, 2011). For example, Egypt has had a highly centralized political system, however, since the 80’s decentralization has been one of the top priorities of public administration tools to transfer the power from the central authority to local governments (Tobbala, 2019). The aim of this shift was to make the government more responsive to local needs and to provide better public services while promoting economic and social development (Tobbala, 2019). This was supported by Law 43/1979 that calls for transferring the power from central ministries to local units and authorising governors to deal with local issues without referring to the central level, which is not achieved yet as ministries are still in full control (Tobbala, 2019). Tobbala (2019) explains that the current system of local administration in Egypt relies heavily on centralized decision-making and that the central control leads to policies and strategies that do not meet real local needs. Top-down administration has created a gap between the central government and the sub-national level (Tobbala, 2019). Ibrahim (2011) clarifies that the government's initiatives towards decentralization in Egypt are influenced by the idea of central planning that lacks flexibility and an adequate response to local needs and public participation.

The current system also lacks transparency in information flows which is essential for effective participation of local communities and accountability of local governments to ensure the efficient and effective use of government resources and delivery of public services (Ibrahim, 2011; Tobbala, 2019; UNDP and INP, 2004). Public participation at local levels is also an indicator of good local governance (UNDP and INP, 2004). Transparency in information flows and accountability of local governments accompanied with good governance reduces information inconsistencies between the government’s different institutions as inconsistencies in existing information provides unreliable data for decision-making, planning, setting targets and monitoring (UNDP and INP, 2004). Information flows should be available vertically with central and local governments and horizontally with all sectors and institutions to serve the integrated holistic objectives of sustainable human development (UNDP and INP, 2004) and with Sustainable Development Goal 16, which aims ‘to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels,’ Target 16.5 ‘Substantially reduce corruption and bribery in all their forms,’ Target 16.6 ‘Develop effective, accountable and transparent institutions at all levels’ and Target 16.7 ‘Ensure responsive, inclusive, participatory and representative decision-making at all levels’ (United Nations, 2015a).

Moreover, Wei et al. 2015 shed light on the importance of legislation and enforceable regulations as effective approaches to improve urban management. Many countries fail to implement urban regulations properly, for example, the lack of management and maintenance (soft infrastructure) is a common problem in developing countries that are leading to a rapid deterioration of existing and newly built infrastructure (physical infrastructure) (Wei et al., 2015).

Urbanization challenges in developing countries indicate that cities are exceeding their urban carrying capacity causing massive environmental impacts, as well as social, economic and urban problems. Most governments in developing countries fail to increase the capacity of cities due to the pressure of the rapid urbanization, climate change and the scarcity of resources. Understanding the existing capacities and limits of cities from natural and man-made resources is necessary to identify the sustainable urban development pathways and strategies open to them. This is important because sustainable urban development strategies are heavily dependent on local conditions and the urban carrying capacity of cities in which they are being developed.

The concept of UCC provides a better understanding of the limits of urban development as it considers both limits: natural resources and man-made resources that enables researchers, urban planners, policy and decision-makers to gain the sense of growth limits of urban areas and cities and it also identifies pathways for sustainable development. The UCC considers the limits of man-made resources (as explained above), which is important because in some cases natural resources could be available, but limited man-made resources (such as infrastructure and institutional settings) could lead to the mismanagement of these natural resources. Despite the importance of the UCC concept as a guide for sustainable development, UCC research strongly lacks theoretical basis and practical approaches to measure the capacity of cities (Shi et al., 2013; Wei et al., 2015). Limited studies are available and the methods of measurement are not well-established and used in the field of sustainability.

2.3.3 Sustainable resource management

Driven by rapid global urbanization, the industrial revolution and technological development, a huge amount of resources are being extracted from the environment to meet increasing demand (Agudelo-Vera et al., 2011). The consequences of the inefficient use of resources and the increase of urban waste generation have massive impacts on environmental and ecological systems. Agudelo-Vera et al. (2011) highlighted the importance of the integration of resource management in sustainable development. It is crucial to manage the available resources efficiently to meet current demands and enable future generations to meet their own needs (Agudelo-Vera et al., 2011). Agudelo-Vera et al. (2011, p.2296) defines resource management as

> the conscious handling of natural resources - energy and materials - and the utilization of infrastructure and technology to meet human needs; including extraction, transformation, consumption or use and disposal of resources. Hence, RM (resource management) includes natural resources and man-made products.

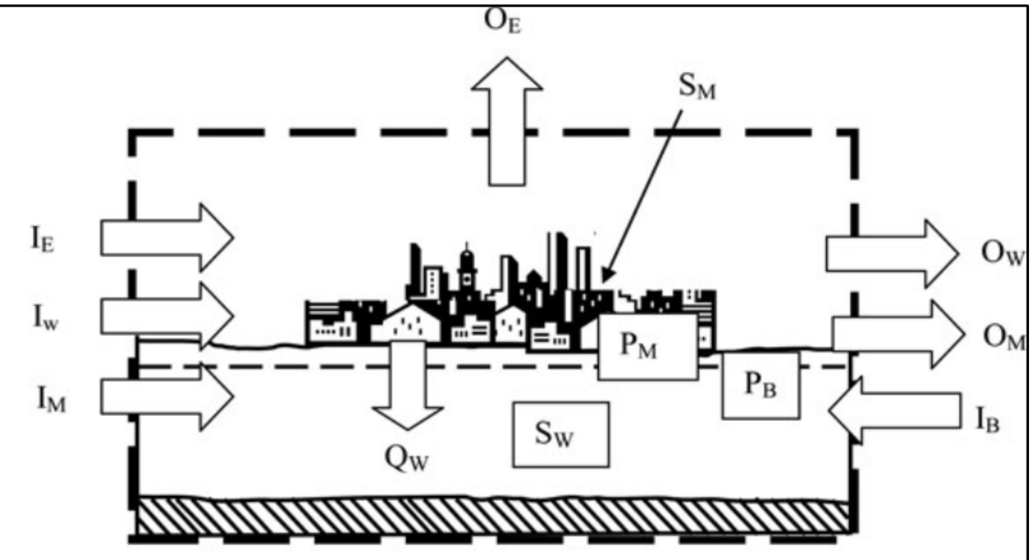
Sustainable resource management leads to a better understanding of the available natural resources of cities and the limits of extraction without causing environmental degradation. It also maximises the use of renewable resources rather than relying on non-renewable resources, minimizes urban waste generation and reduces waste disposal. Sustainable resource management enables policy and decision-makers to achieve the Sustainable Development Goals (SDGs) specifically Goal 2 ‘Zero hunger,’ Goal 6 ‘Clean water and sanitation,’ Goal 7 ‘Affordable and clean energy,’ Goal 11 ‘Sustainable cities and communities,’ Goal 12 ‘Responsible consumption and production,’ Goal 15 ‘Life on land,’ (Hülsmann and Jampani, 2020; United Nations, 2015a) and Goal 13 ‘Climate action’ and resource management is also important for achieving other SDGs even if they are not closely linked to resource management (Bringezu, 2018). This could not be achieved without quantifying, assessing and controlling inputs (consumption of natural and man-made resources) and outputs (such as solid waste, wastewater and carbon dioxide emissions) of cities to assist in creating integrated sustainable resource management strategies (Hülsmann and Jampani, 2020).

2.3.4 The urban metabolism framework

The urban metabolism framework has been widely used in literature to assess the metabolism of cities by quantifying and assessing the flow of materials (resources) in cities. The concept of urban metabolism originates from applying the metaphor of industrial ecology to urban systems; it is a metaphor that invokes nature as a source for new ideas to redesign urban areas or cities to bring them closer to sustainability (Ferrão and Fernández, 2013). Ecosystems are resilient, vigorous and sustainable systems; observing ecological processes could offer ideas to improve the sustainability of urban areas (Ferrão and Fernández, 2013). Urban areas are considered open systems with interlinked subsystems (social, economic and institutional) that interact with the environment by extracting and consuming resources and generating different types of wastes (such as solid waste, wastewater and emissions) that are absorbed and regenerated by the environment (Ferrão and Fernández, 2013). The urban metabolism concept developed and became a practical approach that provides a variety of methods, tools and metrics to understand and examine the metabolism of urban systems, and it also assesses the level of circularity of resource streams to identify deficiencies in urban systems and opportunities for sustainable improvement (Ferrão and Fernández, 2013). Furthermore, the urban metabolism framework provides suitable measures of resources exploitation and consumption, and different types of waste generation that could be used as sustainability indicators (Ferrão and Fernández, 2013).

The urban metabolism framework was first employed by Wolman in 1965 to assess the inputs (water, food and fuel) and outputs (sewage, solid refuse and air pollutants) of a hypothetical U.S. city with a population of one million inhabitants (Wolman, 1965). He believed that cities could be treated as living organisms and if their metabolic processes are understood, it would be possible to sustain and balance the flow of materials and energy without distressing the environment (Kennedy et al., 2007). Kennedy et al. (2007, p.44) defined urban metabolism as ‘the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste.’

An analysis of urban metabolism includes various elements: quantification of a city’s inputs, outputs and storage of energy, materials, nutrients, water, and wastes (Kennedy and Hoornweg, 2012) (see Figure 2-10). Over the years, the concept of urban metabolism evolved. A considerable amount of literature has been published on urban metabolism since it was introduced by Wolman (Kennedy and Hoornweg, 2012). Additionally, the World Bank started to use the concept and collected data for some cities (Kennedy and Hoornweg, 2012). Due to the scarcity and the increasing demand for resources, Kennedy and Hoornweg (2012) shed light on the importance of using urban metabolism as a robust framework to understand the flow of materials in cities. Understanding the flow of materials could assist decision-makers to better manage the available resources and reduce the environmental impacts of cities. To conduct such studies, a huge amount of data is required. Kennedy and Hoornweg (2012) suggested targeting data that could be practically collected and suggested that national statistical agencies should manage the production of data more efficiently to serve the urban metabolism studies for individual cities.



Inflows
Biomass [t & J]
- food
- wood

Fossil Fuel [t & J]
- transport
- heating/industrial

Minerals [t]
- metals
- construction materials

Electricity [kWh]
Natural energy [J]
Water [t]
- Drinking (surface & groundwater)
- Precipitation

Substances [t]
- e.g. nutrients

Produced goods [t]

Production
Biomass [t & J]
Minerals [t]

Outflows
Waste Emissions [t]
- gases
- solid
- wastewater
- other liquids

Heat [J]
Substances [t]
Produced goods [t]

Stocks
Infrastructure / Buildings [t]
- construction materials
- metals
- wood
- other materials

Other (machinery, durable) [t]
- metals
- other materials

Substances [t]

Figure 2-10: Urban systems boundary broadly showing inflows and outflows[5] (Kennedy and Hoornweg, 2012).

Kennedy et al. (2007) reviewed and compared urban metabolism studies of eight metropolitan regions across the world, and the water, materials, energy,

[5] Urban systems boundary broadly showing inflows (I), outflows (O), internal flows (Q), storage (S), and production (P) of biomass (B), minerals (M), water (W), and energy (E), t = tonnes; J = joules; kWh = kilowatt-hours (Kennedy and Hoornweg, 2012).

and nutrient flows of other cities. Although the selected studies were conducted in different years (since 1965) and located in different regions, the comparison indicated that the ‘metabolism of cities is changing’ (Kennedy et al., 2007). The metabolism of cities is increasing though, it differs from one place to another. Variation is based on factors such as climate, energy cost and consumption, age of the city, and stage of development. Kennedy et al. (2007, p.51) described the growth of cities and the increasing demand for resources by

> in some respects the city is like a plant stretching its roots out further and further until its resource needs are met—a concept that parallels the ecological footprint. One aspect of this growth is that cities require greater expenditure of transportation energy as materials travel from increasing distances.

As cities grow, it is first local resources (water, energy, and materials) which are exploited, and this has a great impact on the ecological balance of cities (the impacts of the overuse of water, energy, materials and nutrients were presented in the study). After this, the required resources are imported from peri-urban areas to ensure the continuous growth of cities. More energy is thus required to transfer resources from the surrounding environment to cities. Kennedy et al. (2007) pointed out the importance of studying the urban metabolism of cities is to enhance the efficient use of the local resources and reduce external resource exploitation.

The urban metabolism approach is also important to assess the flow of materials in megacities (Brunner, 2007). The increasing demand of resources is driven by the rapid population growth, specifically in Asia and Africa. The consumption of construction and building materials will increase due to the expansion of existing cities and the increasing number of new cities. Brunner (2007) described the flow of materials of cities as linear flows and most of the resources are imported from the surrounding regions. The inputs of cities exceed the outputs and the stock of materials is increasing due to the continuous growth of urban populations (Brunner, 2007). The output of cities refers to the carbon dioxide emissions, waste, wastewater, and so on. The stock of materials refers to the buildings, infrastructure, roads, and so forth. Brunner (2007) sheds light on the importance of improving the design of stocks for two reasons: first, the design of stocks determines the outputs of cities (for example if the buildings are well insulated, the energy required for heating or cooling will be less and this will reduce carbon dioxide emissions, as well as the quality of infrastructure if it is well designed the leakages will be lower and the flow of resources within the city will be more efficient). Secondly, these stocks could be reused or recycled to reduce the use of primary resources in the future. ‘Today’s stock is tomorrow’s waste and can serve as a future resource’ (Brunner, 2007, p.12). Assessing the flow of materials of cities is necessary to reduce the use of resources and change the linear flows into circular flows.

Researchers’ vision of cities has changed since the concept of urban metabolism was introduced (Broto et al., 2012). Urban metabolism enabled researchers to determine various dimensions of sustainability within cities. Researchers from diverse disciplines developed different approaches for urban metabolism studies. Broto et al. (2012) examined the theoretical interpretations of urban metabolism and the practical approaches of urban metabolism that focused on developing new tools to quantify and assess the flow of materials in cities. Broto et al. (2012) conducted a comparative study for these approaches (industrial ecology, urban ecology, ecological economics, political economy and political ecology) and developed six urban metabolism themes as shown in Table 2-3.

Table 2-3: Six urban metabolism themes developed by Broto et al. (2012).

Theme	*Key question*	*Emphasis on*
The city as an ecosystem	What lessons from the functioning of ecosystems can be applied to design and plan better cities?	Nature-inspired models of development in urban planning and design
Material and energy flows in the city	What methods can account for material and energy flows through the city and can these provide suggestions for their optimization?	Comparative analyses of cities and models of urban planning in relation to their efficiency in allocating materials and energy
The material basis of the economy	What policy measures can break the link between urbanization, economic growth and resource consumption?	The material limits of the economy and macroeconomic models to achieve economic and resource stability
Economic drivers of rural–urban relationships	How do economic relations shape the distribution of flows between urban regions and their surroundings?	Forms of territorial organization in relation to different modes of economic circulation
The reproduction of urban inequality	How do existing urban flows distribute resources across the city and who controls these processes?	Patterns of unequal access to resources and the control of these patterns by urban elites
Resignifying socioecological relationships	What socioecological practices have the potential to reimagine and reconfigure existing socioecological flows?	Alternative visions and models of socioecological flows in cultural production, everyday practices, and policy innovations

These themes shed light on the interdisciplinarity approach of urban metabolism as a theoretical framework. Urban metabolism describes the interactions between cities as subsystems and their urban region as a larger ecosystem where cities are located (Broto et al., 2012). Human beings and their activities are part of these interactions and cannot be isolated as these have a great impact on the environment. Social and economic characteristics of cities affect the metabolism of cities, governance and policies regulate these relations. Broto et al. (2012) referred to the unequal distribution of resources between developed nations and developing countries and between rural and urban areas. Unequal distribution of resources, access to basic services and the quality of infrastructure reflect socioeconomic inequalities in the Global North and South (Broto et al., 2012). Sustainable urban development requires a holistic approach to reshape urban areas to improve the flow of resources and to ensure the equal distribution of resources and the interactions between cities and the surrounding environment. The urban metabolism framework could be used to better understand the complex issues of cities to identify the key challenges of sustainable urban development in order to create resilient urban systems.

Over time, research has extended the use of the urban metabolism framework and developed new methods and approaches to quantify, assess and control the flow of materials at different scales (local, regional, national and global) as shown in Figure 2-11 (Zhang et al., 2015). Many of the environmental assessment methods that have been developed in the field of industrial ecology have been used in other frameworks to assess sustainability and the metabolism of urban areas (Beloin-Saint-Pierre et al., 2017; Ness et al., 2007; Zhang et al., 2015).

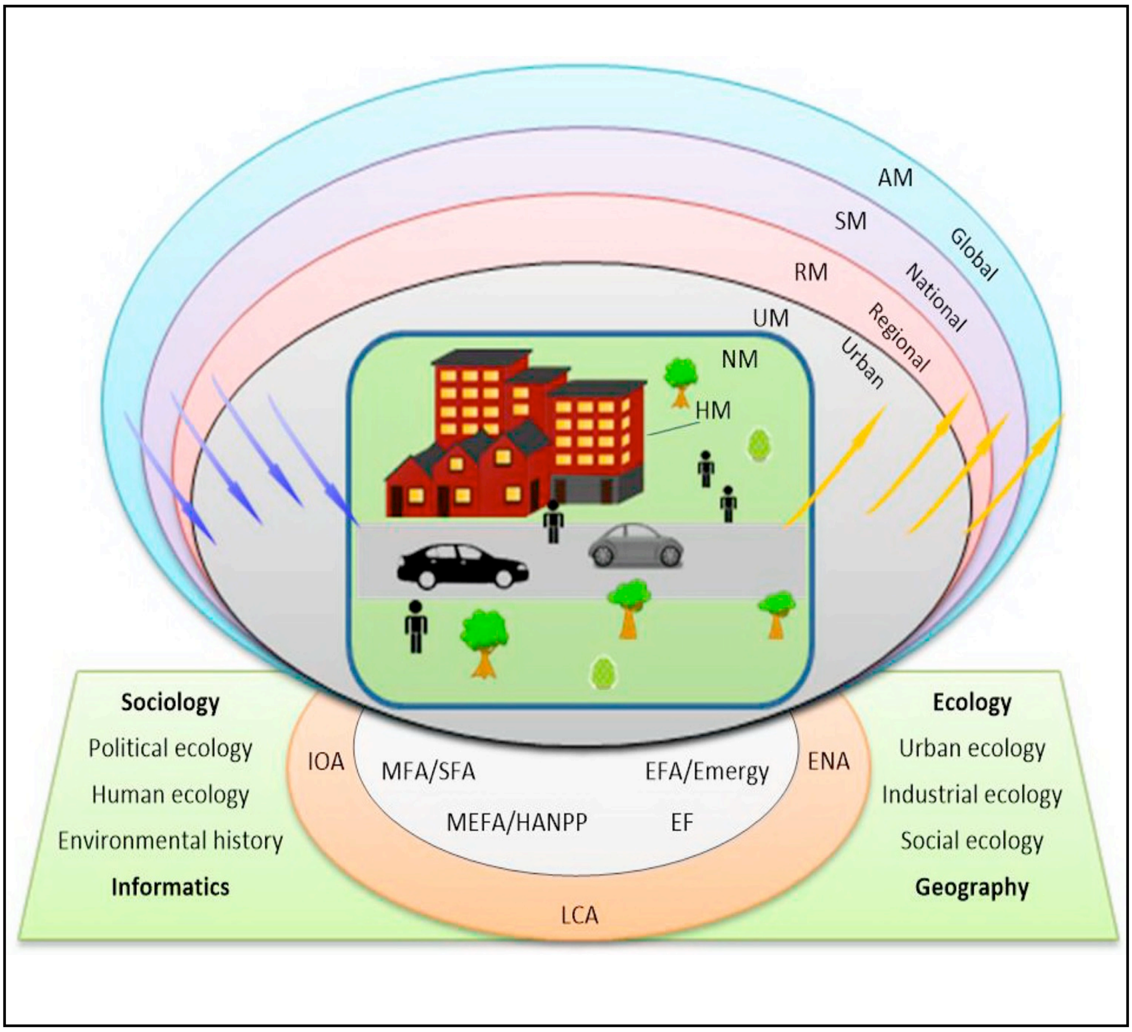


Figure 2-11: Illustration of the multiple scales and disciplines that should be considered in studies of urban metabolism[6] (Zhang et al., 2015).

There has been a huge shift in urban metabolism assessment methods that just accounts the inputs and outputs of cities to methods that provide indicators for metabolic changes and the environmental impacts of cities' metabolisms (Musango et al., 2017). These methods include accounting

[6] Notes: AM, anthroposphere metabolism; EF, ecological footprint; EFA, energy-flow analysis; ENA, ecological network analysis; HANPP, human appropriation of net primary production; HM, household metabolism; IOA, input−output analysis; LCA, life-cycle assessment; MEFA, material and energy-flow analysis; MFA, material-flow analysis; NM, neighbourhood metabolism; RM, regional metabolism; SFA, substance-flow analysis; SM, social metabolism; UM, urban metabolism (Zhang et al., 2015).

approaches, input and output analysis, ecological footprint, life cycle analysis and integrated methods (Beloin-Saint-Pierre et al., 2017; Musango et al., 2017; Zhang et al., 2015). Accounting approaches such as material flow analysis (MFA) has been widely used in previous urban metabolism studies. MFA quantifies resources flows by physical weight or volume at different scales (regional or local) and provides a basis for resource management and could determine public environmental policies (Barles, 2009; Musango et al., 2017). Substance flow analysis is similar to the MFA, but it focuses on quantifying and assessing only one flow such as water or carbon dioxide emissions (Musango et al., 2017). Emergy or exergy studies are accounting approaches that transfer all the resources values to one unifying unit, the solar emjoule (sej) (Currie and Musango, 2017; Musango et al., 2017). Generally, accounting approaches provide some simple characteristics of cities (Fernández, 2014) and they are described as 'black box' because they do not reveal the interactions between the flow of materials and different sectors (Musango et al., 2017).

In contrast, the input and output analysis shows the internal flows and how resources interact with urban activities by conducting empirical analysis of product flows and evaluating the material flows between sectors in an economy through tracking product and sector-specific resource flows (Giljum and Hubacek, 2009; Musango et al., 2017). The input and output analysis to some extent uncovers the ambiguity of the 'black box' but it is not widely used in urban metabolism studies (Beloin-Saint-Pierre et al., 2017; Musango et al., 2017).

The ecological footprint assessment 'accounts for the flows of energy and matter to and from any defined economy and converts these into corresponding land/water area required from nature to support these flows' (Wackernagel and Rees, 1995, p.3). As mentioned previously, the ecological footprint was developed to assess the sustainability of current human activities (Wackernagel and Rees, 1995); it is also used in urban metabolism studies (Fernández, 2014; Musango et al., 2017). Populations are considered unsustainable if their ecological footprints exceeded the actual land available to them (Musango et al., 2017). Ecological footprint assessment is used in urban metabolism studies to evaluate a given metabolism whether it is over-consumptive or is functioning within its limits (Musango et al., 2017). Ecological footprint assessment provides information for decision-makers; however, it is not widely used in urban metabolism studies because it addresses only one single issue (i.e. productive land consumption) (Beloin-Saint-Pierre et al., 2017; Musango et al., 2017).

Life cycle analysis (LCA) 'gathers information on the environmental impact of a product or service over its entire life cycle' (Fernández, 2014, p.13). LCA is rarely used in urban metabolism studies due to the complexity of urban metabolism systems and the difficulty of obtaining information on the start and end of an urban metabolism's cycle (Beloin-Saint-Pierre et al., 2017; Musango et al., 2017).

Furthermore, researchers developed new integrated methods by combining more than one method or adding social, environmental and sustainability indicators to assess the impacts of human interactions and activities on resource flows (Musango et al., 2017). As explained above, other methods mainly focus on resource flows overlooking these aspects. Such information is important to improve resource-efficiency that is highly dependent on human practices (Musango et al., 2017) and to assist policy and decision-makers in promoting appropriate strategies for the socio-technical change, which is crucial for sustainability transitions.

Urban nexus is another concept closely linked to the urban metabolism concept (Chen, B. and Chen, 2015). The nexus concept (particularly the Water, Energy and Food (WEF) nexus) is rooted in earlier integrated resource management concepts such as the Integrated Water Resource Management (IWRM) (Hülsmann et al., 2019). Urban nexus focuses more on understanding the linkages between energy and material flows, and conversion processes embedded in interconnected chains at various scales (including extraction, supply, distribution, end use and disposal) in order to achieve a sustainable city (Chen, B. and Chen, 2015). Instead of focusing on the challenges of an individual sectors of urban ecosystem (such as energy, water, land and carbon), the scope of urban nexus is on the dynamic interactions, uses systematic approaches to increase the efficiency of these interconnections within the whole urban system to ensure the sustainability of cities overtime (Chen, B. and Chen, 2015). For example, the energy-water nexus approach goes beyond a simple comparison between the energy consumption and water use of an urban system to an extensive understanding of water footprint of energy facilities and energy footprint of water infrastructures (Chen, B. and Chen, 2015). The nexus approach seeks to understand and assess interdependencies across different sectors at different scales to mitigate trade-offs and promote synergies in resource management (Hülsmann and Jampani, 2020).

Recent research shows that assessing resources consumption and production patterns have been addressed in many studies, however, understanding their ‘nexus’ did not receive the same attention until recent research and practice (Beck and Villarroel Walker, 2013; Chen B. and Chen, 2015; Kenway et al., 2011). Despite that the nexus approach provides more practical sustainable urban planning and management strategies (Chen, B. and Chen, 2015), the ecosystem perspective, which is a key element for sustainable resource management, has not been considered or addressed in previous or early nexus studies (Hülsmann et al., 2019). Hülsmann et al. (2019) suggest that the ecosystem services should be considered in urban nexus approach to predict systems resilience and the role of ecosystem services within these systems.

The ‘circular economy’ is another emerging concept that has gained the attention of scholars and practitioners, particularly in the world of industry and business, as a method to reduce the environmental impact of production and resource use (Harris et al., 2021; Kalmykova et al., 2018; Lucertini and Musco, 2020; Williams, 2019). A circular economy

> is an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models (Ellen MacArthur Foundation, 2013, p.7).

The circular economy is not a new concept, it draws on other concepts that were developed decades ago such as spaceman economy (Boulding,1966), limits of growth (Meadows et al., 2005), performance economy (Stahel, 2010), ‘cradle-to-cradle’ (Stahel and Reday-Mulvey, 1981) and industrial ecology (Frosch and

Gallopoulos, 1989) (Kalmykova et al., 2018; Williams, 2019). The circular economy aims to maintain the circulation of resources within the economy, reduce environmental degradation and the impacts of extraction, emissions, and disposal (Harris et al., 2021; Lazarevic and Valve, 2017; Williams, 2019). China was the first country to implement the principles of circular economy into the national policy and Europe is currently in the process of developing the circular economy concept to improve the economic and environmental performance of industries (Ellen MacArthur Foundation, 2015; Harris et. al, 2021; Kalmykova et al., 2018).

Despite that, there are currently many initiatives driven by governmental bodies, non-governmental organization and consultancy firms to implement the circular economy in order to address environmental challenges and promote a more sustainable economy, the concept is still lacking a common ground for the variety of existing approaches (Kalmykova et al., 2018; Lucertini and Musco, 2020). Additionally, products, materials and sectors are considered in circular economy implementation while system dynamics (urban ecosystem) are rarely addressed which is important to monitor changes over time and identify undesirable impacts of the implementation of circular economy (Kalmykova et al., 2018; Williams, 2019). The goal of a circular economy is to reduce the use of resources by applying a variety of strategies that have an impact on the whole system and other processes, if these strategies are chosen independently without any coordination among different sectors, negative effects may appear on the whole system and other sectors (Kalmykova and Rosado, 2015). Therefore, Kalmykova and Rosado (2015) suggest the use of a holistic approach, specifically urban metabolism analysis, for the design of a circular economy.

Urban metabolism analysis assesses the flow of materials, changes in consumption and production patterns over time, and assesses the effect of the system's characteristics (including social, economic, political, natural and biophysical conditions) on the flow of resources (Kalmykova and Rosado, 2015). Moreover, urban metabolism analysis identifies resources and materials that could be used more effectively in a circular economy (Kalmykova and Rosado, 2015). A circular economy is still in its early stages of development and it is mostly used in economic and production fields focusing on closed-loop industrial systems, and existing approaches are lacking key aspects that should be considered in order to apply circular economy to cities (Lucertini and Musco, 2020; Williams, 2019).

The advantages and disadvantages of existing resource management frameworks and approaches (as mentioned above) indicate that none of them provides an optimum or complete solution to address sustainability challenges. Each approach is employed for a specific purpose that is affected by the scope of the study or influenced by the researcher field of study. However, several authors from different disciplines highlighted that the analysis of urban metabolism is an important step towards sustainable urban development and resource management (Kennedy and Hoornweg, 2012; Kennedy et al., 2014; Pincetl and Bunje, 2009). Urban metabolism analysis provides the basic information required to conduct ecological footprint assessment (Pincetl and Bunje, 2009), for circular economy implementation (Kalmykova et al., 2018; Kalmykova and Rosado, 2015; Williams 2019) and for nexus approaches (Hülsmann et al., 2019). The urban metabolism framework is also well anchored in existing literature (Céspedes Restrepo and Morales-Pinzón, 2018; Kennedy et al., 2014) and it is a practical approach that allows quick uptake by cities and ease of continued monitoring (Kennedy et al., 2014). Furthermore, urban metabolism framework enables researchers to understand the conditions that created sustainability challenges in urban areas, as Jerneck et al. (2010) suggested that understanding these conditions is key for problem-solving research. Therefore, this study finds that the urban metabolism is the most suitable framework to address the research problem to enable the researcher to understand the system dynamics (Cairo Governorate, case study) and identify complex issues regarding sustainable resource management.

Céspedes Restrepo and Morales-Pinzón (2018) identified the limitations of the urban metabolism framework and existing studies that should be considered in future studies: 1) most previous studies focus on quantifiable aspects (such as resource flows) with minimal consideration to unquantifiable aspects (such as social, cultural, institutional and political aspects), 2) comparative analysis between different cities and regions is difficult due to the concentration of urban metabolism studies in specific countries, and 3) the debate on the sustainability of urban areas is not resolved, yet. As the urban metabolism approach considers that the sustainability of cities is based on reducing the use of non-renewable resources, increasing the use of local resources, reducing resource imports, reducing waste generation, improving the efficiency of resource flows, and favouring circular flows upon linear flows of materials (Acselrad, 1999; Yang et al., 2014). Other researchers argue that even if cities reach the maximum efficiency of resource consumption with minimum imports from other ecosystems, cities will never achieve unlimited growth in a world of limited resources (Kool, 2013; Meadows et al., 2005). Despite, these debates around urban metabolism and sustainability of cities, this study used the urban metabolism framework to identify deficiencies in resource management and evaluate the existing performance of the selected case study towards sustainable development and to provide baseline information that is required to assist policy and decision-makers in order to pinpoint opportunities for improvement towards sustainable development and achieving sustainable development goals. Additionally, this study customized an existing urban metabolism tool to overcome the limitations of existing approaches (this is explained in Chapter 3).

2.3.5 The urban harvest approach

Agudelo-Vera et al. (2012) developed the concept of ‘Urban Harvesting’ as a resource management concept build on the foundations of urban metabolism. At the core of ‘Urban Harvesting’ is the goal of improving the use of resources in cities by changing the linear flow of materials into circular flows. The concept considers cities not only as consumers of primary resources but also as producers of secondary resources (such as solid waste and wastewater), too. Additionally, secondary resources include the wasted quality of resources. Most of the resources’ networks in cities are designed to provide the highest quality of resources, which consumes a huge amount of energy and resources (Agudelo-Vera et al., 2012). However, the required quality of resources differs from one activity to another. Providing the same quality of resources for all activities means that some activities receive a higher quality of resources than what is actually required for their activities. Huge amounts of resources are wasted or the ‘quality losses in the system’ (Agudelo-Vera et al., 2012, p.4). To reduce these losses, Agudelo-Vera et al. (2012) suggested that the provided quality of resources should fit the exact quality that is needed for each activity. In addition, the wasted resources could be captured and fed back into the city to improve the flow of materials of cities by converting the linear flows into circular flows (Figure 2-12).

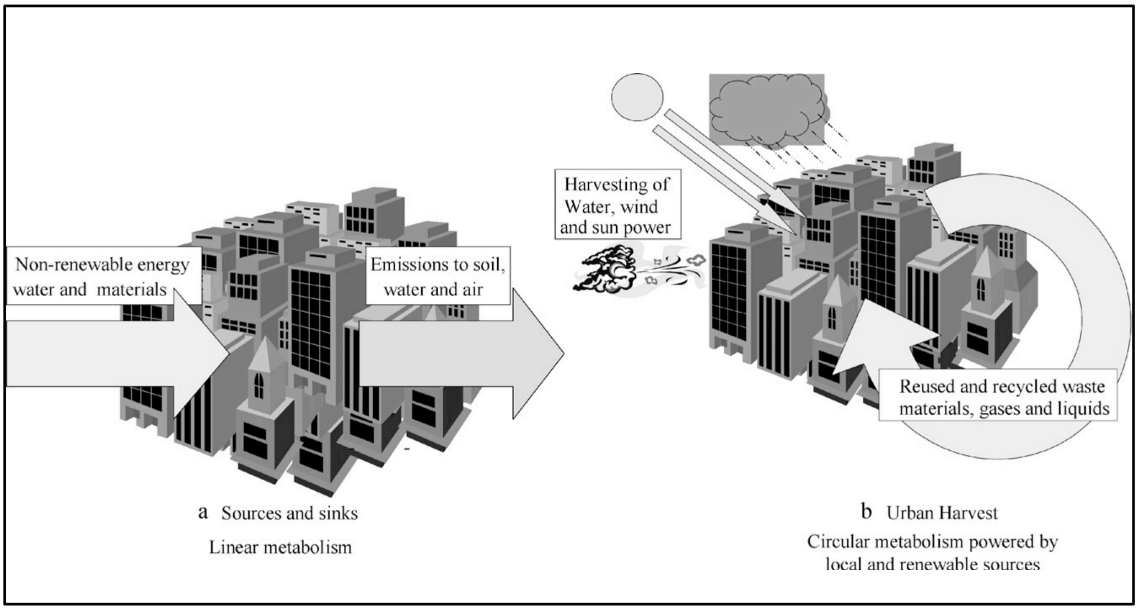


Figure 2-12: Linear vs. circular flow of materials (Agudelo-Vera et al., 2012).

Agudelo-Vera et al. (2012) developed four steps to close the metabolic flows:

1. Quantify the demand.
2. Try to reduce it as a first step.
3. Provide alternative sources.
4. Combine the supply and demand by harvesting the available resources.

To increase the use of local resources, Agudelo et al. (2009) presented four main harvesting strategies:

1. '<u>Multi sourcing</u>' by using both primary and secondary resources, such as renewable energy resources and capturing the rainwater.
2. '<u>Cascading</u>' by making use of the wasted quality in the system, such as using these losses in other activities that do not require high quality of resources.

3. '<u>Quality upgrading and recycling</u>' by treating the outputs of the system to reuse and feed it back into the system.
4. '<u>Quality upgrading and closing loops</u>' by improving the quality of existing systems without relying on non-renewable energy resources.

Agudelo-Vera et al. (2012) tested the water and energy flows at neighbourhood and national scale of the Netherlands to assess the applicability of the new resource management tool. Agudelo-Vera et al. (2012) explored the local flows and the available resources then proposed different scenarios to choose the best option. The local characteristics should be considered in such studies to enable researchers and urban planners to make better decisions (Agudelo-Vera et al., 2012). The outcome of the study shows the potential of using the urban harvest concept to maximize the use of local resources and transform cities into self-sufficient cities. Furthermore, providing a variety of resources will improve resources networks and make them more resilient.

Agudelo-Vero, Mels et al. (2012) introduced the "Urban Harvest Approach" (UHA) that was also based on urban metabolism concept. The main objectives of the proposed approach are to reduce cities' dependency on external resources and increase the use of local resources. To achieve these objectives, three strategies were developed: First, reduce the demand for resources; secondly, reduce outputs of cities; and thirdly, to provide alternative local and renewable sources. Local resources include secondary resources or output of cities such as solid waste. These resources could be used immediately without treatment or could be upgraded and fed back into the city. Agudelo-Vero, Mels et al. (2012) tested the urban harvest approach on a smaller scale than the previous study (at a neighbourhood and national level in the Netherlands). The urban harvest approach was used to investigate the water resources of two similar houses in different contexts: one in Netherlands and the other in Australia. The first step in such studies is to understand the urban metabolism of the case studies by quantifying and assessing the inputs and outputs. Agudelo-Vero, Mels et al. (2012) then applied the three strategies of the urban harvest approach. The outcome of the study showed that the use of water-saving technologies can have a great impact on the reduction of water demand. In addition, the use of secondary water resources (such as rainfall and greywater) met the required water demand. Agudelo-Vero, Mels et al. (2012) highlighted the importance of reducing demand for resources as a first step, then making use of the secondary resources whenever possible to reduce the consumption of primary resources. Moreover, multi-sourcing is vital to secure the stability of the urban metabolic system.

Leduc and Van Kann (2013) proposed a sustainable urban energy approach which includes both the concept of urban harvest and the interaction of urban functions (multi-functionality). This approach is used to explore the potential of harvesting local resources and the remaining qualities in an urban system to convert the linear metabolism into circular metabolism. Understanding the interaction between different functions of an urban system and integrating the industrial ecosystem with the urban ecosystem could provide more productive urban regions (Leduc and Van Kann, 2013). As Leduc and Van Kann (2013) suggested, multi-functionality (mixed used land) could be useful because not all sectors require the same level or quality of energy and resources. The industrial waste or the remaining quality of energy flows, for example, could be used in other industries or could be used to close the metabolic flows of the urban ecosystem. However, to be able to harvest the available resources within a system it is important to understand and improve the linkages between urban functions, reduce the distance between different functions, understand the supply and demand of each function within the urban system and provide adequate infrastructure to enhance the efficient and effective use of resources within industrial and urban ecosystems (Leduc and Van Kann, 2013). Leduc and Van Kann (2013) tested the new approach at a neighbourhood scale (Kerkrade-West, Netherlands). The method includes understanding the distribution of land use, the energy demand and supply, the linkages between different functions and the available resources. The outcome of the study indicated the potential of understanding the local characteristics of urban areas to maximize the use of local resources and reduce imports from other ecosystems.

Although urban metabolism and urban harvest are two important concepts for resource management and sustainability, many researchers have used urban metabolism to quantify and assess the flow of materials in cities, but because urban harvest is a relatively new concept, it is not widely recognized as urban metabolism. This research attempts to address this gap by using both concepts to identify deficiencies of resource management in Cairo Governorate and to explore the potential of harvesting local resources.

2.3.6 Urban metabolism: case studies

John et al. (2019) conducted a systematic review of urban metabolism studies that focused on the practical application of urban metabolism frameworks and approaches. This review included more than 220 case studies. The outcome of this review shows that most of the case studies are located in Europe (mostly in London, Vienna, Stockholm and Barcelona), followed by Asia (mostly for cities in China: Beijing and Shanghai), North America (Toronto and cities in the United States), and a few case studies are located in Africa, South America and Australia. The majority of these case studies followed a problem-oriented approach, were conducted at a city scale, and covered a defined period of time (John et al., 2019). Furthermore, a variety of frameworks were applied to explore the urban metabolism of the case studies with a considerable focus on material flows and stocks. John et al. (2019) shed light on the importance of increasing transdisciplinary research in the field of urban metabolism, specifically in the Global South, to bridge data gaps and to provide better-tailored solutions for urban sustainability.

The next section presents some of the practical approaches of the urban metabolism framework to explore the tools and methods that have been developed by scholars to study the metabolic flows of cities. The selection of case studies is based on their geographical location to show that these insights can be widely applied.

2.3.6.1 International: case studies (megacities and global cities)

Decker et al. (2002) explored the local, regional and global environmental impacts of resource consumption of the world's largest cities by examining the flow of materials (water, fuels, construction materials and food) of these cities. Although the world's largest cities have different characteristics (socioeconomic and biogeochemistry), high resource consumption is a common feature among these cities. Decker et al. (2002, p.377) described the world's megacities as ‘voracious’ due to the high resource consumption. However, resource consumption differs from one place to another based on the socioeconomic and biogeochemistry characteristics of cities. Understanding the characteristics of cities along with the flow of materials and the environmental impacts of megacities are essential to face the future challenges of rapid urbanization. Such studies are difficult due to the lack of standardized methods of data collection at a global level. Decker et al. (2002) outlined the importance of using urban metabolism as a unifying conceptual framework. The urban metabolism framework combines and arranges different types of data including the social, economic, environmental and biophysical characteristics of cities. Organizing these data removes the difficulty of assessing the flow of materials and the environmental impacts of cities that lead to a better understanding of the world’s megacities future challenges (Decker et al., 2002).

Kennedy et al. (2010) used the urban metabolism framework to develop equations to determine the greenhouse gas emissions of ten global cities. This study was driven by climate change and global initiatives to reduce greenhouse gas emissions. Identifying cities with less per capita greenhouse gas emissions is important to develop climate change strategies in different cities (Kennedy et al., 2010). The selection of the ten global cities was based on data availability (Los Angeles (County), Denver (City and County), Greater Toronto, New York City, Greater London, Geneva (Canton), Barcelona, Greater Prague, Cape Town and Bangkok). The study included greenhouse gas emissions from the following sectors: electricity, heating and industrial fuels, industrial processes, ground transportation, aviation, marine, and waste (Kennedy et al., 2009). Such studies are challenging because the methods of quantifying greenhouse gas emissions are inconsistent in previous published studies and the lack of reliable data on energy consumption and GHG emissions of cities. The results of this comparative study identified the factors that affect the quantity of GHG emissions of cities. The GHG emissions of cities differ from one place to another. This is based on the location, climate (energy required for heating or cooling), access to energy resources (specifically renewable energy), the density of cities, the availability of technologies to capture methane from the solid waste and other social and economic factors (Kennedy et al., 2009). Kennedy et al. (2009) suggested that cities with similar socio-economic and biophysical characteristics can adapt the same strategies for climate change.

Although studying the flow of resources and waste generation is crucial for urban sustainability, such studies are challenged by the difficulty of data collection and the complex structures of megacities (Kennedy et al., 2014). To overcome the complexity of studying the flow of resources in megacities, Kennedy et al. (2014) developed a multi-layered indicator set which focused on the data that can be easily collected. It includes layers of qualitative and quantitative data to measure the flow of materials. In addition, it assesses the quality of the infrastructure and the role of utilities through the provision of basic services. It is worth mentioning here that Kennedy et al. (2014) reviewed previous urban metabolism studies in megacities before establishing the indicator set and the outcome of this review showed that there were no previous urban metabolism studies of Cairo (see Table 2-4). One of the most important recommendations of Kennedy et al.'s study (2014) was that low and middle-income countries should fill this gap and start to quantify and assess the urban metabolic flows of their cities.

Table 2-4: Megacities as of 2010, with preliminary assessment of urban metabolism (UM) and greenhouse gas (GHG) studies (note: GHG studies are based on energy and waste flows) (Kennedy et al., 2014).

Megacity		Population (2010)	Notes
Tokyo	Japan	34,000,000	GHG studies conducted annually
Seoul	South Korea	24,200,000	Partial GHG study in early 2000s (Dhakal, 2004)
Mexico City	Mexico	23,400,000	GHG study for central city (8.7million) from 2000. (ELAC, 2000)
Delhi	India	23,200,000	Extended GHG study (incl. water and materials) by Chavez et al. (2012); early partial GHG study by Mitra et al. (2003)
Mumbai	India	22,800,000	UM study under way (Reddy, 2013)
New York City	USA	22,200,000	GHG studies of central city (8.2 million) conducted annually (also see Kennedy et al., 2009)
São Paulo	Brazil	20,900,000	GHG study from 2000 (SVMA, 2005) UM study for municipality (11.3 million; Hoornweg et al., 2012)
Manila	Philippines	19,600,000	UM study for metro region (11.6 million; Hoornweg et al., 2012); early partial GHG study by Mitra et al. (2003)
Shanghai	China	18,400,000	Corresponds to provincial boundary; good data; several GHG studies published (e.g., Dhakal, 2009; Li et al., 2009; Sugar et al., 2012; Chong et al., 2012)
Los Angeles	USA	17,900,000	UM study of LA county (9.5 million) by Ngo and Pataki (2008); large disaggregated UM study in

Megacity		Population (2010)	Notes
			progress www.environment.ucla.edu/ucpe/ GHG study by Kennedy et al. (2009)
Osaka	Japan	16,800,000	GHG studies conducted annually
Guangzhou	China	16,500,000	Megacity includes Foshan and does not correspond with provincial boundary. One published GHG study (Chong et al., 2012)
Kolkata	India	16,300,000	Early partial GHG study by Mitra et al. (2003)
Karachi	Pakistan	16,200,000	No studies found
Jakarta	Indonesia	15,400,000	UM study of central city (Hoornweg et al., 2012); GHG study published for central city (Sugar et al., 2013)
Cairo	Egypt	15,200,000	No studies found
Moscow	Russia	13,600,000	No studies found
Beijing	China	13,600,000	Corresponds to provincial boundary; good data; several GHG studies published. (e.g., Dhakal, 2009; Sugar et al., 2012; Chong et al., 2012); UM studies by Zhang et al. (2009) and Hoornweg et al. (2012).
Dhaka	Bangladesh	13,600,000	GHG study of central city conducted by ICLEI
Buenos Aires	Argentina	13,300,000	UM study for municipality (2.9 million; Hoornweg et al., 2012)
Istanbul	Turkey	12,800,000	No studies found
Tehran	Iran	12,800,000	No studies found
Rio de Janeiro	Brazil	12,600,000	GHG studies from 2005 (Dubeux and La Rovere, 2007) and 1998 (Rio Prefeitura Meio Ambiente, 2003), UM study for

Megacity		Population (2010)	Notes
			municipality (6.3 million; Hoornweg et al., 2012)
London	United Kingdom	12,400,000	GHG studies conducted annually for GLA (7.4 million; also see Kennedy et al., 2009); UM study for GLA in early 2000s (Chartered Institute of Wastes Management, 2002)
Lagos	Nigeria	11,800,000	No studies found
Shenzhen	China	10,400,000	No studies found
Paris	France	10,400,000	Published UM study (Barles, 2009)

The urban metabolism indicator set consists of four parts that merge quantitative and qualitative layers of information relevant to the physical flows of resources and wastes through megacities, as well as the social dimensions of such flows (see Table 2-5) (Kennedy et al., 2014).

Table 2-5: Layers of qualitative and quantitative information of the urban metabolism indicator set (Kennedy et al., 2014).

Layer 1	Definition of megacity (spatial boundaries; constituent cities; population; economy).
Layer 2	Biophysical characteristics (land area; urbanized area; climate; building gross floor area).
Layer 3	Aggregate urban metabolism parameters (consumption of energy [all types]; electricity sources; consumption of water; consumption of food and building materials; generation of solid wastes and wastewater).
Layer 4	Role of utilities (number and ownership of distributors and suppliers [electricity, natural gas, district heating or cooling, water, wastewater]; access to basic services [e.g., drinkable water, sewerage, waste collection]).

Kennedy et al. (2015) tested the indicator set to measure and compare the flow of materials of the world's 27 megacities. Data was collected from 2001 to 2011 to examine the changes in the flow of materials over a period of ten years. Quantifying energy and resource consumption of the world's megacities shows the huge amount of resources being consumed and waste generated in megacities (see Figure 2-13). The flows of materials differ from one city to another based on its characteristics. Comparing the flow of materials of the world's megacities enabled Kennedy et al. (2015) to identify the key challenges for each megacity based on its resource consumption and specific characteristics that affect its flow of materials.

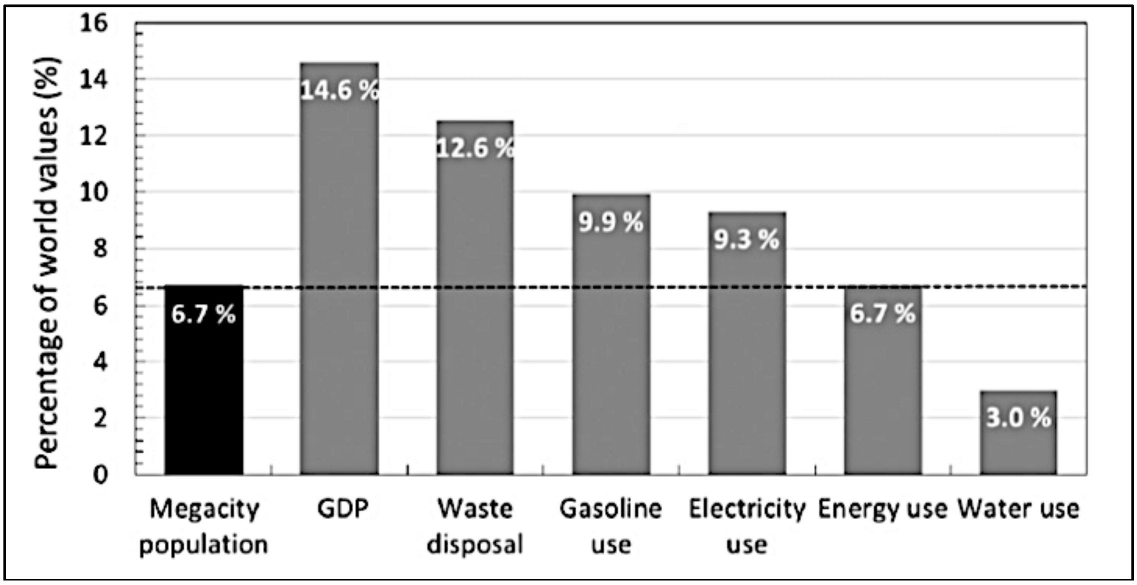


Figure 2-13: Megacity resource and waste flows as a percentage of world values (Kennedy et al., 2015).

Furthermore, Facchini et al. (2017) used the multi-layered indicator set that was developed by Kennedy et al. (2014) and the data that was collected by Kennedy et al. (2015) to compare the energy metabolism of the world's 27 megacities. Facchini et al. (2017) focused on energy metabolism to better understand the relationship between energy flows and different urban systems. The comparison included the sources of energy, energy consumption by sector, electricity generation mix, electricity consumption by sector and mobile energy (Figure 2-14).

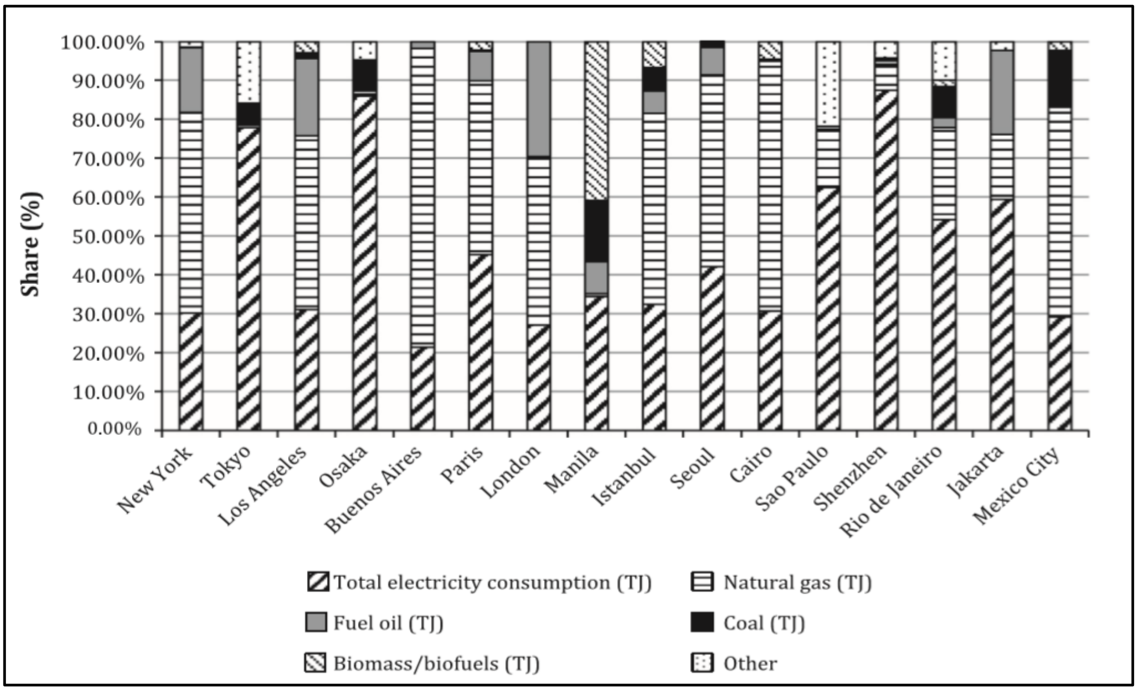


Figure 2-14: Share of different energy sources for end-use stationary energy consumption (Facchini et al., 2017).

Facchini et al. (2017) found that per capita energy consumption scales with urban population density, indicating that high-density cities (compact cities as mentioned in the study) are more energy-efficient than low-density cities (dispersed cities as used in the study). However, if the urban density exceeded 10,000 inhabitants per square kilometre the energy savings become less. This shows that cities with more than 10,000 inhabitants per square kilometre should develop other energy efficiency strategies. The study also revealed that the highest energy consumption is from the residential sector in most of the megacities that are located in developing countries (such as Cairo, Kolkata, Mumbai and Delhi). The energy consumption of the residential sector is expected to increase in the future due to more rapid urbanization in the developing countries. This requires the development of the energy strategies and replacing traditional fuels with other renewable sources of energy to meet the increasing demand for energy and to reduce the emissions of the residential sector.

Both Kennedy et al. (2015) and Facchini et al. (2017) used the multi-layered indicator set to better understand the urban metabolism and the flow of materials of the world's megacities. However, the multi-layered indicator set could be applied to other urban agglomerations, not only megacities (Facchini et al., 2017).

2.3.6.2 Developed countries: case studies

Codoban and Kennedy (2008) used urban metabolism as a framework to assess the sustainability of four neighbourhoods in Toronto. They excluded the construction materials of buildings and focused on the water, energy and food as inflows, and solid waste and wastewater as outflows. Codoban and Kennedy (2008) followed the five steps of the material flow analysis (MFA) to assess the inflows and outflows of the neighbourhoods. The five methodological steps of the (MFA) includes the following:

1. Definition of the scope and purpose of the study.
2. System description.
3. Data collection.
4. Material balances, modelling and scenario building.
5. Interpretation of the results.

The researchers provided a full description for the data collection as they mentioned that 'the biggest challenge of this study was to find reliable data' (Codoban and Kennedy, 2008, p.22). The data at the neighbourhood level was rare; they had to use multiple sources of data. Even when the Canadian data was not found they had to use data from other countries. By assessing the inflows and outflows of the four neighbourhoods, Codoban and Kennedy (2008) were able to identify deficiencies in the urban systems that affect sustainable resource management. They suggested reducing the use of energy and water and make it more efficient. In addition, they highlighted the importance of increasing the use of solid waste and wastewater to close the metabolic flows and to reduce environmental impacts.

Moles et al. (2008) employed the Metabolism Accounting and Modelling of Material and Energy Flows and Sustainable Development Index Modelling to assess the performance of 79 Irish settlements towards sustainable development. The aim of this study was to test the applicability of both methods, to compare the results and identify the most important characteristics of the selected settlements that influence sustainability. Moles et al. (2008) focused on the transport, energy, waste, water and food flows to assess the flow of materials in the selected settlements. The main purpose of assessing the flow of materials was to change the linear flows of materials to circular flows. Interestingly for this thesis, a questionnaire was developed to overcome the lack of data. Additionally, a huge amount of data was analysed for each settlement that was not practical (Moles et al., 2008). The outcome of this comparative study enabled Moles et al. (2008) to identify the main characteristics that have a great impact on the performance of the case studies towards sustainable development. These characteristics assisted Moles et al. (2008) to develop a set of 40 sustainability indicators divided into four main categories: transport; environmental quality; equity and quality which they found were the most important indicators for sustainability.

Barles (2009) tested the applicability of the material flow analysis (MFA) on a regional and urban scale in France. MFA is broadly used at a national scale, but not in developing countries (Barles, 2009). Barles (2009) suggested that it should be tested on a smaller scale to better understand the flow of materials and make better decisions to reduce the use of materials. Decisions were made all through the study based on the availability of data (quality and quantity) to conduct an adequate MFA study. At the beginning of the study, Barles (2009) chose Paris to test the MFA, then expanded her scope to take in not just Paris and its suburbs but also the greater region of Paris. Data was collected for the year 2003 due to its availability. Barles (2009) explained how she was able to obtain this data and whether it was available or not, in some cases, she had to make assumptions or used different sources to reach the most accurate data. Sharing this information with other researchers is important because one of the major challenges of MFA studies is the availability of accurate data. The outcome of this study shows that the flow of materials varies from one place to another based on its characteristics. These characteristics include the type of activities and the density of urban areas. In this study, the flow of materials in Paris was different from the surrounding suburbs and the greater region of Paris. Barles (2009) compared the results of the case study with other cities (Hamburg, Vienna and Leipzig), but the comparison was impractical because various methods were used to assess the flow of materials and the cities differed in size, density and other features.

The lack of data at the city level is a common problem in most of the material flow accounting MFA studies. To overcome the limitations of MFA studies, Niza et al. (2009) established a novel method that mostly relies on existing published data. An existing methodology, EUROSTAT (2001), that was originally designed to quantify material flows at a national level was customized to apply it on a smaller scale. The method was tested to quantify the material flows of Lisbon city for 2004. Niza et al. (2009) were able to calculate the material balance of Lisbon city and to examine the validity of the results they compared with other published data and compared the results with previous MFA case studies. This study shows how to make use of the existing published data, customize existing methods to fit in another purpose and make assumptions whenever required. Moreover, examining the efficiency of the new method by comparing the results with other similar case studies or other sources of data.

Most urban metabolism studies focus on assessing the flow of materials and ignore the resource demand of cities. Keirstead and Sivakumar (2012) outlined the importance of assessing the resource demand of cities to design and provide the equitable infrastructure that has a great impact on the efficient use of resources. Keirstead and Sivakumar (2012) employed activity-based modelling (land use and transportation, LUT) that was developed for Toronto to assess the electricity and natural gas demands in London. The land-use and transportation (LUT) approach is originally used to calculate the travel demand due to the land use changes by assessing individuals' activities within a study area. In the study, the same approach was employed to assess the resource demands. The model includes the following steps: case study definition, input data gathering, generate activity schedules and convert these schedules to resource demands (Keirstead and Sivakumar, 2012). This model requires a huge amount of data, in this study, the researchers used data on the travel behaviour of Toronto when London's data was not available. Despite the difference between London and Toronto, Keirstead and Sivakumar (2012) clarified that these differences were acceptable for the present analysis. The use of such models is not essential for all aspects of urban metabolism. However, Keirstead and Sivakumar (2012) recommended the use of activity-based modelling when the demand of specific resources is variable (such as energy) in order to design effective infrastructure.

Previous urban metabolism studies indicate that the flow of materials varies from one place to another based on the characteristics of each place. This shows that urban metabolism can be used as a tool to identify the environmental quality of urban areas (González et al., 2013). Urban metabolism was integrated into the impact assessment process to form a decision-support system (DSS). The DSS combines qualitative (environmental and socio-economic) and quantitative (components of the urban metabolism) data to enable decision-makers to evaluate the urban planning alternatives and development based on the impact of each alternative on the efficient use of resources and the environmental quality of urban areas (González et al., 2013). The DSS was developed by the European FP7 project BRIDGE (sustainaBle uRban plannIng Decision support accountinG for urban mEtabolism) and was tested on five European cities (Athens, Firenze, Gliwice, Helsinki and London). The size and scope of the five European cities were different based on their political priorities.

This study was different from other urban metabolism studies as it revealed the importance of studying the flow of resources and pollutants within cities and the impact of the urban planning and infrastructure on the efficiency of resource consumption and the outputs of cities.

Rosado et al. (2014) developed the urban metabolism model to overcome the lack of a unified methodology for material flow accounting (MFA) studies. The focus of this model was on quantifying the flow of materials and stocks from 2003 to 2009 and their correlation with the economic activities. This model includes types of materials, and economic activities and their drivers for resource consumption. Moreover, this model can only be used for material flow accounting studies within the European Union since it is based on the Eurostat standard statistical data for products to overcome the lack of reliable data. The proposed model was tested on Lisbon Metropolitan Area. Results of this study were compared with other MFA studies that used different approaches to validate the new model. This model is not suitable for material flow accounting studies in developing countries because a huge amount of data is required.

Sustainable urban development differs from one place to another as it depends on the local conditions of urban areas (Rosado et al., 2017). Urban metabolism also differs from one place to another. Understanding the drivers of resource consumption and the flow of materials in urban areas is important to identify the suitable strategies to achieve the sustainable development goals. Rosado et al. (2017) used the material flow accounting indicators to identify the urban metabolism characteristics of three different cities in Sweden (Stockholm, Gothenburg and Malmo). Drawing on Rosado et al. (2014)'s urban metabolism model, Rosado et al.'s study (2017) was based on the economic activities of the selected case studies. Data were collected from 1996 to 2011. Eight different urban metabolism characteristics were developed in this study (see Table 2-6). The main focus of these characteristics is to evaluate the resiliency of the selected case studies from an economic perspective. None of these characteristics included the environmental, social and biophysical conditions and the quality of the existing infrastructure, although they have a huge impact on the urban metabolism characteristics.

Table 2-6: The material flow accounting indicators to describe the urban metabolism characteristics (Rosado et al., 2017).

MFA indicators to describe urban metabolism characteristics.

Characteristics / *MFA indicators*	*DMC*	*NAS*	*DMI*	*IMP*	*DE*	*IP*	*EXP*	*DPO*	*Recovery*	*Combination*
1.1 Total Needs			■							
1.2 Final consumption needs	■									
2. Accumulation		■								
3. Efficiency	■								■	Recovery/DMC
4. Diversity of Processes					■	■				DE + IP
5. Support exogenous systems							■			
6. Dependency			■							IMP/DMI
6.1 Dependency from ROW			■	■						iIMP/DMI
6.2 Dependency from ROC			■	■						nIMP/DMI
7. Self-sufficiency	■	■			■					DMC-DE-NAS
8.1 Outputs to nature								■		
8.2 Depletion			■							non renewable DMI/DMI

Note: MFA: Material Flow Accounting; Direct Material Input (DMI), Imports (Imp), Domestic extraction (DE), Domestic Material Consumption (DMC), Net Addition to Stock (NAS), Industrial production (IP), Domestic Processed Output (DPO) and Recovery, International imports (iIMP) and Intranational Imports (nImp); Rest of the country (ROC) and Rest of the World (ROW)

Gonzalez-Garcia et al. (2018) developed a multi-criteria approach to evaluate the performance of 26 Spanish cities towards sustainable development. This approach includes three methodologies: Material Flow Analysis (MFA), Life

Cycle Assessment (LCA) and Data Envelopment Analysis (DEA). MFA, as previously explained, is a method used in urban metabolism studies to quantify the inputs and outputs of cities or urban areas. The life cycle analysis (LCA) is a method used to identify the environmental impacts of products. However, in this study, it is combined with the material flow analysis to quantify the direct and indirect environmental impacts of cities metabolism (Gonzalez-Garcia et al., 2018). Data envelopment analysis (DEA) is a linear programming methodology used to evaluate the relative efficiency of a set of comparable entities called decision-making units (DMUs) with multiple inputs and outputs (Cooper et al., 2007). The objective of this integration was to develop a new approach that integrates the urban metabolism components with the three pillars of sustainability; social, economic and environmental indicators to assess the sustainability of cities and categorize them based on the level of efficiency (efficient and inefficient cities). Data for this study were collected from 2005 to 2014. Results of such studies are intended to provide decision-makers with detailed scientific data that could improve the development of sustainable strategies and the efficiency of the urban metabolism of cities by addressing the environmental, social and economic indicators that reduce the level of efficiency of cities (Gonzalez-Garcia et al., 2018).

2.3.6.3 Developing countries and China: case studies

Previous urban metabolism studies indicate a relationship exists between land use and urban metabolism. Huang and Chen (2009) explored the relationship between the socioeconomic metabolism of Taipei and its urbanization. The emergy synthesis was employed to investigate the socioeconomic metabolism of Taipei. Emergy is defined as,

> all the available energy that is used, directly and indirectly, in making a product, expressed in units of one type of energy; transformity is the emergy of one type required to make a unit of energy of another type (Huang and Chen, 2009, p.78; Odum 1996).

Huang and Chen (2009) outlined the importance of the emergy synthesis to better understand the quality of energy material flows rather than simply measuring the inputs and outputs of materials. The emergy concept was used to explore Taipei urban areas and its surroundings; undeveloped forests and agricultural areas for years 1982, 1992 and 2002. Additionally, Huang and Chen (2009) used satellite images for Taipei from 1992 to 2002 to explore the land changes associated with the rapid urbanization of the city. The outcome of the study shows that urbanization had a great impact on the socioeconomic metabolism of Taipei. The increased demand for energy and other resources exceeded the capacity of the natural ecosystem. Most of the energy and material flows of the surrounding areas were directed towards Taipei. Huang and Chen (2009) highlighted that Taipei's economy is strongly tied by its surroundings and it is vital to reduce the urban sprawl in these areas to improve the performance of Taipei towards sustainable development.

Zhang et al. (2009a) compared three Chinese megacities: Beijing the capital of China, Shanghai and Guangzhou. The comparison was based on emergy analysis over a period of 15 years (from 1990 to 2005). The study considered the following perspectives for the emergy analysis: emergy intensity; resource structure; environmental pressure and resource use efficiency. Zhang et al. (2009a) presented the main characteristics of each case study by explaining its biophysical and geographical characteristics; economic and industrial structure; resource consumption and pollution. The emergy analysis in this study enabled the researchers to identify which megacity has the highest economic growth and to what extent this growth is dependent on fossil fuels or renewable energy resources, and which has the highest levels of pollution and environmental pressures. The results of the emergy analysis of the three megacities were compared with previous studies of Taipei and Macao. The comparison showed that the emergy analysis varies from one place to another based on the specific characteristics of each city. Additionally, Zhang et al. (2009a) indicated that the deindustrialization and economic reconstruction of China have a great impact on the urban sustainability that should be considered in the future.

Zhang et al. (2009b) presented a new method that combined emergy analysis with ecological network analysis to explore the structure and function of the urban metabolic systems. Emergy analysis was used to quantify eco-flows (materials, energy and currency flows). Zhang et al. (2009b) preferred to use this method that was originally developed by Odum (1996) because it transfers all the quantities to one unifying unit, the solar emjoule (sej). An ecological network model was developed to assess the ecological relationships between the five basic components of an urban metabolic system that were identified in this study. These five components are: the internal and the external environment, the agricultural, industrial and domestic sectors. The proposed method was tested on four Chinese cities (Beijing, Shanghai, Tianjin and Chongqing). The results of study indicated the importance of exploring the relationships between the structure and function of an urban metabolic system rather than focusing only on quantifying the inputs and outputs of the flow of materials.

Yang et al. (2012) used the emergy synthesis framework to explore the use of resources and the environmental impact of their case study, Xiamen. To study the urban household metabolism of Xiamen, two different areas were selected. The first is a highly urbanized island in Xiamen and the other is less urbanized. Data were obtained from the Statistical Yearbook of Xiamen, questionnaire surveys and face-to-face surveys with well-informed respondents of the inflows and outflows of the selected areas. Results were compared using the urban spatial conceptual framework. The urban spatial conceptual framework was presented in previous studies to explore the environmental impacts of urban areas. It divides the urban areas into the Urban Sprawl Region (USR) and the Urban Footprint Region (UFRs) (Yang et al., 2012). The integration of the emergy synthesis framework and the urban spatial conceptual framework enabled the researchers to compare the efficient use of resources and the environmental impacts of both urban areas. The findings of the study show that urban household metabolism varies from one place to another. It is highly affected by the urban and social context. Yang et al. (2012) indicated that changing the behaviour and lifestyle of households could improve urban sustainability.

Miller et al. (2013a) quantified the end-use energy intensity (EUEI) and the greenhouse gas emissions of the water and wastewater infrastructures in India. They then calculated the share of the water and wastewater infrastructures to the total urban energy metabolism of the Indian cites. Additionally, the EUEI and the greenhouse gas emissions of the Indian cities were compared with cities in the

United States. All through the study, Miller et al. (2013a) demonstrated the lack of data and how it influenced their work, for example, water data did not include the quality of water and the type of treatment, the distance and pressure required to pump water from the water treatment plants to other places, all these factors will have a great impact on the energy consumption and GHG emissions in the water sector. Miller et al. (2013a) noted that it was the first study to quantify the end-use of energy intensity for the water and wastewater sectors for rapidly industrializing cities. The outcome of the study shows that the water and wastewater infrastructures have a considerable share of the urban energy metabolism of the Indian cities. The authors highlighted the importance of such studies in the future to improve infrastructure and to reduce greenhouse gas emissions.

2.3.6.4 Africa: case studies

By 2050, most of the rapid urbanization will be in Africa and Asia. African countries are being challenged by urbanization, limited resources and the impacts of climate change. Existing sustainable development studies do not consider the impacts of urbanization on the increasing demand for resources (Currie and Musango, 2017). Furthermore, many of the existing development strategies in Africa are ineffective because they are not based on a scientific background (Currie and Musango, 2017). Currie and Musango (2017) highlighted the importance of conducting urban metabolism studies for African cities to explore resource flows. These studies enable a better understanding of the local characteristics and promote sustainable development strategies that fit in the African context (referring to the informal settlements and informal economy) rather than following the same approaches of the developed nations. In general, most of the existing urban metabolism studies are for cities in developed nations and there are few studies for cities in developing countries due to the limited research capacity and funding (Currie and Musango, 2017). The major challenges of the urban metabolism studies in Africa are the lack of reliable data at the city level, the methods of data collection are inconsistent and the complexity of tracking the flow of resources in informal settlements (Currie and Musango, 2017).

Currie and Musango (2017) employed the urban metabolism approach to explore resource consumption (water, fossil fuels, biomass and electricity) and carbon dioxide emissions of 120 African cities. Unlike previous urban metabolism studies that measured resource consumption of cities over a period of time, data for this study were collected for the year 2010 only. To overcome the lack of reliable data at a city level, the data was estimated (scaled down) from the national resource data. Then cities were categorized into ten different groups based on their resource consumption and carbon dioxide emissions to determine the priorities of resource development strategies. As some cities will need to focus on resource efficiency strategies and other cities will need to focus on increasing resource access and the per capita resource consumption. It is worth noting here that the results of Currie's and Musango's study (2017) shows that Cairo[7] had the highest annual total resource consumption compared to the rest of Africa's cities. However, the resource consumption per capita of Cairo was less than other cities, but it is still considered high due to its large population (Figure 2-15).

[7] Cairo refers to Greater Cairo Region in Currie's and Musango's study (2017).

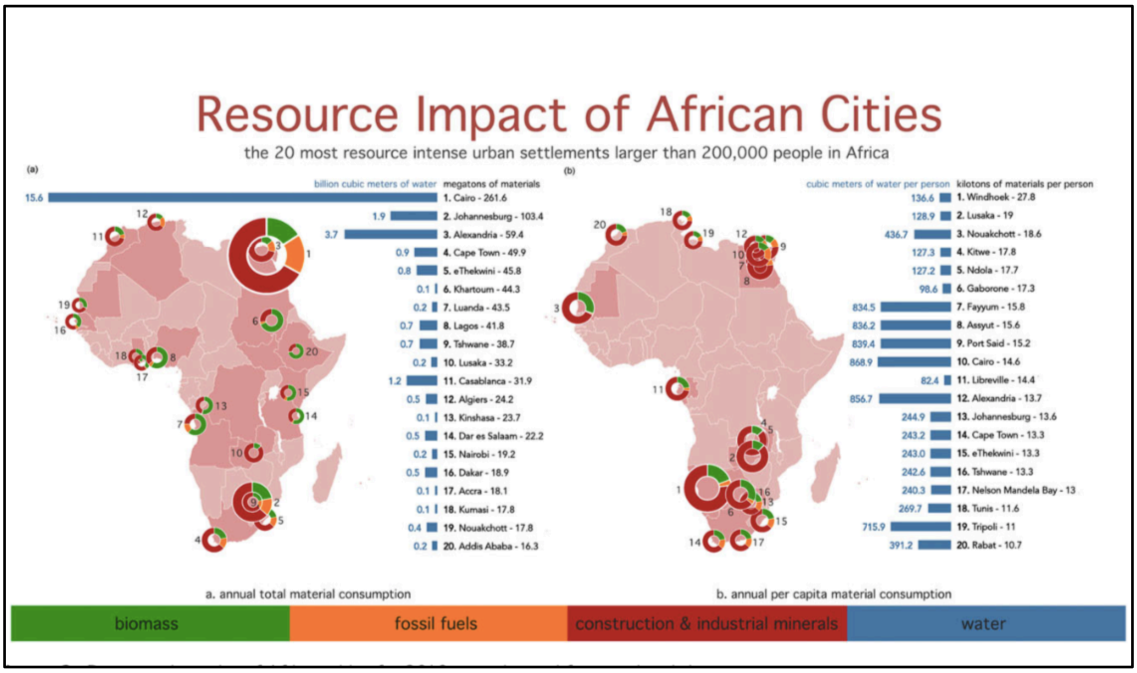


Figure 2-15: Resource intensity of African cities for 2010 as estimated from national data (Currie and Musango, 2017).

Hoekman and Blottnitz (2017) modified the Eurostat framework to explore the urban metabolism of Cape Town, South Africa. The Eurostat framework was previously used to explore the urban metabolism of the European countries so in this study it was modified to fit in the African context. Data for this study were collected for the year 2013 only, unlike previous urban metabolism studies. Like many other researchers, Hoekman and Blottnitz (2017) shed light on the absence of a standardized methodology for urban metabolism studies. Although new urban metabolism approaches target the available data to reduce the time and effort for data collection, Hoekman and Blottnitz (2017) described the difficulty of the data collection process in this study. They pointed out that the quality of data for resource flows are significantly different. Hoekman and Blottnitz (2017) described the data that is monitored by the government is considered as high-quality data. However, this data is inaccessible as it is only provided upon request. The urban metabolism of Cape Town was compared with other cities in Europe that have used the same framework and two previous studies in the Global South that used different methodologies. The outcome of this comparison with European cities indicated that resource consumption of European cities (such as Paris) is higher than Cape Town. This was previously explained in this chapter as the level of resources accessibility is higher in developed countries than in developing countries. The quality of infrastructure and economic and industrial development also requires more resources that is higher in developed countries than in developing countries. Hoekman and Blottnitz (2017) suggested for future urban metabolism studies that the inequality of resource consumption (high and low-income residents) should be considered, the resource flows should be assessed for longer periods of time to identify the patterns of resource consumption and finally increase the data publicly.

The lack of reliable data is a common problem in urban metabolism studies all over the world, specifically the flows of food, materials and informal goods (Currie et al., 2017). This problem also exists in the flows of water and energy in the Global South (Currie et al., 2017). The lack of data has a huge impact on the number of urban metabolism studies in the Global South compared to other studies in the Global North and China. Since most urbanization is expected to be in the Global South, and there is a substantial need for such studies. Previous urban metabolism studies vary from simple urban metabolism assessments to more complicated and in-depth analysis that is based on data availability. Currie et al. (2017) employed a simple urban metabolism assessment to explore the resource consumption of Cape Town. The urban metabolism approach in this study is based on an existing multi-layered indicator set that was developed by

Kennedy et al. (2014). The flows of people, housing and transportation and the climate change risks in Cape Town were added in this study. The climate change risks in Cape Town are an important indicator to develop adequate climate change adaptation strategies. The flow of people affects the metabolism of cities and identifies the daily resource requirements (Currie et al., 2017). The transportation sector determines the use of energy and greenhouse gas emissions. Data for this study was collected from secondary data resources (available information and previous studies on Cape Town). Like many other African cities, 21% of Cape's Town households live in informal settlements with minimal access to basic services (water, electricity, sanitation and waste collection) (Currie et al., 2017). Currie et al. (2017) presented the challenges of the water, energy, food, housing, solid waste and transportation sectors and suggested the following intervention opportunities for each flow as presented in Table 2-7. Furthermore, Currie et al. (2017) explained that the concept of nexus suggests that any changes occurring in the flow of one of the resources will have impacts on other flows and that all resources are interlinked. This leads to the need of an integrated approach for resource management and infrastructure development (Currie et al., 2017).

Table 2-7: Intervention opportunities for both internal and relational sustainability in Cape Town developed by (Currie et al., 2017).

Intervention opportunities for both internal and relational sustainability in Cape Town.

Flow	Intervention options for improving	
	Internal sustainability	Relational sustainability
Water	Improved access to clean water and sanitation will improve health, productivity and lifestyle among the underserviced	Water reuse, either through greywater application or tertiary wastewater treatment will reduce reliance on water catchments for raw water and improve resilience to drought
Energy	Improved access to safe and clean energy will improve productivity and lifestyle among the underserviced	Locally augmenting the electricity grid with renewable electricity will reduce embodied carbon and water footprint
	Reducing the quantity of energy expended on transportation through extension of public transport and dis-incentivisation of single-occupancy vehicles	
Food	Promoting urban agriculture will improve local resilience and can be used as a nutrition literacy tool if coupled with public space development	Reclamation of nutrients from wastewater systems and organic solid waste to enrich soils will reduce the need for importing fertilizers.
Solid waste	Changing the valuation of waste streams enables a shift from a landfill-based waste management system	Effective waste-management systems will reduce biophysical damage caused through leakage
	Facilitating industrial symbiosis between industries improves the efficacy of waste products	
Housing	Investment in low income areas, focused on delivery of bulk infrastructure, as well as community-led upgrading of informal settlements, to ensure retention of economic livelihood, will address the patterns of hypersegregation in these areas and encourage further investment therein	Estimating the future housing demand and population growth in the city will inform all other resource needs and impact of the city
Transportation	Reduction of single-occupancy private vehicles on roads will reduce the congestion which unjustly slows and blocks formal bus systems and informal taxi systems	Transport behavior patterns that reduces the amount of cars of the road will improve the energy and carbon footprint of the city
	Investment in industry and commerce in multiple nodes or industrial corridors across the city will reduce the need for distance transportation for employment	

2.3.6.5 Egypt: case studies

The Greater Cairo Region was part of urban metabolism comparative studies for the world's megacities. Some other cities in Egypt including the Greater Cairo Region were part of an urban metabolism comparative study for some African cities. After reviewing urban metabolism studies, the author found that there is only one published (conference proceedings) study that focused on the Greater Cairo Region. Attia and Khalil (2015) employed the urban metabolism approach (material flow analysis) to assess the flow of water and the quality of the water service in Imbaba district, one of the largest informal areas in the Greater Cairo Region, Egypt. This was part of their study to assess the quality of life in Imbaba. The case study, Imbaba district is an informal unplanned settlement that spread illegally on agricultural land and accommodates more than 1 million inhabitants (Attia and Khalil, 2015). Students from Cairo University were trained to use the geographic information system (GIS) and the urban metabolism information system and public participation techniques to facilitate the bottom-up data collection. Local non-governmental organizations (NGOs) and community-based organizations (CBOs) also participated in the field study. Students, local NGOs and the CBOs were able to engage Imbaba residents in roundtable discussions to gain better understanding of their priorities and concerns of the water services. At the same time urban data (land uses and building characteristics) was collected to produce GIS maps and water samples were collected to assess the water quality. The analysis of the flow of water in Imbaba indicates that the local conditions and the aging infrastructure have a huge impact on water quality. As the quality of the tested water samples from the water facilities and the Nile intake were better than the water quality in Imbaba (Attia and Khalil, 2015). This study reveals the importance of understanding the local conditions to provide affordable and suitable solutions with minimal technological capacities for maintenance (Attia and Khalil 2015). Additionally, this study sheds light on the role of the non-governmental organizations to increase the public participation in informal areas to facilitate the data gathering on resource consumption which is considered a huge challenge for urban metabolism studies in informal areas and where data is limited.

2.5. Conclusion:

Resource management has become crucial for urban sustainability in the Global South, where most future urbanization will take place. The existing literature shows that there is already extensive deployment of urban metabolism as a concept in the Global North and China. A variety of methods and tools have been developed and employed by researchers to assess the flow of materials of urban areas at different scales. The common outcome of those studies shows that measuring and assessing the flow of materials enables a better understanding of the challenges of resource management. Urban metabolism studies identify the deficiencies in urban ecosystems that affect the use and flow of resources that can have a great impact on the directions of future decisions for urban and infrastructure planning.

Early urban metabolism studies started with a simple assessment of the inputs and outputs of case studies. Then researchers developed new tools and approaches that transformed the urban metabolism framework into an integrated approach to better understand the physical (such as resources flows, infrastructure and quality of services) and socio-economic characteristics that affect the inputs (primary resources, such as renewable and non-renewable resources) and outputs (secondary resources, such as solid waste, wastewater and carbon dioxide emissions) of urban areas.

Most of the previous urban metabolism studies focused on developing a new tool and testing it on a case study then compared the results with other case studies. Moreover, some researchers used existing tools that were previously developed by other scholars and applied them on new case studies. This shows that despite the increasing interest in the field of urban metabolism research, it is still lacking a unifying framework that could be applied worldwide to conduct comparative studies.

Multiple sources of data are required for urban metabolism studies. The major challenges to urban metabolism studies are the lack of reliable data at a city level, this is a common challenge in developed countries (rich data) and developing countries (poor data). For the Global South, this is not the only challenge; the informal context of urban areas ends up with informal flow of materials and resources which makes it difficult to track these resources and the methods of data collection are inconsistent.

Data availability has a great impact on researchers' decisions all through urban metabolism research, starting with the research approach, design and methods. The reviewed literature shows a variety approaches and tools that have been employed in urban metabolism studies. Some of these tools were successfully tested in the Global North, however due to the lack of reliable data and the informal areas these tools cannot be used in the Global South.

The existing literature on urban metabolism shows a huge gap for such studies in the Global South apart from China. This gap is addressed in this thesis by employing the urban metabolism framework to explore the challenges of resource management for urban sustainability in the Global South. The selected case studies were Cairo Governorate (the capital of Egypt) and the surrounding Governorates Giza and Qalyubia. The study customized an existing urban metabolism tool, the multi-layered indicator set that was developed by Kennedy et al. (2014). Due to the lack of reliable data and the informal context of some areas in the selected case studies, the most suitable tool was the multi-layered indicator set as it targets data that could be practically collected. It was previously tested in different contexts (the world's megacities). The study is also informed by a number of semi-structured interviews with members from public authorities and site visits (low, medium and high-density settlements). The interviews and the site visits were added to the multi-layered indicator set to overcome the ambiguity of the urban metabolism "black box" approaches and to consider other unquantifiable aspects aiming to gain better understanding of the challenges of resource management in Cairo Governorate.

3 Chapter Three: Methodology

This chapter focuses on the research design and approach to explore the challenges of resource management for urban sustainability in the Global South.

3.1 Research design and approach

3.1.1 Convergent mixed methods case study design

The literature review in Chapter 2 indicated that urban metabolism is an integrated approach that has been applied to better understand resource management. Most previous studies of urban metabolism employed the framework to measure and assess the flow of materials of a selected case study or to conduct comparative studies for a number of case studies. The outcome of these studies shows that urban metabolism studies should not be limited to measuring the inputs and outputs (primary and secondary resources) of cities. Understanding the environmental, social and economic and biophysical characteristics of cities enables researchers to develop sustainable strategies for resource management that fit in the characteristics of individual cities where these strategies are being implemented. In this study, to better understand the complex issues in resource management of Cairo Governorate, the research was guided by a mixed methods case study design. Mixed methods research combines qualitative and quantitative methods in one study to collect multiple forms of data that leads to a better understanding of the research problem and questions (Creswell, 2014). Johnson et al. (2007, p.123) defines the mixed methods research as,

> Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the breadth and depth of understanding and corroboration.

A mixed methods case study is a type of complex mixed methods design where both qualitative and quantitative data are collected from multiple sources, analysed and the results are merged to gain a better understanding of a case study (Creswell and Plano Clark, 2017). A mixed methods case study designs provide a better understanding of complex case studies (Creswell and Plano Clark, 2017; Luck et al., 2006; Plano Clark and Ivankova, 2016). The use of mixed methods case study designs also provides a detailed level of description that presents a practical understanding of the case study (Creswell and Plano Clark, 2017). To gain an in-depth understanding of the complex issues regarding resource management in Cairo Governorate the research utilized two principal data gathering methods: 1) a quantitative data collection to fill an existing multi-layered indicator set; and 2) qualitative interviews with representatives from public authorities and site visits to explore the drivers and barriers to resource management. The research involved collecting and analysing existing published quantitative data and used social science methods to collect qualitative data, principally through semi-structured interviews.

In this study, the convergent approach was used to implement the mixed methods case study design (see Figure 3-1). The convergent approach includes the following procedures:

- Both qualitative and quantitative data are collected in parallel using the qualitative data collection approaches and quantitative data collection approaches.
- Qualitative and quantitative data are analysed separately using the qualitative data analyses approaches and quantitative data analyses approaches.
- Quantitative and qualitative results are merged to find out whether they confirm or disconfirm each other.
- The merged results are interpreted (Creswell, 2014; Creswell and Plano Clark, 2017).

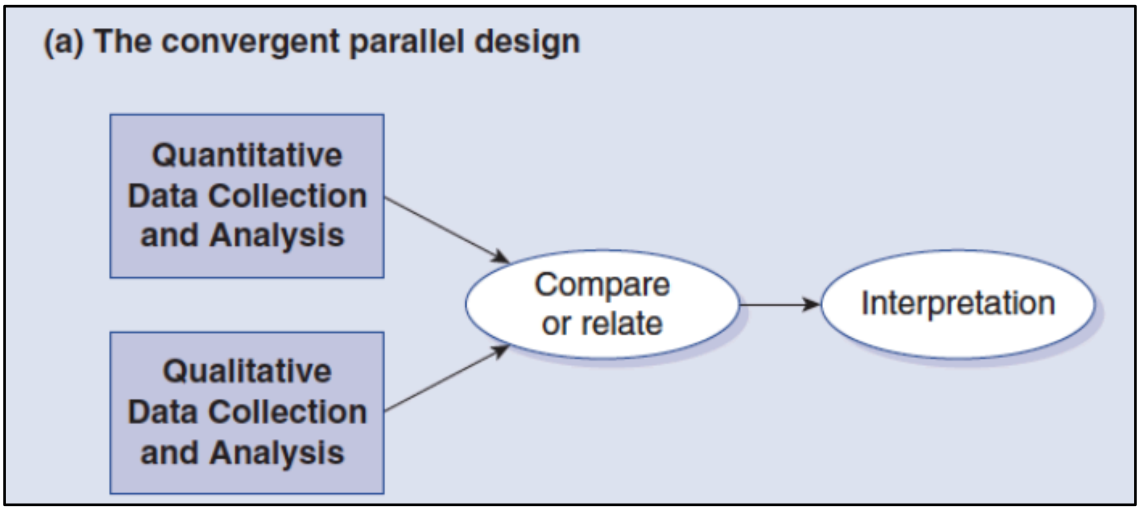


Figure 3-1: Convergent parallel mixed methods design (Creswell, 2014).

In this study, the quantitative data and the qualitative data were collected and analysed separately. Then the results of the quantitative data and the qualitative data were merged and presented in Chapters 4, 5, 6 and 7. The purpose of this integration was to better understand the research problem (depth and breadth of the complex issues regarding the resource management in Cairo Governorate and the surrounding governorates). Figure (3-2) shows the research approach and design for this study, this is followed by an in-depth explanation for each step.

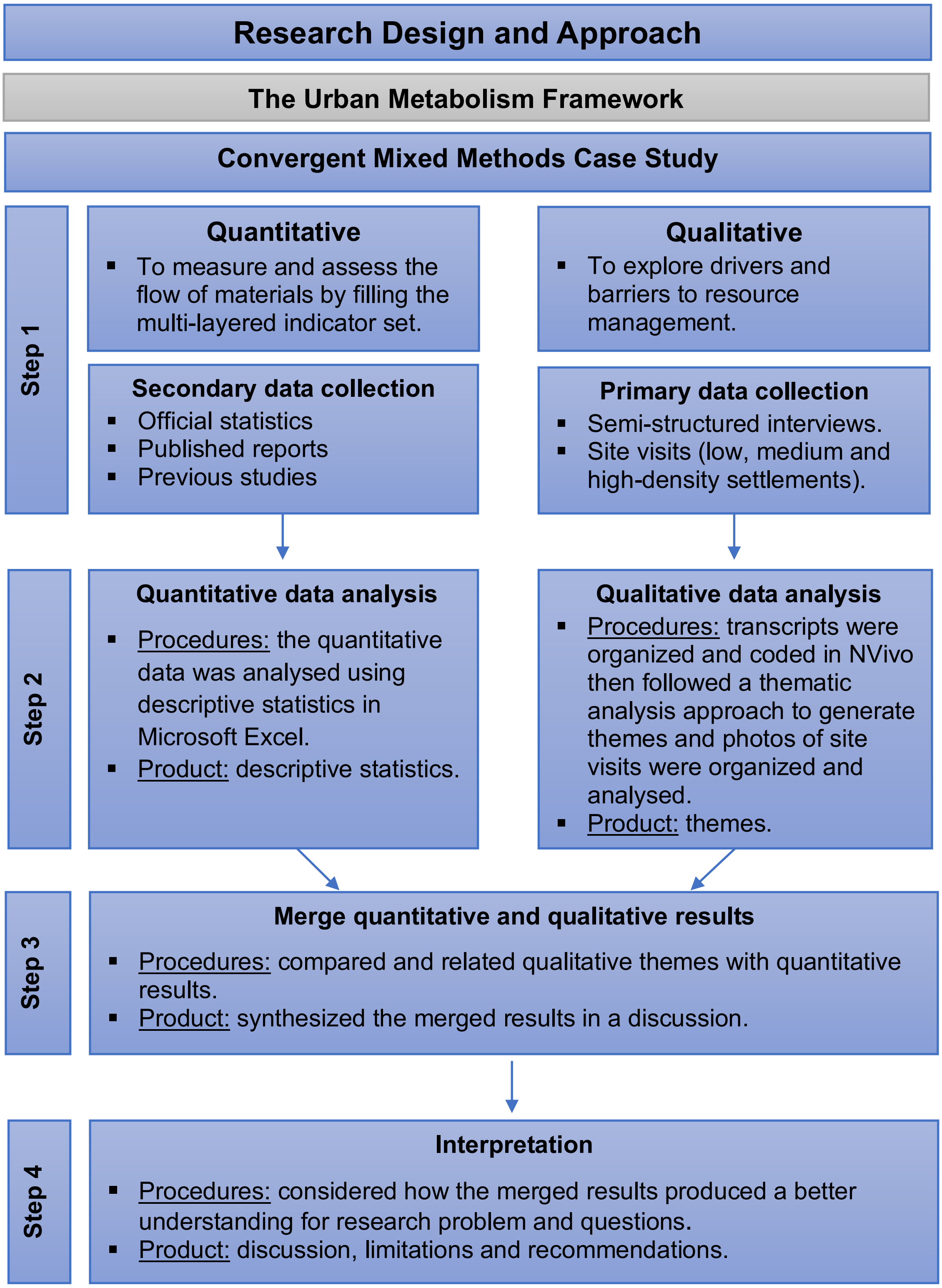


Figure 3-2: Research design and approach for this study, adapted from Creswell and Plano Clark (2011).

3.1.2 Quantitative data collection

(Linked to answering research questions 1, 2 and 3, see Chapter 1)

This research used an existing urban metabolism tool, the ‘multi-layered’ indicator set. The indicator set was developed by Kennedy et al. (2014) to collect data on spatial boundaries, constituent cities, population, economy, biophysical characteristics (climate, population density, building floor area), and metabolic flows (water, waste, materials, and all types of energy) of megacities. It also addresses the role of utilities in the provision of services and regulatory actions that, along with public governance, may influence the flow of materials (Kennedy et al., 2014). This ‘multi-layered’ indicator set guides the collection of data that can be used for the comparison of material flows of cities (the form of data collection is provided in Appendix 1).

Although there are many urban metabolism tools that were successfully employed to assess the metabolism of cities (outlined in Chapter 2) the most suitable tool for this study was the multi-layered indicator set that was developed by Kennedy et al. (2014) because it targets data that could be practically collected. Other urban metabolism tools are more complicated and require data that is usually unavailable for cities in the Global South. The lack of reliable data is a common problem in developing countries (see Chapter 2). Moreover, I compared the data that is required to fill in the multi-layered indicator set with other urban metabolism tools. I found that the required data could be obtained by minimal customization to the existing multi-layered indicator set based on my personal experience.

Before testing the multi-layered indicator set in Cairo Governorate, the existing tool was customised by excluding or adding information and collecting data from multiple sources. This was an essential procedure to overcome the difficulty of tracking the flow of materials and the lack of reliable data at the city level in developing countries (see Chapter 2).

In this study, the quantitative approach was used to collect numerical data and relevant information to fill in the multi-layered indicator set. The data was collected for Cairo Governorate. To understand the challenges of Cairo Governorate, the same data was collected for the surrounding Governorates of Giza and Qalyubia. Cairo Governorate and the urban parts of Giza and Qalyubia are the constituent cities of Greater Cairo Region that is considered one of the largest megacities in Africa (Kennedy et al., 2015). Additionally, it was important to compare the data of the three governorates with the whole country to ascertain and quantify, where possible, specific challenges and differences. The data for Cairo, Giza and Qalyubia Governorates and the whole country Egypt was collected from 2000-2001 to 2016-2017. The data was collected for more than 15 years to identify the patterns of resource consumption and production over the years and to overcome the lack of accurate data in some situations. In some situations, data were excluded if it appeared inaccurate and in other situations the quality of the published reports was poor and the data was not clearly presented so the reports for specific years were excluded and replaced by other years (further explanation is provided in Chapters 4, 5, 6 and 7 and Appendix 12).

The focus of data collection for the multi-layered indicator set was on population growth, biophysical characteristics, and the metabolic flows of the selected case studies and the access to basic services. The metabolic flows focused on the flows of water, energy and electricity as examples of inputs of cities and the flows of wastewater and solid waste as examples of outputs of cities. The purpose of this selection is to provide a baseline for future urban metabolism studies in Egypt and for cities that have similar characteristics in developing countries.

<u>The quantitative data was collected from the following secondary data resources:</u>

- Official statistics.
- Published reports.
- Previous studies.

Official statistics were taken from reports published by the government that include data on the population, GDP (Gross Domestic Product), primary energy resources, energy mix, electricity consumption, waste generation, treatment and collection percentages, and so on. The official statistics, published reports and previous studies that were used in this study to obtain data on the population, economy, the biophysical characteristics, energy, electricity, water, wastewater and solid waste for Egypt and Cairo, Giza and Qalyubia Governorates are presented in Table 3-1. The reasons for selecting or excluding specific reports are explained in depth in Appendix 12.

Table 3-1: Sources of secondary data collection for each sector.

Data	Sources of secondary data
1. Population, economy and the biophysical characteristics	▪ Abdel-Shafy, H., El-Saharty, A., Regelsberger, M. & Platzer, C., 2010, Rainwater in Egypt: quantity, distribution and harvesting, *Mediterranean marine science,* vol. 11, no. 2, pp. 245-257. ▪ CAPMAS 2017d, *Population, Housing and Establishment Census, Egypt Census 2017,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2019, *Current Population* [Homepage of Central Agency for Public Mobilization and Statistics] [Online]. Available: https://www.capmas.gov.eg/HomePage.aspx [Accessed: 2 February 2019]. ▪ CAPMAS 2018d, *Egypt Statistical Yearbook 2018,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2017f, *Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2016a, *Egypt Statistical Yearbook 2016,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2012b, *Egypt in Figures 2012,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2011a, *Egypt in Figures 2011,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2009, *Egypt in Figures 2009,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2007a, *Egypt in Figures 2007,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2006a, *Egypt in Figures 2006,* Central Agency for Public Mobilization and Statistics, Egypt.

- CAPMAS 2003a, *Egypt in figures 2002,* Central Agency for Public Mobilization and Statistics, Egypt.
- DTU, 2018a, *Global Wind Atlas, Arab Republic of Egypt* [Homepage of The World Group Bank] [Online]. Available: https://globalwindatlas.info/en/area/Arab%20Republic%20of%20Egypt?print=true [Accessed: 23 February 2019].
- DTU, 2018b, *Global Wind Atlas, World* [Homepage of The World Bank Group] [Online]. Available: https://globalwindatlas.info/en/downloads/World [Accessed: 24 February 2019].
- FAO 2016, *AQUASTAT Country Profile- Egypt*, Food and Agriculture Organization of the United Nation (FAO), Rome, Italy.
- GOPP 2012, *Greater Cairo Urban Development Strategy, Part 1: Future Vision and Strategic Direction*, The General Organisation for Physical Planning, Egypt.
- IMF 2019, *World Economic Outlook (October 2019) - Unemployment rate* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/external/datamapper/LUR@WEO [Accessed: 30 March 2020].
- IMF DataMapper 2018a, *Country Data, Egypt* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/en/Countries/EGY [Accessed: 13 February 2019].
- IMF DataMapper 2018b, *World Economic Outlook, People, Unemployment Rate* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/external/datamapper/LUR@WEO/ADVEC/EGY [Accessed: 13 February 2019].
- MPMAR, 2019, *Economic Indicators- GDP* [Homepage of Ministry of Planning Monitoring and Administrative Reform] [Online].

	Available: http://mpmar.gov.eg/ [Accessed: 8 February 2019]. ▪ Solargis 2017a, *Global Solar Atlas, Egypt* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/downloads/egypt [Accessed: 23 February 2019]. ▪ Solargis 2017b, *Global Solar Atlas, World* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/downloads/world [Accessed: 24 February 2019]. ▪ The World Bank 2019a, *Average precipitation in depth (mm per year)* [Homepage of The World Bank Group] [Online]. Available: https://data.worldbank.org/indicator/ag.lnd.prcp.mm?view=map [Accessed: 22 February 2019]. ▪ The World Bank 2019b, *DataBank World Development Indicators* [Homepage of The World Bank Group] [Online]. Available: https://databank.worldbank.org/data/reports.aspx?source=2&series=NY.GDP.PCAP.CD&country=EGY [Accessed: 9 February 2019]. ▪ The World Bank Group 2018, *Global Wind Atlas* [Homepage of The World Bank Group] [Online]. Available: https://globalwindatlas.info/ [Accessed: 10 February 2019]. ▪ The World Bank Group 2016b, *Global Solar Atlas* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/ [Accessed: 10 February 2019]. ▪ UNDP 2003, *Egypt Human Development Report 2003,* United Nations Development Programme and the Institute of National Planning, Cairo, Egypt.
Data	Sources of secondary data
2. Energy and electricity	▪ Cabinet of Ministers 2016, *Sustainable Development Strategy: Egypt Vision 2030*, Cabinet of Ministers, Egypt.

- CAPMAS 2018d, *Egypt Statistical Yearbook 2018,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017b, *Electricity and Energy annual report 2015-2016*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017c, *The Energy Balance 2015-2016 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017d, *Population, Housing and Establishment Census, Egypt Census 2017,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017f, *Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2016a, *Egypt Statistical Yearbook 2016,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2016b, *Electricity and Energy annual report 2014-2015*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2016c, *Statistical Yearbook - Environment 2016,* The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2015a, *The Energy Balance 2014-2015 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2015b, *Statistical Yearbook - Environment 2015,* The Central Agency for Public Mobilization ad Statistics, Egypt.
- CAPMAS 2014b, *The Energy Balance 2013-2014 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.

- CAPMAS 2014c, *The Future of Energy in Egypt 2014 report*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2014d, *Statistical Yearbook - Environment 2014,* The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2013a, *Electricity and Energy annual report 2011-2012*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2012b, *Egypt in Figures 2012,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2012c, *Electricity and Energy annual report 2010-2011*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2011a, *Egypt in Figures 2011,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2011b, *Electricity and Energy annual report 2009-2010*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2009, *Egypt in Figures 2009,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2008a, *Electricity and Energy annual report 2006-2007*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2007a, *Egypt in Figures 2007,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2007b, *Electricity and Energy annual report 2005-2006*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2006a, *Egypt in Figures 2006,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2004a, *Electricity and Energy annual report 2002-2003*, The Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2003a, *Egypt in figures 2002,* Central Agency for Public Mobilization and Statistics, Egypt.

	▪ CAPMAS 2003b, *Electricity and Energy annual report 2001-2002*, The Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2001, *Electricity and Energy annual report 1999-2000*, The Central Agency for Public Mobilization and Statistics, Egypt. ▪ EgyptERA 2017, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2015-2016*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt. ▪ EgyptERA 2014, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2012-2013*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt. ▪ EgyptERA 2012, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2010-2011*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt. ▪ GOPP 2012, *Greater Cairo Urban Development Strategy, Part 1: Future Vision and Strategic Direction*, The General Organisation for Physical Planning, Egypt.
Data	Sources of secondary data
3. Water and wastewater	▪ Abdel-Shafy, H., El-Saharty, A., Regelsberger, M. & Platzer, C., 2010, Rainwater in Egypt: quantity, distribution and harvesting, *Mediterranean marine science,* vol. 11, no. 2, pp. 245-257. ▪ AbuZeid, K.M. & Elrawady, M., 2014, *2030 Strategic Vision for Treated Wastewater Reuse in Egypt*, Water Resources Management Program - CEDARE, Egypt. ▪ CAPMAS 2018b, *The Annual Bulletin of Pure Water and Sanitation Statistics 2016-2017*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2018c, *Egypt in Figures 2018*, The Central Agency for Public Mobilization and Statistics, Egypt.

- CAPMAS 2018d, *Egypt Statistical Yearbook 2018,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017a, *The Annual Bulletin of Drinking Water and Sanitation Statistics 2015-2016*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2017f, *Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2016a, *Egypt Statistical Yearbook 2016,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2014a, *The Annual Bulletin for Drinking Water Purification, Distribution and Selling 2012-2013*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2012a, *The Annual Bulletin for Drinking Water Purification, Distribution and Selling 2010-2011*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2012b, *Egypt in Figures 2012,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2011a, *Egypt in Figures 2011,* Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2010, *Statistics of Water Collection, Purification and Distribution 2008-2009*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2008c, *Statistics of Water Collection, Purification and Distribution 2006-2007*, Central Agency for Public Mobilization and Statistics, Egypt.
- CAPMAS 2007c, *Statistics of Water Collection, Purification and Distribution 2005-2006*, Central Agency of Public Mobilization and Statistics, Egypt.
- CAPMAS 2006a, *Egypt in Figures 2006,* Central Agency for Public Mobilization and Statistics, Egypt.

	▪ CAPMAS 2006b, *Statistics of Water Collection, Purification and Distribution 2004-2005*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2004b, *Statistics of Water Collection, Purification and Distribution 2002-2003*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2003c, *Statistics of Water Collection, Purification and Distribution 2001-2002*, Central Agency of Public Mobilization and Statistics, Egypt.
Data	Sources of secondary data
4. Solid waste	▪ CAPMAS 2017d, *Population, Housing and Establishment Census, Egypt Census 2017,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2017e, *Statistics of Public Utility Services Supervised by the Local Councils 2016 Report*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2013b, *Statistics of Public Utility Services Supervised by the Local Councils 2012 Report*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2008b, *Statistics of Public Utility Services Supervised by the Local Councils 2006 Report*, Central Agency for Public Mobilization and Statistics, Egypt. ▪ CAPMAS 2012b, *Egypt in Figures 2012,* Central Agency for Public Mobilization and Statistics, Egypt. ▪ Hoornweg, D. & Bhada-Tata, P. 2012, *What a Waste: A Global Review of Solid Waste Management*, World Bank, Washington, DC. ▪ SWEEP-Net 2014, *Country Report on the Solid Waste Management in Egypt*, GIZ, Egypt. ▪ Zaki, T., Kafafi, A.G., Mina, M.B. & Abd El- Halim, M., 2013, *Annual Report for Solid Waste Management in Egypt, 2013*, Ministry of State for Environmental Affairs, National Solid Waste Management Programme (NSWMP), Egypt.

3.1.3 Quantitative data analysis and interpretation

This study followed the quantitative data analysis and interpretation procedures for mixed methods research that were developed by Creswell and Plano Clark (2017). These procedures are presented in Table 3-2.

Table 3-2: The procedures of the quantitative data analysis and interpretation for this study.

Procedures of quantitative data analysis and interpretation	
1. Preparing data for analysis	In this stage, I used the Excel Software and I started to create a sheet for each layer of information (population, economy, biophysical characteristics, metabolic flows and the access to basic services) then I created sub-sheets for each topic. For example; for the metabolic flows I created a sheet for each sector that included the following sectors: the water, energy, electricity, wastewater and solid waste. Then each sector included data on its sources, production and consumption from 2000-2001 to 2016-2017.
2. Exploring the data	In this stage, I started to create tables to fill in the data for each sector or topic. This was a critical step because I had to revise all the previously collected data several times to use the most accurate and consistent data for each sector.
3. Analysing the data	Then I conducted descriptive analysis for each sector to identify the trends of growth over the years and to identify the patterns of resources production and consumption.

4. Representing the data	I used the Excel Software to create charts, graphs and tables to summarize and represent the results of the quantitative data analysis. The quantitative results were merged with the qualitative results and presented in Chapters 4, 5, 6 and 7.
5. Interpreting the results	In this stage, the merged quantitative and qualitative results were interpreted in a discussion and presented in Chapter 8. The purpose of this discussion was to explain whether the results and findings answer the research questions and relate to previous studies in literature. In addition, to identify the limitations of the study and the implications for future research.

3.1.4 Qualitative data collection

(Linked to research questions 1, 3 and 4, see Chapter 1)

This study used a qualitative approach to gain a better understanding of the complex factors that affect decision-making and the drivers and barriers to the efficient flow of materials in Cairo Governorate. Semi-structured interviews were conducted to examine the role of utilities and other public institutions in the provision of services and regulatory actions that influence resource management in Cairo Governorate and the government's future plans. Site visits to different settlements (low, medium and high-density) in Cairo Governorate were also undertaken to examine the urban characteristics that affect the quality of the flow of resources.

<u>The qualitative data was collected from primary data resources:</u>

- **Semi-structured interviews:**

(Informs answers to research questions 1 and 4, see Chapter 1)

Semi-structured interviews were conducted with representatives of local authorities within Cairo Governorate. Representatives were selected based on their personal knowledge and experience in each sector (the energy, electricity, water, wastewater and solid waste) to gain a better understanding of the context in which infrastructure exists and decisions are made. The participants of the semi-structured interviews were selected by a purposive sampling strategy which targets key policy actors who are representatives of five policy sectors which constitute key elements of the "multi-layered indicator set" (see Table 3-3).

Table 3-3: List of the selected interviewees for the semi-structured interviews.

Representatives from the following authorities were selected	Interviews were on the following topics	Reference in text
The Ministry of the Environment	All sectors (energy, electricity, water, wastewater and solid waste)	Interviewee 1
The Ministry of Electricity and Renewable Energy	Energy and electricity	Interviewee 2
The Public Authority of Cleaning and Beautification of Cairo Governorate	Solid waste	Interviewee 3
The Holding Company for Water and Wastewater	Water and Wastewater	Interviewee 4

The selection of the participants for the semi-structured interviews was based on the roles of the authorities that they represent. A representative from the **Ministry of the Environment** was selected because the role of the ministry is:

- To draw-up the general policy and preparing the necessary plans for the preservation and development of the environment and to follow-up the implementation in coordination with the competent administrative authorities, and the implementation of some pilot projects.
- To recommend the necessary legal measures to join international and regional conventions related to the environment and prepare draft laws and decisions necessary for the implementation of these agreements.
- Moreover, the Ministry is the national authority for the promotion of environmental relations between Egypt and other countries, international and regional organizations.

A representative from **the Ministry of Electricity and Renewable Energy** was selected because the role of the ministry is:

- To set and implement policies and plans in the fields of electricity generation, transmission and distribution to be up-to-date with the most technical and scientific proven developments and technologies.
- To follow-up and monitor different activities to provide electrical power for social and economic development to support the government's framework and plans.
- To suggest tariff rates for electrical power to the cabinet.
- To supervise the implementation and evaluation of important electrical projects.
- To set data and statistical systems related to electricity in all fields.
- To provide technical support for Arab countries in the electrical field.

A representative from **the Public Authority of Cleaning and Beautification of Cairo Governorate** was selected because the public authority performs all the cleaning services at the level of Cairo Governorate as it:

- Supervises the national Egyptian company and foreign companies working in the cleaning sector at the governorate in different regions (East, West, North, South)
- Carries out direct cleaning works through Al-Fustat National Company, which includes:
  - Residential waste collection.
  - Commercial and industrial waste collection.
  - Street sweeping and cleaning.
  - Signs and billboards washing.
  - Sewage and water suction from damaged pipes.
  - Removes all waste resulting from the construction works of the public utilities.
  - Carries out street and road repairs.
  - Monitors and controls landfills in the governorate.
  - Provides the required labour and equipment for landfills.

A representative from **the Holding Company for Water and Wastewater** was selected because the company is responsible for both the drinking water sector and the wastewater sector of the whole country. The main duties of the company are to provide clean drinking water including the water purification, desalination, transport, distribution and selling of the drinking water. The company is also responsible for the collection, treatment and safe disposal of the wastewater.

The roles of the public authorities show that the selected representatives for the semi-structured interviews were expected to provide insight into relevant strategic and operational factors that are needed to provide context to published quantitative data.

Invitation letters were prepared, translated from English to Arabic language and were sent by email to the potential interviewees (Appendix 2). Additionally, information sheets that explain the project were prepared, translated into Arabic language and sent by email to the potential participants (Appendix 3). Consent forms were prepared and translated into the Arabic language to get the participants' permission to conduct the interview and to use their quotes anonymously (Appendices 4 and 5). The interviewees signed the consent forms before starting the interviews. After the interview, participants were asked if they still agreed to use their quotes anonymously or if they had any concerns. Lists of open-ended questions were prepared for the interviews based on the field of expertise of each interviewee (Appendices 6, 7, 8 and 9). Questions were designed to identify the drivers and barriers of sustainable resource management for each sector (water, wastewater, energy, electricity and solid waste). The definition of open-ended questions are questions that are designed to collect information (qualitative data) from the interviewees without using categories or scales that restrict their options for responding (Creswell and Plano Clark, 2017). The open-ended questions enabled interviewees to provide more information during the interview. Some of the information was relevant to the research questions and some were unrelated, so they were disregarded during the qualitative data analysis. Each interview lasted for about 90 minutes. The semi-structured interviews (face-to-face) were audio-recorded then transcribed and translated from Arabic to English.

- **Site visits:**

(informs answers to research question 3, see Chapter 1)

This study included site visits to different settlements in Cairo Governorate to gain a better understanding of the physical environment that affects and results from the flow of resources. The selection of site visits was based on the density of settlements: low, medium and high-density settlements. Handwritten notes and photographs were taken during these visits.

The criteria of the site visits selection were also based on my previous studies and experience in Cairo Governorate. I understand the unique characteristics of the urban settlements in Cairo and I wanted to share this data visually to show the challenges of resource management. The quality of infrastructure and buildings differs from one place to another and this has a great impact on the flow of resources within the city. Urban metabolism studies specifically in the Global South should explore the quality of the flow of material within cities not only measuring and assessing the quantities of the inputs and outputs of cities.

3.1.5 Qualitative data analysis and interpretation

3.1.5.1 Qualitative data analysis for the semi-structured interviews

This study followed the qualitative data analysis and interpretation procedures for mixed methods research that were developed by Creswell and Plano Clark (2017). The procedures of the qualitative data analysis and interpretation for the semi-structured interviews that were conducted in this study are presented in Table 3-4.

Table 3-4: The procedures of the qualitative data analysis and interpretation (for the semi-structured interviews) for this study.

Procedures of qualitative data analysis and interpretation	
1. Preparing data for analysis	The recorded semi-structured interviews were transcribed and translated from Arabic to English. I preferred to translate the transcripts by myself from Arabic to English in order not to lose the meaning and it also gave me the opportunity to read more through the transcripts and be familiar with the content and digest the meanings better. Transcripts were organized by participants and entered in NVivo (qualitative data analysis software).
2. Exploring the data	In this stage, I read all the transcripts carefully (4 transcripts) several times to gain a sense of them all. Then I started to develop initial codes. 'Codes are the smallest units of analysis that capture interesting features of the data (potentially) relevant to the research question. Codes are the building blocks for themes, (larger) patterns of meaning, underpinned by a central organizing concept - a shared core idea' (Clarke and Braun, 2017).
3. Analysing the data	This study followed a thematic analysis approach to analyse the qualitative data. Thematic analysis is a qualitative data analysis approach that organizes the qualitative data by coding to identify, analyse and interpret patterns of meaning 'themes' that are relevant to research questions within the qualitative data (Clarke

	and Braun, 2017). Codes were assigned to chunks of data based on the research objectives and questions (structural coding) (Ryan and Bernard, 2003). Transcripts were coded using NVivo (qualitative data analysis software). Then the codes were grouped, and themes were developed.
4. Representing the data	The results of the qualitative data analysis were organised, description and evidence (quotes) for the developed themes were presented. The quantitative results were merged with the qualitative results and presented in Chapters 4, 5, 6 and 7.
5. Interpreting the results	In this stage, the merged quantitative and qualitative results were interpreted in a discussion and presented in Chapter 8. The purpose of this discussion was to explain whether the results and findings answer the research questions and relate to previous studies in literature. In addition, to identify the limitations of the study and the implications for future research.

3.1.5.2 Qualitative data analysis for the site visits

All the photos that were taken during the site visits were organized and coded (labelled). Then these photos were analysed and merged with the results of the qualitative data analysis of the semi-structured interviews and the results of the quantitative data analysis. The merged results are presented in Chapters 4, 5, 6 and 7.

3.2 Research structure and writing-up

This thesis is divided into nine chapters. Chapter 1 includes the introduction, research aim, objectives and questions. Chapter 2 includes the background of the study and the literature review. Chapter 3 includes the research design and approach. The results of the qualitative and quantitative data analysis were merged and presented in Chapters 4, 5, 6 and 7. Chapter 4 includes the results of the quantitative data analysis of the population, economy and the biophysical characteristics of Cairo, Giza and Qalyubia Governorates and for all Egypt. These results were merged with the results of the qualitative data analysis of the semi-structured interviews that were conducted with all the representatives of the public authorities. Chapter 5 includes the results of the quantitative data analysis of the energy and electricity sectors of Cairo, Giza and Qalyubia Governorates and all Egypt. These results were merged with the results of the qualitative data analysis of the semi-structured interview that was conducted with the representative of the Ministry of Electricity and Renewable Energy. Chapter 6 includes the results of the quantitative data analysis of water and wastewater sectors of Cairo, Giza and Qalyubia Governorates and for all Egypt. These results were merged with the results of the qualitative data analysis of the semi-structured interview that was conducted with the representative of the Holding Company for the Water and Wastewater. Chapter 7 includes the results of the quantitative data analysis of solid waste of Cairo, Giza and Qalyubia Governorates and for all Egypt. These results were merged with the results of the qualitative data analysis of the semi-structured interviews that were conducted with the representative of the Ministry of the Environment and the representative of the Public Authority of Cleaning and Beautification of Cairo Governorate. The results of the site visits were merged with the results of the quantitative and qualitative data analysis and presented in Chapters 4, 5, 6 and 7 to provide a better understanding of the characteristics of Cairo Governorate. Figure 3-3 demonstrates the distribution of the merged results of the quantitative and qualitative data analysis among the empirical chapters to answer the research questions for this study. Chapter 8 merges the outputs of the empirical chapters (4, 5, 6 and 7) to answer the research questions. Chapter 9 summarizes the conclusion of the study and suggests future research areas for urban metabolism studies for urban sustainability in the Global South.

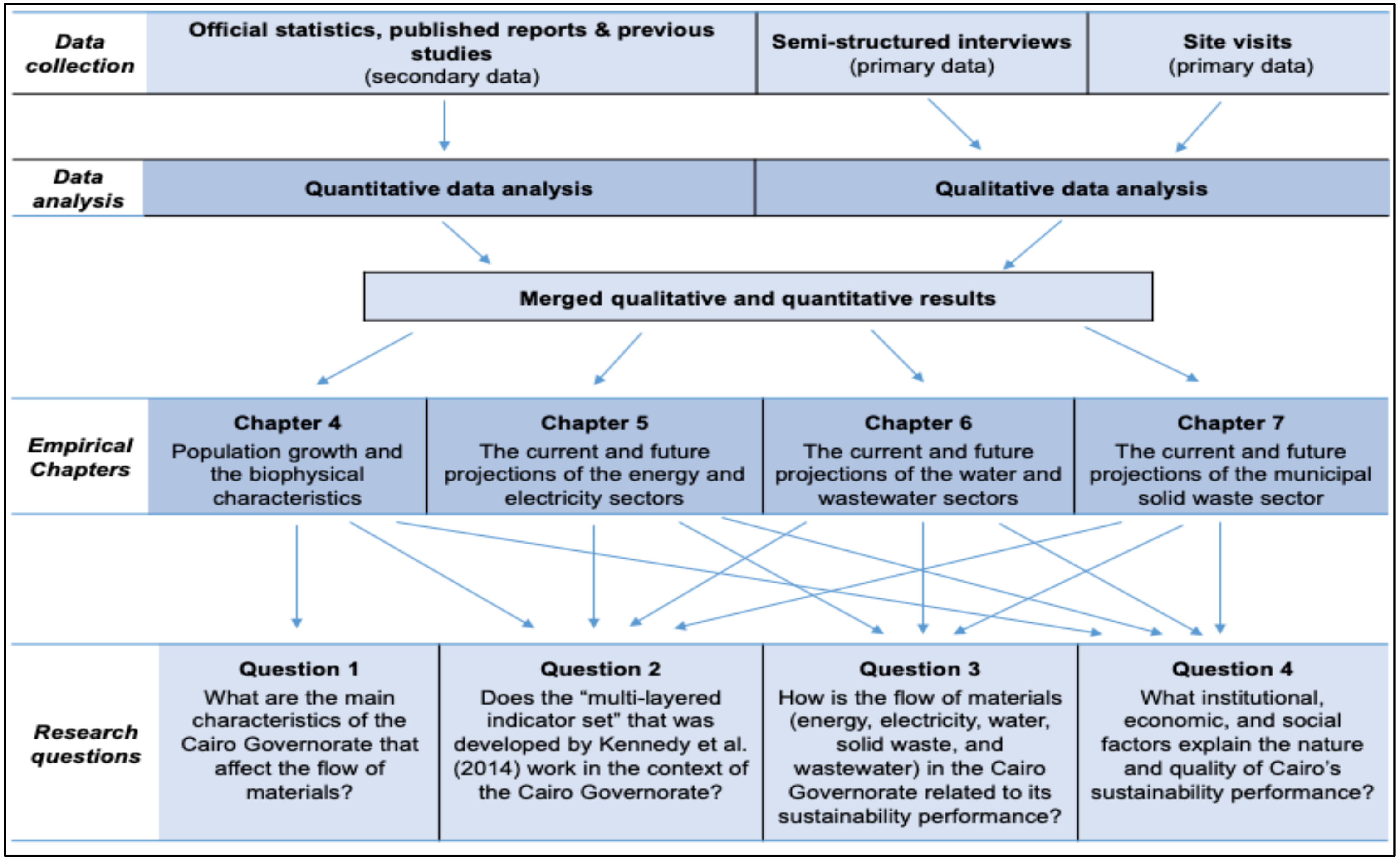


Figure 3-3: The distribution of the merged results of the quantitative and qualitative data analysis among the empirical chapters to answer the research questions for this study. (Source: The Diagram is adapted from Guibrunet (2017)).

3.3 Ethical considerations

An ERP (Ethical Review Panel) application form was submitted to gain the ethical approval of research ethics committee (REC) of Keele University. The ethical approval was required to be able to conduct the semi-structured interviews with representatives of the local authorities in Cairo Governorate and to undertake the site visits. A copy of the ERP application and the ethical approval letter are attached (Appendices 10 and 11). Invitation letters were sent to the interviewees to conduct the semi-structured interviews (Appendix 2). Information sheets were also sent to the interviewees before the interview to explain the research (Appendix 3). Consent forms were given to the interviewees to sign before the interview to gain their approval to conduct the interview and use their quotes anonymously (Appendices 4 and 5). Interviewees were informed in the information sheets and were reminded verbally before the interviews that if they wish to withdraw from the research they can withdraw at any time after the interview by emailing the researcher and all the data will be destroyed. All quotes were anonymised and participants were not identified in the transcriptions.

4 Chapter Four: Population growth and the biophysical characteristics of Cairo, Giza and Qalyubia Governorates and the whole country Egypt

4.1 Introduction

This chapter presents the main characteristics of Cairo Governorate. I used the first two layers of the multi-layered indicator set that was developed by Kennedy et al. (2014) to collect the data for Cairo, Giza, Qalyubia Governorates and Egypt. The urban mass of Cairo Governorate, the urban areas of Giza and Qalyubia are the constituents of Greater Cairo Region as shown in Figure 4-1 (GOPP, 2012). Exploring the main features of the three Governorates was essential to gain a better understanding of the case study, Cairo Governorate, and its surroundings. In addition, it was necessary to compare the data of Cairo Governorate and compare its share to the total of Egypt. This requires collecting the same data for Egypt. Layer 1 (see section 4.2) presents data on the population growth (urban and rural), economy and unemployment rates. These indicators are important to identify the impact of the population growth rates over the years and the economic situation of the case study on the flow of resources. Layer 2 (see section 4.3) presents data on the biophysical characteristics (land area, inhabited density, number of buildings and climate) of the case study and the surrounding environment. These are important indicators to better understand the nature of urban planning and the inhabited density that have a huge impact on the flow of resources. The climatic conditions are also important to identify whether the required energy is for heating or cooling purposes and to identify the potential of renewable energy resources.

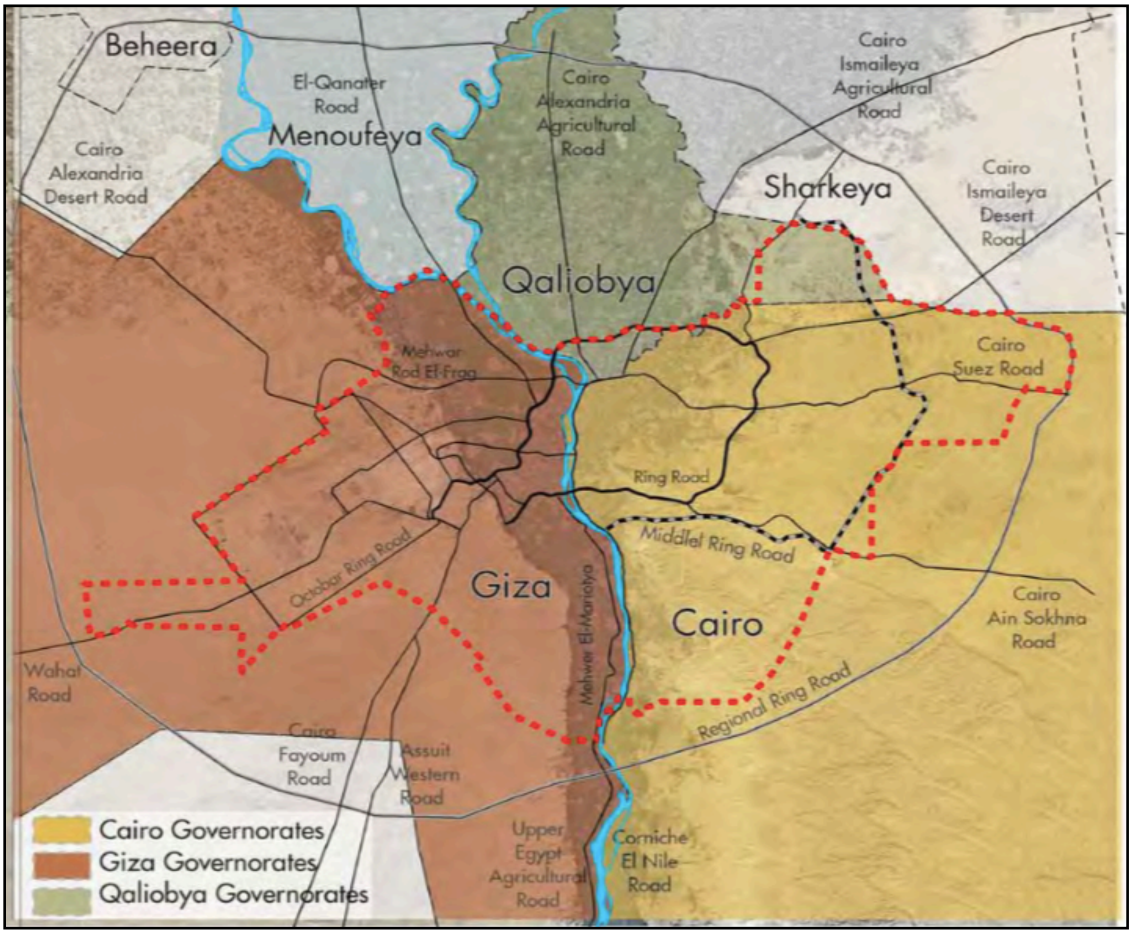


Figure 4-1: Cairo, Giza, Qalyubia and the boundaries of Greater Cairo Region (GCR) (GOPP, 2012).

4.2 Layer 1: the population growth and economy of Cairo Governorate, Giza, Qalyubia and Egypt

Layer 1 of the multi-layered indicator set includes the definition of a megacity: spatial boundaries, constituent cities, population and economy (Kennedy et al., 2014). In this study, Layer 1 includes the following data:

a) Population:

- The population growth for Cairo, Giza and Qalyubia Governorates and Egypt from 2001 to 2016.

- Percentage of the population of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt's population in 2001 and 2016.
- Urban and rural population from 2001 to 2016 for Cairo Governorate and Egypt, and the projected urban and rural population of Egypt by 2050.
- Urban and rural population for Giza and Qalyubia Governorates from 2006 to 2016. (data was not available for 2001)
- The average annual population growth rates for Cairo, Giza and Qalyubia Governorates and Egypt from 2001 to 2016.
- The average annual growth rates for Cairo, Giza and Qalyubia Governorates and Egypt from 2001-2006, 2006-2011 to 2011-2016.

b) <u>Economy:</u>

- GDP (Gross Domestic Product): the total GDP (US $ Billions) and the GDP per capita (US $) for Egypt are available from 2001 to 2017 but are not available for each Governorate.
- The total GDP of Egypt (million Egyptian pounds) from 2002-2003 to 2017-2018. It is worth mentioning here that I included the GDP of year 2017 because during 2017 the Egyptian Pound was devalued that had a huge impact on the economy.

c) <u>Unemployment rates:</u>

- The unemployment rates for Cairo, Giza and Qalyubia Governorates and Egypt from 2010 to 2016.

Sources of the secondary data are presented in Chapter 3 Table 3-1 and the criteria of including or excluding reports are presented in Appendix 12.

4.2.1 The population growth in Cairo Governorate, Giza, Qalyubia and Egypt

From 2001 to 2016, the total population of Egypt increased by 25 million inhabitants of which 15 million in rural areas and 10 million in urban areas (Figure 4-2). This shows that an average of 1.67 million inhabitants was added every year to the total population of Egypt from 2001 to 2016. The total population of Egypt reached 98 million inhabitants in 2019 and is projected to reach almost 122 million in 2050 (United Nations, 2014; CAPMAS, 2019).

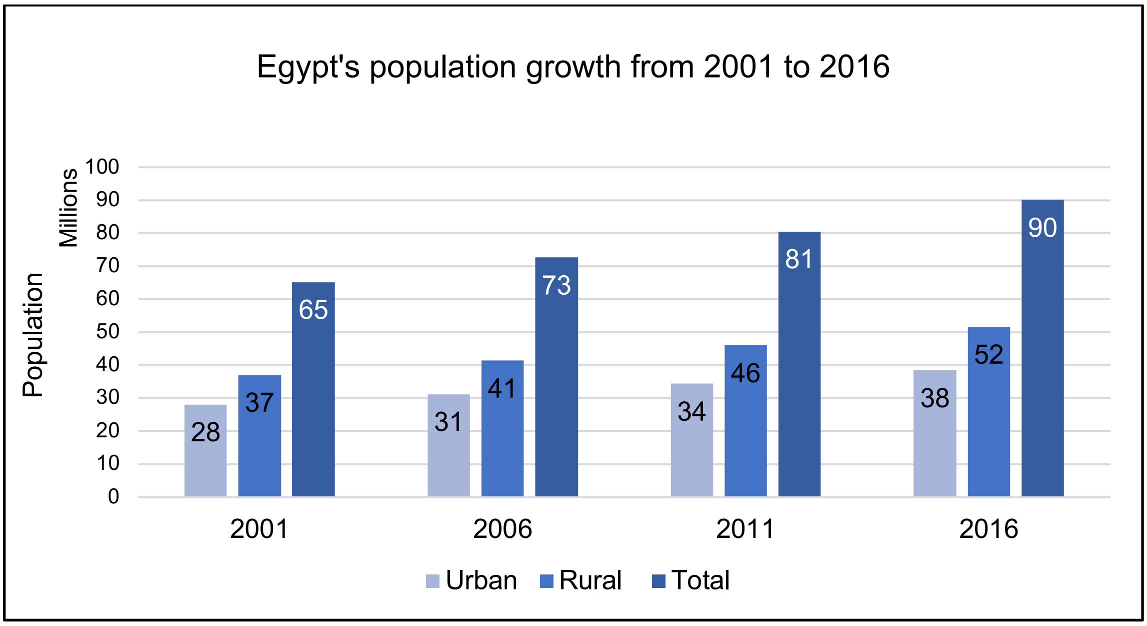


Figure 4-2: Population growth of Egypt from 2001 to 2016.

The percentages of the rural and urban population from 2001 to 2016 (15 years) in Egypt were almost stable at an average of 57% rural and 43% urban (Figure 4-3). By 2050, it is expected that more than half of the population will be living in urban areas, as the percentage of the urban population will reach 56.5%. This will add more than 30 million inhabitants to urban areas of Egypt. More pressure will be added to existing cities and infrastructure. Moreover, to absorb this growth a huge amount of resources will be required to build new cities and for the expansion of existing urban areas, and to provide adequate infrastructure.

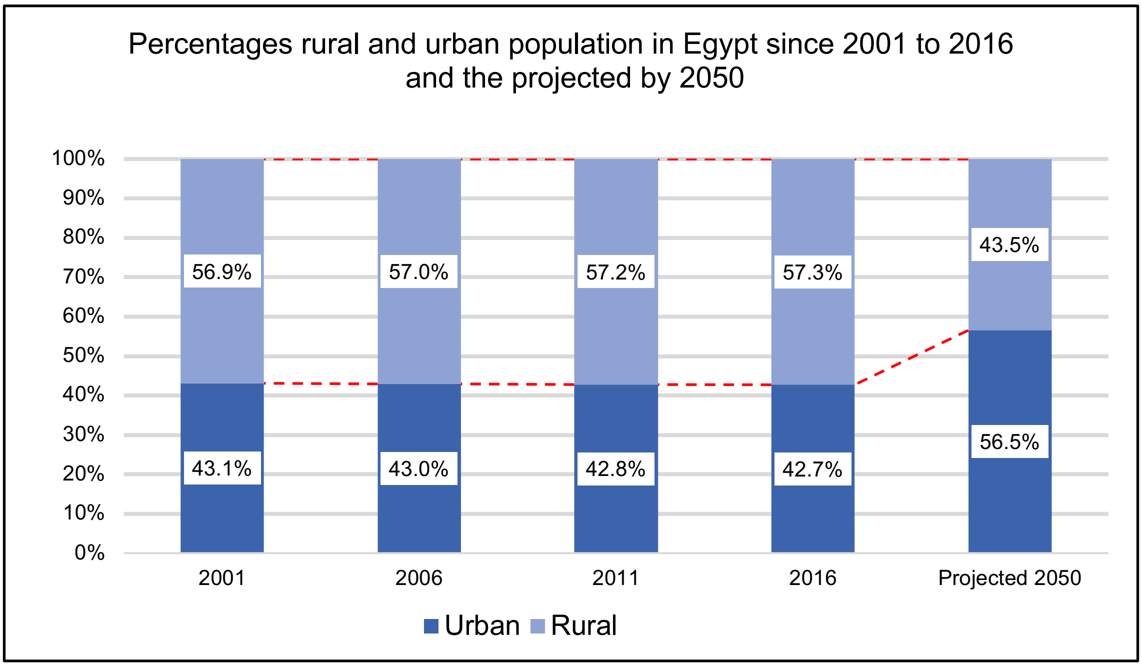


Figure 4-3: Percentages of rural and urban population of Egypt since 2001 to 2016 and the projected by 2050.

The total population of Cairo Governorate reached 9.4 million inhabitants in 2016 (Figure 4-4). The United Nations defines a megacity as a city that has 10 million inhabitants or more (United Nations, 2016d). If the population of Cairo Governorate continues to grow at the same rate it will become a megacity within the next few years. The linear trendline in Figure 4-4 indicates that the population of the three governorates has been consistently increasing from 2001 to 2016. An average of 2 million inhabitants was added to the population of each Governorate over a period of 15-years. The highest population increase since 2001 to 2016 was the population of Giza Governorate that was 2.5 million inhabitants followed by Cairo Governorate 2.1 million inhabitants and the lowest population increase was the population of Qalyubia Governorate that increased 1.6 million inhabitants. Almost a quarter of the total population increase of Egypt

(25 million inhabitants) from 2001 to 2016 was concentrated in the three governorates Cairo, Giza and Qalyubia.

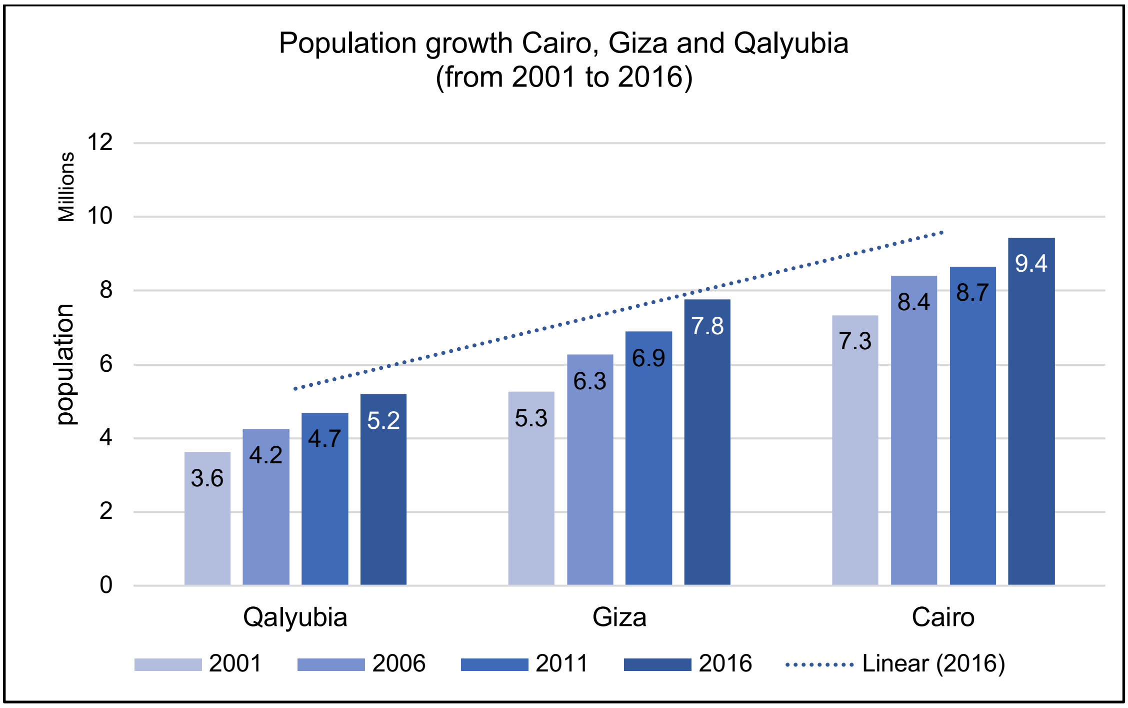


Figure 4-4: Population growth of Cairo, Giza and Qalyubia from 2001 to 2016.

In 2001, the total population of Egypt was 65 million inhabitants. The total population of Cairo Governorate, Giza and Qalyubia was quarter the total population of Egypt (Figure 4-5). The percentage of the population of the three governorates remained the same in 2016 when the total population of Egypt reached 90 million (Figure 4-6). If we compare the percentages of the population of Giza and Cairo in 2001 and 2016, we will notice that the percentage of Giza increased 1% while the percentage of the population of Cairo relatively decreased 1%. The population of both Giza and Cairo Governorates increased, but the rate of growth in Giza was higher than in Cairo. The percentage of Qalyubia in 2001 and 2016 remained the same. From 2001 to 2016, the percentage of the population of the three governorates remained 25% of the total population of Egypt.

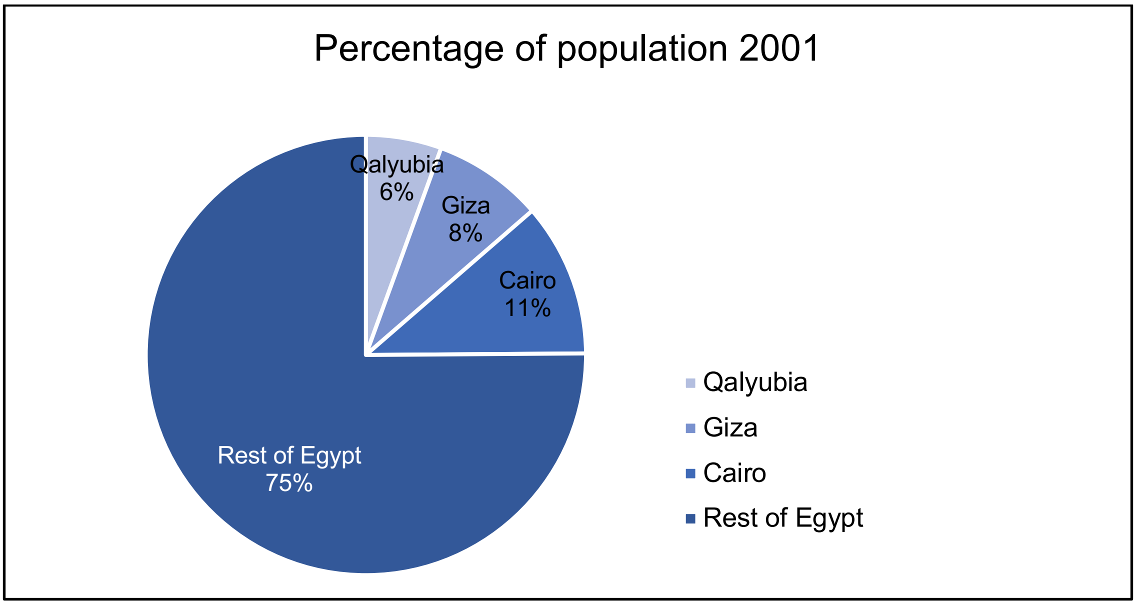


Figure 4-5: Percentages of the population of Cairo, Giza and Qalyubia compared to the rest of Egypt in 2001.

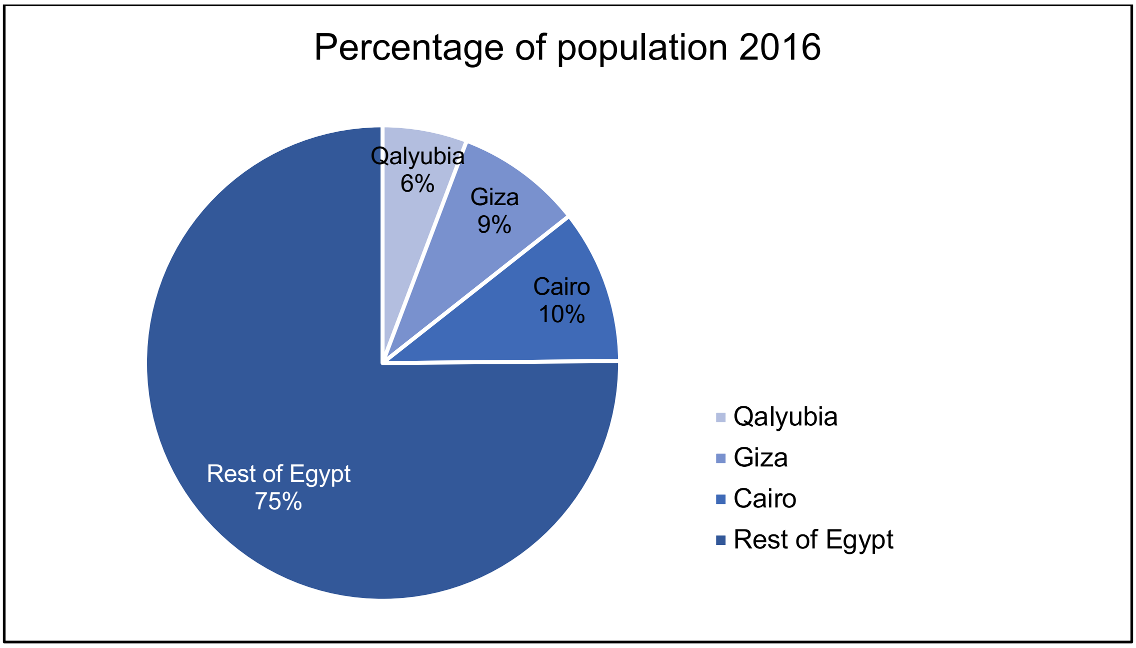


Figure 4-6: Percentages of the population of Cairo, Giza and Qalyubia compared to the rest of Egypt in 2016.

Cairo Governorate is mostly urban while the average percentage of the urban population of Giza is 58% and Qalyubia is 45% (Figure 4-7 and 4-8). Qalyubia has the highest percentage of rural population compared to Cairo and

Giza (Figure 4-7). Later on, this will explain the low level and quality of services in Qalyubia (Chapters 5, 6 and 7).

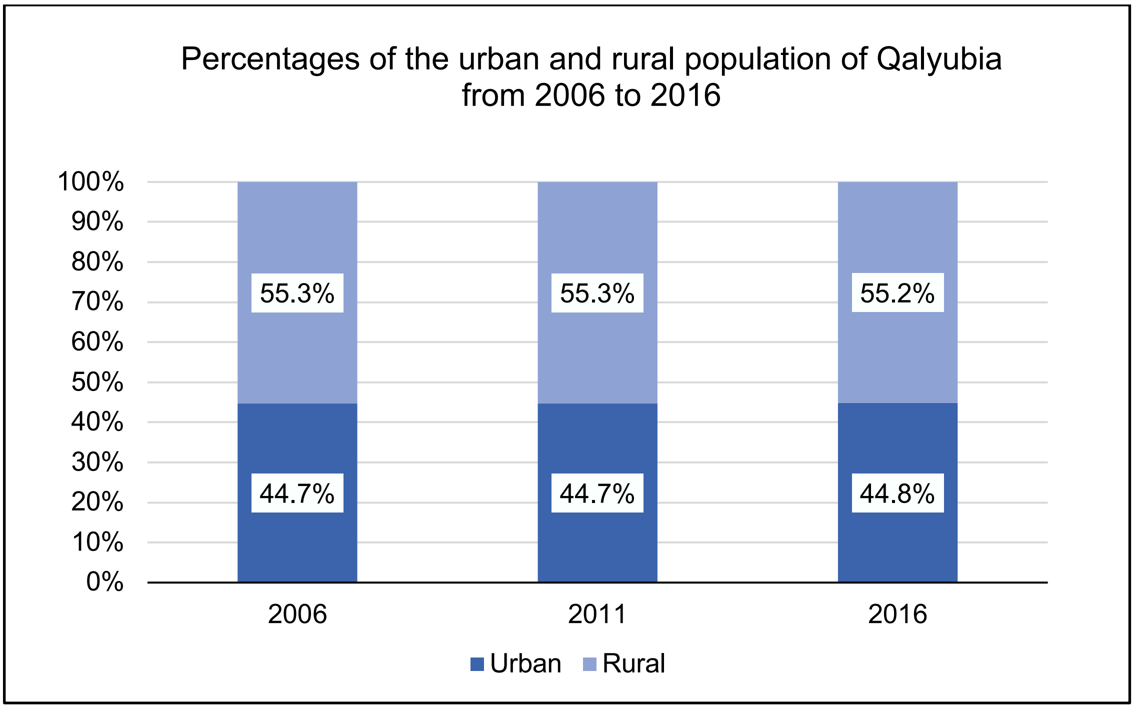


Figure 4-7: Percentages of the urban and rural population of Qalyubia from 2006 to 2016.

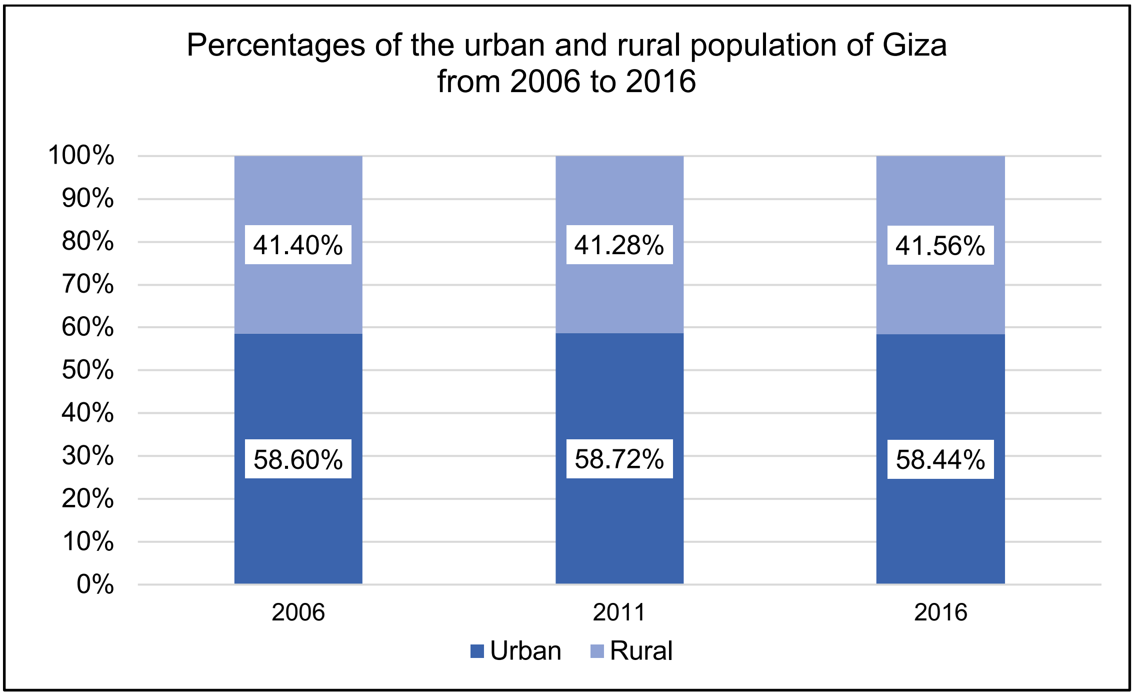


Figure 4-8: Percentages of urban and rural population of Giza from 2006 and 2016.

The average annual population growth rates of the three governorates and Egypt from 2001 to 2016 were calculated to compare the rates of growth. Giza and Qalyubia have the highest average annual population growth rates. The average annual population growth rate of Cairo Governorate is below the average of Egypt (see Figure 4-9). The overall average annual population growth rates of the three governorates are considered high compared to cities in developed countries. For example, the average annual population growth rate of Tokyo is 0.6%, New York and Los Angles is 0.3% over a period of 16-years from 2000 to 2016 (United Nations, 2016d).

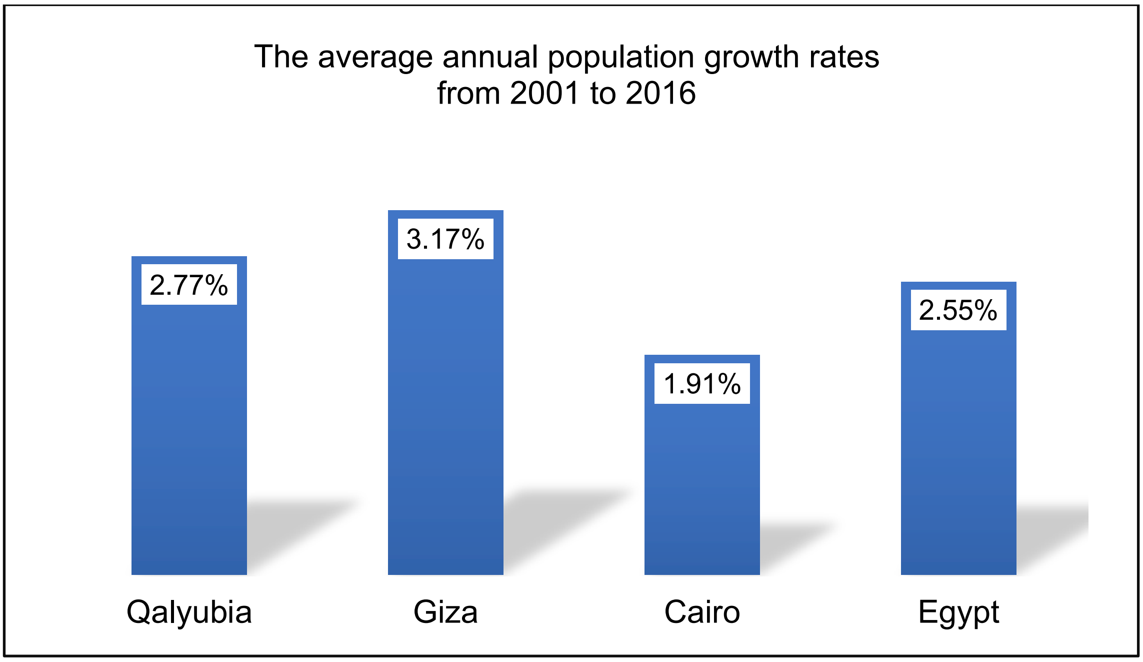


Figure 4-9: The average annual population growth rates of Egypt, Cairo, Giza and Qalyubia from 2001 to 2016.

I calculated the average annual growth rates during 2001-2006, 2006-2011, and 2011-2016 to identify whether the growth rates of the three governorates and Egypt were stable or changeable over the years. The average annual growth rate for Egypt was almost stable during 2001-2006, 2006-2011, and 2011-2016 (Figure 4-10). The highest growth rates in Cairo, Giza and

Qalyubia Governorates were from 2001 to 2006 (Figure 4-10). The average annual growth rate in Giza Governorate was the highest as it reached 3.8% followed by Qalyubia Governorate 3.5% and the lowest was Cairo Governorate 2.9%. During 2006 and 2011, the average annual population growth rate decreased as it reached 0.6% in Cairo Governorate, 2% in Giza and 2.1% in Qalyubia. This drop was due to the government's attempts to divert the population growth from the Greater Cairo Region to new satellite cities. However, in 2011 to 2016 the average annual population growth rates started to increase once more in Cairo and Giza Governorates.

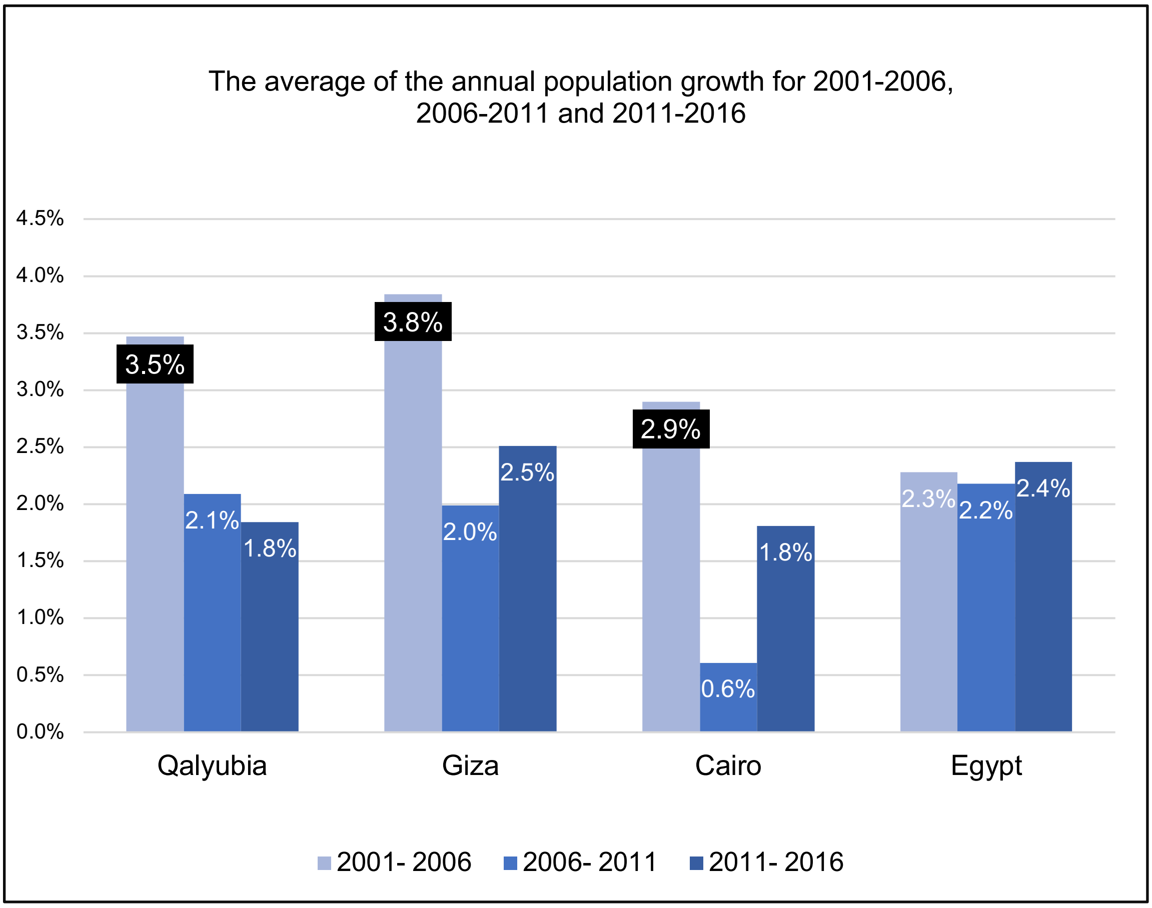


Figure 4-10: The average annual population growth rates of Egypt, Cairo, Giza and Qalyubia during (2001-2006), (2006-2011) and (2011-2016).

Unfortunately, a huge percentage of the population growth of Cairo, Giza and Qalyubia Governorates was unplanned and spread on the agricultural land in Giza and Qalyubia. Despite the government's efforts to reduce the density of the Greater Cairo Region by diverting the urban growth towards the new satellite cities and removing or upgrading the informal areas, they failed to prevent the growth of informal settlements in many areas (Figure 4-11 to 4-18).

Figure 4-11: The growth of informal settlements surrounding one of the tourist attractions of Cairo Governorate (Source: author's site visits).

Figure 4-12: The growth of informal settlements surrounding one of the tourist attractions of Cairo Governorate (Source: author's site visits).

Figure 4-13: The growth of informal settlements surrounding one of the tourist attractions of Cairo Governorate (Source: author's site visits).

Figure 4-14: Unplanned growth on agricultural land (Source: author’s site visits).

Figure 4-15: Unplanned growth on agricultural land (Source: author’s site visits).

Figure 4-16: Unplanned growth on agricultural land (Source: author's site visits).

Figure 4-17: Unplanned growth on agricultural land (Source: author's site visits).

Figure 4-18: Unplanned growth on agricultural land (Source: author's site visits).

Some of the unplanned settlements are located near the tourist attractions in Cairo and Giza Governorates, other settlements are spread on the agricultural land on both sides of the Ring Road, and some informal areas are located near the high, middle and low-income settlements (4-11 to 4-18). Interviewee 4 described the unplanned settlements by:

> *"of course, it is difficult because Cairo includes 120 informal settlements. These are unplanned areas, with narrow streets and no previous infrastructure planning. Nowadays, the government is upgrading and replacing the existing unplanned settlements by planned and formal settlements with appropriate infrastructure"* (Interviewee 4).

The photos of the unplanned settlements and the description of Interviewee 4 show the poor quality of these areas and the low level of services. While Interviewee 3 was explaining the solid waste collection in Cairo Governorate, he said that, *“it includes 38 neighbourhoods of Cairo Governorate. For example, Misr El Gedida is one of the high-income settlements. It includes some informal areas such as Esbat El Muslimeen. We collect the solid waste from all areas whether it’s formal or informal”* (Interviewee 3).

This indicates that the unplanned areas in Cairo Governorate are located near the high-income settlements not just surrounding Cairo Governorate. Interviewee 2 mentioned that the number of levels of the informal buildings in Egypt could reach 15 to 20 levels not just 1 or 2 levels as the slums of Brazil and Mexico.

“not, all of them are fragile some informal buildings are 15 storeys. They are multi-storey buildings. Actually, there are some informal buildings in a place called Ared El Lewaa; the buildings are up to 15 to 20 storeys. They are different from the slums of Brazil and Mexico” (Interviewee 2).

Even if the unplanned buildings are not fragile as Interviewee 2 explained, this does not indicate that the level and quality of services will be higher than other informal areas because they are all considered informal settlements and will not receive the same level of services as the formal areas.

4.2.2 Economy

The total GDP (million Egyptian pounds) of Egypt was available in the Egyptian official statistics from (2002-2003) to (2017-2018) as shown in Figure 4-19. As discussed above, the data for this thesis is collected from 2001 to 2016, but the total GDP of 2016-2017 and 2017-2018 are included because as shown in Figure 4-19 the total GDP grew gradually since 2002-2003 to 2014-2015, then there was a significant increase from 2015-2016 to 2017-2018.

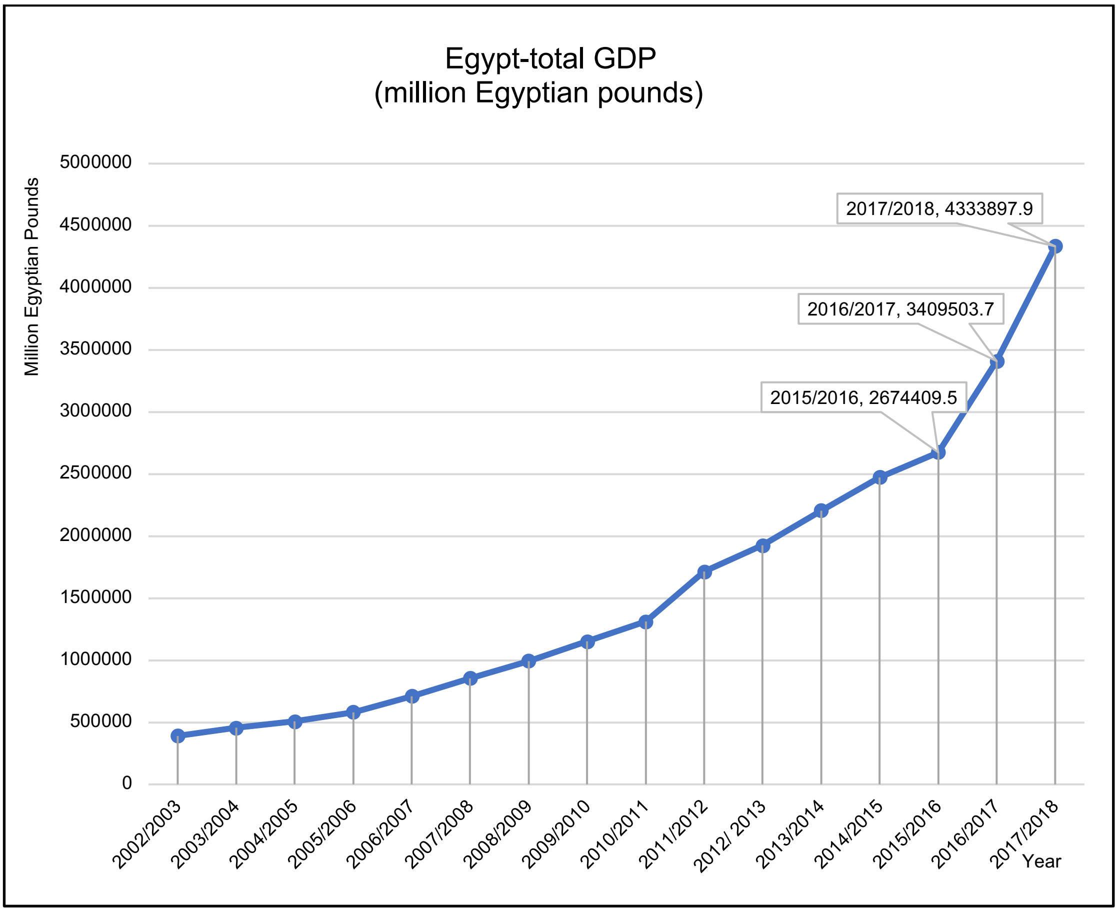


Figure 4-19: Egypt's total GDP (million Egyptian pounds) from 2002-2003 to 2017- 2018.

On the other hand, the total GDP in (US $) and the GDP per capita in (US $) as presented in Figure 4-20 and Figure 4-21 from 2001 to 2017, both dropped sharply in 2017. This drop was due to the devaluation of the Egyptian pound in 2017.

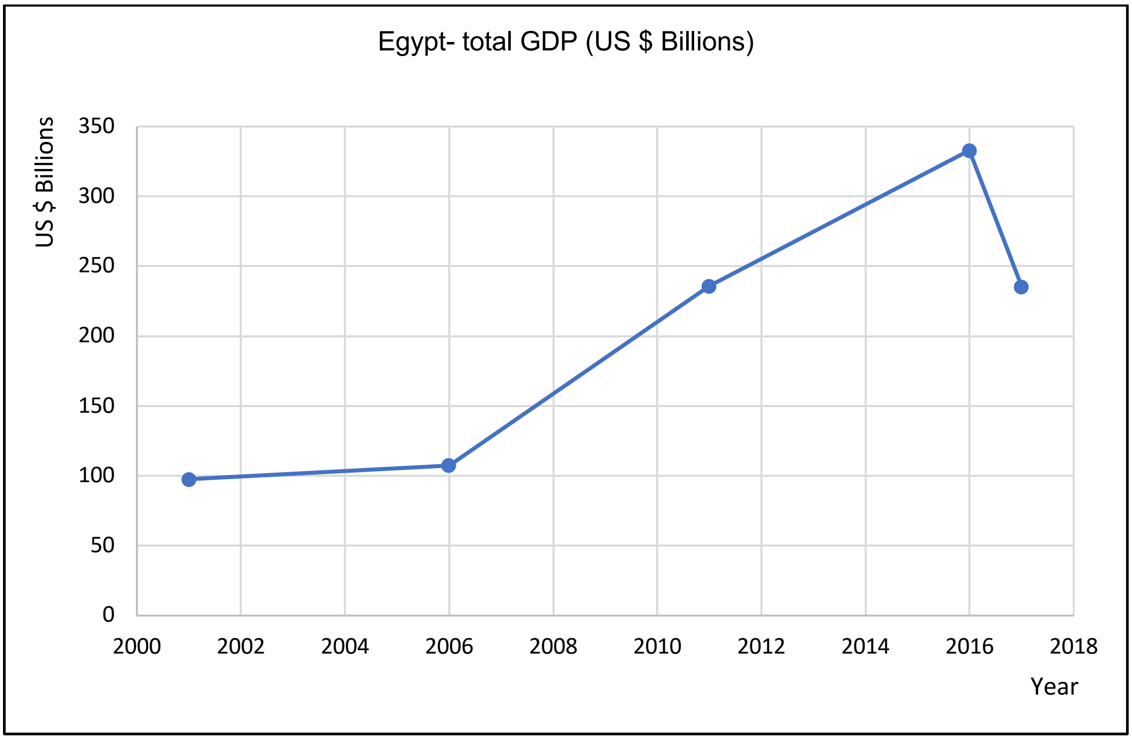


Figure 4-20: Egypt’s total GDP (US $ Billions) from 2001 to 2017.

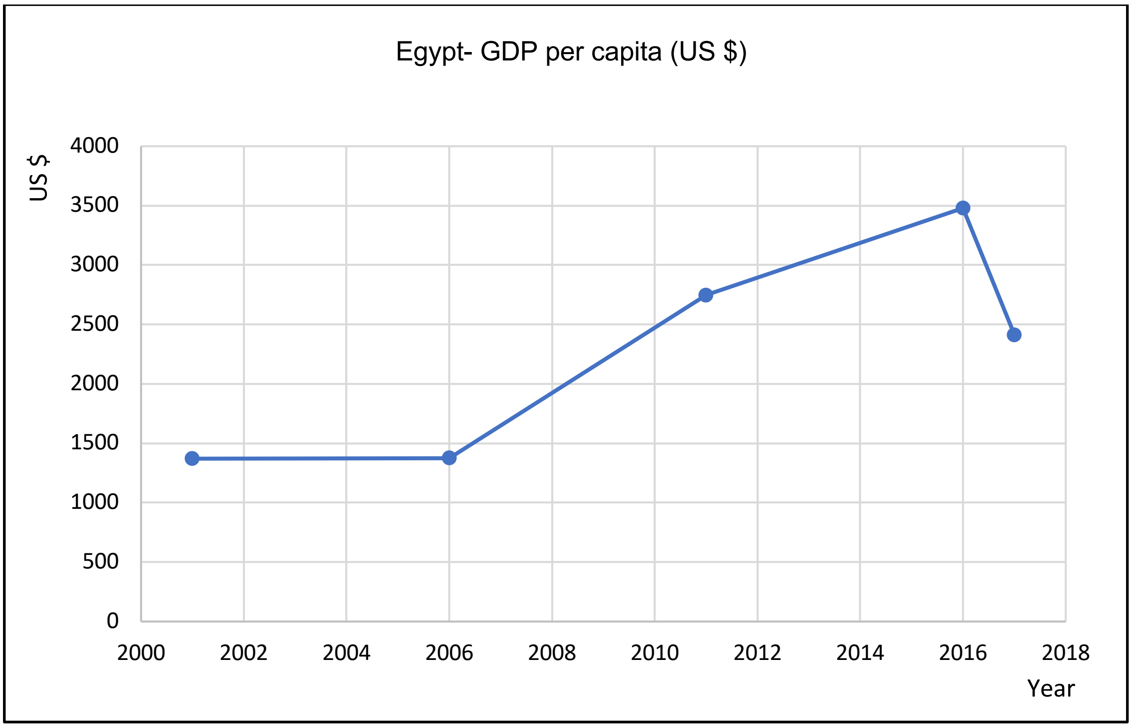


Figure 4-21: Egypt’s GDP per capita (US $) from 2001 to 2017.

The devaluation of the Egyptian pound had a great impact on the inflation rate[8]. The inflation rate was 10.2% in 2016 and after the devaluation, it reached 23.5% in 2017 (Figure 4-22). Furthermore, the real GDP growth[9] (annual per cent change) remained almost the same after the devaluation (IMF DataMapper, 2018a). As shown in Figure 4-22 it is expected that the inflation rate will decrease over the next few years.

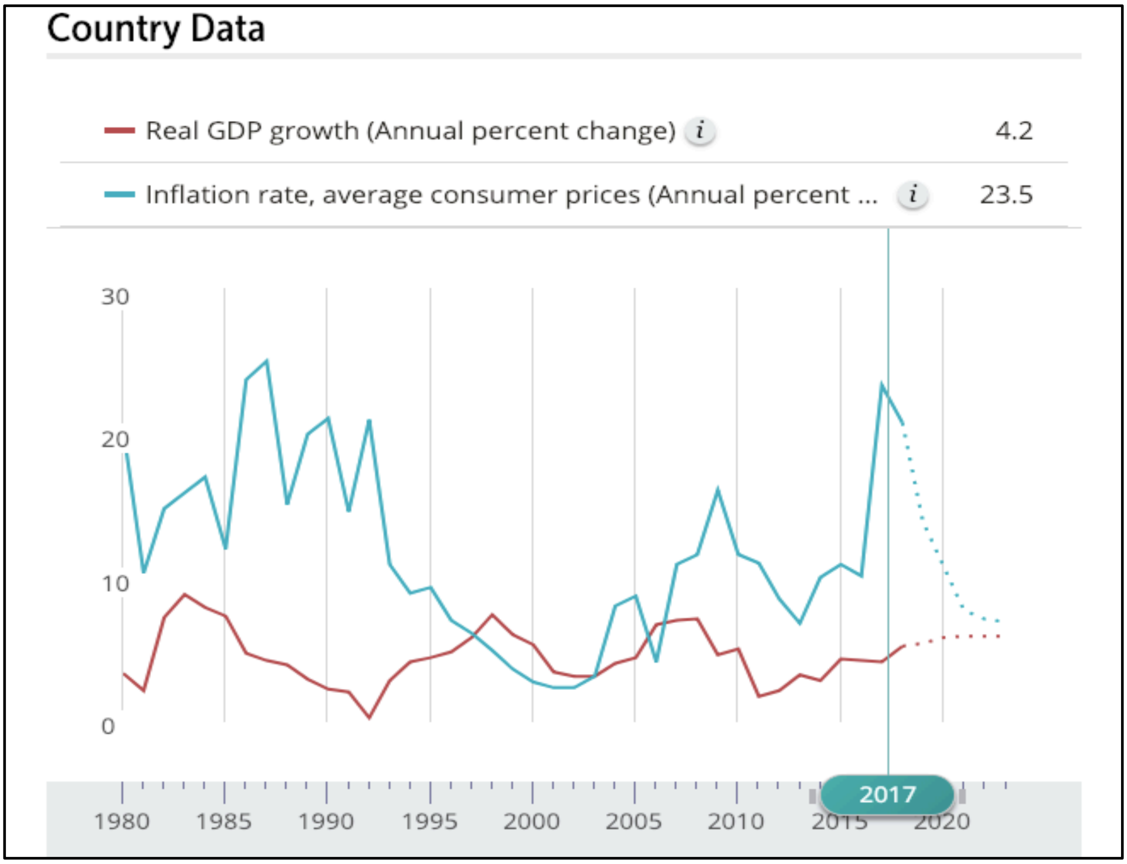


Figure 4-22: Egypt's real GDP growth (annual percent change) compared to the inflation rate in 2017 (IMF DataMapper, 2018a).

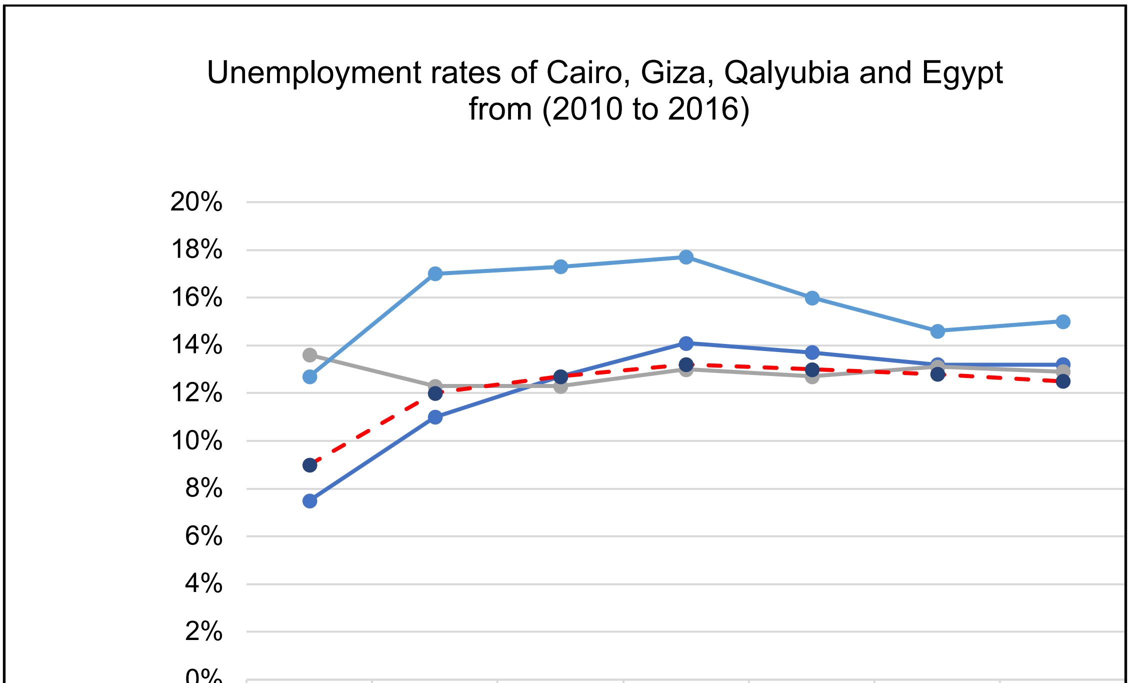
[8] The average consumer price index (CPI) is a measure of a country's average level of prices based on the cost of a typical basket of consumer goods and services in a given period. The rate of inflation is the percent change in the average CPI, (World Economic Outlook, 2018)

[9] Gross domestic product is the most commonly used single measure of a country's overall economic activity. It represents the total value at constant prices of final goods and services produced within a country during a specified time period, such as one year, (World Economic Outlook, 2018)

4.2.3 Unemployment rate (percentages)

The unemployment rate is not included in the original multi-layered indicator set. In this study, the unemployment rates for Cairo, Giza and Qalyubia Governorates and Egypt are presented. The unemployment rate is an important indicator of resource management. It shows the job opportunities that could be provided, for example, from the development of renewable energy projects and the establishment of an integrated sustainable waste management system.

Unemployment rates (age 15 and above) are collected for Cairo, Giza and Qalyubia Governorates and Egypt from 2010 to 2016. Unemployment rates of previous years were unavailable for each Governorate. Cairo Governorate has the highest unemployment rates as shown in Figure 4-23 compared to Egypt, Giza, and Qalyubia Governorates. The highest unemployment rates of Cairo Governorate were during 2011, 2012 and 2013. This was due to the political situation in Egypt as the revolution started in 2011 and it had a huge impact on the social and economic stability of the country. This made the country unattractive for new investments and businesses and it also affected the existing ones. Cairo Governorate being the capital of Egypt was the most affected Governorate compared to the rest of the country. By 2014, the unemployment rate of Cairo Governorate decreased gradually when the country started to recover from the impacts of the revolution. The unemployment rates in Giza, Qalyubia Governorates are almost equal to the average unemployment rate of Egypt; Qalyubia is slightly higher.



	2010	2011	2012	2013	2014	2015	2016
Qalyubia	7.5%	11.0%	12.7%	14.1%	13.7%	13.2%	13.2%
Giza	13.6%	12.3%	12.3%	13.0%	12.7%	13.1%	12.9%
Cairo	12.7%	17.0%	17.3%	17.7%	16.0%	14.6%	15.0%
Egypt	9.0%	12.0%	12.7%	13.2%	13.0%	12.8%	12.5%

Figure 4-23: Unemployment rates of Egypt, Cairo, Giza, and Qalyubia from 2010 to 2016.

The unemployment rate of Egypt is significantly higher than the rates of advanced economies as shown in Figure 4-24. For example, in 2016 the unemployment rate of Egypt was 12.7%, while the average unemployment rate of advanced economies was 6.2% (IMF DataMapper, 2018b). Recent reports show that the unemployment rate in Egypt reached 8.6% in 2019 (IMF, 2019). This indicates that the unemployment rate of Egypt is decreasing gradually and the country started to become more stable. However, the government should provide more job opportunities in Cairo, Giza and Qalyubia Governorates to reduce the unemployment rates. This could be achieved by establishing an integrated sustainable waste management system and investing in renewable energy projects. Both sectors require a huge number of labourers, technicians, engineers and a range of skills.

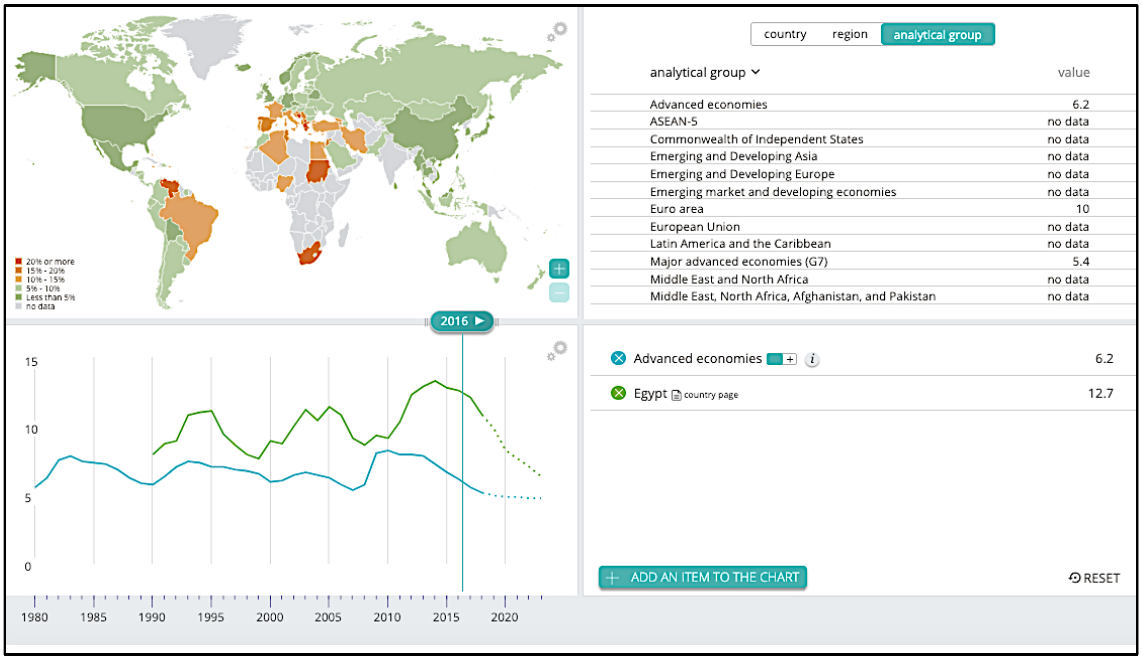


Figure 4-24: The unemployment rate of Egypt compared to the rate of advanced economies from 1980 to 2020 (IMF DataMapper, 2018b).

4.3 Layer 2: the biophysical characteristics of Cairo Governorate, Giza, Qalyubia and Egypt

Layer 2 of the multi-layered indicator set includes the land area, urbanized area, climate and the building gross area (Kennedy et al., 2014). In this study, Layer 2 includes the following data:

a) Land area, inhabited area and the population density for Cairo, Giza, Qalyubia and Egypt.

b) The total number of residential, commercial and institutional industrial buildings in Cairo, Giza, Qalyubia and Egypt. (Data was not available for the buildings' gross area).

c) Climate: heating degree-days (HDD), cooling degree-days (CDD), annual precipitation (mm) and rainfall, annual solar radiation and wind speed.

Sources of the secondary data are presented in Chapter 3 Table 3-1 and the criteria of including or excluding reports are presented in Appendix 12.

4.3.1 Land area, inhabited area and population density

The total area of Greater Cairo Region is almost 3.3 thousand square kilometres of which 48% is located in Cairo Governorate, 47% in Giza and 5% in Qalyubia (Figure 4-25).

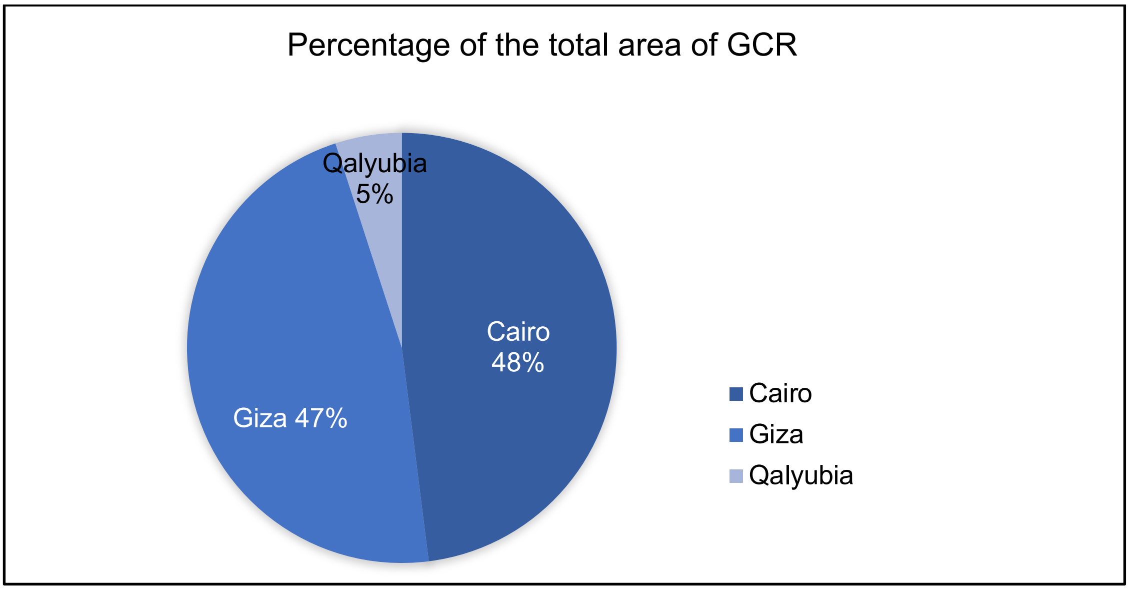


Figure 4-25: The percentage of the total area of Greater Cairo Region.

The total area of Egypt is one million square kilometres, and the percentage of the inhabited area is only 6.8% of its total area. The area of Cairo, Giza and Qalyubia Governorates do not exceed 1.72% of the total area of Egypt (Cairo 0.31%, Giza 1.3% and Qalyubia 0.11%). As mentioned earlier in this chapter, the total population of the three governorates is 25% of the total population of Egypt; this shows that 25% of Egypt's population live in only 1.72%

of its total area. The land area of Giza Governorate is the largest compared to Cairo and Qalyubia as shown in Figure 4-26. The percentages of the inhabited area of Cairo and Giza Governorates are less than Qalyubia as the percentage of the inhabited area of Qalyubia is 95.4%, Cairo 6.2% and Giza 9%.

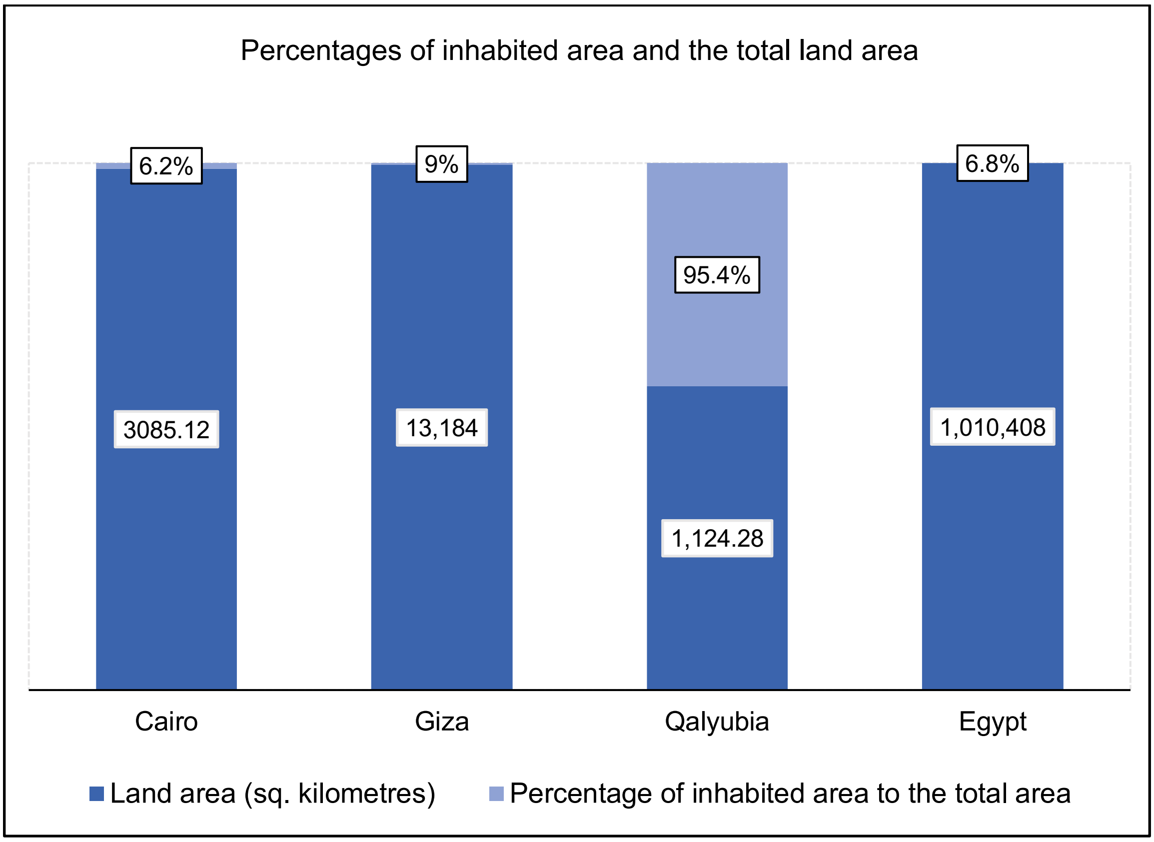


Figure 4-26: Percentage of the inhabited area to the total area of Cairo, Giza and Qalyubia Governorates and Egypt.

The total inhabited area of Egypt is less than 70 thousand square kilometres. The percentage of the inhabited area of each Governorate compared to the total inhabited area of Egypt is presented in Figure 4-27. In addition, the percentage of the population in each Governorate compared to the total population of Egypt in 2016 is presented in Figure 4-27. The outcome of this comparison shows that 10.48% of the total population of Egypt occupied 0.28% of the total inhabited area of Egypt (in Cairo Governorate) in 2016. In addition, 8.62% of the total population of Egypt occupied 1.74% of the total inhabited area of Egypt (in Giza Governorate) in 2016. Moreover, 5.69% of the total population of Egypt occupied 1.57% of the total inhabited area of Egypt (in Qalyubia Governorate) in 2016. The rest of Egypt's population occupied 96.4% of the total inhabited area of Egypt in 2016.

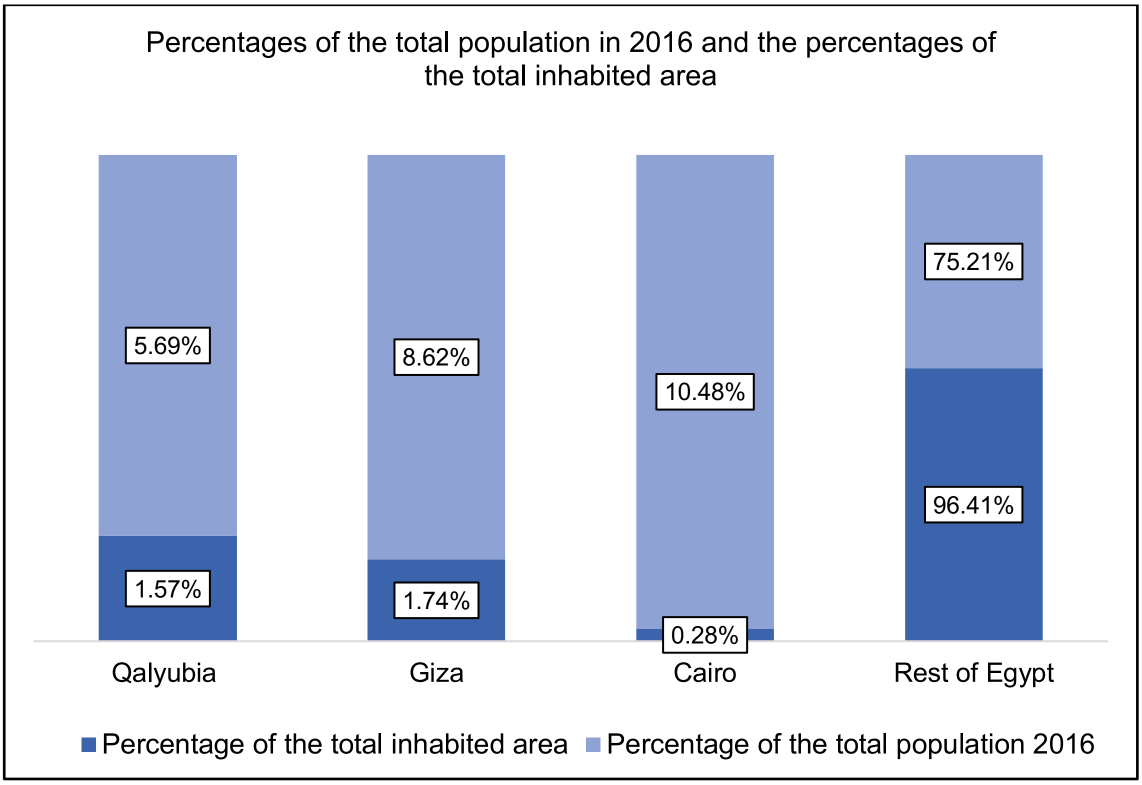


Figure 4-27: Percentages of the total population in 2016 and the percentages of the total inhabited area for the three governorates and the rest of Egypt.

The data of the inhabited density of Cairo, Giza and Qalyubia Governorates and Egypt for 2001 to 2016 is not available in the official statistics so it is replaced by the available data of 2003, 2011, 2015 and 2017. The inhabited density of Egypt reveals the uneven distribution of the population of Egypt as it reaches more than 50,000 inhabitants per square kilometres in Cairo Governorate and on the other hand, the inhabited density of Egypt is less than 1400 inhabitants per square kilometres (Figure 4-28). Cairo Governorate has the highest inhabited density compared to Giza and Qalyubia Governorates (Figure 4-28).

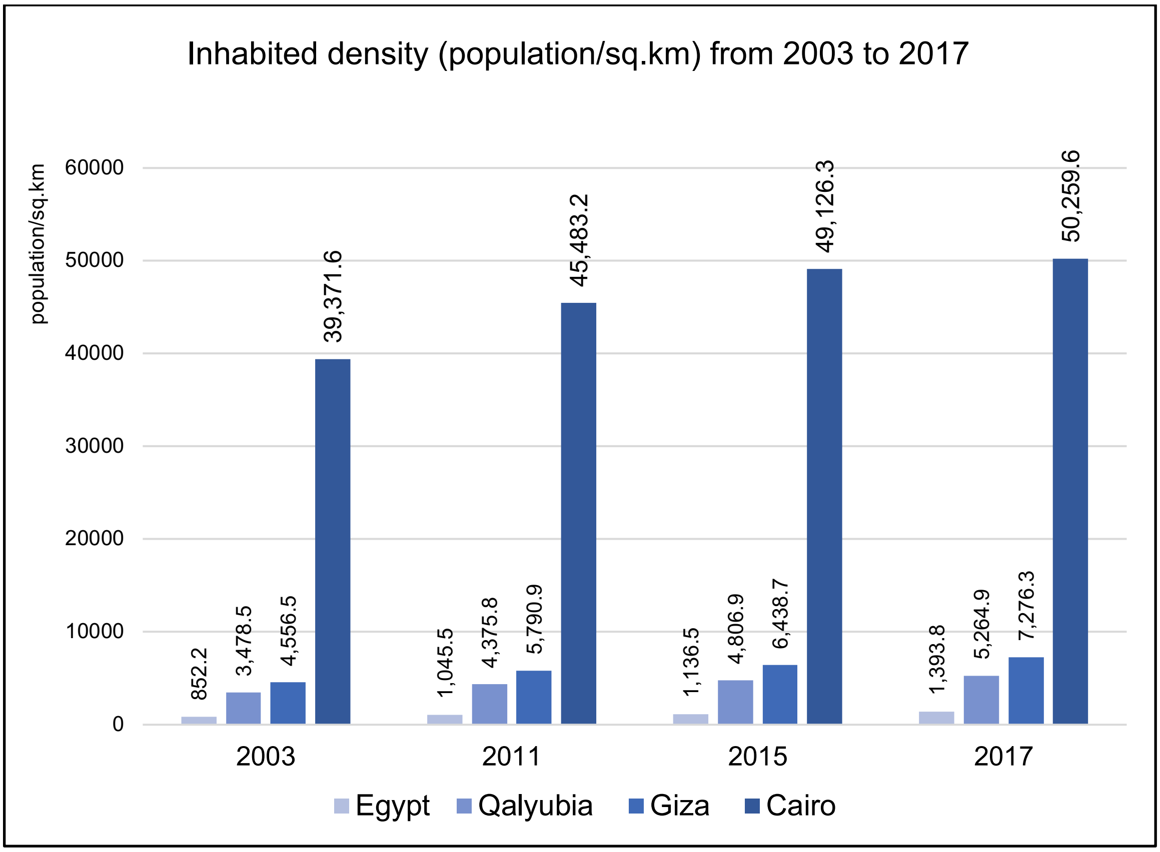


Figure 4-28: The inhabited density (population/sq.km) of the three governorates and Egypt from 2003 to 2017.

The inhabited density of Cairo Governorate reached more than 50,000 inhabitants per square kilometres in 2017, making it one of the world's most densely cities. Cairo Governorate is a high-density Governorate to the extent that residents apart from the new satellite cities occupy most of the roofs of residential buildings. This is a major challenge to the installation of solar panels on the roofs of residential buildings in Cairo Governorate. Additionally, in high-density settlements in Cairo Governorate specifically the unplanned settlements the streets are narrow that hinders the flow of resources in and out these areas and the provision of services (Figures 4- 29 and 4-30).

Figure 4-29: Narrow streets of an unplanned settlement in Cairo Governorate (Source: author's site visits).

Figure 4-30: Narrow streets of an unplanned settlement in Cairo Governorate (Source: author’s site visits).

4.3.2 Number of buildings

4.3.2.1 Residential buildings

The original multi-layered indicator set included the building gross floor areas for residential buildings, but in this study, this data was missing so it is replaced by the number of buildings. This total is available for years 2006 and 2017 but not in previous official reports. The total number of buildings might not be important as the building gross floor areas because the latter could identify, for example, the energy required for heating or cooling and the construction materials. However, one of the objectives of this study is to highlight the importance of the missing data that could be considered in the future by the Central Agency for Public Mobilization and Statistics or researchers. The total number of buildings in Egypt was more than 11.5 million in 2006, of which 6% were in Cairo Governorate, 6% in Giza and 5% in Qalyubia (Figure 4-31).

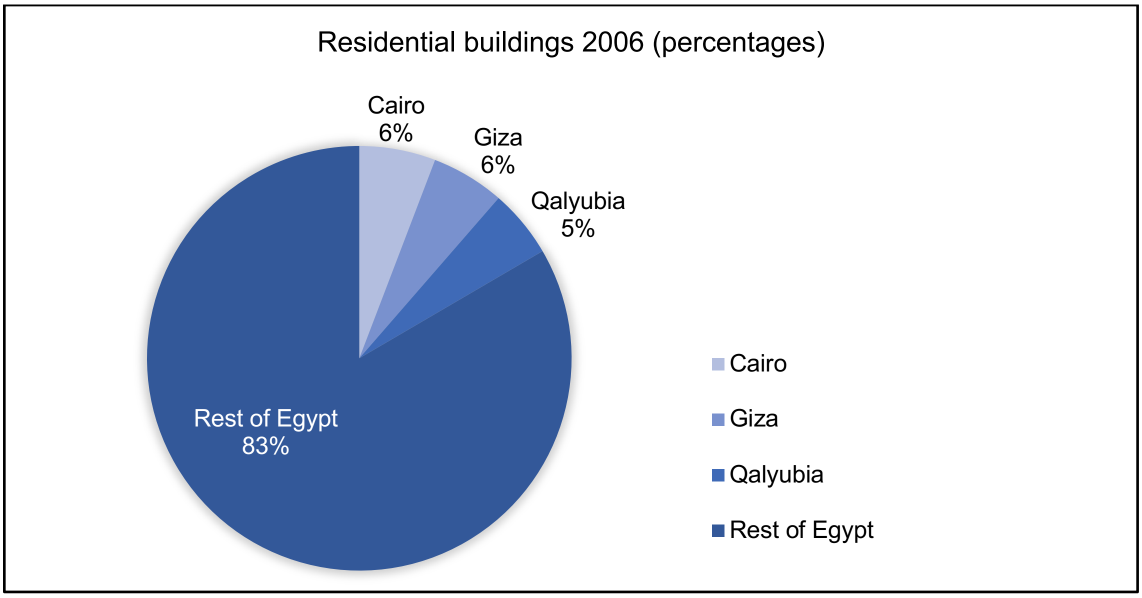


Figure 4-31: The percentages of residential buildings in the three governorates and the rest of Egypt in 2006.

The number of buildings in the three governorates was almost the same in 2006; Cairo was slightly higher, followed by Giza and Qalyubia was the least (Figure 4-32). In 2017, the total number of buildings in Giza Governorate and Qalyubia increased significantly and Cairo remained almost the same with a minimal increase. This shows that the government's efforts to reduce the density of Cairo Governorate had a huge impact on diverting the growth towards Giza and Qalyubia Governorates, however, it is noticed that the inhabited density of

Cairo Governorate has been increasing over time. Some of the old buildings of Cairo Governorate are demolished and replaced with multi-storey buildings to absorb more residents. In other cases, if the structure of the building is suitable, more levels are added to the existing buildings instead of replacing them with new ones. Accordingly, the number of residential buildings of Cairo Governorate increased slightly in 2017 as shown in Figure 4-32, but the capacity of these buildings increased to absorb more residents. The problem is that increasing the capacity of these buildings does not increase the capacity of their infrastructure and networks. This adds more pressure and weakens the existing infrastructure and networks. The infrastructure and networks are designed to meet a specific demand of electricity, drinking water and other services when the demand exceeds their capacity, this leads to the failure of the whole system.

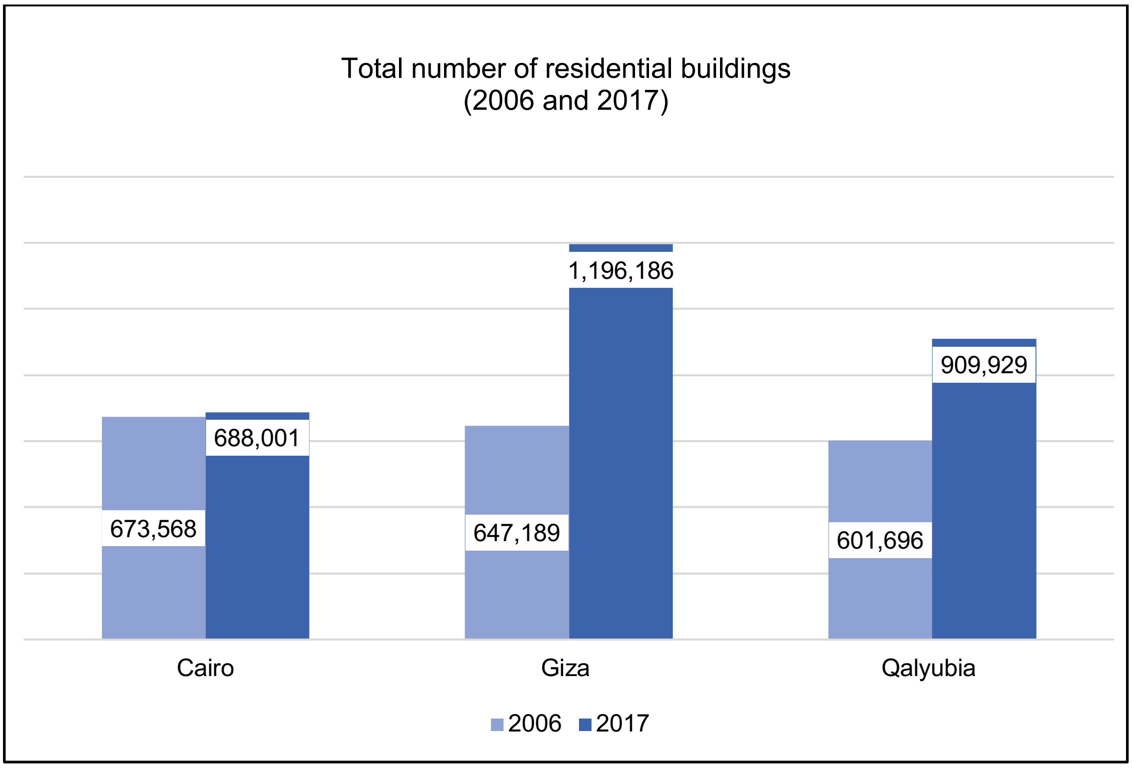


Figure 4-32: The total number of residential buildings in Cairo, Giza and Qalyubia Governorates in 2006 and 2017.

The total number of buildings in Egypt in 2017 was more than 16 million, of which 4% were in Cairo Governorate, 7% in Giza and 6% in Qalyubia (Figure 4-33). This shows that the percentage of the number of buildings in Giza Governorate and Qalyubia increased by 1% each and Cairo relatively decreased by 2%. The number of buildings increased in the three governorates, but the rate of increase was higher in Giza and Qalyubia. This increase was based on the government's strategy to absorb population growth and reduce the pressure from Cairo Governorate.

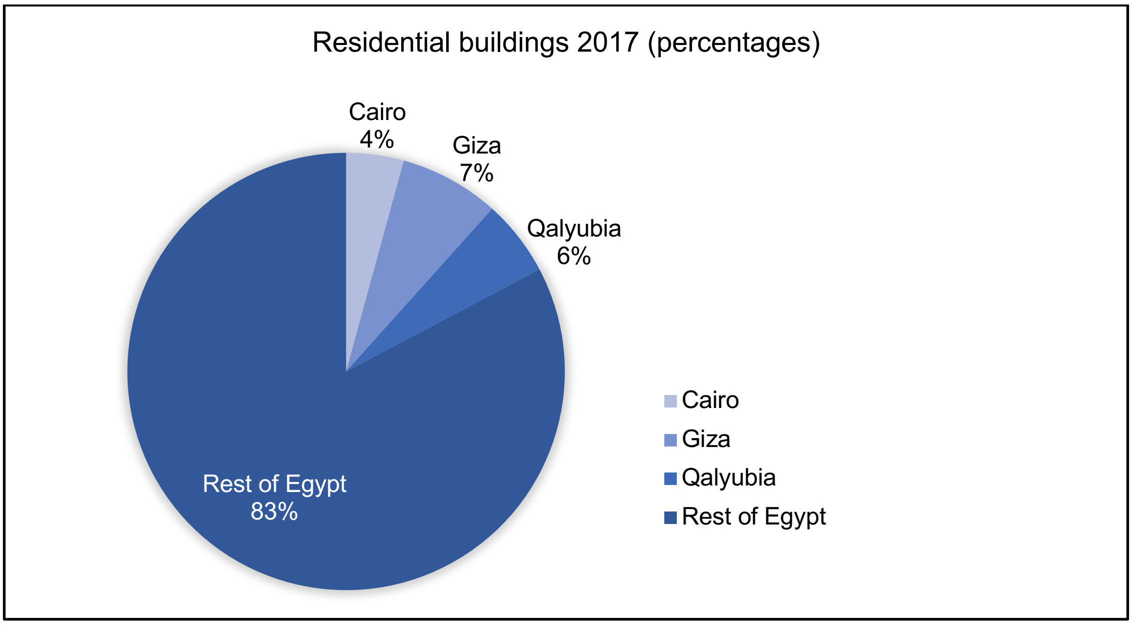


Figure 4-33: The percentages of residential buildings in the three governorates and the rest of Egypt in 2017.

A recent report of the Central Agency of Public Mobilization and Statistics included the number of residential units for 2017. This data was not available in previous reports. The total number of residential units in Egypt was more than 43 million in 2017, of which 11% was in Cairo Governorate, Giza 10% and Qalyubia 7% (Figure 4-34). The residential units of the three governorates present 28% of the total number of residential units in Egypt.

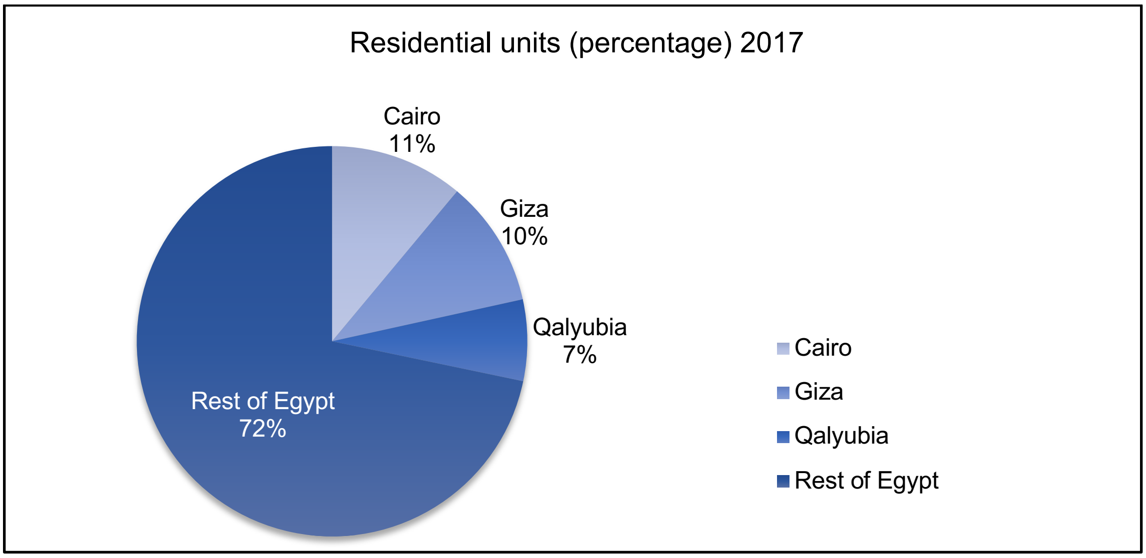


Figure 4-34: The percentages of the residential units for the three governorates and the rest of Egypt in 2017.

4.3.2.2 Commercial and institutional industrial buildings

The total number of commercial and institutional industrial buildings in Egypt was more than 4.5 million in 2006 of which 16% were in Cairo Governorate, 9% in Giza and 6% in Qalyubia (Figure 4-35).

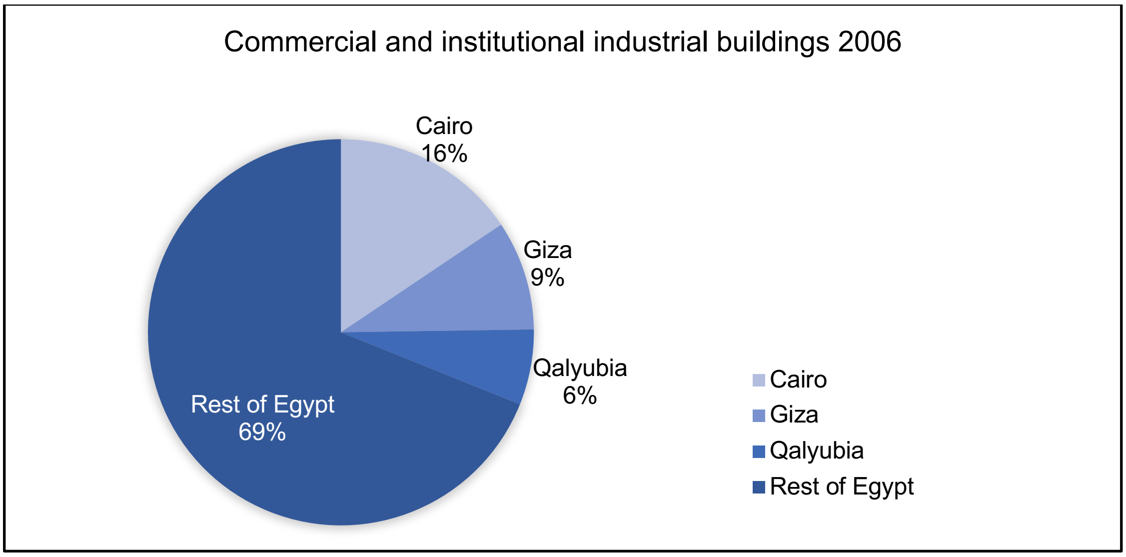


Figure 4-35: The percentages of the commercial and institutional industrial buildings of the three governorates and the rest of Egypt in 2006.

Cairo Governorate, being the capital of Egypt, has the highest number of commercial and institutional industrial buildings in 2006 and 2017 (Figure 4-36). However, the rate of increase of commercial and institutional industrial buildings in Giza Governorate and Qalyubia was higher than Cairo Governorate in 2017.

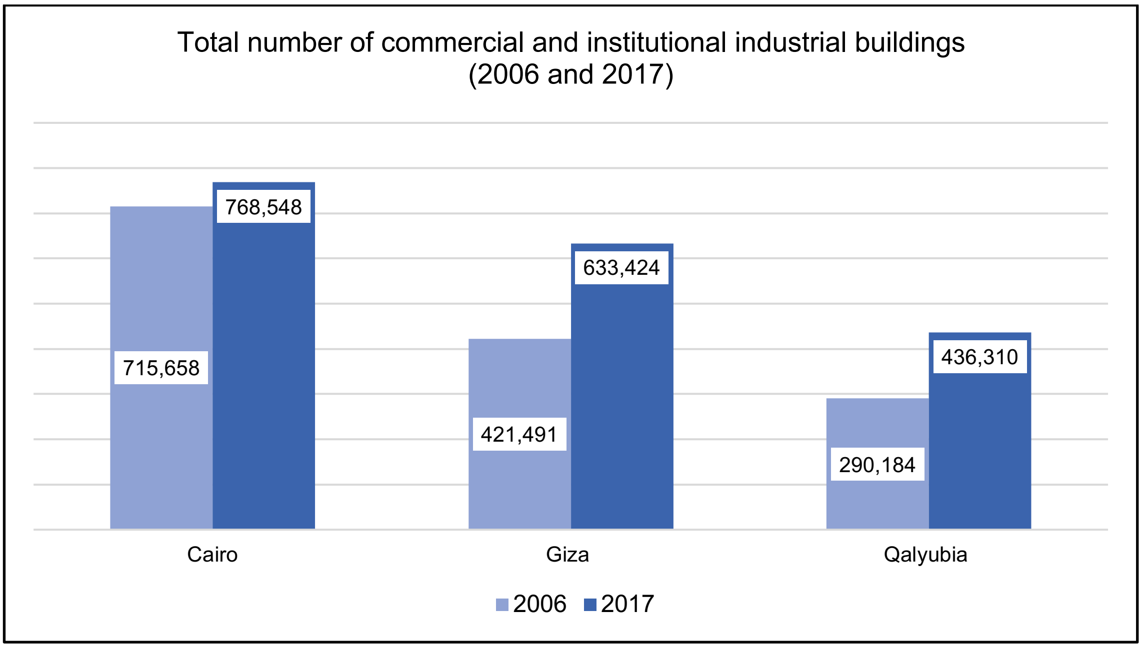


Figure 4-36: The total number of commercial and institutional industrial buildings in Cairo, Giza and Qalyubia Governorates in 2006 and 2017.

The total number of commercial and institutional industrial buildings in Egypt was more than 6.4 million in 2017 of which 12% were in Cairo Governorate, 10% in Giza and 7% in Qalyubia (Figure 4-37). This shows that the percentage of the number of commercial and institutional industrial buildings increased in Giza Governorate and Qalyubia by 1% each and relatively decreased in Cairo Governorates by 4% compared to the percentages of 2006. The number of commercial and institutional industrial buildings increased in the three governorates, but the rate of increase was higher in Giza and Qalyubia than in Cairo. Moreover, the percentage of the commercial and institutional industrial buildings of the rest of Egypt increased by 2% in 2017 compared to 2006.

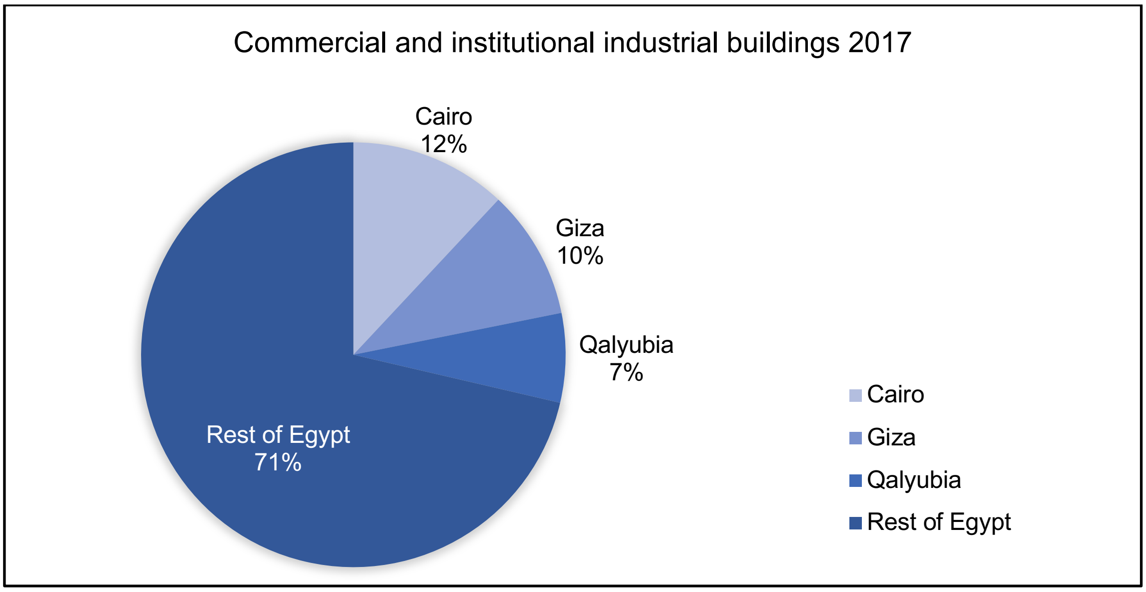


Figure 4-37: The percentages of the commercial and institutional industrial buildings of the three governorates and the rest of Egypt in 2017.

4.3.3 Climate

4.3.3.1 Heating degree days (HDD) and cooling degree days (CDD)

Heating degree-days (HDD) and cooling degree-days (CDD) are weather-based technical indexes that are used to identify the energy required for heating and cooling buildings (Eurostat, 2017). The Heating and cooling degree-days for Cairo Governorate, Giza and Qalyubia are obtained from the Degree Days.net. Degree.Days.net is a website that provides data weather for energy professionals. Kennedy et al. (2015) used this website to collect the heating and cooling degree-days for the 27 world's megacities. The website generates the heating and cooling degree-days based on the selected location. For this study, Cairo International Airport was the nearest available station to Cairo, Giza and

Qalyubia Governorates. The generated data is the average of the heating and cooling degree-days from 2014 to 2018. Data for previous years was unavailable.

The heating degree-days (HDD) is 311 for the selected location Cairo International Airport (Table 4-1) and the cooling degree-days (CDD) is 770 (Table 4-2). This indicates that most of the energy in Cairo, Giza and Qalyubia Governorates is required for cooling rather than heating. In contrast, the heating degree-days (HDD) of London for the same period is 2385 (Table 4-3) and the cooling degree-days (CDD) is 16 (Table 4-4). This indicates that most of the energy in London is required for heating rather than cooling. The heating and cooling degree-days are important indicators as they differ from one place to another and they identify whether the energy is required for heating or cooling. This could enable decision-makers to develop more suitable energy and electricity systems.

Table 4-1: The average of the heating degree-days (HDD) from 2014 to 2018 for Cairo, Giza and Qalyubia.

Description:	**Celsius-based 5-year-average (2014 to 2018) heating degree days for a base temperature of 18.0C**	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)	
Station:	Cairo Airport, EG (31.41E,30.11N)	
Station ID:	HECA	

	HDD	% Estimated
Jan	116	0.08
Feb	72	0
Mar	30	0
Apr	12	0
May	0	0.6
Jun	0	0
Jul	0	0
Aug	0	0.01
Sep	0	0
Oct	0	0
Nov	12	0
Dec	69	0
Total	311	0.06

Table 4-2: The average of the cooling degree-days (CDD) from 2014 to 2018 for Cairo, Giza and Qalyubia.

Description:	**Celsius-based 5-year-average (2014 to 2018) cooling degree days for a base temperature of 25.0C**	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)	

Station:	Cairo Airport, EG (31.41E,30.11N)	
Station ID:	HECA	
	CDD	% Estimated
Jan	0	0.08
Feb	4	0
Mar	15	0
Apr	43	0
May	95	0.6
Jun	131	0
Jul	152	0
Aug	162	0.01
Sep	117	0
Oct	47	0
Nov	4	0
Dec	0	0
Total	770	0.06

Table 4-3: The average of the heating degree-days (HDD) from 2014 to 2018 for London, UK.

Description:	**Celsius-based 5-year-average (2014 to 2018) heating degree days for a base temperature of 18.0C**	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	
Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how	

	much each figure was affected (0% is best, 100% is worst)	
Station:	London, GB (0.45W,51.48N)	
Station ID:	EGLL	
	HDD	% Estimated
Jan	374	0.04
Feb	343	0
Mar	313	0
Apr	225	0
May	138	0.006
Jun	62	0
Jul	29	0
Aug	48	0
Sep	90	0
Oct	169	0
Nov	274	0
Dec	320	0
Total	2385	0.004

Table 4-4: The average of the cooling degree-days (CDD) from 2014 to 2018 for London, UK.

Description:	**Celsius-based 5-year-average (2014 to 2018) cooling degree days for a base temperature of 25.0C**	
Source:	www.degreedays.net (using temperature data from www.wunderground.com)	

Accuracy:	Estimates were made to account for missing data: the "% Estimated" column shows how much each figure was affected (0% is best, 100% is worst)	
Station:	London, GB (0.45W,51.48N)	
Station ID:	EGLL	
	CDD	% Estimated
Jan	0	0.04
Feb	0	0
Mar	0	0
Apr	0	0
May	0	0.006
Jun	3	0
Jul	9	0
Aug	3	0
Sep	1	0
Oct	0	0
Nov	0	0
Dec	0	0
Total	16	0.004

4.3.3.2 Annual precipitation (mm) and rainfall

The definition of precipitation 'is any kind of water that falls from clouds as a liquid or a solid. Average precipitation is the long-term average in depth (over space and time) of annual precipitation in the country' (The World Bank, 2019a). The annual precipitation of Egypt is 51mm; it is the lowest precipitation worldwide as shown in Figure 4-38, (FAO, 2016). The rainfall in Egypt is limited and unpredictable as the average annual rainfall of Egypt is 12mm and Cairo is 25mm (Abdel-Shafy et al., 2010). The average annual rainfall for Giza and Qalyubia is expected to be the same as Cairo Governorate.

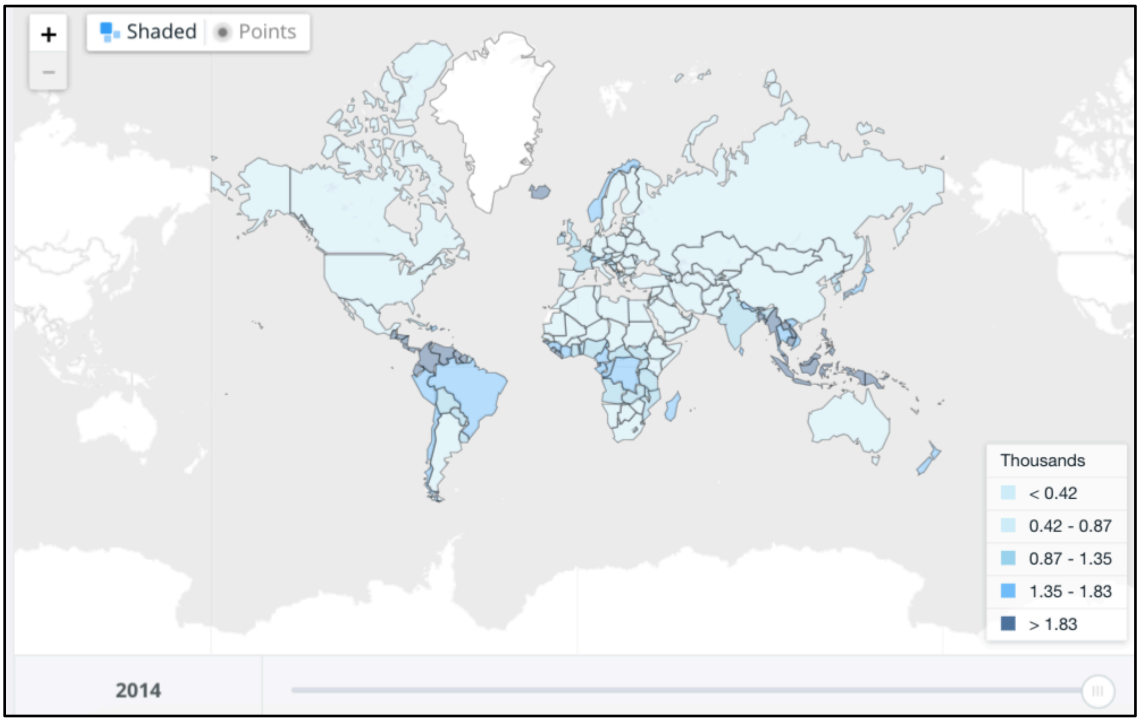


Figure 4-38: The world's average precipitation in depth (mm per year) (The World Bank, 2019a).

4.3.3.3 Annual solar radiation

This is an important indicator as it identifies the availability of solar energy. The long-term average of the direct normal irradiation (DNI) of Egypt since 1994 to 2015 varies from1899 kWh/m^2 /year to 2775 kWh/m^2/year as shown in Figure 4-39. It is worth noting here that the direct normal irradiation of Spain is almost 2100 kWh/m^2/year and it dominates 69% of the world's concentrated solar power (CSP) (Shouman and Khattab, 2015). This indicates the huge potential of solar energy in Egypt as the average DNI of Egypt is higher than Spain.

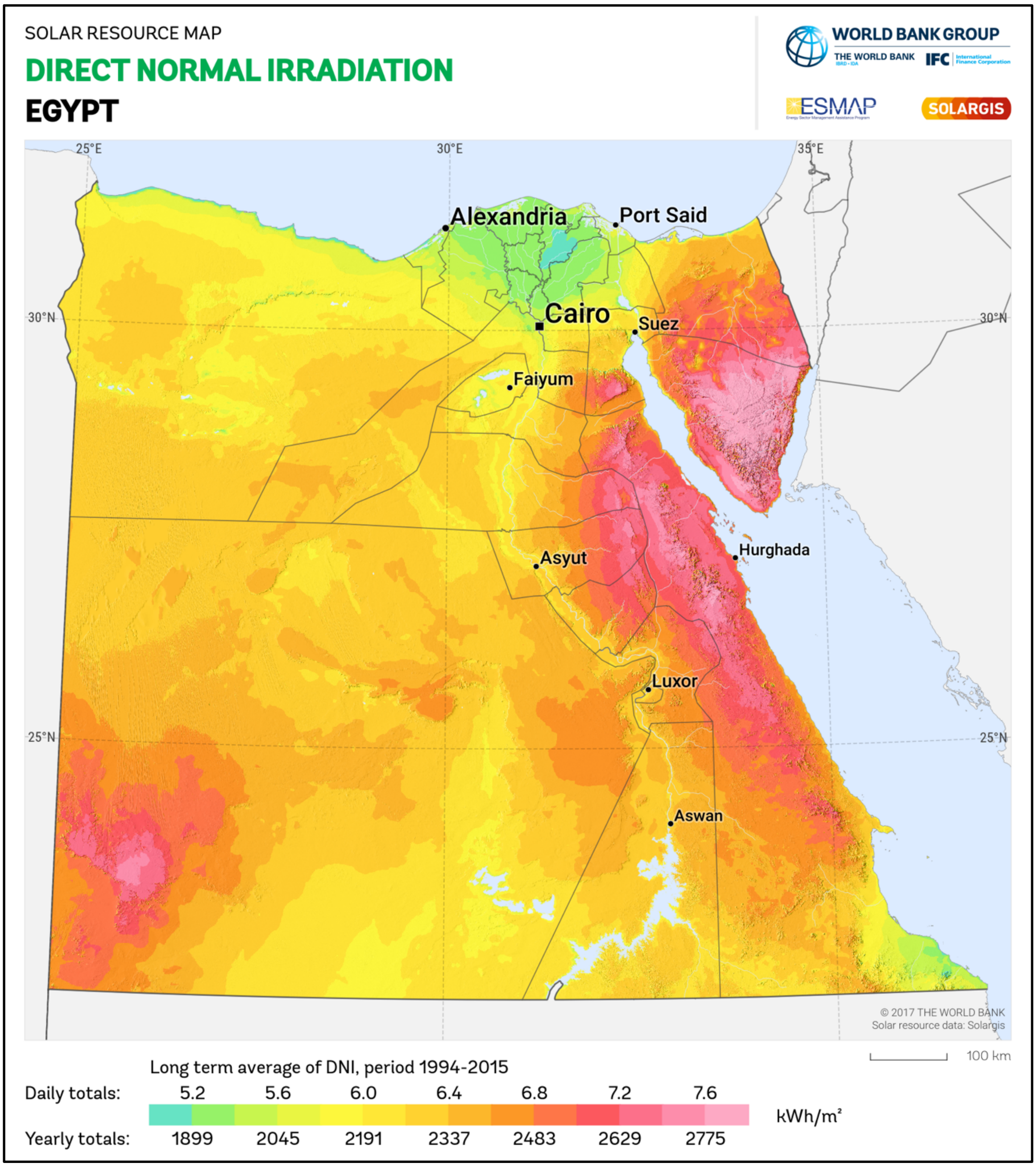


Figure 4-39: The long-term average of the direct normal irradiation since 1994 to 2015 for Egypt (Solargis, 2017a).

The direct normal irradiation of Cairo, Giza and Qalyubia Governorates is less than the average direct normal irradiation of Egypt (Figure 4-40). This indicates that the three governorates might not be the best locations for solar energy in Egypt. However, the DNI of the three governorates is considered high if compared to the DNI of other countries as shown in Figure 4-41 as it varies from 365 kWh/m²/year to 3652 kWh/m²/year. This shows the huge potential for solar energy in Cairo, Giza and Qalyubia Governorates.

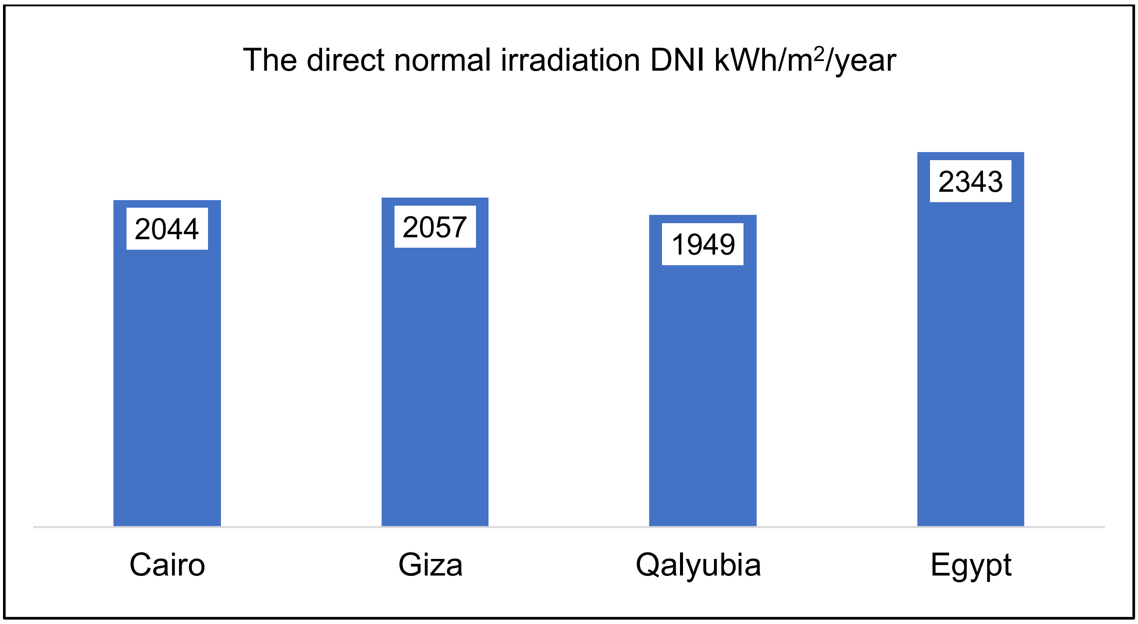


Figure 4-40: The direct normal irradiation (DNI) kWh/m²/year of Cairo, Giza, and Qalyubia Governorates and Egypt.

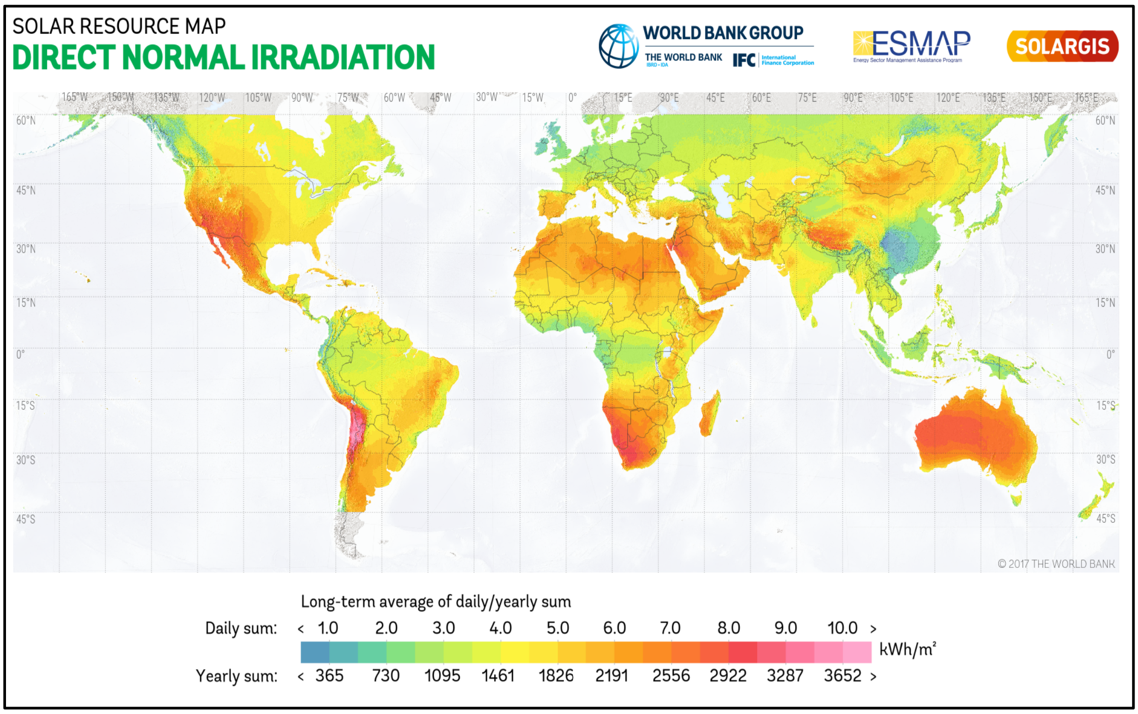


Figure 4-41: The Global direct normal irradiation (Solargis, 2017b)

4.3.3.4 Annual wind speed

This is an important indicator as it identifies the availability of wind power. The annual wind speed of Egypt is 8.26 m/s. The wind speed varies from 5 m/s to 9.75 m/s as shown in Figure 4-42. The annual wind speed of China is 8.77 m/s and the annual wind speed of United States is 8.38 m/s, both countries have the highest installed wind power capacity worldwide. This shows the high potential of wind power in Egypt as the annual wind speed of Egypt is almost similar to the annual wind speed of China and the United States.

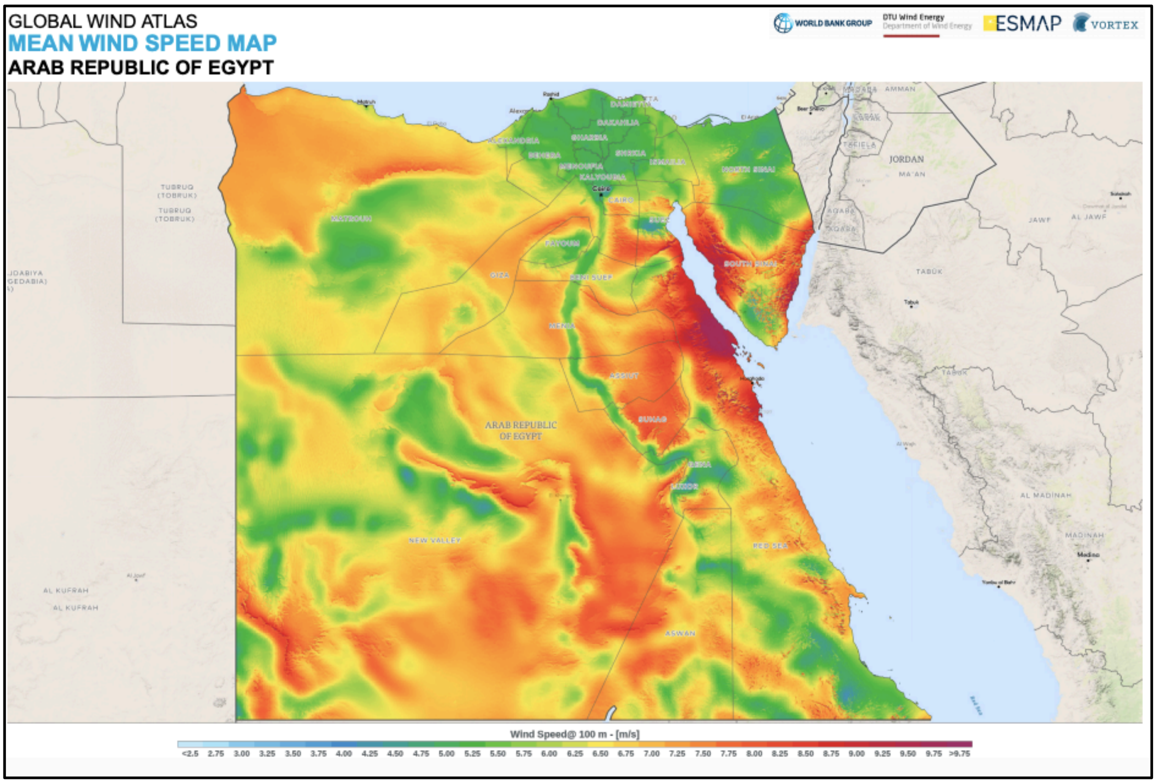


Figure 4-42: The annual wind speed of Egypt (DTU, 2018a).

The annual wind speed of Cairo, Giza and Qalyubia Governorates is less than the annual wind speed of Egypt (Figure 4-43). This indicates that the three governorates might not be the best locations for wind power in Egypt, however, the value of the wind speed is considered suitable for power generation if it is above 5 m/s.

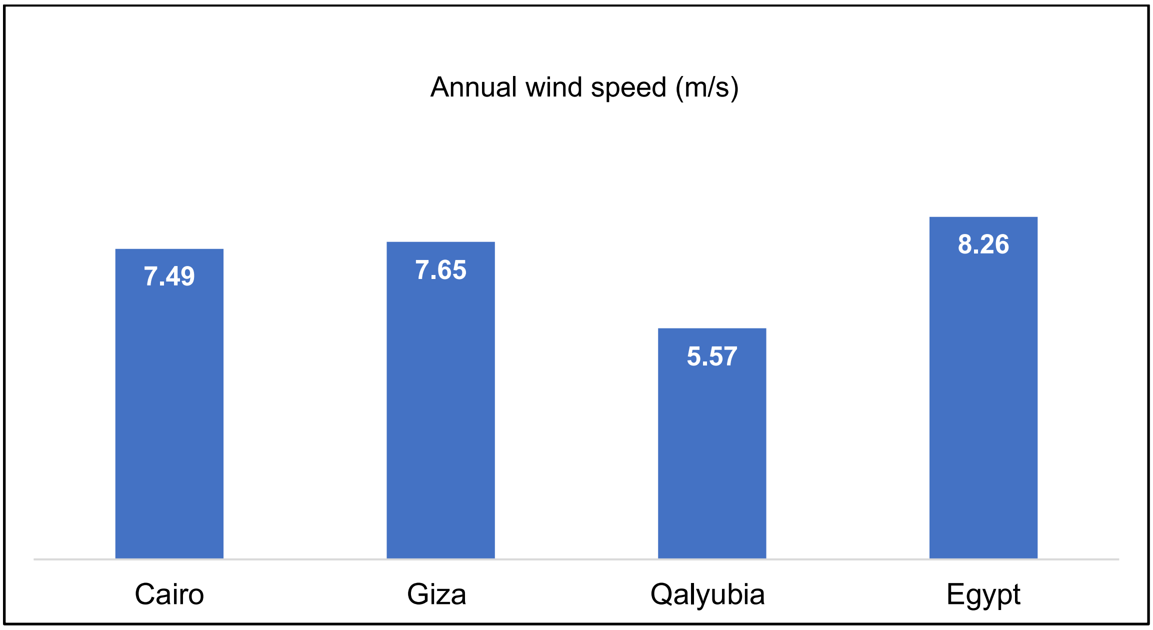


Figure 4-43: The annual wind speed of Cairo, Giza and Qalyubia Governorates and Egypt.

4.4 Conclusion:

This chapter shows the rapid growth of population in Cairo, Giza and Qalyubia, the constituent Governorates of Greater Cairo Region. A quarter of Egypt's population lives in the three Governorates. The population of the three Governorates has been consistently increasing over a period of 15 years (2001 to 2016). The population growth rates in Giza were higher than Cairo Governorate due to the government's efforts to reduce the pressure from Cairo Governorate. However, a huge percentage of the population growth of Giza Governorate is unplanned and the inhabited density of Cairo Governorate has been consistently increasing. The inhabited density of Egypt reveals the uneven distribution of the population of Egypt as it reaches more than 50,000 inhabitants per square kilometres in Cairo Governorate and on the other hand, the inhabited density of Egypt is less than 1400 inhabitants per square kilometres. Cairo Governorate is a high-density Governorate to the extent that residents apart from the new satellite cities occupy most of the roofs of residential buildings. This is a major challenge to the installation of solar panels on the roofs of residential buildings in Cairo Governorate. Additionally, in high-density settlements in Cairo Governorate specifically the unplanned settlements the streets are narrow that hinders the flow of resources in and out these areas and the provision of services. This has a huge impact on the existing infrastructure, the flow of materials in and out the governorates and the quality of services provided. The government should consider the urban carrying capacity of Cairo Governorate before replacing the old buildings with multi-storey buildings. Furthermore, the carrying capacity of Giza Governorate should be considered in the future to absorb the population growth.

The economic situation in Egypt was highly affected after the devaluation of the Egyptian pound in 2017, which increased inflation. Cairo Governorate has the highest unemployment rates compared to the average of Egypt, Giza and Qalyubia. In general, more job opportunities are required in the future to reduce the high rates of unemployment in Egypt and the three governorates. This could be achieved by establishing an integrated sustainable waste management system (see Chapter 7) and investing in renewable energy projects as there is a huge potential to develop such projects (see Chapter 5). Both sectors require a huge number of labourers, technicians, engineers and a range of skills. It is also important to increase the investments in other governorates to provide more job opportunities and reduce internal migration.

The heating degree-days and the cooling degree-days of the three governorates show that most of the energy is required for cooling rather than heating. The average annual precipitation of Egypt and the three governorates is extremely low as Egypt has the lowest precipitation worldwide causing massive water shortages. The annual solar radiation and the annual wind power show the huge potential of solar and wind power in Egypt and the three governorates. However, the nature of urban planning and the inhabited density of Cairo Governorate and the surrounding environments hinder the development of such projects.

5 Chapter Five: Current and future projections of the energy and electricity sectors in Cairo, Giza and Qalyubia Governorates and the whole country Egypt

5.1 Introduction

This chapter presents the current situation of, and projections for, the energy and electricity sectors in Egypt and Cairo, Giza and Qalyubia Governorates. The data of the energy and electricity sectors were collected for more than 15 years to identify patterns of production and consumption. To target the most important quantitative data to measure and assess the energy and electricity sectors, I used the third layer of the multi-layered indicator set that was developed by Kennedy et al. (2014). Additionally, the semi-structured interview that was conducted with the representative of the Ministry of Electricity and Renewable Energy in Egypt was critically analysed to better understand how the energy and electricity sectors are being managed. The quantitative and qualitative data of the energy sector (see section 5.3) and the electricity sector (see section 5.4) in Cairo, Giza and Qalyubia Governorates and Egypt are merged and explained in depth. The energy and electricity sectors are presented in the same chapter as the representative of the Ministry of Electricity and Renewable Energy mentioned that both sectors are strongly linked in Egypt.

> *"The main goals of the Ministry of Electricity are part of the energy strategy. I will start with the energy strategy of Egypt up to 2035 first. The goals of the Ministry of Electricity fit into the strategy"* (Interviewee 2).

5.2 Layer 3-1: energy and electricity sectors in Cairo, Giza and Qalyubia Governorates and Egypt

The third layer of the original multi-layered indicator set includes: the consumption of energy (all types); electricity sources; consumption of water; consumption of food; building materials; generation of solid wastes and wastewater (Kennedy et al., 2014). The focus of this study is on the energy, electricity and water sectors as examples of the inputs of cities and the solid waste and wastewater as examples of the outputs of cities. The energy and electricity sectors (Layer 3-1) are presented in this chapter, while the water and wastewater sectors (Layer 3-2) are presented in Chapter 6 and the solid waste (Layer 3-3) is presented in Chapter 7. This chapter (Layer 3-1) includes the following data:

a) <u>The energy sector:</u>

- Primary energy production and consumption of Egypt for 2013-2014, 2014-2015 and 2015-2016, this data includes all types of primary energy: renewable and non-renewable energy.
- Renewable energy resources (hydropower, wind and solar) production and consumption from 2009-2010 to 2015-2016.
- Natural gas and crude oil production and consumption of Egypt from 2013-2014, 2014-2015 to 2015-2016.
- Percentages of households according to the type of fuel used in cooking for Cairo, Giza and Qalyubia Governorates and Egypt.
- Energy consumption of Egypt by sector (percentages) from 2009-2010 to 2016-2017.

- Energy consumption of Cairo, Giza and Qalyubia Governorates by sector in 2015-2016.
- Carbon dioxide emissions of Egypt by sector (percentages) from 2009-2010 to 2016-2017.

b) <u>The electricity sector:</u>

- The electricity production mix of Egypt includes renewable and non-renewable energy resources from 2002-2003 to 2015-2016.
- The percentages of electricity sources of Egypt from 2002-2003 to 2015-2016.
- The electricity production and line losses of Egypt from 2005-2006 to 2015-2016.
- The electricity production of Cairo, Giza and Qalyubia Governorates and Egypt from 1999-2000 to 2015-2016.
- The total electricity consumption of Cairo, Giza and Qalyubia Governorates and Egypt from 1999-2000 to 2015-2016.
- The electricity consumption by sector (percentages) of Cairo, Giza and Qalyubia Governorates from 1999-2000 to 2014-2015 and Egypt from 1999-2000 to 2016.
- Percentages of households without grid electricity connection in 2017.

Sources of the secondary data are presented in Chapter 3 Table 3-1 and the criteria of including and excluding reports are presented in Appendix 12.

5.3 The energy sector in Egypt, Cairo, Giza and Qalyubia Governorates

5.3.1 The primary energy production and consumption of Egypt

The main sources of non-renewable primary energy production of Egypt are natural gas and crude oil, as shown in Figure 5-1. The linear trendlines in Figure

5-1 indicate that the production of natural gas from 2013-2014 to 2015-2016 is decreasing and the production of crude oil in the same period is almost stable. The share of LPG, hard coal and renewable energy is low compared to the natural gas and crude oil.

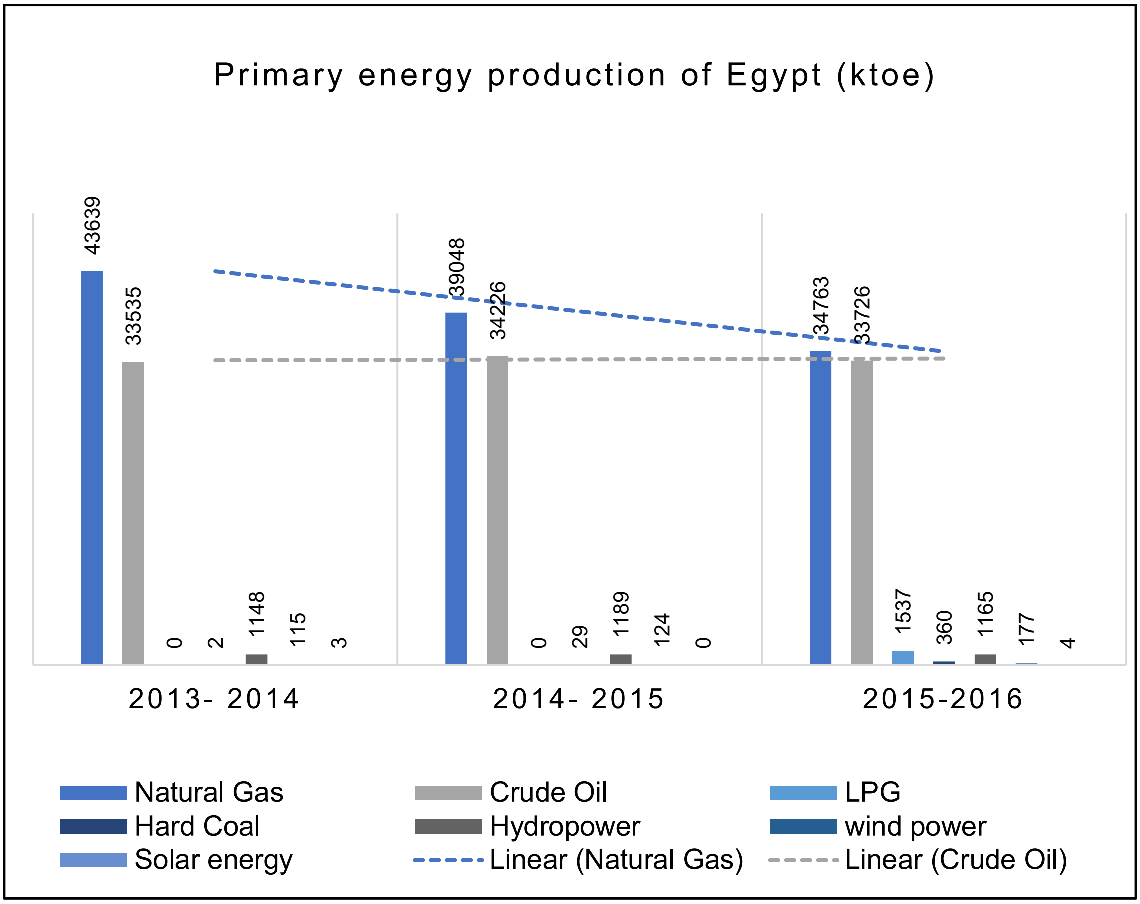


Figure 5-1: Primary energy production of Egypt from 2013-2014 to 2015-2016.

The highest rate of primary energy consumption of Egypt is natural gas followed by crude oil (Figure 5-2). The linear trendlines in Figure 5-2 indicate that the consumption of natural gas slightly decreased and the consumption of crude oil slightly increased from 2013-2014 to 2015-2016. The consumption of other sources of primary energy is low compared to the consumption of natural gas and crude oil.

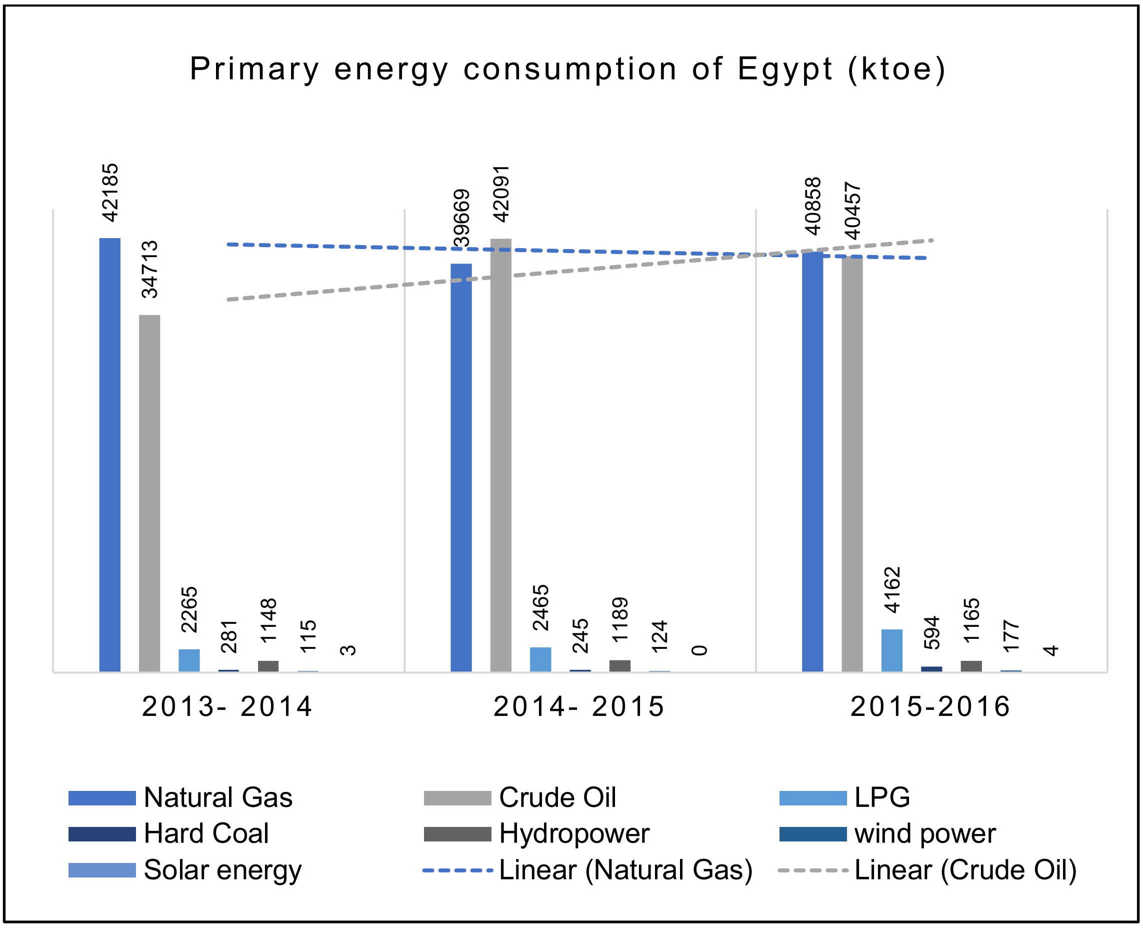


Figure 5-2: Primary energy consumption of Egypt from 2013-2014 to 2015-2016.

The consumption of natural gas and crude oil is exceeding production as shown in Figures 5-3 and 5-4. This transforms Egypt from a net export country to a net import country (Ibrahim, 2012). This transformation affects the flow of foreign currency, which is necessary for importing other essential products (EIA, 2015). Moreover, it is expected that energy demand will increase in the future due to the rapid population growth and urbanization.

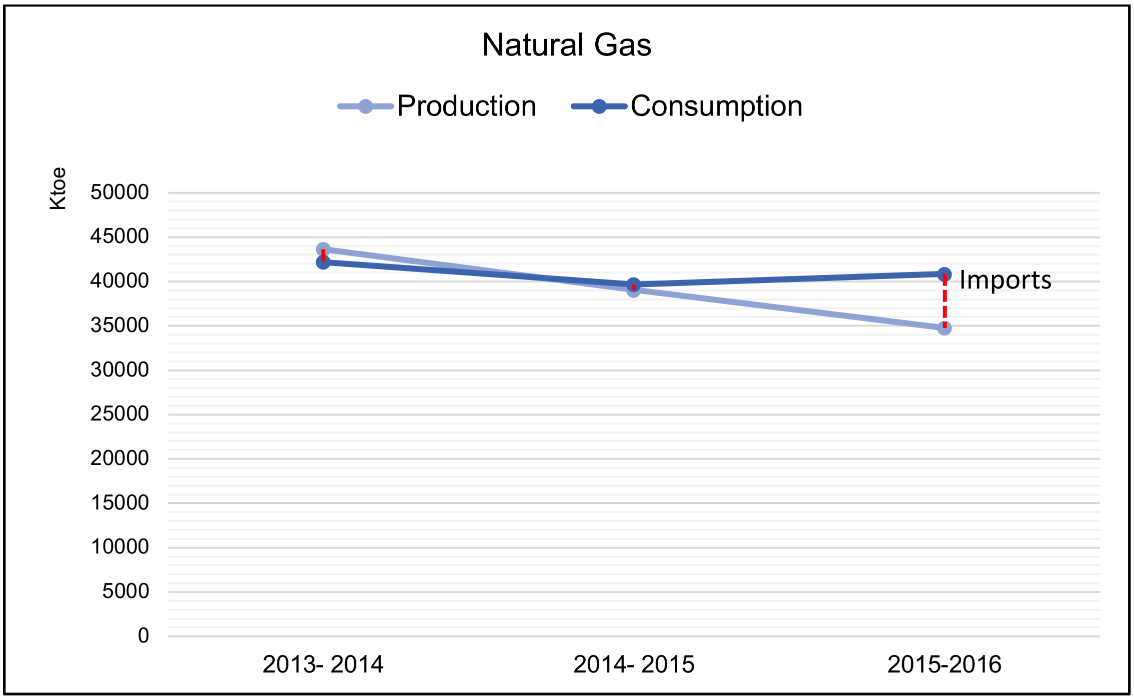


Figure 5-3: The natural gas production and consumption from 2013-2014 to 2015-2016 showing the import gap.

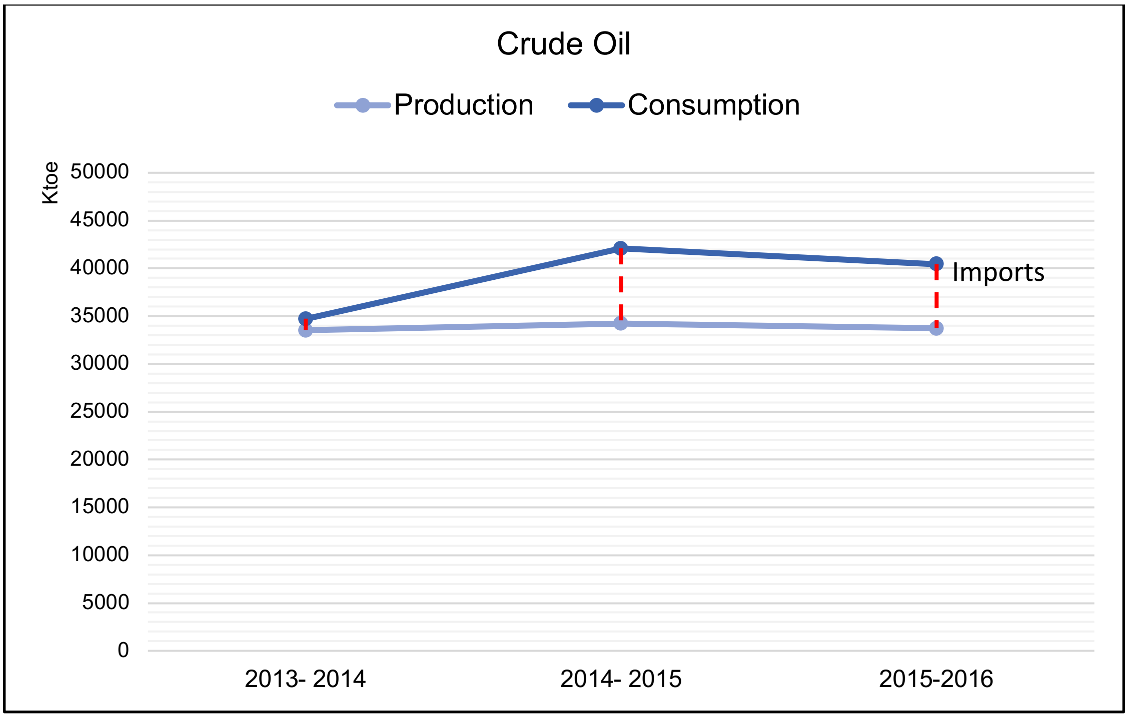


Figure 5-4: The crude oil production and consumption from 2013-2014 to 2015-2016 showing the import gap.

The representative of the Ministry of Electricity and Renewable Energy mentioned that the production of natural gas is increasing due to the new discoveries. This became apparent from the description of the electricity production mix in 2018 as it indicated that the share of natural gas is increasing.

> *"The average percentage of natural gas is 84% daily, but the annual average for this year is almost 80% (2018), 8% from heavy oil. These percentages are for this year (2018). During the previous years, there was a shortage in natural gas, so the share of oil was higher. Nowadays (2018), the share of oil is decreasing, and the share of natural gas is increasing again due to the new discoveries of natural gas. The average for this year (2018) will be 82% natural gas, 8% oil, 7% hydropower and 3% renewables"* (Interviewee 2).

The current energy situation in Egypt is similar to most of the African countries, particularly the Northern African countries. Most African countries rely on traditional fuels: oil, natural gas in Northern Africa; biofuels and waste in Middle, Eastern and Western Africa; and oil and biofuels in Southern Africa. Most Northern African countries are resource-driven economies as their economies rely on exporting oil and natural gas (Mandelli et al., 2014). A better use of energy resources is required instead of relying on one or two types of energy (Mandelli et al., 2014). In South Africa, there is a mixed-use of traditional resources, but in general, the majority of African countries depend on fossil fuels with minimal exploitation of renewable resources even though their huge potential and availability (Mandelli et al., 2014).

Despite the availability of natural gas in Egypt due to the new discoveries, the Egyptian government developed a new energy strategy for Egypt. This strategy was driven by international agreements on climate change and sustainable development goals. It is called the "Integrated Sustainable Energy Strategy 2035" and has four goals, presented in Table 5-1.

Table 5-1: The goals and sub-goals of the energy strategy of Egypt.

The Energy Strategy of Egypt "Integrated Sustainable Energy Strategy 2035"	
Goals	Sub-goals
1. Ensuring energy security of supply	▪ Diversification of energy supply. ▪ Improving energy efficiency. ▪ Upgrading energy infrastructure and transmission infrastructure. ▪ Encouraging private sector participation.
2. Ensuring sustainability	▪ Ensuring financial sustainability of the service providers. ▪ Ensuring subsidy reforms of energy (which means removing the subsidies or having objective subsidy specifically for vulnerable consumers).
3. Improving institutional and corporate governance	▪ Improving corporate governance for service providers either for generation, transmission or distribution companies. ▪ Enhancing the government institutional setup for energy efficiency activities in Egypt (as there is a problem within the governance and the energy efficiency setup within the country). ▪ Ensuring the availability of continuous updating and energy modelling to the system for planning.

4. Strengthening competitive markets and regulations	▪ Connecting to a future regional market. ▪ Developing as gas market. ▪ Complementary gas market regulation. ▪ Strengthening the electricity market. ▪ Support for the renewable sector. ▪ Improving the sector for customers.

The four goals and sub-goals of the energy strategy of Egypt indicate that the government is focused on ensuring the sustainable growth of the energy and electricity sectors. The representative of the Ministry of Electricity and Renewable Energy shed light on one of the most important sub-goals of this strategy, “enhancing energy efficiency.” As the government established an action plan called “The National Energy Efficiency Action Plan” (NEEAP). Every three years the government will establish an action plan with specific targets until the energy 2035 target is achieved. The main target for the current NEEAP is to enhance the institutional setup and the governance of the energy efficiency sector through coordination between different sectors because it is a cross-sectional activity. Its role is to coordinate, create good governance within the sectors, finalize and establish a monitoring and evaluating system for the energy target, and to create a financial stream to support energy efficiency activities. Moreover, to develop an energy efficiency fund, energy efficiency laws and guarantees, so it will use all kinds of available finances in the country and target it towards energy efficiency.

This indicates that there is currently a huge development in the energy sector in Egypt. For example, the government established an energy strategy followed by an action plan that will be updated every three years. This shows the consistency of implementing the energy strategy. Even if the ministers change at any time, the new ministers will have to adhere to the energy strategy goals. This was one of the major challenges in Egypt in the past in all sectors as the strategies were dependent on the newly formed government and ministers, often leading to disjointed strategy making and policy implementation.

5.3.2 Renewable energy resources of Egypt

The main types of renewable energy resources of Egypt are hydropower, wind and solar energy. The share of all types of renewable energy resources was 1% of the primary energy production of Egypt in 2015-2016 (Figure 5-5). This share is considered low compared to the potential of wind and solar power in Egypt (see Chapter 4), the potential of sludge-to-energy (see Chapter 6) and waste-to-energy (see Chapter 7).

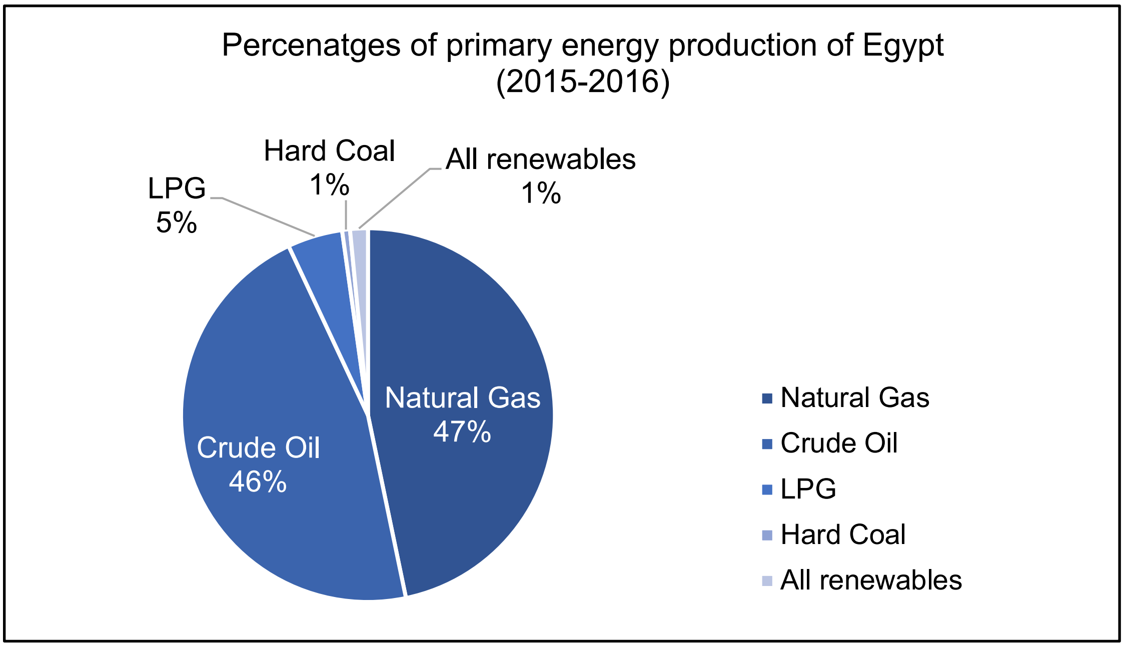


Figure 5-5: Percentages of primary energy production of Egypt in 2015-2016.

The share of hydropower is higher than wind, which, in turn, is higher than solar energy (Figure 5-6). Hydropower production was almost stable from 2009-2010 to 2015-2016. The main source of hydropower is the High Dam in Aswan. The representative of the Ministry of Electricity and Renewable Energy

(Interviewee 2) pointed out that there is no potential to increase the production of hydropower in the future.

"The objective is by 2022 the percentage of renewable energy will reach 20%. I would like to distinguish between two things: the energy balance and the electricity balance (mix) of Egypt. The energy balance of Egypt consists of 95% oil and gas, 5 % renewable (2018). The electricity balance (production mix) is 90% oil and gas, 10% renewable that includes 7 to 8% hydropower and it is relatively decreasing. There is no potential in increasing hydropower in Egypt. And only 2 to 2.5% of other renewable energy resources mostly wind (2018)" (Interviewee 2).

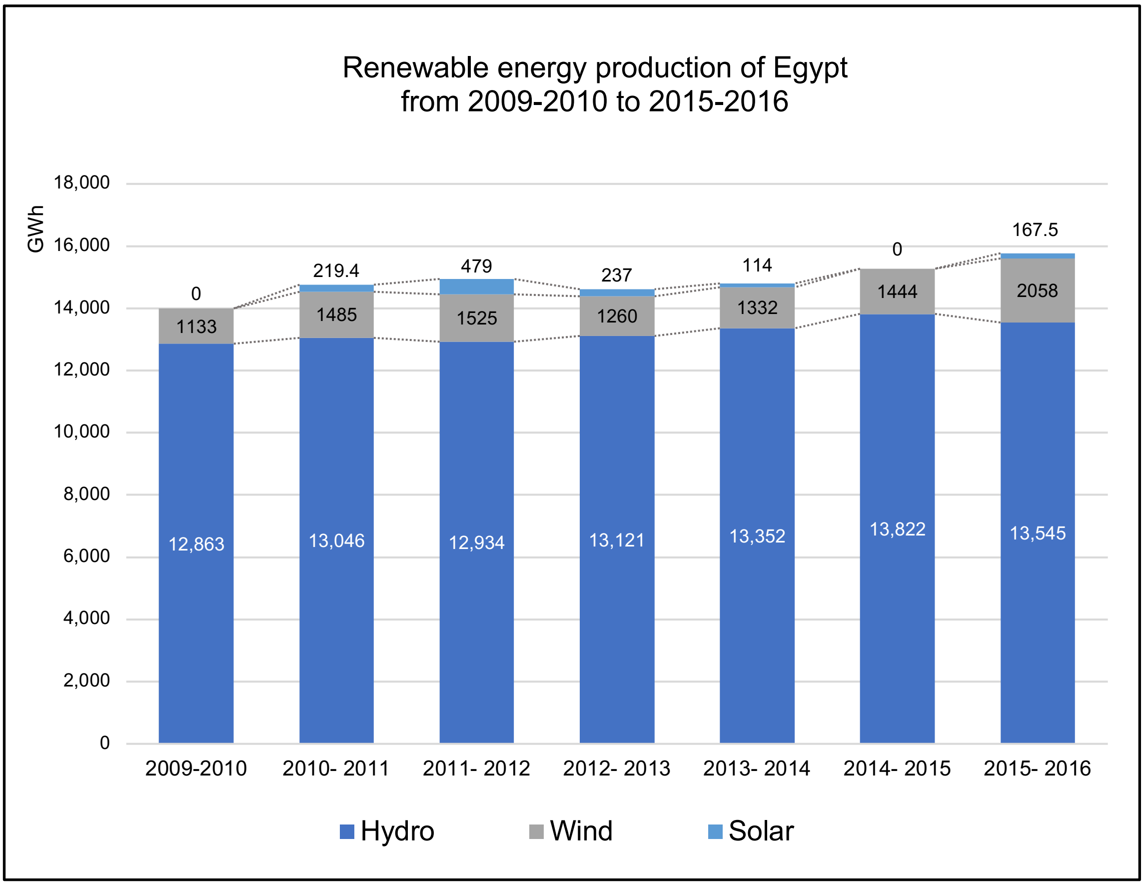


Figure 5-6: The renewable energy (hydropower, wind and solar) production of Egypt from 2009-2010 to 2015-2016.

Despite the limited potential of hydropower in Egypt, the government set a target to increase the share of renewable energy to reach 20% by 2022 and 35% by 2030 of which 5% hydropower, 16% solar and 14% wind power (Cabinet of Ministers - Arab Republic of Egypt, 2016). By 2035, the share of renewable energy is targeted to reach 42%, but, as this interviewee revealed, this is under revision. This shows that the government is focused on enhancing the solar and wind power to achieve these targets rather than the hydropower. The representative of the Ministry of Electricity and Renewable Energy outlined the huge potential of solar energy in Egypt, considered one of the world's best locations for solar energy.

> *"Egypt has a huge potential for solar power, it is one of the world's best locations for solar power"* (Interviewee 2).

Despite the huge potential of solar energy in Egypt, Figure 5-6 shows that the share of wind energy is higher than the share of solar energy. The representative of the Ministry of Electricity and Renewable Energy (Interviewee 2) explained that the development of wind energy in Egypt exceeded solar power in the past due to the following reasons:

- Internationally, the development of wind energy exceeded the solar energy.

  > *"This was an international trend at that time"* (Interviewee 2).

- The availability of the world's best locations for wind power in Egypt.

  > *"But it also has one of the world's best locations for wind power Gabel El Zeit near the Gulf of Suez. The capacity factor of Gabel El Zeit is around 60%. A wind plant becomes as a thermal plant"* (Interviewee 2).

- The capacity factor of wind energy is higher than solar energy.

"Wind power has another advantage; wind has a capacity factor. If you install one megawatt, it could generate a capacity factor, which means that the quantity of energy divided by the installed capacity multiplied by 8760 (the number of hours per year). Wind energy has double the capacity factor. For wind power, we are talking about 40% capacity factor while for solar power it is about 20% maximum" (Interviewee 2).

- Wind power contributes to the peak demand (night) of Egypt.

  "Usually the wind energy is available in Egypt during the sunset and by night, which is the time of our peak demand. Solar energy is available in the morning that is not during our peak demand. We consider the capacity credit. The capacity credit is how much this renewable energy source could contribute to the peak demand. Wind energy has a contribution around 25% of this capacity. Solar is zero because it is available in the morning not during our peak demand" (Interviewee 2).

- Wind power was a well-proven technology compared to solar power.

  "By 2014, the prices of solar power started to drop, but wind power was a much more mature technology compared to solar power. Solar energy was not that mature enough like wind energy. Wind energy has an older history in the country" (Interviewee 2).

- Wind power was cheaper at that time.

  "As at that time, the price of solar power was more expensive than wind power. For example, the first wind project, during 2010 and 2014 the price of solar power was 20 cent per kilowatt-hour on average, while for wind power it was 10 cent per kilowatt-hour" (Interviewee 2).

Although the development of wind power in Egypt was higher than solar power in the past, nowadays, the government's target indicates that the share of both solar energy and wind energy will increase in the future. The representative of the Ministry of Electricity and Renewable Energy explained the drivers of increasing the share of renewable energy in Egypt are due to the following reasons:

- In general, the price of renewable energy (solar and wind) now has gone below the price of conventional energy.

  "Recently we received offers for a tender of 200 megawatt PV solar plant. The offers were starting from 2.8 cent per kilowatt-hour compared to what we generate from the best efficient oil and gas facility is around 5 cent per kilowatt-hour" (Interviewee 2).

  "The cost of large solar and wind power is below 4 cent per kilowatt-hour while the conventional power plants or oil and gas are around 5 and 6 cent per kilowatt-hour. It is no longer that renewable energy is more expensive than non-renewable energy" (Interviewee 2).

  "Nowadays, the solar energy specifically the introduction of PV and the improvement of its efficiency reduced its price" (Interviewee 2).

- The contractual capacity and practices for renewable energy projects improved in Egypt.

  "We reached a level of prices that beats, the last tender in Egypt is one of the lowest internationally either for wind or solar. This proves two things the good contractual practices that means the good quality of your documents. This includes the power purchases agreements and the solicitation process" (Interviewee 2).

- The experience and knowledge of managing solar energy projects are increasing.

  "In addition, we have two rounds of feed-in tariff for solar power, so the country has an experience in dealing with such projects" (Interviewee 2).

- The renewable energy sector in Egypt has a conducive environment for investment compared to other countries due to its huge capacity and the substantial growth of renewable energy projects to achieve the government's target.

  "The potential of the renewable energy growth market is substantial as the target is to achieve 42% of electricity generated from renewable energy by 2035. This is equivalent to 80 gigawatts. This means that the Egyptian market is expanding substantially. If you compare it to the Moroccan market, Jordanian or the Emirati they might be growing faster nowadays, but in the end, these markets have a capacity. The capacity of these markets is small and limited" (Interviewee 2).

- Public pressure on the government to increase the share of renewable energy, as this will ensure that the price of electricity will remain fixed in the future rather than relying on traditional fuels that have unpredictable prices each year.

  "There is a public pressure on the government to maximize the use of renewable energy to reduce the price of energy in the future. One of the things that I have not mentioned about renewable energy is that renewable energy provides a fixed price for electricity so if we build a power plant now; we know the cost of electricity will not change too much for the next twenty years because it is an investment cost. For conventional power

plants, we cannot predict the price of energy next year so we cannot know the cost of electricity because conventional power plants rely on oil and gas that are variable parameters you cannot predict their prices next year" (Interviewee 2).

5.3.3 Challenges of the development of renewable energy projects in Egypt

- There is a lack of clear perspective of implementing renewable energy projects. Despite the potential of renewable energy resources in Egypt, the representative of the Ministry of Electricity and Renewable Energy described the process of transferring these resources into energy as "complicated". He clarified that the process includes resources identification, project identification, technology challenges, biding and financing and many other challenges. This indicates that the barriers of increasing the share of renewable energy include many other aspects, not only the lack of knowledge as mentioned in previous studies but also the lack of the experience of biding, contracting and financing such projects.

  "Many people might think that the use of renewable energy because we just have the resource means that we have this energy, but in order to transfer this source into useful energy it is a complicated process which includes resource identification, project identification, technology challenges, biding and financing and many other challenges" (Interviewee 2).

- The government will be able to increase the share of solar power and meet 2022 target as most of the projects are already identified, but for wind power, the projects are not yet resolved. Therefore, the share of solar energy will exceed the share of wind energy in the future.

> *"It is a challenge, as I mentioned to achieve the target; we need to build 7000 megawatt of wind energy and 3000 megawatts of solar energy. I expect that we could achieve the solar power target. The wind target is still being challenged because as I mentioned we have between operation, contracting and under contractual processes at different stages are about 5000 megawatts. We still have a gap of 2000 megawatt to achieve the target by 2022. To achieve it within the next four years it is a challenge. Regarding the solar power target, it is achievable because already the projects that are under development or contracting would cover the target. For wind energy, we still have a gap of 2000 megawatt that should be covered. Even the 3000 megawatt of wind power includes 2000 megawatt which is the mega-contract with Siemens that is still being under negotiations because the price of Siemens offer is too high and unacceptable"* (Interviewee 2).

- There is difficulty operating the grid with a high share of renewable energy resources (such as hybrid systems). This indicates that the existing grid is not suitable for receiving and transmitting renewable energy resources. Therefore, the government is currently upgrading the grid.

> *"It is not easy to operate a grid with high share of renewable energy regarding the grid's stability"* (Interviewee 2).

- Community acceptance: the utility size is much more accepted than the distributed systems.

"Actually, if we talk about the social aspect, I will differentiate between two things; utility size use of renewable energy which we mean large power plants; I think the community will cope with this size of projects. From a social aspect regarding the utility size, yes, it is very much accepted socially" (Interviewee 2).

5.3.4 Challenges of distributed systems in Egypt

- Urban planning: high buildings beside short buildings create shaded areas that reduces the efficiency of solar panels. This is a common problem in high and medium-density settlements in Egypt (Figure 5-7).

Figure 5-7: High buildings and short buildings high-density settlements in Egypt (Source: author's site visits).

- The ownership pattern of the roofs is not identified.
- The prices of distributed systems are more expensive than the utility size.

- The weak connections in informal settlements are not suitable for distributed systems.
- Financing: the lack of interest and developed bank systems to finance such businesses for high-income households who are able to install solar panels. Moreover, the lack of guarantees that could be provided by customers, specifically households of informal settlements, most of which do not have bank accounts.

> *"Regarding distributed renewable energy resources that is basically, although there might be a convincement within the public regarding their importance, there are many other challenges. First, if we talk about top roof solar systems actually the urban planning, you will find high buildings beside short buildings. The high buildings will create a shaded area on top of the short buildings that will affect the efficiency of solar panels. The second challenge is the ownership pattern, you might have a building that the roof is not owned by anyone each apartment can be owned by separate entity or whatever, it is a challenge in that aspect and it is not that easy to have a kind of collective system to serve a building so, this is another challenge. The third challenge is the distributed solar systems are still expensive. The prices of the utility size as mentioned previously is going low quickly, but the prices of distributed systems are not that elastic in price changes, they are still expensive. Another challenge is the financing; the banks are not willing very much for this retail businesses. Second, there is not enough guarantees that could be provided by customers. There should be a bank system developed for this. I am talking about high-income consumers who are able to install solar systems. I am*

> *not talking about middle and low-income households. Regarding unofficial buildings and areas, I think there is a challenge regarding the grid because some of these areas are informal, they are prevented from the grid* (not allowed to be connected to the national grid) *so they connect to the grid in an informal way* (illegally). *The grid is not that strong to deal with such illegal connections so, it weakens the strength of the grid. They are low-income households, they are not able to provide any kind of credit any form of bank statements, many of them do not deal with banks and they do not have bank accounts"* (Interviewee 2).

However, solar panels can be more efficient in new satellite cities (low-density settlements) as urban planning is better and the ownership pattern of roofs is clear (Figure 5-8). For wind energy, it is not suitable for inner cities.

Figure 5-8: Low-density settlements in New Cairo, a new satellite city in Cairo Governorate (Source: author's site visits).

5.3.5 Challenges of waste-to-energy technology in Egypt

Despite the barriers of developing solar and wind energy in Egypt as mentioned above, the government is mostly focused on removing these barriers and increasing the share of solar and wind power. Additionally, the representative from the Ministry of the Electricity and Renewable Energy did not discuss waste-to-energy technologies. However, there is a huge potential of waste-to-energy technologies in Egypt as organic waste represents 60% of the total municipal solid waste. The amount of organic waste is rising and is expected to increase in the future due to the rapid population growth. When I asked the representative of the Ministry of Electricity and Renewable Energy about the potential of waste-to-energy in Egypt, he highlighted the advantages and disadvantages of this sector in Egypt as presented in Table 5-2.

Table 5-2: Advantages and disadvantages of waste-to-energy technology in Egypt.

Advantages	Disadvantages
▪ *Available all the time not limited as the solar and wind power.* ▪ *Much more controllable compared to the solar and wind power.*	▪ *Limited capacity (maximum 1000 megawatt) compared to the solar and wind power.* ▪ *From administrative point of view, it is very much complicated compared to solar and wind power.* ▪ *The lack of a proper waste management system.* ▪ *The process is complicated as it includes collection, storage,*

	transportation, disposal and generation. ▪ *Low quality fuel.* ▪ *The cabinet has issued a feed in tariff for the waste and some activities, but still the governance of this sector is not well defined.* ▪ *Many partners are involved such as the Ministry of Electricity, the Ministry of Environment, the Ministry of Local Development, the city council and municipalities.*

This indicates that the major challenges of the development of waste-to-energy in Egypt are the lack of governance, the lack of a proper waste management system, many partners are involved in this sector and there is a lack of coordination between them. Even the Ministry of Environment is acting as a champion for waste management and developing waste-to-energy technologies in Egypt, but it is not an implementing entity (see in Chapter 7). For renewable energy like solar and wind, the Ministry of Electricity and Renewable Energy is acting as a champion and it is an implementing entity. Therefore, the development of solar and wind energy is exceeding waste-to-energy technologies because they are being supported by the energy and electricity sectors in Egypt. Both sectors are more powerful than the Ministry of Environment. While conducting the semi-structured interview with the representative of the Ministry of Electricity and Renewable Energy the discussion was focused on solar and wind and the semi-structured interview with the representative of the Ministry of the Environment most of the discussion was focused on waste management and waste-to-energy technologies. This indicates that the energy and electricity sectors in Egypt are not interested in developing waste-to-energy technologies. The interviewee described organic waste as a ‘dirty fuel’ and they are not interested in investing in, due to the complicated nature of the process of converting the organic waste-to-energy. However, the Ministry of the Environment is interested in developing waste-to-energy technologies because it is aware of their potential not just as a source of clean and renewable energy, but also as means to improve the country’s environmental conditions.

5.3.6 The primary energy production and consumption of Cairo, Giza and Qalyubia Governorates

The Energy and Electricity annual reports from 1999 to 2016 indicate that Cairo, Giza and Qalyubia Governorates do not produce energy and rely on other governorates to meet their energy demands. The available data of the primary energy (natural gas and LPG) consumption of Cairo, Giza and Qalyubia is shown in Table 5-3, as mentioned previously the data of the primary energy consumption of the three governorates were limited. The natural gas consumption in 2013-2014 and 2014-2015 includes Cairo and Giza Governorates while in 2014-2015 the natural gas consumption of Cairo and Giza Governorates is presented separately. This is an example of the inconsistent methods of data collection, which complicates the identification, and assessment of the energy consumption of each governorate.

Table 5-3: The primary energy consumption of Egypt, Cairo, Giza and Qalyubia Governorates from 2013-2014 to 2015-2016.

Year	Natural gas consumption				LPG (liguid petroleum gas) consumption				Units
	Qalyubia	Giza	Cairo	Egypt	Qalyubia	Giza	Cairo	Egypt	
2013-2014	_	10524100*		37579522	308794	366443	360483	4157000	Tons
2014-2015	_	10499861*		35335000	283150	312464	331428	4140762	Tons
2015-2016	_	_	12667621	36755000	296304	319933	317260	4260008	Tons
* includes both Cairo and Giza									

The available data of natural gas consumption as presented in Table 5-3 is used to calculate the percentages of natural gas consumption of the three governorates and the rest of Egypt as shown in Figure 5-9. The percentage of the natural gas consumption of Cairo and Giza in 2013-2014 is more than a quarter the consumption of Egypt.

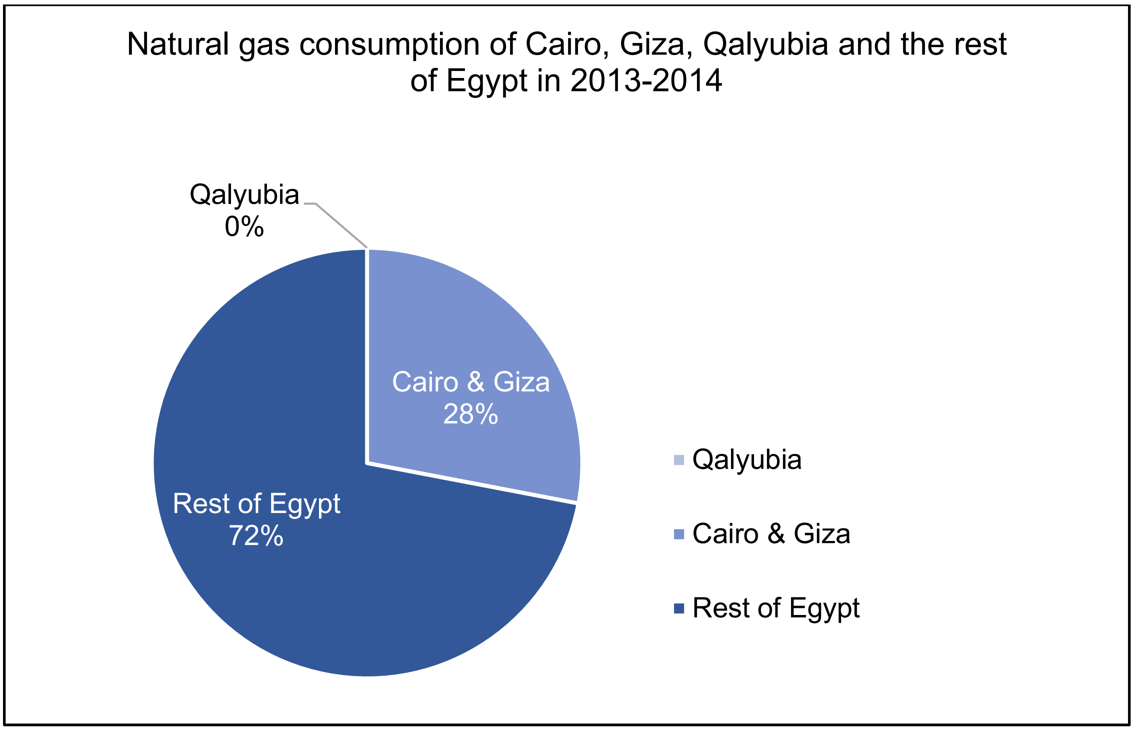


Figure 5-9: The natural gas consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 2013-2014.

The percentages of natural gas consumption in 2015-2016 are calculated as shown in Figure 5-10. The percentage of natural gas consumption of Cairo Governorate in 2015-2016 is 34% and Giza 0% and, as mentioned previously, the natural gas consumption of Cairo and Giza Governorates in 2015-2016 are presented separately (see Table 5-3).

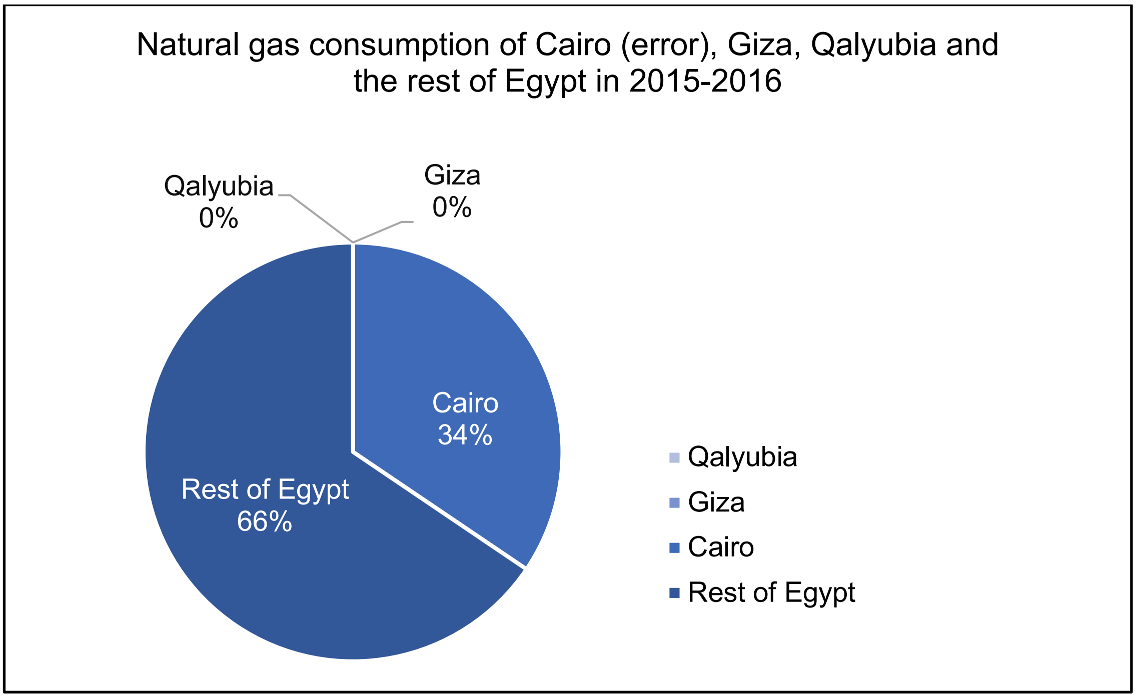
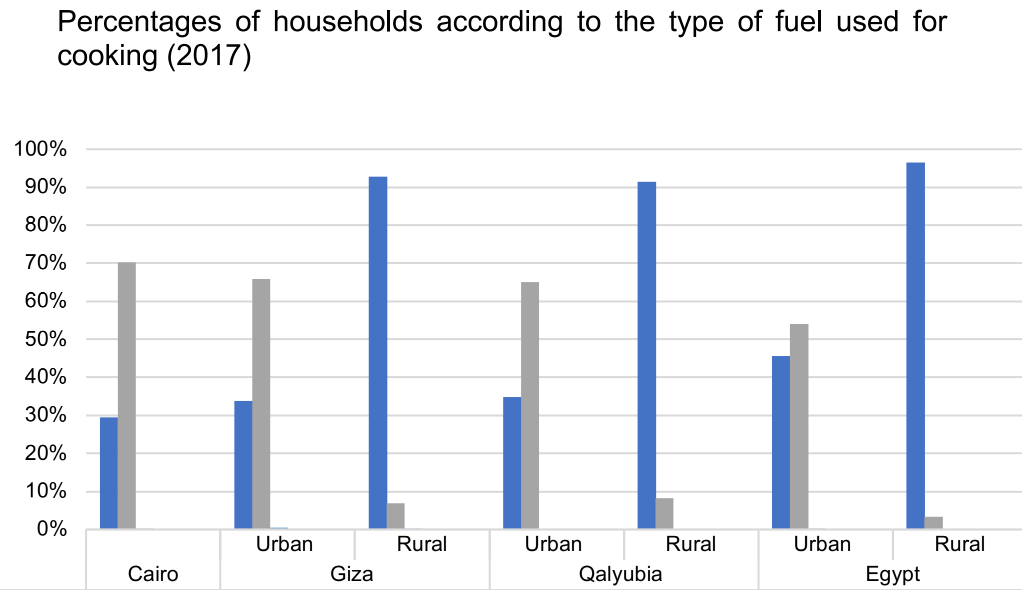


Figure 5-10: Natural gas consumption of Cairo (error), Giza, Qalyubia Governorates and the rest of Egypt in 2015-2016.

Although this data is collected from the Central Agency of Public Mobilization and Statistics, it is inaccurate because the percentages of the households according to the type of fuel used in cooking in 2017 as shown in Figure 5-11 indicate that 65% of households in Giza Governorate use natural gas as cooking fuel. This proves that the value of natural gas consumption of Giza Governorate should be more than 0%. It is assumed that 34% of natural gas consumption of Cairo Governorate includes Giza Governorate, too.

The Central Agency for Public Mobilization and Statistics published the percentages of households according to the type of fuel used in cooking for the first time in 2017. Natural gas is used mostly as a cooking fuel in urban areas of Cairo, Giza and Qalyubia Governorates and Egypt and the gas cylinder is mostly used as a cooking fuel in rural areas. This shows the potential of using biogas (renewable sources of energy) as a cooking fuel instead of the natural gas (non-renewable source of energy) specifically in urban areas because the biogas could be fed into the existing natural gas grid with minimal adjustments.



	Cairo	Giza Urban	Giza Rural	Qalyubia Urban	Qalyubia Rural	Egypt Urban	Egypt Rural
Gas Cylinder	29.51%	33.77%	92.82%	34.81%	91.48%	45.61%	96.48%
Natural Gas	70.19%	65.78%	6.83%	64.98%	8.30%	54.10%	3.35%
Electricity	0.24%	0.41%	0.32%	0.16%	0.18%	0.24%	0.10%
Solar Energy	0.03%	0.03%	0.01%	0.03%	0.02%	0.02%	0.01%
Kerosene	0.02%	0.01%	0.02%	0.01%	0.02%	0.03%	0.04%
Other	0.01%	0.01%	0.00%	0.01%	0.01%	0.01%	0.02%

Figure 5-11: Percentages of households according to the type of fuel used for cooking in 2017.

The liquified petroleum gas (LPG) consumption of Cairo, Giza and Qalyubia totalled quarter the consumption of all Egypt in 2013-2014 (Figure 5-12). This percentage slightly decreased in 2015-2016 (Figure 5-13), although the overall LPG consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt was almost stable from 2013 to 2016 (Figure 5-14).

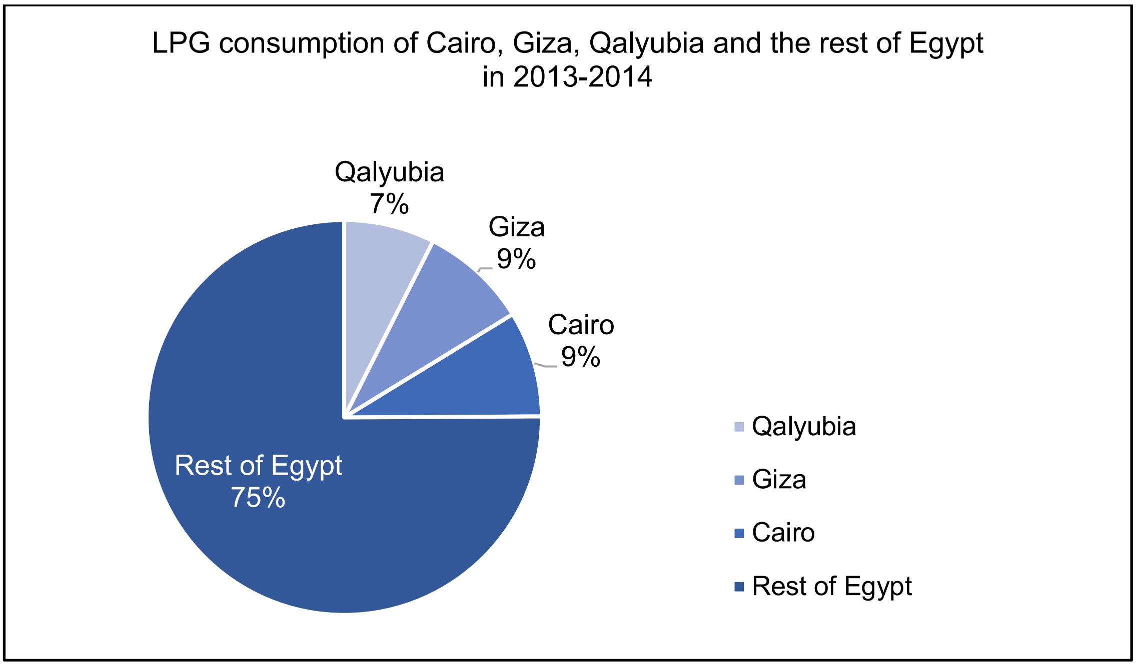


Figure 5-12: LPG consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 2013-2014.

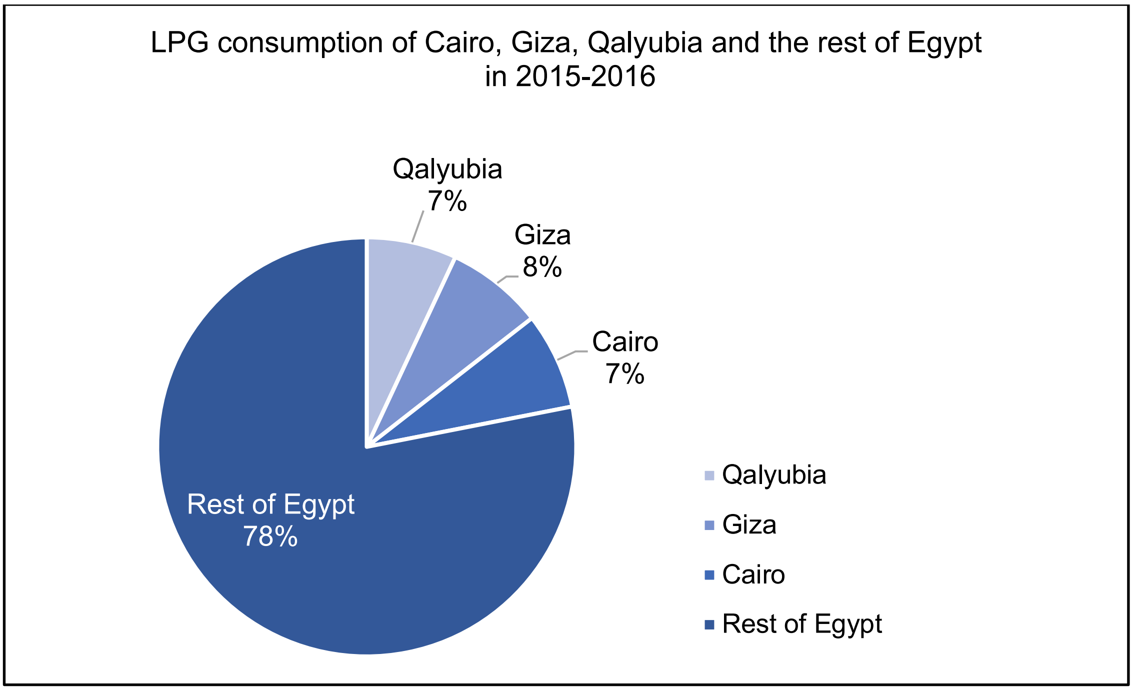


Figure 5-13: LPG consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 2015-2016.

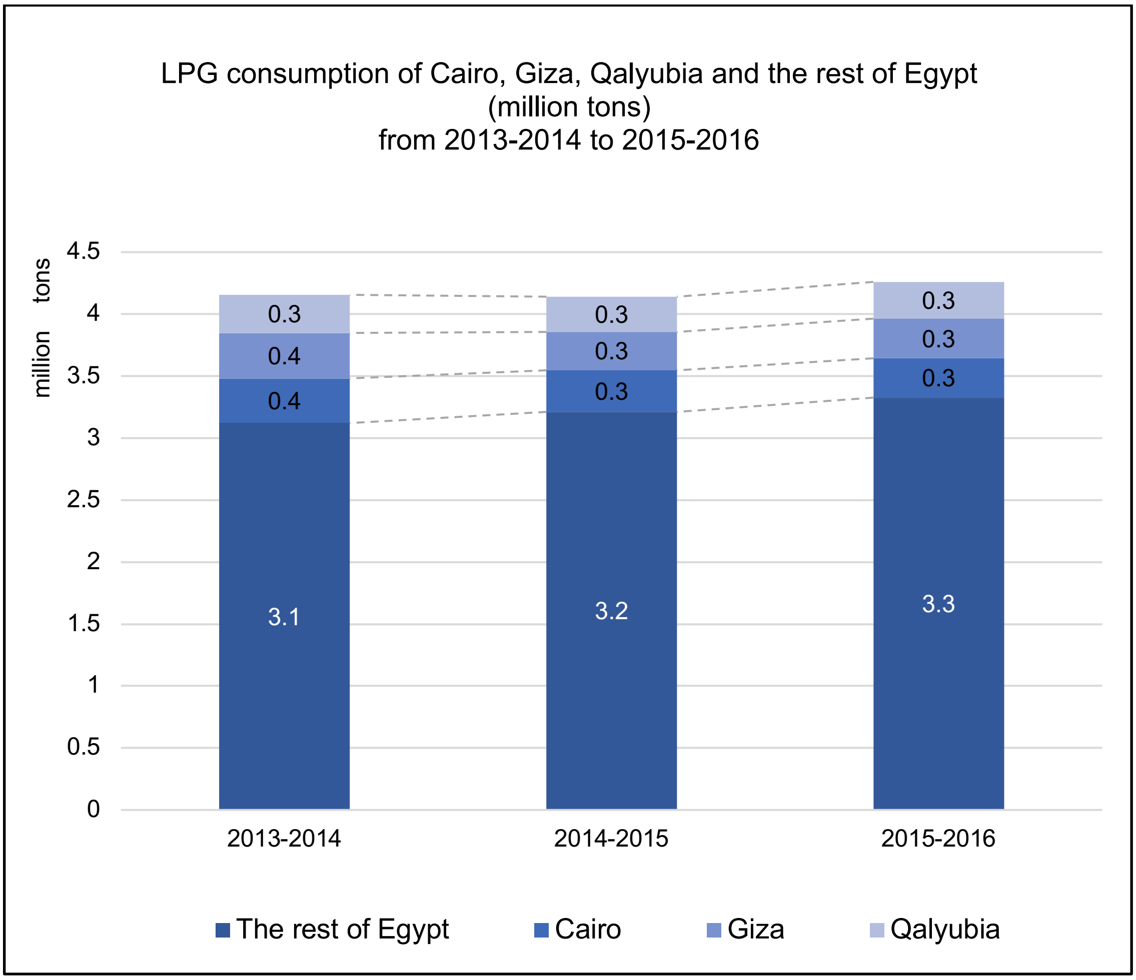


Figure 5-14: The LPG (liquified petroleum gas) consumption of Cairo, Giza, Qalyubia and the rest of Egypt in from 2013-2014 to 2015-2016.

5.3.7 Energy consumption of Egypt by sector (percentages) from 2009-2010 to 2016-2017

The electricity sector has the highest energy consumption compared to the other sectors and has been consistently increasing from 2009-2010 to 2016-2017 as shown in Figure 5-15. This is followed by the energy consumption of the industrial sector that has been consistently decreasing over the same period. The energy consumption of transport, residential, petroleum and construction sectors were almost stable. The energy consumption of the tourism sector has been slightly increasing, and the agriculture sector has the lowest energy consumption compared to other sectors and has been consistently decreasing.

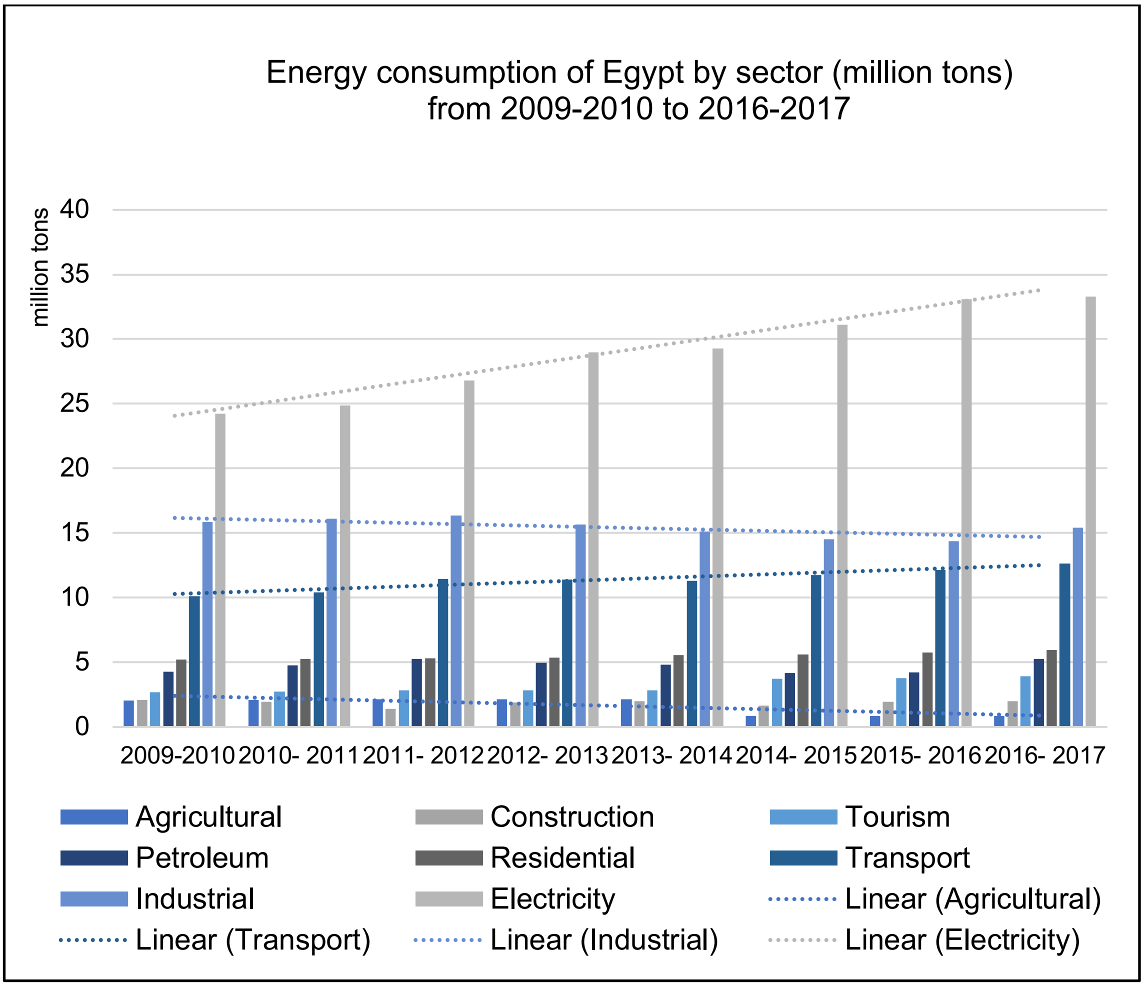


Figure 5-15: Energy consumption of Egypt by sector from 2009-2010 to 2016-2017.

In 2009-2010, the energy consumption of the electricity sector was 36%, followed by the industrial sector that was 24% and then the transport sector 15% (Figure 5-16). The total energy consumption of the three sectors was three quarters the total consumption of Egypt.

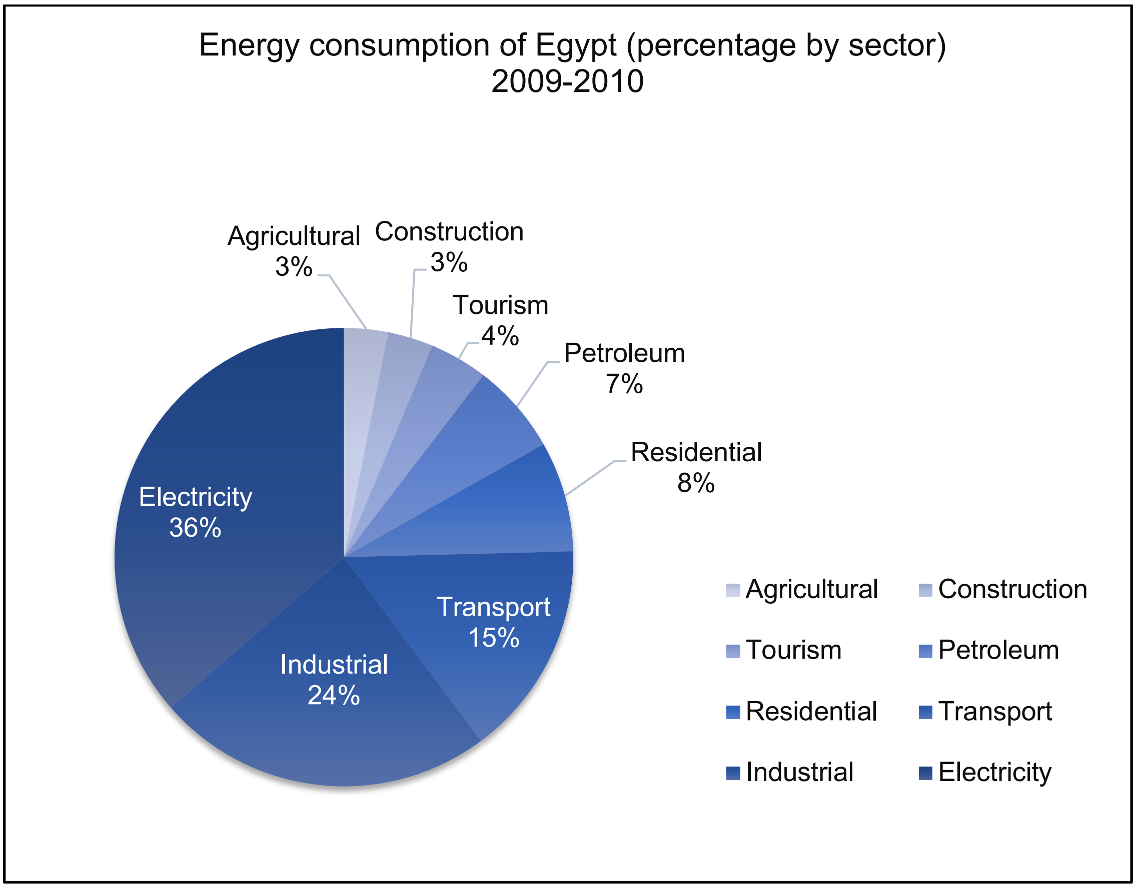


Figure 5-16: Percentages of energy consumption of Egypt by sector in 2009-2010.

In 2016-2017, the energy consumption of the electricity sector increased as it reached 42%, followed by the industrial sector that was 19% and then the transport sector 16% (Figure 5-17). The total energy consumption of the three sectors became more than three-quarters of the total consumption of Egypt. The energy consumption of the agriculture and construction sectors decreased, and the residential and petroleum sectors remained the same in 2009-2010 and 2016-2017.

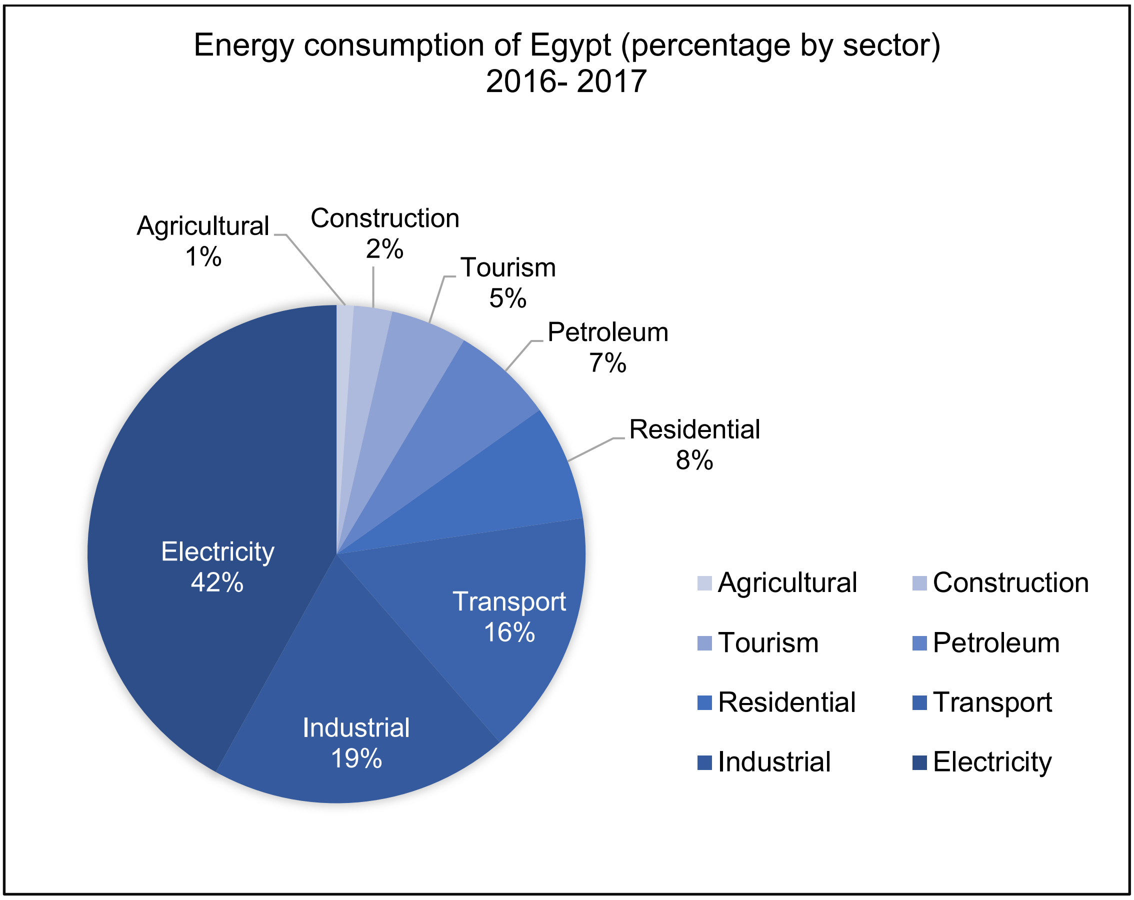


Figure 5-17: Percentages of energy consumption of Egypt by sector in 2016-2017.

5.3.8 Energy consumption of Cairo, Giza and Qalyubia Governorates by sector in 2015-2016

The energy consumption of Cairo, Giza and Qalyubia Governorates by sector is available in the Central Agency for Public Mobilization, Electricity and Energy annual reports from 1999-2000 to 2015-2016. The quality of these reports is poor, so it was difficult to obtain the required data. However, the quality of the Electricity and Energy 2015-2016 report was better than the previous reports, so I was able to present the available data in Table 5-4. Due to the missing data of the energy consumption of Giza and Qalyubia as shown in Table 5-4, I could not calculate the percentages of energy consumption of each sector. Even the natural gas and

LPG consumption of Egypt in Table 5-4 is not equal to the energy consumption mentioned in Figure 5-15. This is an example of the misleading and inaccurate data that is published in official reports specifically at the city or governorate level.

Table 5-4: The energy (natural gas and LPG) consumption by sector of Egypt, Cairo, Giza and Qalyubia Governorates in 2015-2016.

Energy Consumption (Natural Gas and LPG) 2015-2016													
Sector	Industrial		Residential		Commercial		Vehicle services		Services		other		units
	NG	LPG	NG	LPG	NG	LPG	NG	LPG	NG	LPG	NG	LPG	Tons
Qalyubia	_	424	_	231077	_	64803	_	_	_	_	_	_	Tons
Giza	3049	_	_	284669	_	32156	_	_	_	59	_	_	Tons
Cairo	768331	1900	1072002	241803	_	69693	11853	_	373	_	10815435	3491	Tons
Egypt	3817276	9214	1437449	3685135	_	559471	23230	_	2687	_	31477045	3501	Tons

5.3.9 Carbon dioxide emissions of Egypt by sector (percentages) from 2009-2010 to 2016-2017

The electricity sector has the highest CO_2 emissions in Egypt and has been increasing since 2009-2010 as it reached 43% in 2016-2017, as shown in Figures 5-18 and 5-19. Electricity production is expected to increase in the future due to the rapid population growth and the economic and social growth. Therefore, the percentage of CO_2 emissions of the electricity sector will increase significantly in the future if renewable energy resources do not replace conventional fuels. The electricity sector is followed by the CO_2 emissions of the transport sector that is around 18% that remained almost stable over a period of 17 years. Then the CO_2 emissions of the industrial sector that has been decreasing since 2009 and reached 15% in 2017. The total percentage of the CO_2 emissions of the electricity, transport and industrial sectors is 77% of the total CO_2 emissions of

Egypt. Focusing on improving the performance of these sectors towards sustainable development will have a great impact on the environmental conditions in Egypt.

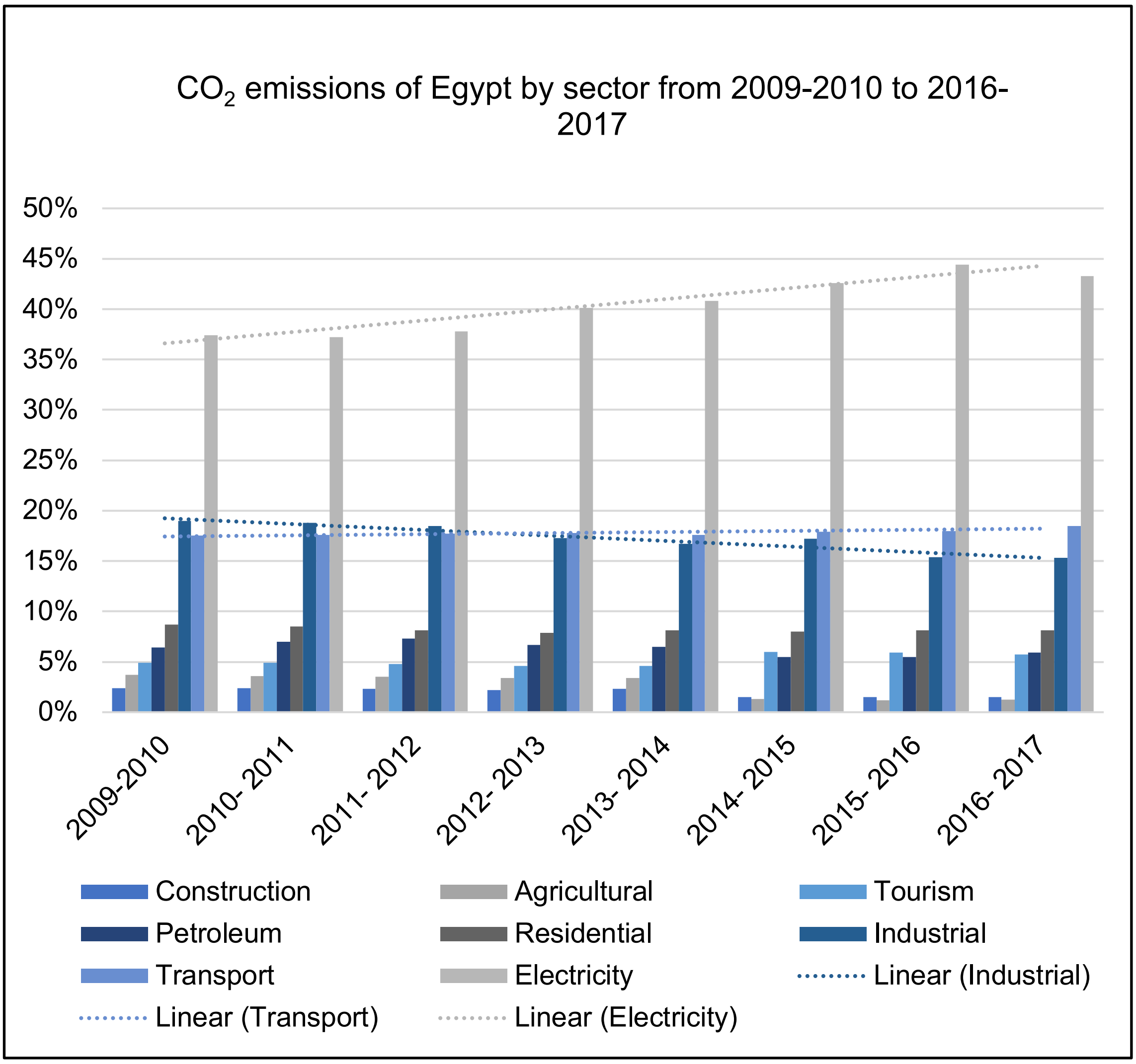


Figure 5-18: CO_2 emissions of Egypt by sector from 2009-2010 to 2016-2017.

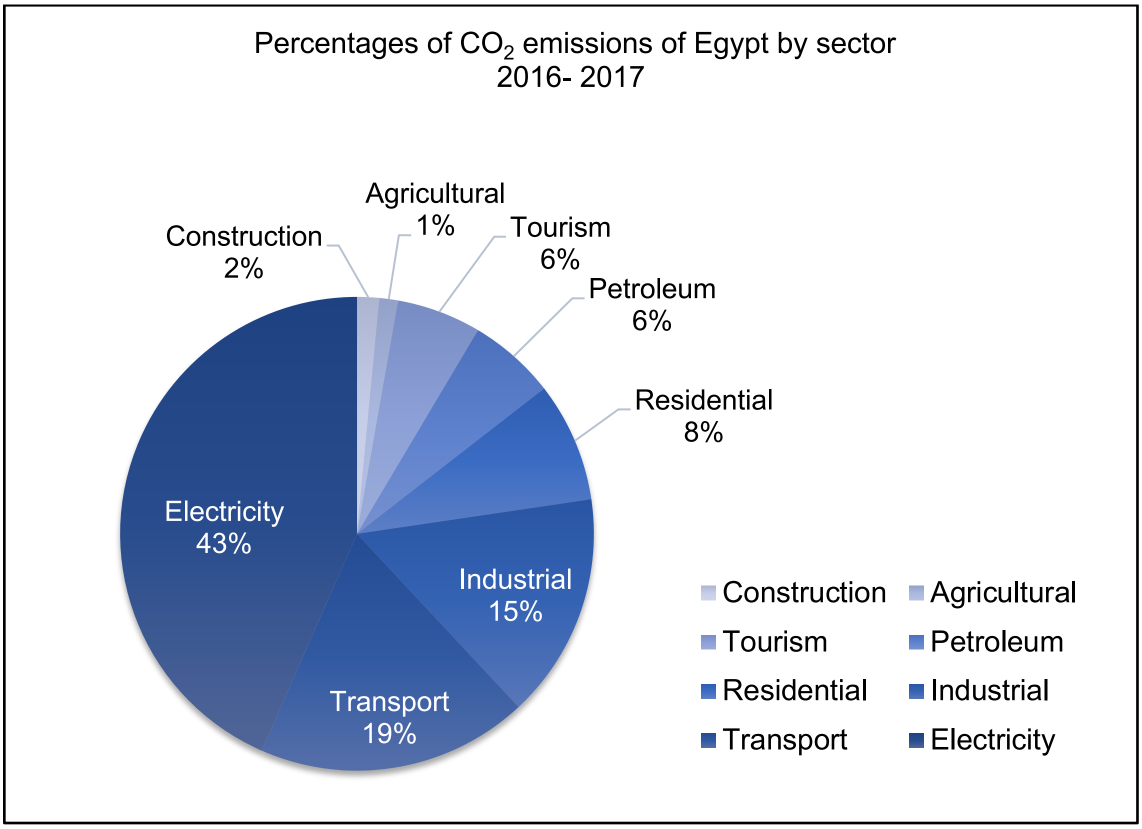


Figure 5-19: Percentages of CO_2 emissions of Egypt by sector in 2016-2017.

The energy consumption and CO_2 emissions of Egypt by sector are presented in Figure 5-20. The results of this integration indicate the strong correlation between energy consumption and CO_2 emissions. This is due to the high consumption of conventional fuels (natural gas and crude oil) in Egypt. This data was not available for Cairo, Giza and Qalyubia Governorates, however, if this is the situation of Egypt (at a country level), so it is expected that the three governorates will be mostly relying on non-renewable energy resources and emitting a huge amount of CO_2.

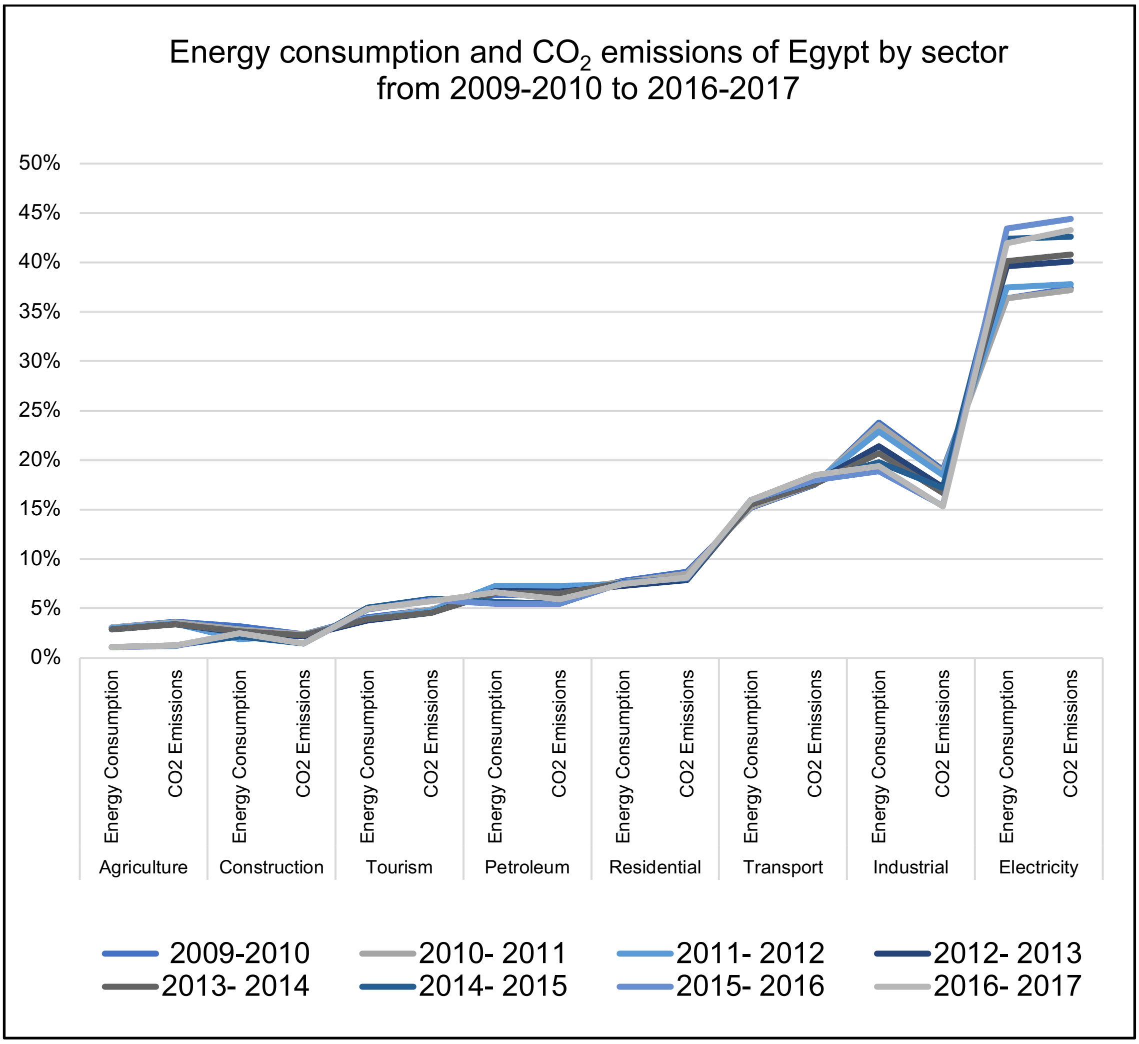


Figure 5-20: Energy consumption and CO_2 emissions of Egypt by sector from 2009-2010 to 2016-2017.

5.3.10 The government's current initiatives for the energy sector

The current situation of the energy sector in Egypt, Cairo, Giza and Qalyubia Governorates indicates the high dependency on traditional fuels that have a huge impact on the environment. The energy strategy of Egypt mainly focuses on energy efficiency rather than energy conservation. The representative of the Ministry of Electricity and Renewable Energy explained that in the following quote, "*Actually, it is not to reduce the consumption because we are still under consuming electricity. The share per capita is around 1600 kWh per capita (kilowatt-hour per capita), which is extremely low compared to other developed countries. The modest consumption we normally talk about 3000 to 4000 kWh per capita (kilowatt-hour per capita). It is expected to reach a modest consumption is basically to increase the consumption per capita to reach 3000 to 4000 kWh and this is why the energy policy is focusing on energy efficiency not energy conservation"* (Interviewee 2).

This indicates that the government is focused on increasing electricity consumption in the future but will ensure that this increase is an efficient increase. The representative of the Ministry of Electricity and Renewable Energy also revealed that the objective of the energy strategy of Egypt is to reduce the energy intensity of the country. This will require developing the GDP of the country with less energy consumption. To ensure this, the government set a target to reach relative reduction from the expected energy consumption by 2035 to 18% by focusing on three main sectors: the residential, industrial and transportation. Moreover, the government established the following:

- The National Energy Efficiency Action Plan (NEEAP), which is an action plan (see above) to ensure the implementation of the energy strategy.
- Legislate for energy efficiency:
  a. To support the distributed generation including (mostly) renewable energy resources and coal generation.
  b. To support the establishment of a monitoring and assessment network. Each customer who has an energy contracting capacity beyond a certain limit

should have an energy manager. All energy managers will be reporting to the National Energy Register, which is still underdeveloped.

c. To support a programme for disseminating efficient appliances and equipment and to start approving energy labels and standards.

- Energy efficiency indicators that are issued by the Egyptian Electricity Utility and Consumer Protection Regulatory Agency (EgyptERA) to enhance the energy efficiency of the electricity sector in Egypt (Table 5-5).

Table 5-5: The energy efficiency indicators.

Energy efficiency indicators	
1. Energy intensity	This is the value added per kilowatt-hour consume that is the energy intensity. How much each kilowatt-hour is being consumed in the country generates an addition to the GDP.
2. Energy consumption per product	This indicator is specifically for energy consumption that means how many tons per each product are being used or how much energy is being consumed.
3. Social indicator	How many kilowatt-hours are costing the government to create one job opportunity per each sector?

These are the government's initiatives to enhance the efficient use of energy resources in Egypt. The government also set a target to increase the share of renewable energy resources to reach 20% of the total primary energy production by 2022. To meet this target the government issued a law in 2014 to enhance the generation of electricity using renewable energy. This law includes four schemes; the first is the statutory investment, which is done through NREA (New and Renewable Energy Authority). The second is the concession kind of activity like the BOO contract (BOO: build, own, operate). The third is the feed in tariff, "*tariff reform as we mentioned increases the financial attractiveness for the renewable energy projects*" (Interviewee 2). The fourth is the merchant type that enables anyone to generate electricity from renewable energy and sell it directly to customers through energy banking.

> *"There is a net metering scheme that is issued by the Regulatory Agency* (Egyptian Electricity Utility and Consumer Protection Regulatory Agency EgyptERA)*, which allows you to produce energy from renewable energy resources and export your excess energy to the grid and exchange electricity with the grid and being paid for whatever excess energy to support the distributed solar energy"* (Interviewee 2).

The second part of this law is about the responsibility for the management of the grid. This means that when the grid is contracting for generation capacity, it contracts on a take-or-pay contract. The third part of this law is the priority of dispatch. This means that if there are grid bottlenecks, the priority for electricity to pass should go to that generated from renewable energy resources. The fourth part of this law is about enabling state land that is suitable for renewable energy projects in return the government receives 2% of the generated renewable energy. This is regulated and the 2% is a fixed rate. Governors are not allowed to increase or change this rate.

The final part of this law is to create a mechanism to enhance demand for renewable energy. It creates a quota-like system that gives the power to the cabinet to request some of the sectors to consume a percentage or a share of renewable energy and pay the renewable energy at its cost. The Egyptian

Electricity Utility and Consumer Protection Regulatory Agency (EgyptERA) issues ‘guarantee of origin’ certificates to make sure that the credited energy is generated from renewable energy. Every producer should have this guarantee of origin certificate and sell this certificate to customers who consume renewable energy. This certificate could be used as a settlement mechanism for the quota or any future incentives that could be offered by the government for consumers who use renewable energy. This is to encourage consumers to use renewable energy.

- The government also established international interconnection to support the development of renewable energy and to improve the system’s stability and security of supply.

  “For example, the interconnection between Egypt and Saudi Arabia that is expected to be in operation by 2021. We are talking around 3000 megawatts. The motive operation for this interconnection is that Saudi Arabia has a peak demand during daytime, while we have a peak demand during night-time. We will export to Saudi Arabia during daytime and we will import back during night-time. When we export to Saudi Arabia, we will export electricity that is generated from solar energy. Then we will import it back from Saudi Arabia as if we are using Saudi Arabia as a storage facility. We will export the excess solar energy that we produce during the daytime and import it back during the night-time. This was an example of how international interconnections can support the growth of renewable energy” (Interviewee 2).

5.4 The electricity sector in Egypt, Cairo, Giza and Qalyubia Governorates

5.4.1 Electricity production mix (hydro, solar, wind and thermal) of Egypt

The electricity production mix of Egypt since 2002-2003 to 2015-2016 shows that Egypt has been relying on two types of non-renewable energy resources: natural gas and oil with a small share of renewable energy (Figure 5-21).

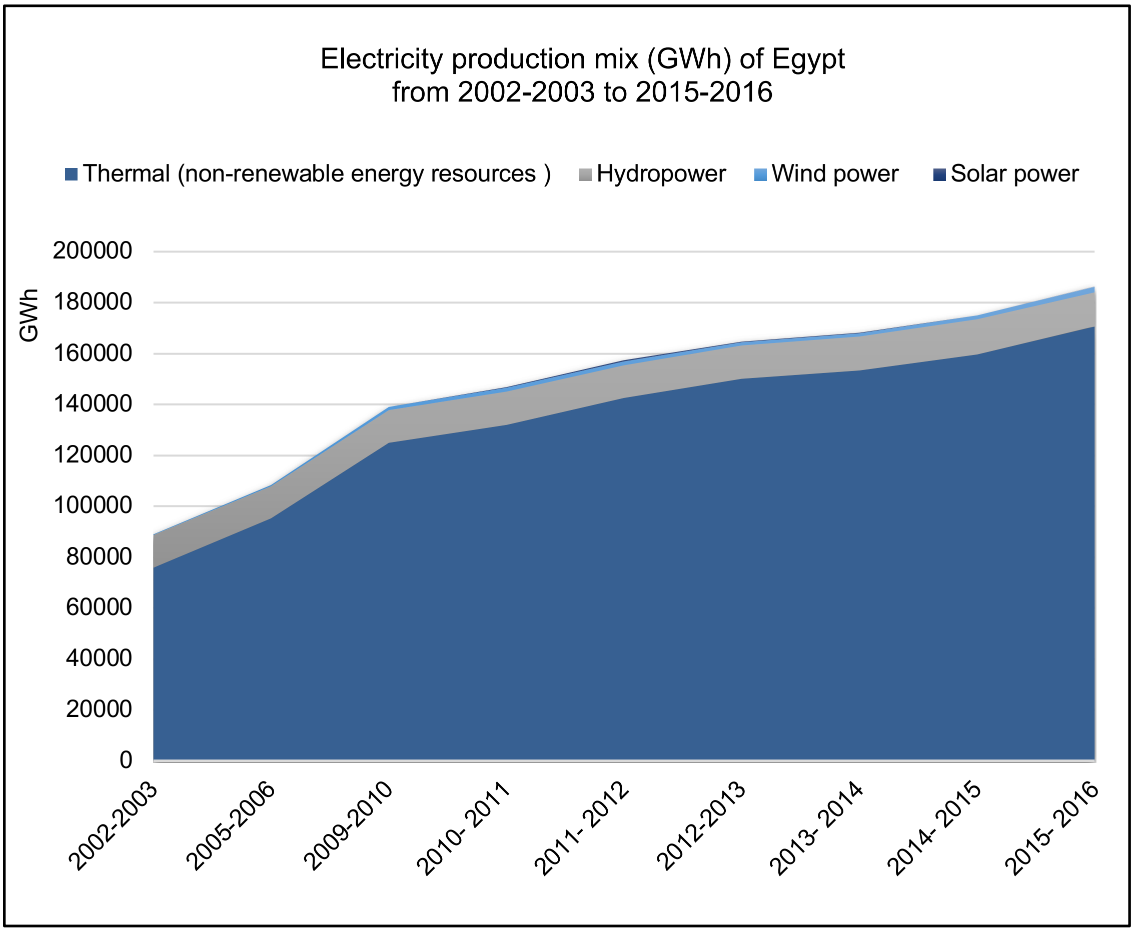


Figure 5-21: The electricity production mix (GWh) of Egypt since 2002-2003 to 2015-2016.

All types of non-renewable energy resources are presented in Figure 5-21 as "thermal" because this data was not available for each type individually. However, the representative of the Ministry of Electricity and Renewable Energy

(Interviewee 2) clarified that for 2018, the share of natural gas is 82%, heavy oil is 8%, 7% hydropower and 3% renewables.

> *"The average percentage of natural gas is 84% daily, but the annual average for this year is almost 82%* (2018), *8% from heavy oil. These percentages are for this year* (2018). *During the previous years, there was a shortage in natural gas, so the share of oil was higher. Nowadays, the share of oil is decreasing, and the share of natural gas is increasing again due to the new discoveries of natural gas. The average for this year will be 82% natural gas, 8% oil, 7% hydropower and 3% renewables. There are some substantial renewables added this year. The target by 2022 is to achieve 20% of renewable including the hydropower. By 2022, it is expected that the hydropower will be 5.5% to 6% that means that additional 14% will come from wind and solar energy"* (Interviewee 2).

This indicates that the total of non-renewable energy resources (natural gas and oil) in 2018 is 90%, 7% hydropower and 3% renewables (wind and solar). If we compare these percentages with the electricity production mix of Egypt in 2015-2016 (Figure 5-22), we will find that the share of non-renewable energy resources decreased 1.5%, hydropower decreased 0.3% and the share renewable energy (solar and wind) increased 1.8% in 2018.

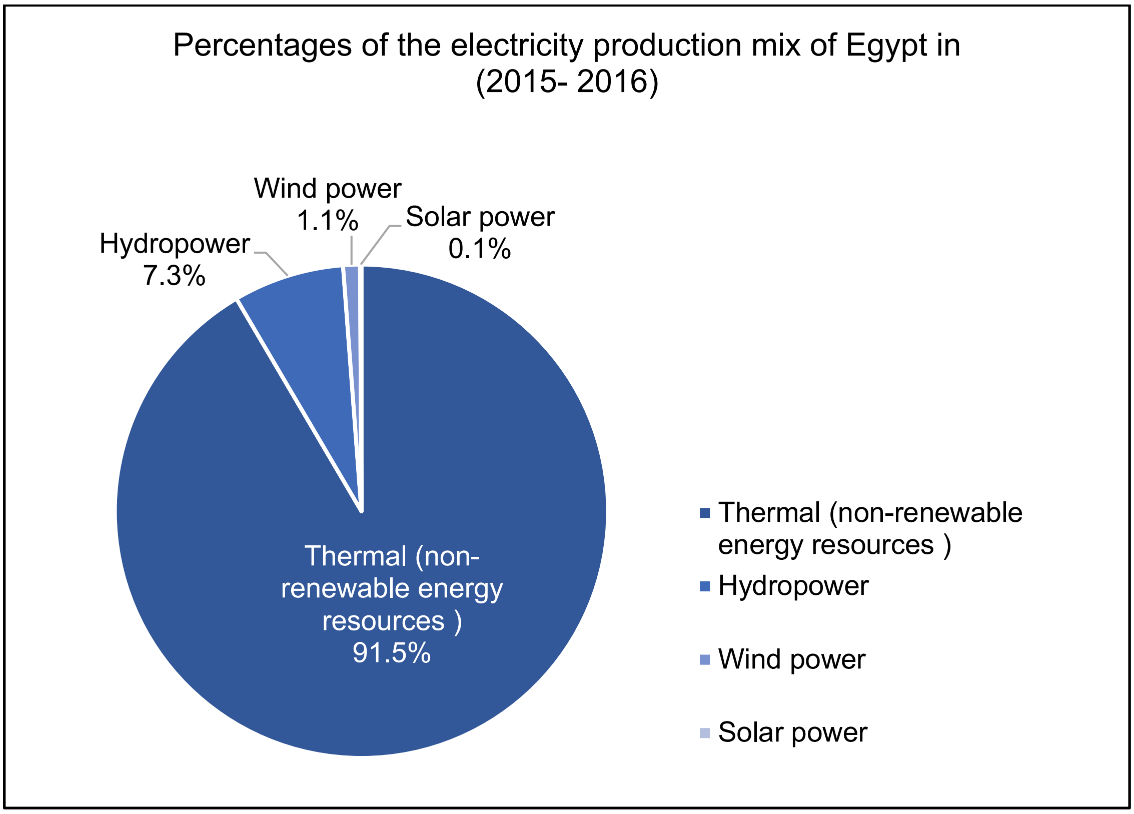


Figure 5-22: Percentages of the electricity production mix of Egypt in 2015-2016.

The electricity production mix of Egypt is similar to most developing countries that rely on one or two types of non-renewable energy resources for electricity production that is mainly used in the residential sector (Facchini et al., 2017). In developed countries, in contrast, the electricity production mix usually includes different types of energy resources rather than relying on one or two types (Facchini et al., 2017).

5.4.2 Sources of electricity generation in Egypt (percentages)

Calculating the percentages of the sources of electricity generation is an important indicator because it identifies which types of resources have been mostly used over time to generate electricity. Moreover, this indicator shows which resources have been increasing or decreasing over time. In Egypt, the share of the non-renewable energy resources has been increasing significantly from 2002 to 2016 (Figure 5-23). The share of the hydropower is relatively decreasing, as mentioned previously in this chapter that the main source of hydropower is the High Dam in Aswan and this share is expected to continue decreasing in the future. The representative of the Ministry of Electricity and Renewable Energy outlined that

> *"the energy balance of Egypt you have 95% oil and gas, 5 % renewable, but for the electricity balance (production mix) 90% oil and gas, 10% renewable which includes hydropower 7 to 8% that is relatively decreasing. There is no potential in increasing the hydropower in Egypt"* (Interviewee 2).
>
> *"There are some substantial renewables added this year. The target by 2022 is to achieve 20% of renewable including the hydropower. By 2022, it is expected that the hydropower will be 5.5% to 6% that means that additional 14% will come from wind and solar energy"* (Interviewee 2).

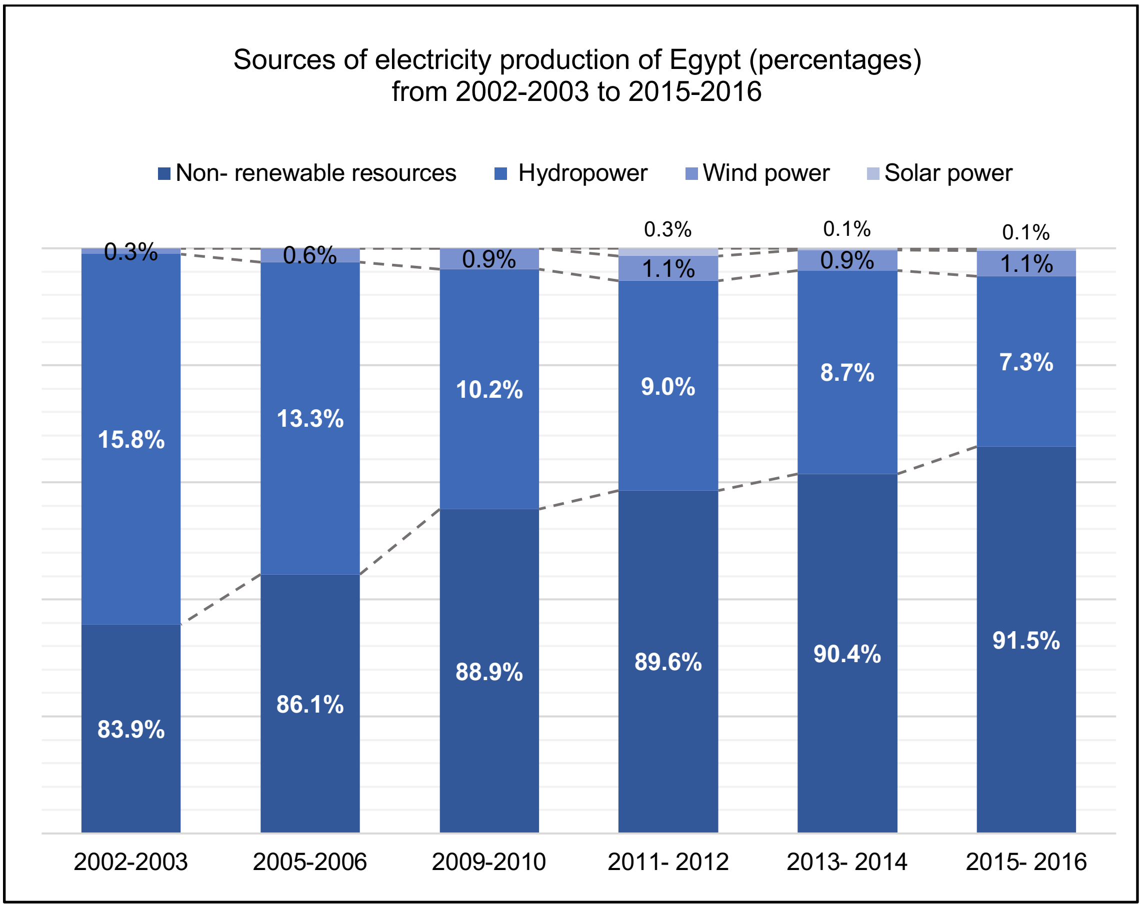


Figure 5-23: Percentages of electricity production mix of Egypt from 2002-2003 to 2015-2016.

5.4.3 Electricity production and consumption of Egypt

The average annual growth rate of electricity production in Egypt was 10.3% over a period of 16 years from 1999-2000 to 2015-2016 (Figure 5-24). The annual growth rate of electricity consumption was 7.48% over a period of 16 years from 1999-2000 to 2015-2016 (Figure 5-24). Electricity production and consumption are expected to increase in the future, as the government’s target is to increase the electricity consumption per capita. This will be achieved through increasing the share of renewable energy resources and enhancing the efficient use of energy (see above).

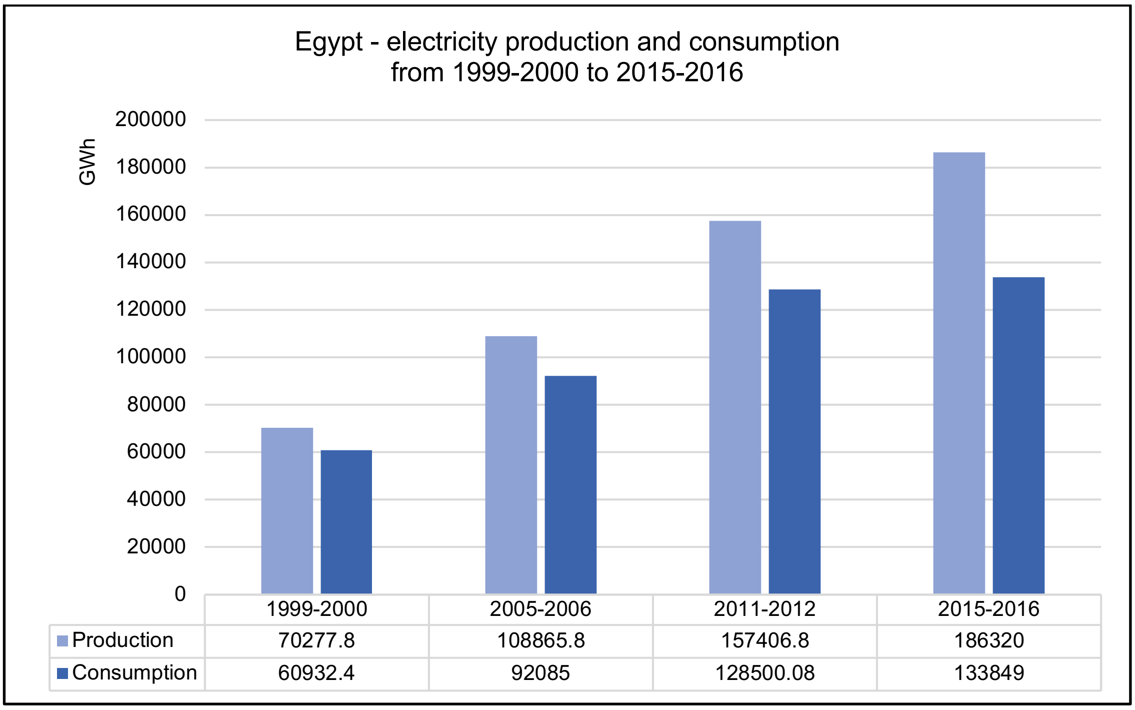


Figure 5-24: Electricity production and consumption of Egypt from 1999-2000 to 2015-2016.

5.4.4 Electricity production and line losses of Egypt

The line losses include both the losses from the grid and the self-consumption of the power plants. The average percentage of annual electricity line losses in Egypt was 15% of the electricity production over a period of 10 years (from 2005-2006 to 2015-2016) see Figure 5-25. However, the representative of the Ministry of the Electricity and Renewable Energy Resources revealed that these losses are not accurate as the actual losses are 15% to 18%. The Ministry of Electricity publishes a report that shows the total electricity production by kilowatt in a specific year and the total number of bills by kilowatt that were issued in the same year. If the difference between the two numbers were calculated, that will be the electricity losses in that specific year. Usually, the official reports of the Ministry of Electricity show losses that are less than are actually the case to show the achievements of the Ministry by changing the financial balance of the price of the electricity for different categories, so they make it a financial balance, not an energy balance. For example, the official reports of the distribution companies show that the total losses of electricity are around 12%, but the actual total losses are around 15% to 18% the difference is due to the changes that they do in the financial balance. The average annual electricity losses of Egypt are high compared to high-income countries (6%) and is almost equal to lower-middle-income countries (16%) in 2014 (The World Bank, 2020).

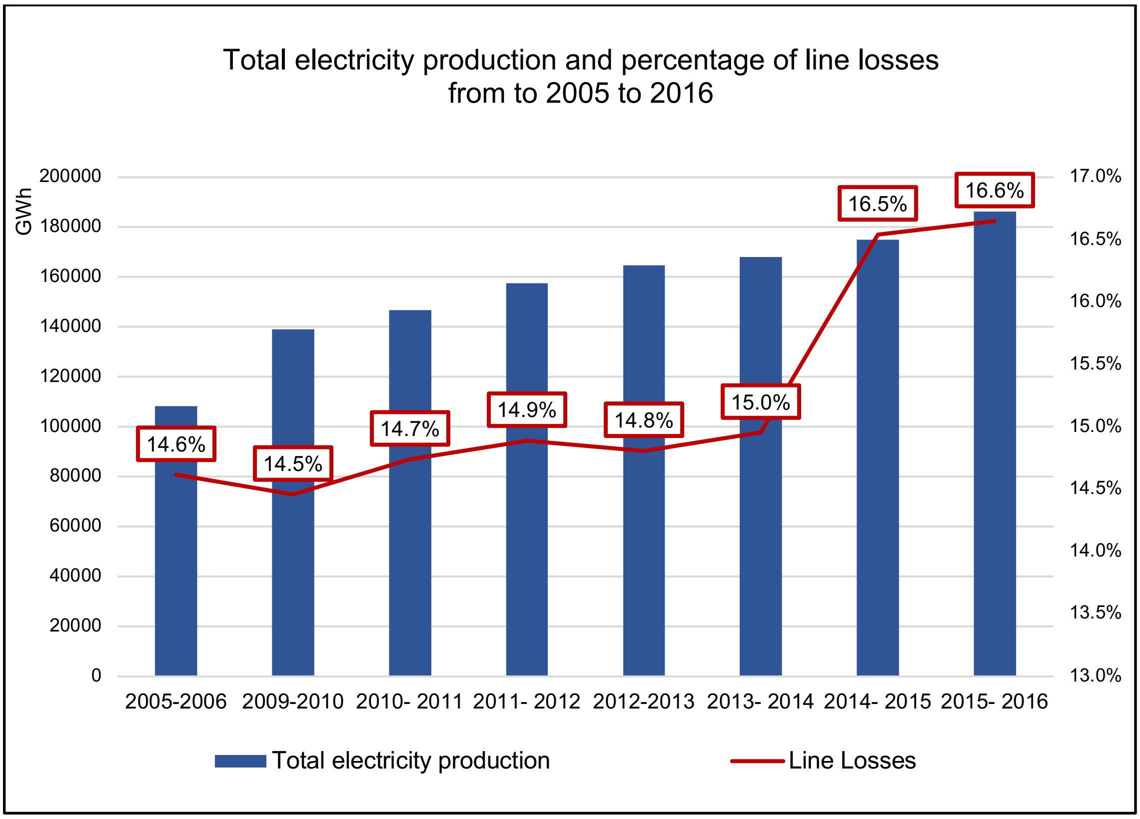


Figure 5-25: Total electricity production of Egypt and the percentages of line losses (includes the line losses and the non-revenue losses) from 2005-2006 to 2015-2016.

5.4.5 Types of electricity losses in Egypt

- Technical losses: include losses from the grid itself.
- Commercial losses include three types of losses:

a. Inaccurate readings of electricity meters, some which, due to age, fail to accurately measure electricity consumption.

b. Illegal connections from the main grid. There are two types of theft: some steal directly from the grid (Ministry of Electricity owned), while others steal from another customer like the city council by connecting to street lighting poles. In other cases, some residents build illegal levels on top of their existing units. By law it is forbidden to install electricity meters for illegal units, but the owners connect these to their existing electricity meters.

c. Non-accurate estimates of electricity consumption. In some informal settlements there are no electricity meters because these are illegal connections. The residents of informal settlements are forced to pay a fixed fine every month (usually an estimated lump sum). The police is responsible to collect this money, for which it top slices 30% of the fine, and the rest goes to the Ministry of Electricity. Usually the fine is not accurate because it is an estimate and it is a fixed amount, so it is a poor proxy for the actual levels of electricity consumed.

- Technical losses: include losses from the grid itself.
- Commercial losses include three types of losses:

a. Inaccurate readings of electricity meters, some which, due to age, fail to accurately measure electricity consumption.

b. Illegal connections from the main grid. There are two types of theft: some steal directly from the grid (Ministry of Electricity owned), while others steal from another customer like the city council by connecting to street lighting poles. In other cases, some residents build illegal levels on top of their existing

units. By law it is forbidden to install electricity meters for illegal units, but the owners connect these to their existing electricity meters.

c. Non-accurate estimates of electricity consumption. In some informal settlements there are no electricity meters because these are illegal connections. The residents of informal settlements are forced to pay a fixed fine every month (usually an estimated lump sum). The police is responsible to collect this money, for which it top slices 30% of the fine, and the rest goes to the Ministry of Electricity. Usually the fine is not accurate because it is an estimate and it is a fixed amount, so it is a poor proxy for the actual levels of electricity consumed.

The government established a smart meter scheme programme to reduce the line losses as the existing metering infrastructure is aged, being 30 to 40 years old. Most of them are mechanical and give inaccurate readings. Currently, the government is installing 250,000 smart meters. The short-term target is to install 10 million smart meters within 3 years. This is followed by a long-term target to install 33 million smart meters in the future (the time frame is not specified). These smart meters provide a real time measurement that will enable the Ministry of Electricity to balance the grid and identify those who steal electricity. One more advantage of smart meters is that it detects bypasses, which could not be detected by mechanical meters. Smart meters can be used to apply more advanced types of tariffs as customers can pay more during peak hours and pay less during off peak times. Smart meters also create a kind of interaction between customers and electricity companies that is called ‘interactive demand side management.’ This interaction is important to improve the management of the electricity sector in Egypt.

5.4.6 Electricity production mix of Cairo, Giza and Qalyubia Governorates

All the electricity and energy reports that are published by the Central Agency of Public Mobilization and Statistics since 1999 to 2016 indicated that the electricity production mix of Cairo, Giza and Qalyubia Governorates relies totally on non-renewable energy resources; there is no evidence of the use of renewable energy resources, even though they have a huge potential of solar and wind power as shown in Chapter 4. Additionally, the three governorates have a huge potential to produce biogas by the treatment of organic waste that is usually left without treatment (see Chapter 7) and sludge-to-energy (see Chapter 6).

5.4.7 The electricity production of Cairo, Giza and Qalyubia Governorates and the rest of Egypt

The electricity production of Cairo, Giza and Qalyubia Governorates increased significantly between 1999-2000 and 2015-2016, as shown in Figure 5-26. However, the average annual growth rate of electricity production between 1999-2000 and 2015-2016 was unequal in the three governorates. In Cairo, the average annual growth rate for electricity production was 24.5%, followed by Giza 17.2% and the lowest rate was Qalyubia 4.2% over a period of 16 years (from 1999-2000 to 2015-2016). The average annual growth rate of electricity production in Cairo and Giza was higher than the average of Egypt (10.3%), while Qalyubia was lower over the same period.

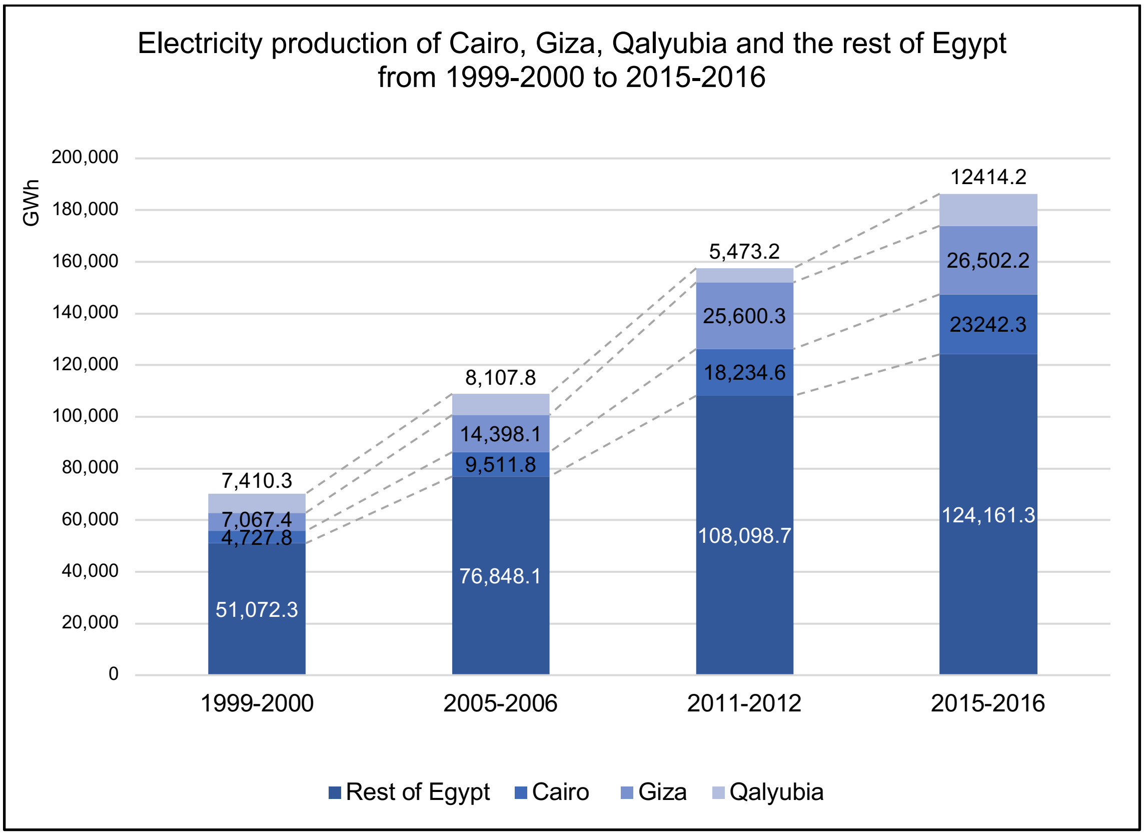


Figure 5-26: Electricity production of Cairo, Giza, Qalyubia Governorates and the rest of Egypt from 1999-2000 to 2015-2016.

In 1999-2000, the total electricity production of Egypt was 70,277.8 GWh. In the same year, the electricity production of Cairo, Giza and Qalyubia was 27% of the total production of Egypt (Figure 5-27). While in 2015-2016, the total electricity production of Egypt was 186,320 GWh and the percentage of the electricity production of Cairo, Giza and Qalyubia increased and reached 33% of the total production of Egypt (Figure 5-28). Most of the increase was in Cairo and Giza Governorate as their percentage of the electricity production was 26% of the total production of Egypt in 2015-2016 (Figure 5-28). This shows the increasing production of electricity specifically in Cairo and Giza Governorates to meet the increasing demand and to increase per capita electricity.

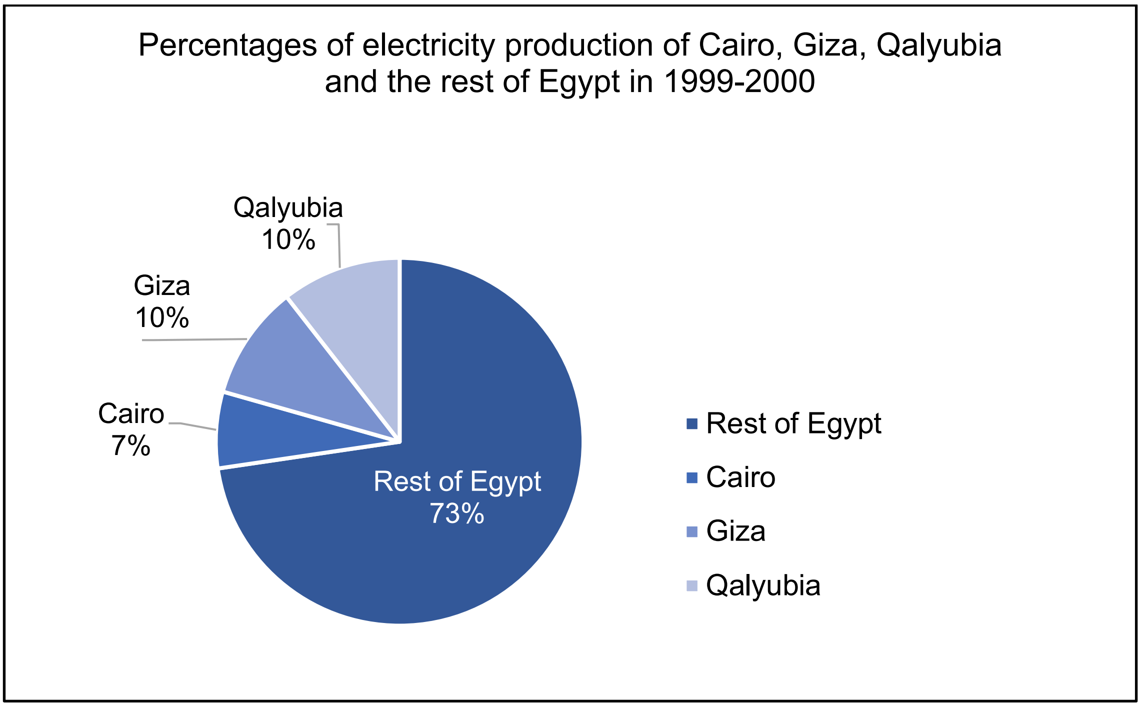


Figure 5-27: Percentages of electricity production of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 1999-2000.

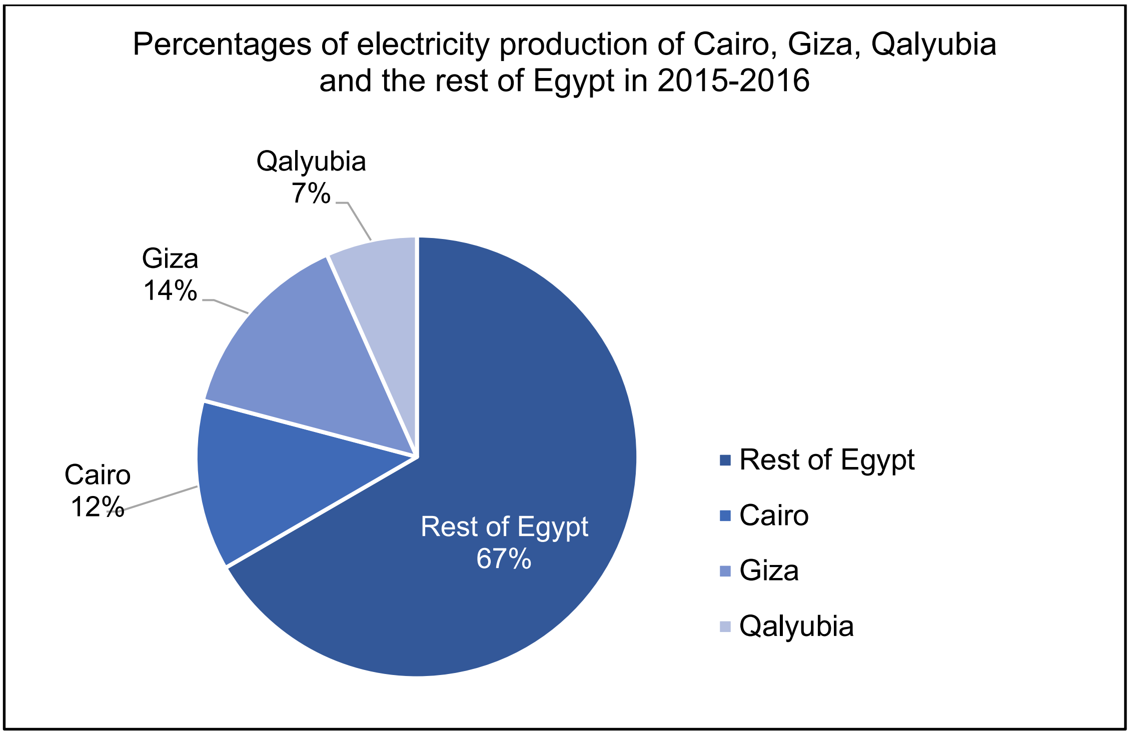


Figure 5-28: Percentages of electricity production of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 2015-2016.

5.4.8 The electricity consumption of Cairo, Giza and Qalyubia Governorates and the rest of Egypt

The electricity consumption of Cairo, Giza and Qalyubia Governorates increased significantly between 1999-2000 and 2015-2016, as shown in Figure 5-29. However, the average annual growth rate of electricity consumption between 1999-2000 and 2015-2016 was unequal in the three governorates. In Giza, the average annual growth rate of electricity consumption was 11.5%, followed by Qalyubia (10.5%), with the lowest rate in Cairo (4.7%) over a period of 16 years (from 1999-2000 to 2015-2016). The average annual growth rate of electricity consumption in Giza and Qalyubia was higher than the average of Egypt (7.48%) and Cairo was lower over the same period.

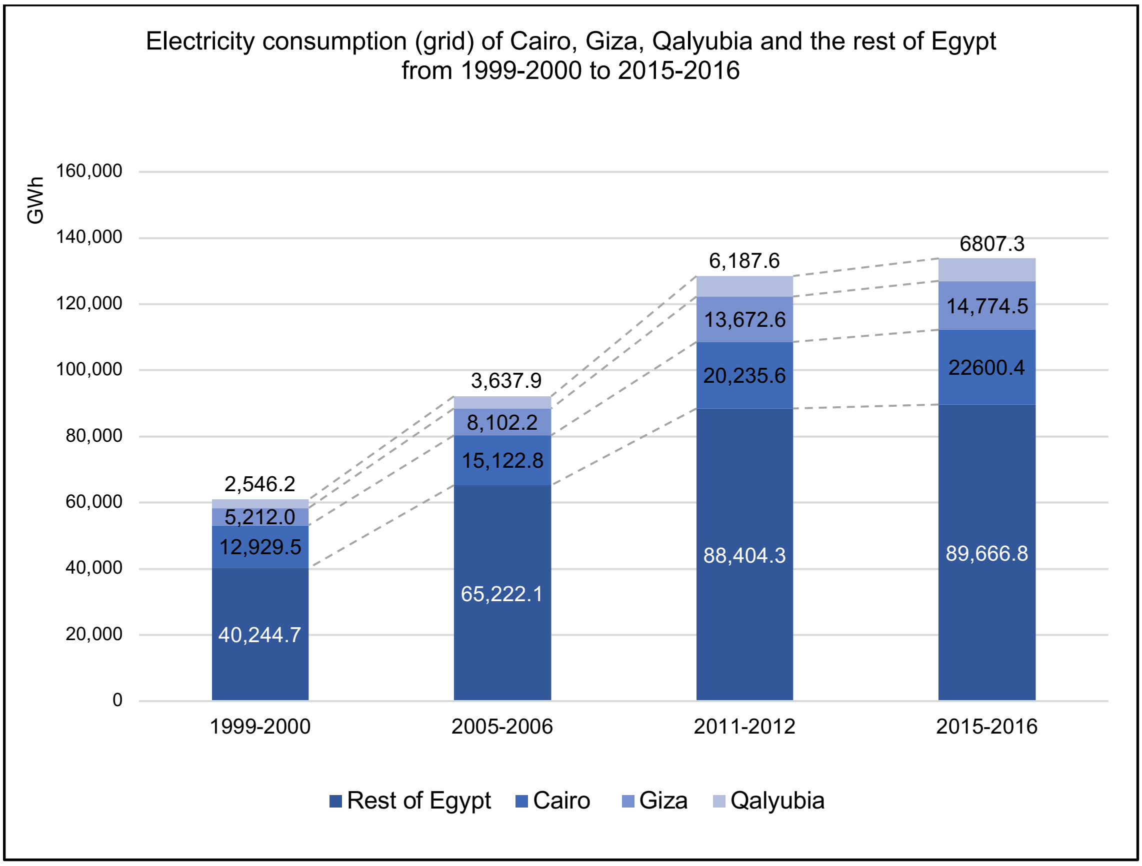


Figure 5-29: Electricity consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt from 1999-2000 to 2015-2016.

In 1999-2000, the total electricity consumption of Egypt was 60,932.4 GWh. In the same year, the electricity consumption of Cairo, Giza and Qalyubia was 34% of the total consumption of Egypt (Figure 5-30). In 2015-2016, the total electricity consumption of Egypt was 133,849 GWh and the percentage of the electricity consumption of Cairo, Giza and Qalyubia was 33% of the total consumption of Egypt (Figure 5-31).

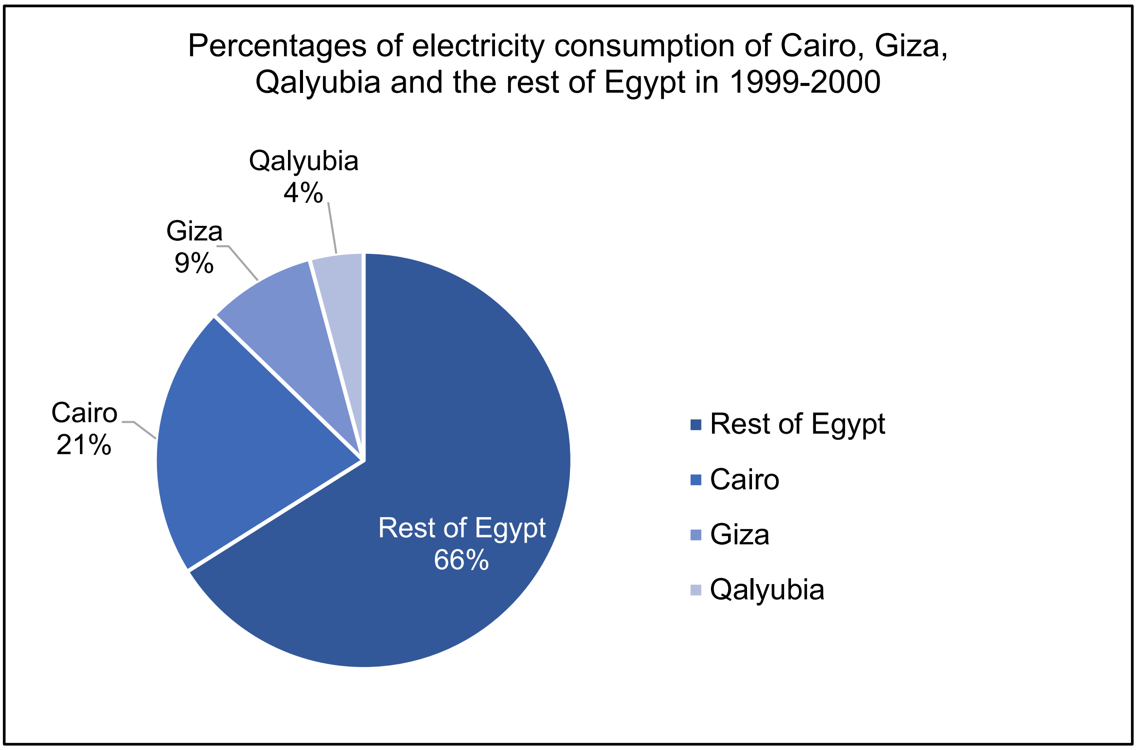


Figure 5-30: Percentages of electricity consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 1999-2000.

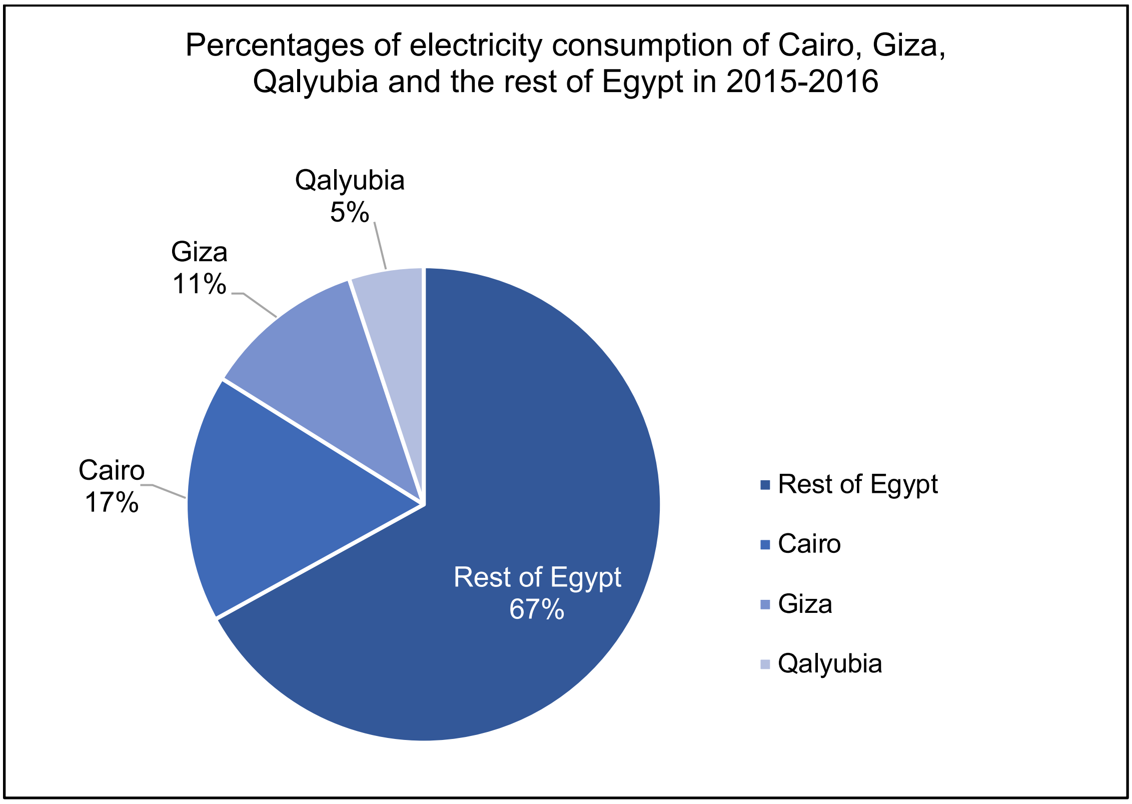
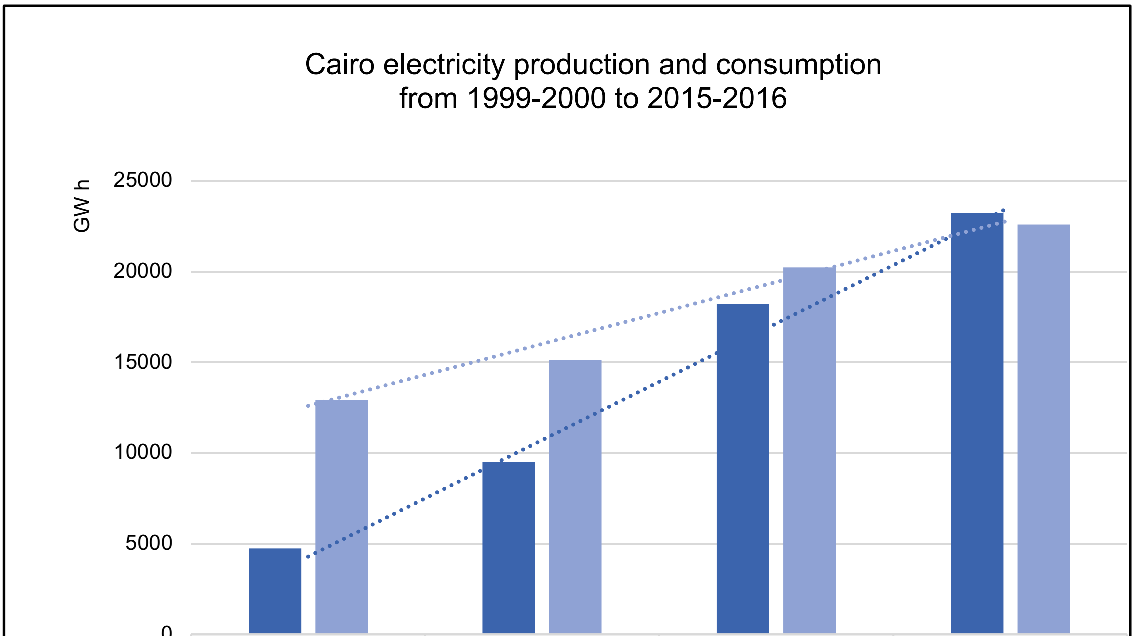


Figure 5-31: Percentages of electricity consumption of Cairo, Giza, Qalyubia Governorates and the rest of Egypt in 2015-2016.

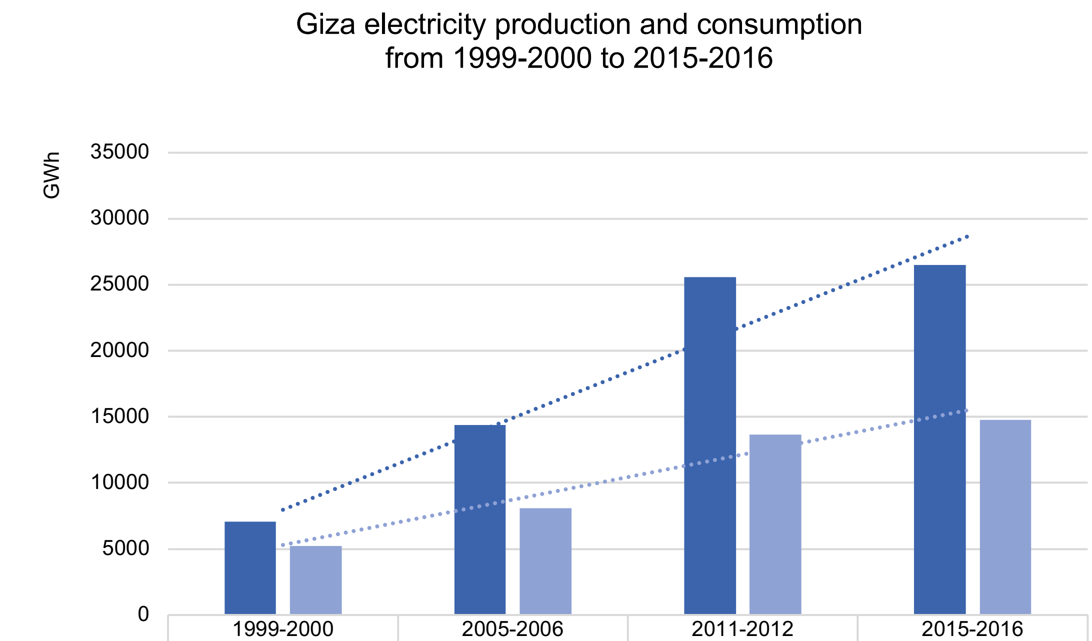
This shows that in 1999-2000, the percentage of electricity consumption (34%) was higher than the percentage of electricity production (27%) for the three governorates. While in 2015-2016, the percentage of electricity consumption (33%) of the three governorates was equal to the percentage of electricity production (33%). If we split the percentages of electricity production and consumption of the three governorates, it is clear that the electricity consumption of Cairo Governorate is higher than its production between 1999-2000 and 2015-2016. While the electricity production of Giza and Qalyubia Governorates is higher than consumption between 1999-2000 and 2015-2016. This indicates that Cairo Governorate imports electricity from other surrounding governorates to fill the supply and demand gap. On the contrary, Giza and Qalyubia Governorates export electricity to other surrounding governorates as its production exceed its consumption. This explains the significant increase in electricity production in Cairo Governorate to fill the supply and demand gap without importing electricity from other governorates (Figure 5-32).



	1999-2000	2005-2006	2011-2012	2015-2016
Production	4727.8	9511.8	18234.6	23242.3
Consumption	12929.5	15122.8	20235.6	22600.4

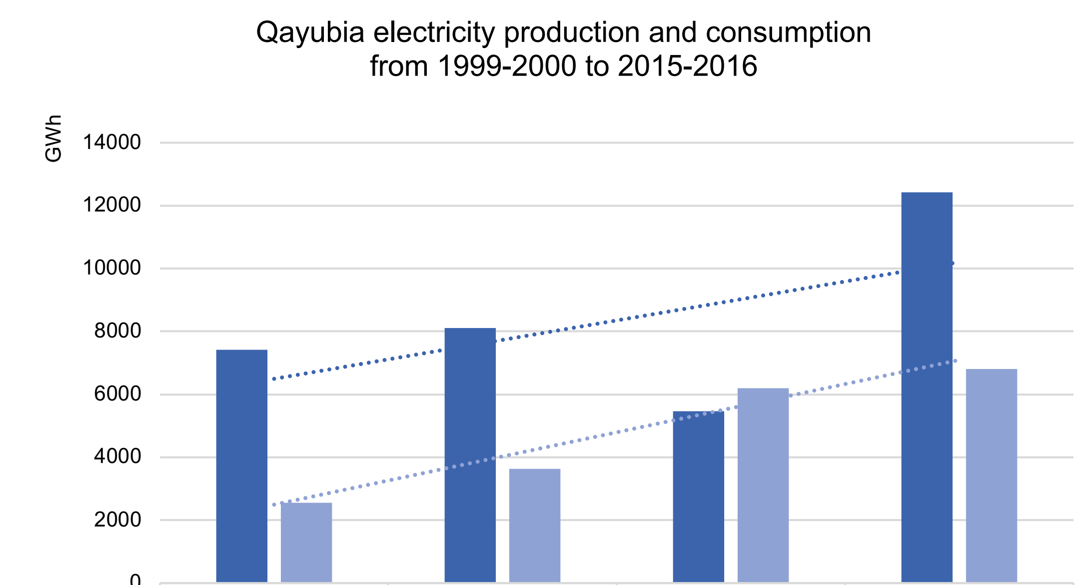
Figure 5-32: The electricity production and consumption of Cairo Governorate from 1999-2000 to 2015-2016.

The situation in Giza Governorate is different from Cairo Governorate as shown in Figure 5-33: electricity production exceeds consumption, which enables Giza Governorate to export electricity excesses to other surrounding settlements or to increase electricity consumption per capita. The situation in Qalyubia Governorate is similar to Giza Governorate; electricity production exceeds consumption as shown in Figure 5-34. This enables Qalyubia Governorate to export electricity excesses to other surrounding settlements or to increase per capita electricity consumption.



	1999-2000	2005-2006	2011-2012	2015-2016
Production	7067.4	14398.1	25600.3	26502.2
Consumption	5212	8102.2	13672.6	14774.5

Figure 5-33: Electricity production and consumption of Giza Governorate from 1999-2000 to 2015-2016.



	1999-2000	2005-2006	2011-2012	2015-2016
Production	7410.3	8107.8	5473.2	12414.2
Consumption	2546.2	3637.9	6187.6	6807.3

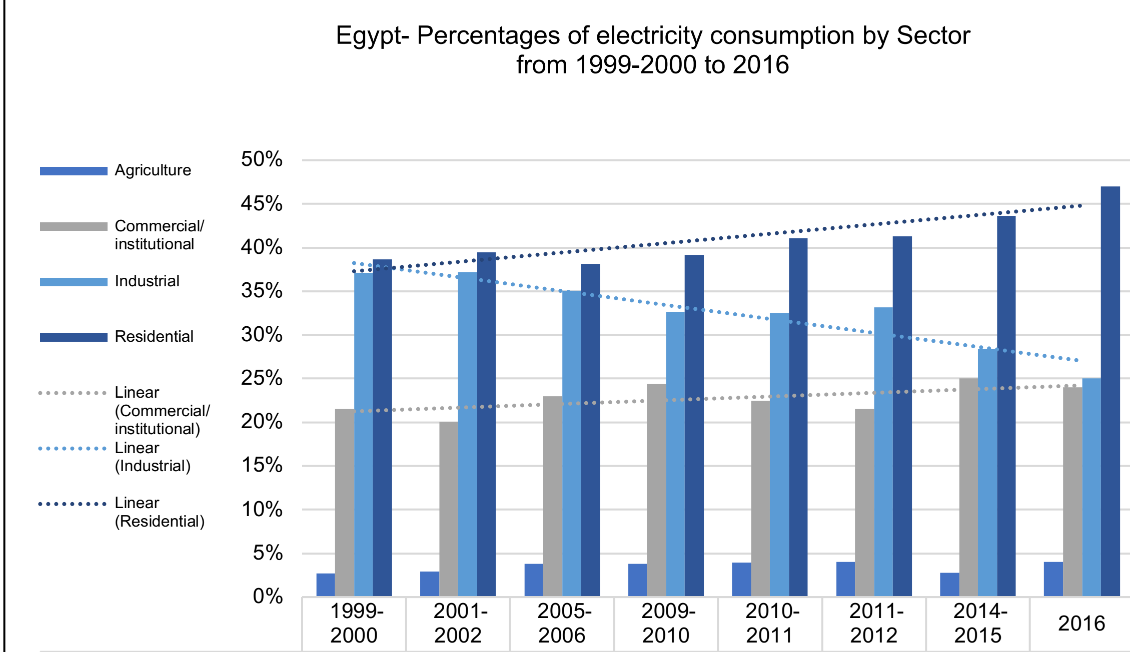
Figure 5-34: Electricity production and consumption of Qalyubia Governorate from 1999-2000 to 2015-2016.

If electricity production is higher than consumption in Giza and Qalyubia Governorates, this might change in the future as the average annual population growth rates of both governorates are high (see Chapter 4). This shows that if Giza and Qalyubia Governorates continue to grow at the same rate, electricity consumption will increase. This might prevent Giza and Qalyubia Governorates' ability to export electricity to other surrounding settlements in the future.

5.4.9 Percentages of electricity consumption by sector in Egypt, Cairo, Giza and Qalyubia Governorates

5.4.9.1 Egypt

Egypt is similar to most developing countries as the residential sector has the highest rates of electricity consumption compared to other sectors as shown in Figure 5-35. This is followed by the industrial sector, then the commercial, and then institutional sectors. The agricultural sector has the lowest percentage of electricity consumption and it was almost stable over a period of 16 years. The linear trendlines in Figure 5-35 show the continuous increase of the electricity consumption of the residential sector and the relative decrease of electricity consumption of the industrial sector. The commercial and the institutional sectors slightly increased (Figure 5-35).



	1999-2000	2001-2002	2005-2006	2009-2010	2010-2011	2011-2012	2014-2015	2016
Agriculture	2.69%	2.92%	3.83%	3.82%	3.94%	4.02%	2.78%	4.00%
Commercial/ institutional	21.53%	20.06%	22.99%	24.36%	22.50%	21.50%	25.00%	24.00%
Industrial	37.10%	37.17%	35.05%	32.66%	32.50%	33.17%	28.40%	25.00%
Residential	38.68%	39.48%	38.13%	39.16%	41.04%	41.31%	43.60%	47.00%

Figure 5-35: Percentages of electricity consumption by sector in Egypt from 1999-2000 to 2016.

The percentages of electricity consumption of the residential, industrial, commercial and institutional, and agricultural sectors of Egypt in 1999-2000 and 2016 are presented in Figure 5-36. This comparison indicates that electricity consumption of the service sectors (residential, commercial and institutional sectors) increased significantly and reached 71% of total electricity consumption of Egypt in 2016. While electricity consumption of the production sector (industrial) relatively decreased, and the agricultural sector slightly increased, however, the electricity consumption of both sectors was 29% of the total electricity consumption of Egypt in 2016. This shows that the rapid population growth in Egypt has had a great impact on the electricity consumption of the services sector (residential and commercial/institutional).

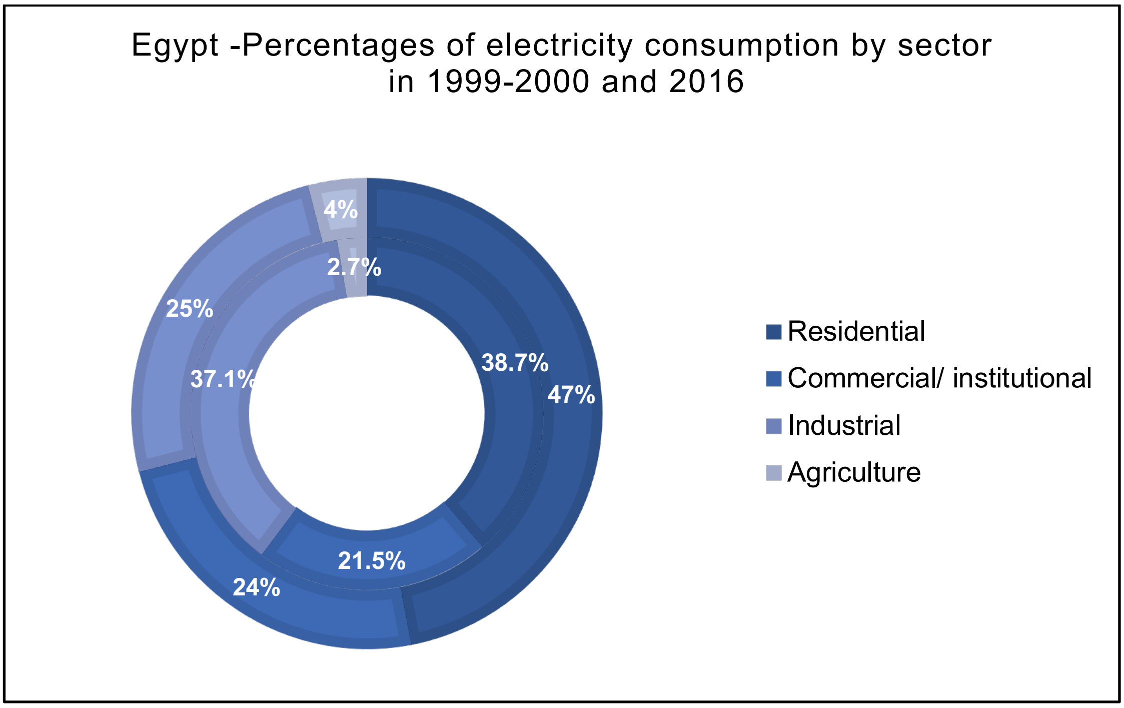
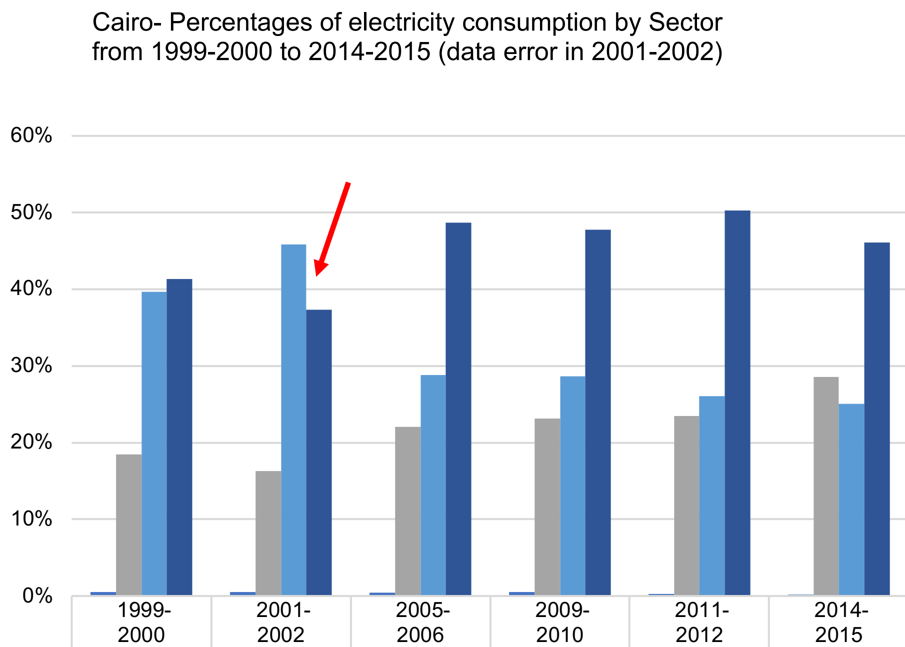


Figure 5-36: Percentages of electricity consumption by sector in Egypt, in 1999-2000 and 2016.

The representative of the Ministry of Electricity and Renewable Energy revealed that the electricity consumption of the residential sector increased from 37% to 47% due to urbanization and the change in the usage patterns. For example, he mentioned that during the revolution in 2011-2012 the government increased the salaries for everybody. This encouraged people to buy new electrical appliances, so the annual electricity consumption increased by 10.5%. Unfortunately, this increase was not associated with a production increase. The government is now reforming energy subsidies and will gradually remove them. Therefore, the electricity consumption of the residential sector is expected to decrease in the future as Interviewee 2 mentioned that "*because the elasticity of the customers' consumption as there is a rule of thumb in the residential sector that every 10% increase in the tariff it is associated with a 1.5% decrease in the consumption."* This indicates that the customers' practices will need to change to avoid paying higher electricity bills by reducing their electricity consumption. To reduce the energy intensity of Egypt the government will be focusing on developing sectors that provide more job opportunities with less energy consumption.

5.4.9.2 Cairo Governorate

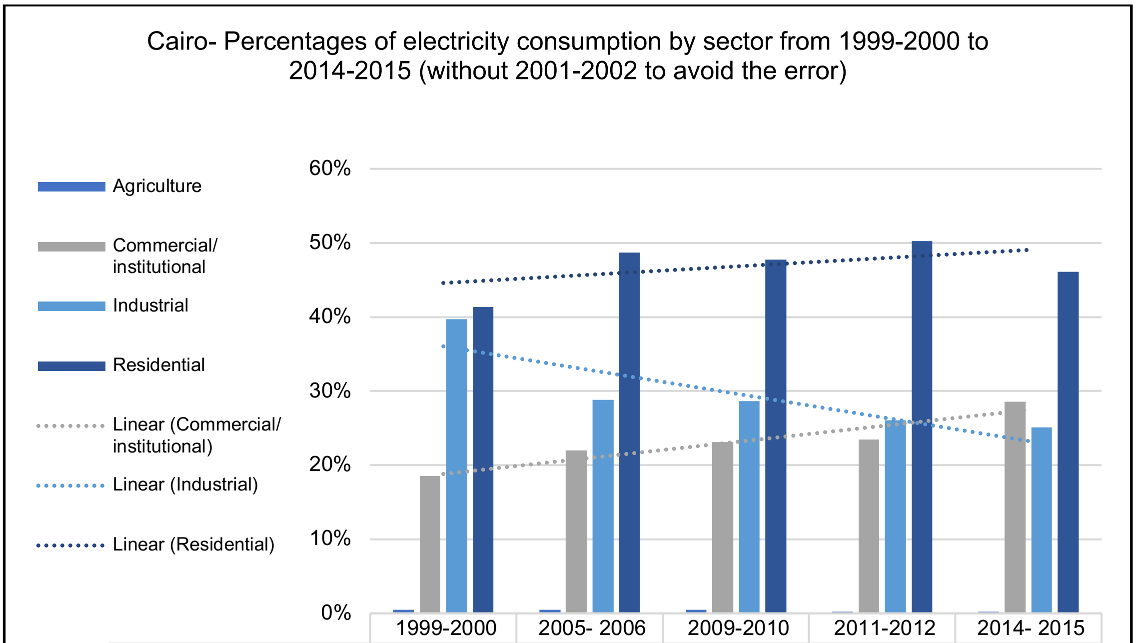
The percentages of the electricity consumption by sector in Cairo Governorate from 1999-2000 to 2014-2015 are presented in Figure 5-37. The data for the year 2001-2002 is inconsistent if compared to the rest of the years. This is due to a lack of consistent data reporting. Therefore, the data for 2001-2002 are excluded and the data of the rest of the years is presented in Figure 5-38.



	1999-2000	2001-2002	2005-2006	2009-2010	2011-2012	2014-2015
Agriculture	0.51%	0.5%	0.45%	0.52%	0.24%	0.19%
Commercial/ institutional	18.50%	16.32%	22.02%	23.11%	23.44%	28.6%
Industrial	39.67%	45.85%	28.83%	28.64%	26.03%	25.1%
Residential	41.31%	37.34%	48.7%	47.7%	50.29%	46.1%

Figure 5-37: Percentages of electricity consumption by sector in Cairo Governorate from 1999-2000 to 2014-2015 (data error in 2001-2002).

The residential sector has the highest rates of electricity consumption in Cairo Governorate compared to other sectors. The electricity consumption of the industrial sector was higher than the commercial and institutional sectors until 2011-2012. Then the electricity consumption of the commercial and institutional sectors increased and exceeded the industrial sector in 2014-2015, as shown in Figure 5-38. The trendlines in Figure 5-38 indicate that electricity consumption by the residential, commercial and institutional sectors have been consistently increasing, while the industrial sector has been relatively decreasing. This is expected as Cairo Governorate is the capital of Egypt and most of the commercial and institutional sectors are located there and are increasing due to the rapid population growth and urbanization. The agriculture sector has the lowest rates of electricity consumption, as Cairo Governorate is mostly urban (see Chapter 4).



	1999-2000	2005- 2006	2009-2010	2011-2012	2014- 2015
Agriculture	0.51%	0.45%	0.52%	0.24%	0.19%
Commercial/ institutional	18.50%	22.02%	23.11%	23.44%	28.6%
Industrial	39.67%	28.83%	28.64%	26.03%	25.1%
Residential	41.31%	48.7%	47.7%	50.29%	46.1%

Figure 5-38: Percentages of electricity consumption by sector in Cairo Governorate from 1999-2000 to 2014-2015 (without 2001-2002 to avoid the error).

The percentages of the electricity consumption of the residential, industrial, commercial and institutional, and agricultural sectors of Cairo Governorate between 1999-2000 and 2014-2015 are presented in Figure 5-39. This comparison shows that the services sectors (residential, commercial and institutional) increased and reached 75% of the total electricity consumption in 2014-2015, while the production sectors (industrial and agricultural) relatively decreased, specifically the industrial sector. This is part of the government's plan to relocate the industries and factories outside the boundaries of Cairo Governorate (GOPP, 2012).

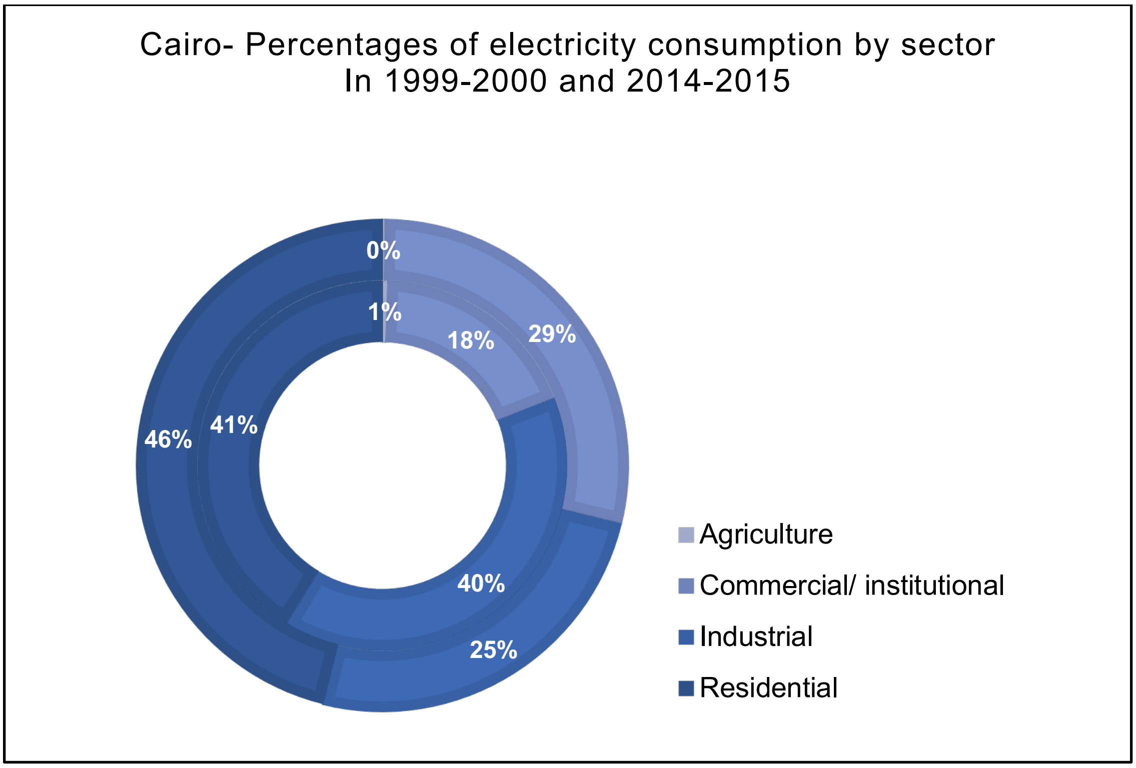
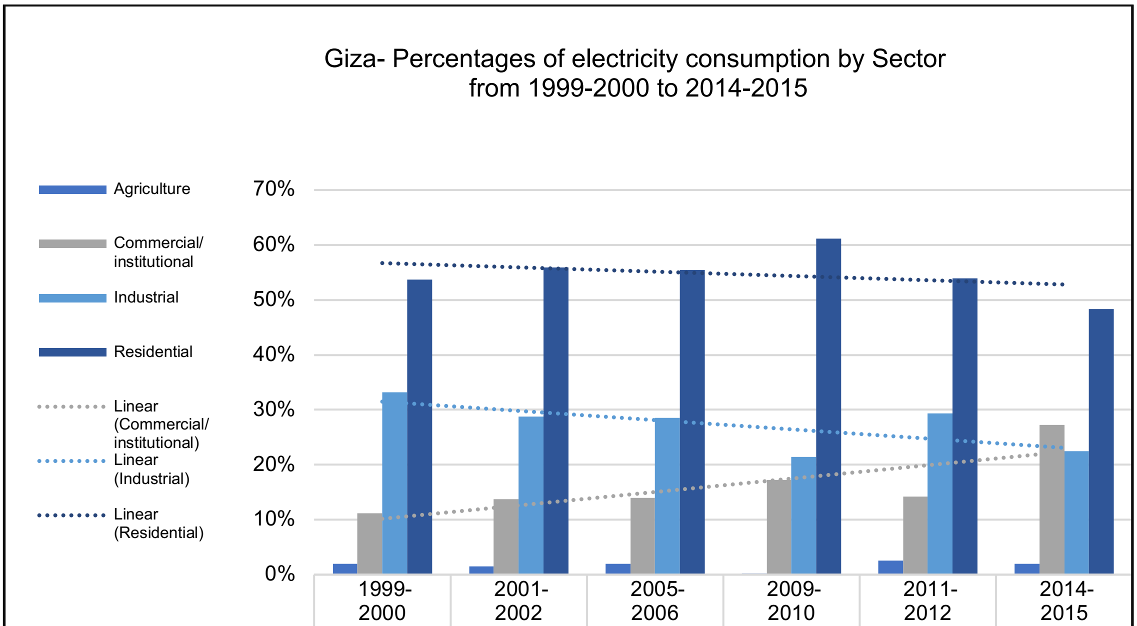


Figure 5-39: Percentages of electricity consumption by sector in Cairo Governorate, in 1999-2000 and 2014-2015.

5.4.9.3 Giza Governorate

The situation in Giza Governorate is similar to Cairo Governorate. The residential sector has the highest rates of electricity consumption (Figure 5-40). The electricity consumption of the industrial sector relatively decreased, and the commercial and institutional sectors increased and even exceeded the industrial sector in 2014-2015. The trendlines in Figure 5-40 indicate that while electricity consumption by the commercial and institutional sectors significantly increased over the period of 15 years, the residential and the industrial sectors relatively decreased. This is expected because there was a substantial increase in the number of commercial and institutional buildings in Giza Governorate from 2006 to 2017 (see Chapter 4). Additionally, the number of residential buildings increased significantly during the same period to meet the rapid population growth and urbanization in the area. The average annual growth rates from 2001 to 2016 was 3.17%, which is considered high compared to Cairo and Qalyubia Governorates and also higher than the average population growth of Egypt (see Chapter 4).



	1999-2000	2001-2002	2005-2006	2009-2010	2011-2012	2014-2015
Agriculture	1.99%	1.52%	2.02%	0.17%	2.50%	1.96%
Commercial/ institutional	11.14%	13.74%	13.99%	17.23%	14.17%	27.3%
Industrial	33.18%	28.8%	28.5%	21.4%	29.37%	22.48%
Residential	53.69%	55.94%	55.49%	61.20%	53.93%	48.3%

Figure 5-40: Percentages of electricity consumption by sector in Giza Governorate from 1999-2000 to 2014-2015.

The percentages of electricity consumption by the residential, industrial, commercial and institutional, and agricultural sectors of Giza Governorate in 1999-2000 and 2014-2015 are presented in Figure 5-41. This comparison shows that the services sectors (residential, commercial and institutional) increased and reached 75% of the total electricity consumption in 2014-2015, while the production sectors (industrial and agricultural) relatively decreased, specifically the industrial sector. This is part of the government's strategy to keep traditional industries and relocate highly polluting industries outside the boundaries of the Greater Cairo Region (GOPP, 2012). This strategy applies in Giza Governorate, being part of the Greater Cairo Region.

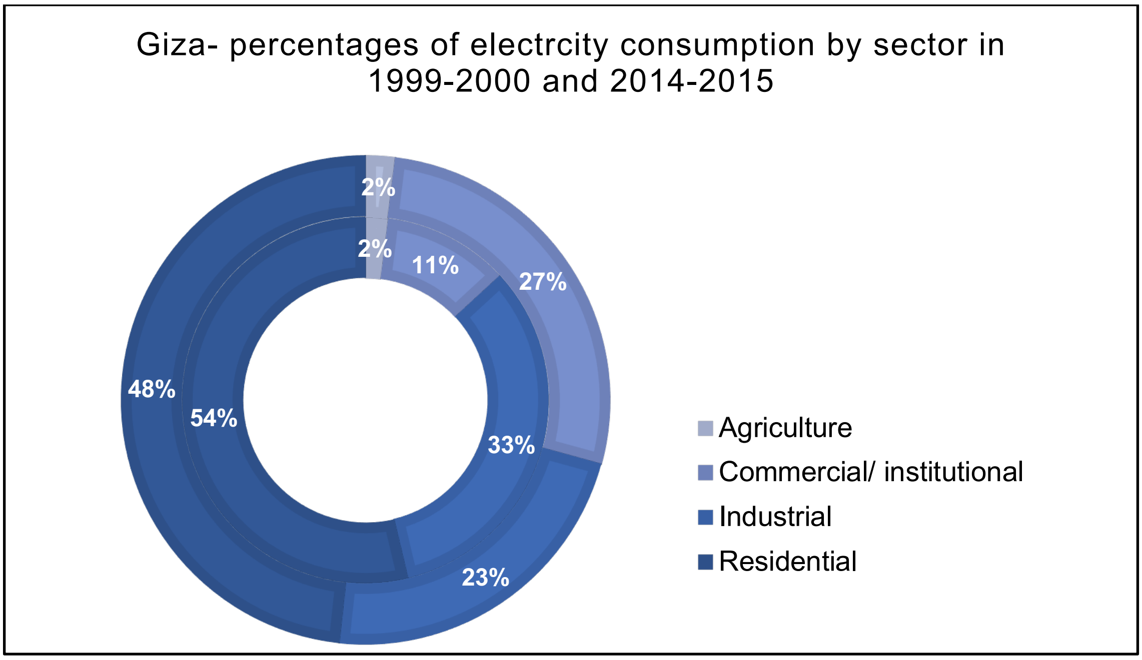
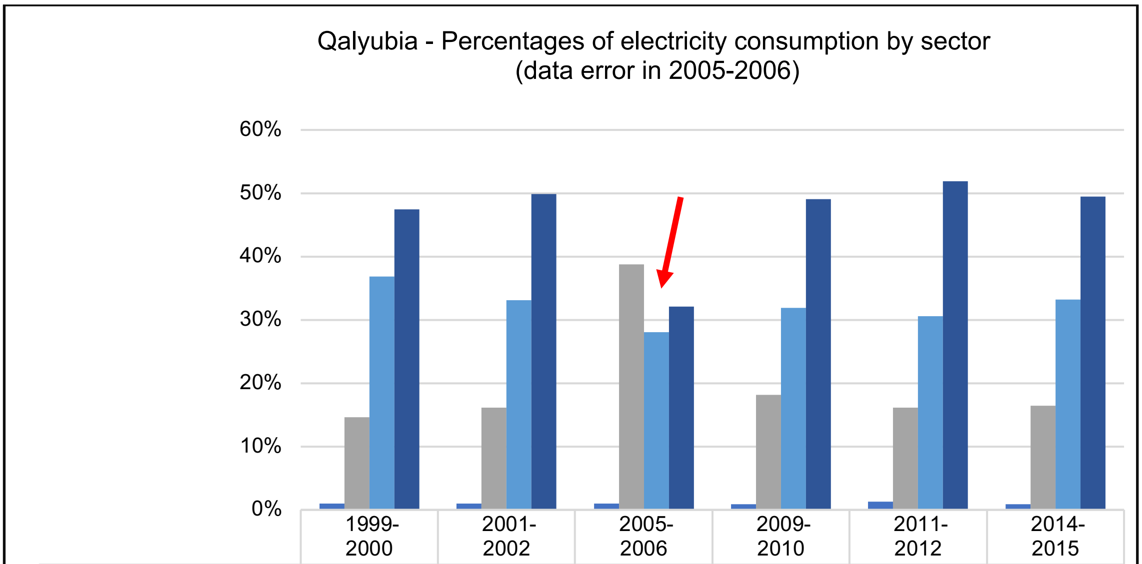


Figure 5-41: Percentages of electricity consumption by sector in Giza Governorate, in 1999-2000 and 2014-2015.

5.4.9.4 Qalyubia Governorate

The percentages of the electricity consumption by sector in Qalyubia Governorate from 1999-2000 to 2014-2015 are presented in Figure 5-42. The data for 2005-2006 is considered inconsistent if compared to the rest of the years.

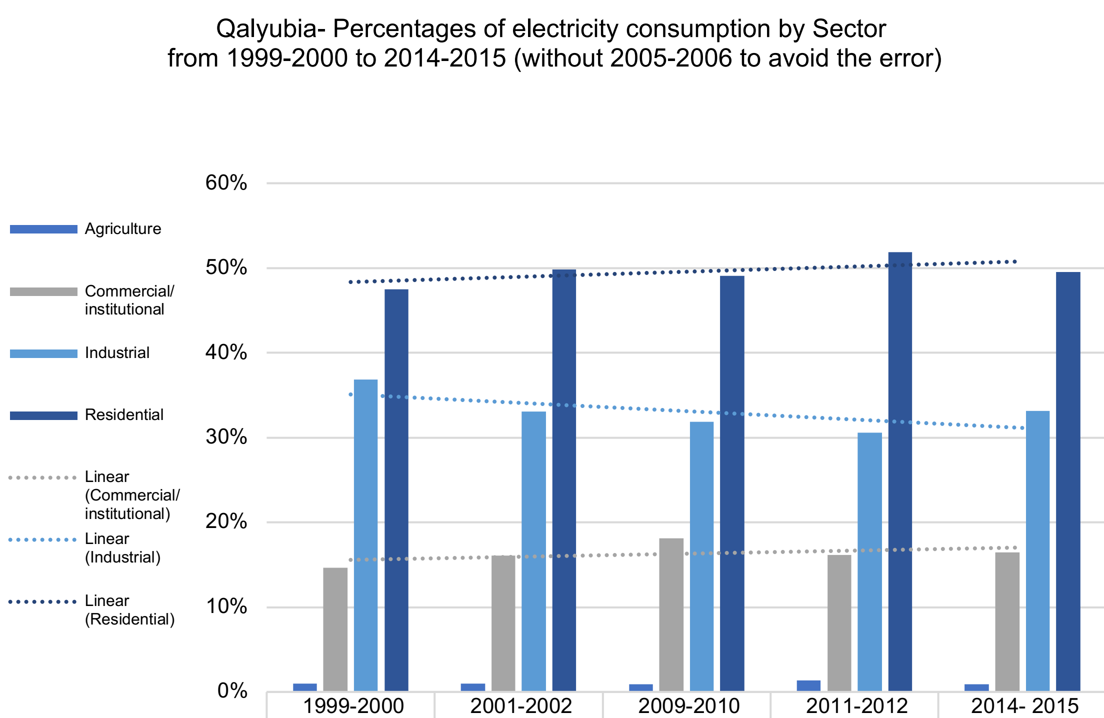
Therefore, the data of year 2005-2006 is excluded and the data of the rest of the years is presented in Figure 5-43.



	1999-2000	2001-2002	2005-2006	2009-2010	2011-2012	2014-2015
Agriculture	1%	1%	0.95%	0.89%	1.34%	0.88%
Commercial/ institutional	14.66%	16.1%	38.8%	18.2%	16.17%	16.5%
Industrial	36.85%	33.1%	28.11%	31.86%	30.59%	33.17%
Residential	47.49%	49.83%	32.13%	49.10%	51.90%	49.5%

Figure 5-42: Percentages of electricity consumption by sector in Qalyubia Governorate from 1999-2000 to 2014-2015 (error in 2005-2006).

The electricity consumption by sector in Qalyubia Governorate is different from Cairo and Giza Governorates. The residential and industrial sectors have the highest electricity consumption, followed by the commercial and institutional sectors and the agricultural sector is the lowest (Figure 5-43). The trendlines in Figure 5-43 indicate that the residential, commercial and institutional sectors have been slightly increasing, whereas the industrial sector has been slightly decreasing over the period of 15 years. The situation of Qalyubia Governorate is different from Cairo and Giza because it is mostly rural, therefore the commercial and institutional sectors' share is not as high as Cairo and Giza (see Chapter 4). With Cairo being the capital of Egypt, it is expected to have more commercial and institutional buildings than other governorates.



	1999-2000	2001-2002	2009-2010	2011-2012	2014- 2015
Agriculture	1%	1%	0.89%	1.34%	0.88%
Commercial/ institutional	14.66%	16.1%	18.2%	16.17%	16.5%
Industrial	36.85%	33.1%	31.86%	30.59%	33.17%
Residential	47.49%	49.83%	49.10%	51.90%	49.5%

Figure 5-43: Percentages of electricity consumption by sector in Qalyubia Governorate from 1999-2000 to 2014-2015.

Although electricity consumption by sector of Qalyubia Governorate is currently different from Cairo and Giza, this might change in the future. Figure 5-44 shows that the services sectors (residential, commercial and institutional sectors) increased and reached 66% of the total electricity consumption in 2014-2015, while the production sectors (industrial and agricultural sectors) relatively decreased. This indicates that the trends of the electricity consumption growth of the services and production sectors are similar to Cairo and Giza; however, the rate of change in Qalyubia Governorate is slower than the rate of change in Cairo and Giza Governorates.

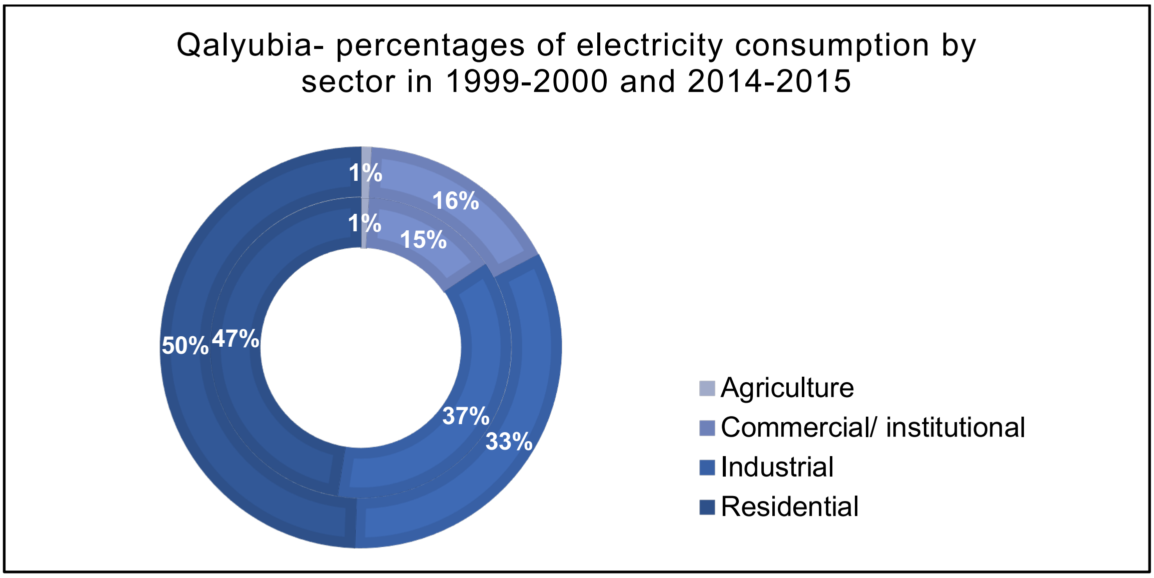


Figure 5-44: Percentages of electricity consumption by sector in Qalyubia Governorate, in 1999-2000 and 2014-2015.

5.4.10 Percentages of households without grid electricity connection in Egypt, Cairo, Giza and Qalyubia Governorates

Cairo Governorate has the lowest percentage of households without grid connection compared to Giza and Qalyubia and the average for Egypt (Figure 5-45). This is expected as Cairo Governorate, being the capital of Egypt, has more services than the rest of the governorates. This is the situation in most of the developing countries. However, the electricity coverage in Egypt, Giza and Qalyubia is considered high compared to the rest of the services, as presented in Figure 5-46. Figure 5-47 shows that the percentages of the population with access to internet and percentages of the population using mobile phones in Cairo Governorate are higher than Giza and Qalyubia and the average of Egypt. Internet access is important for the rollout of smart meters, specifically that the government has established a smart meter scheme programme as mentioned above (see Chapter 5, section 5.4.5). Despite, that the percentages of the population with access to the internet is the highest in Cairo compared to other governorates in Egypt, these percentages are considered extremely low if compared to developed nations and should be increased in the future.

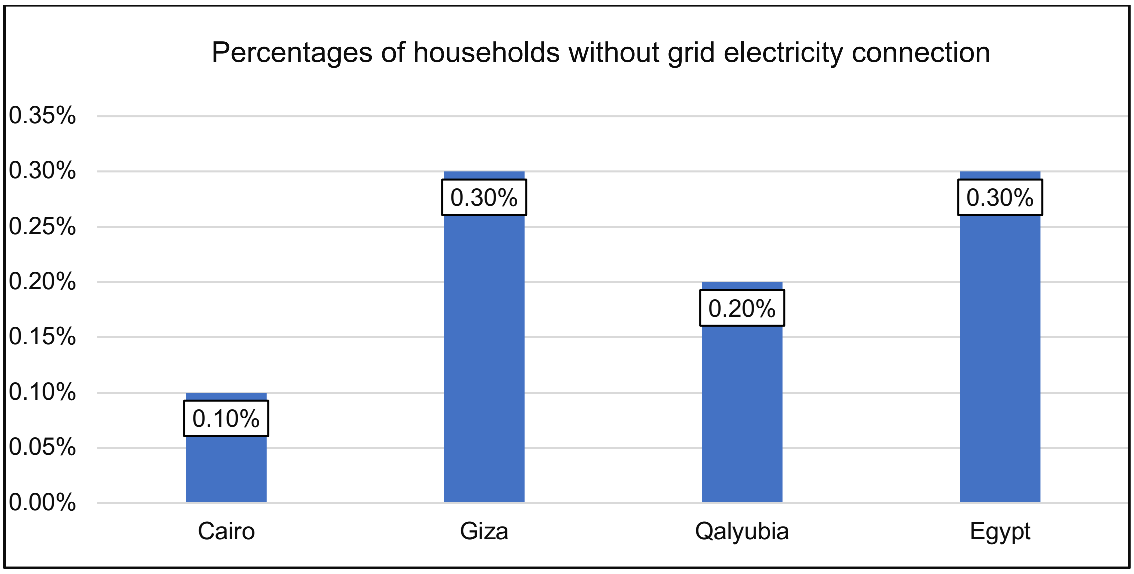
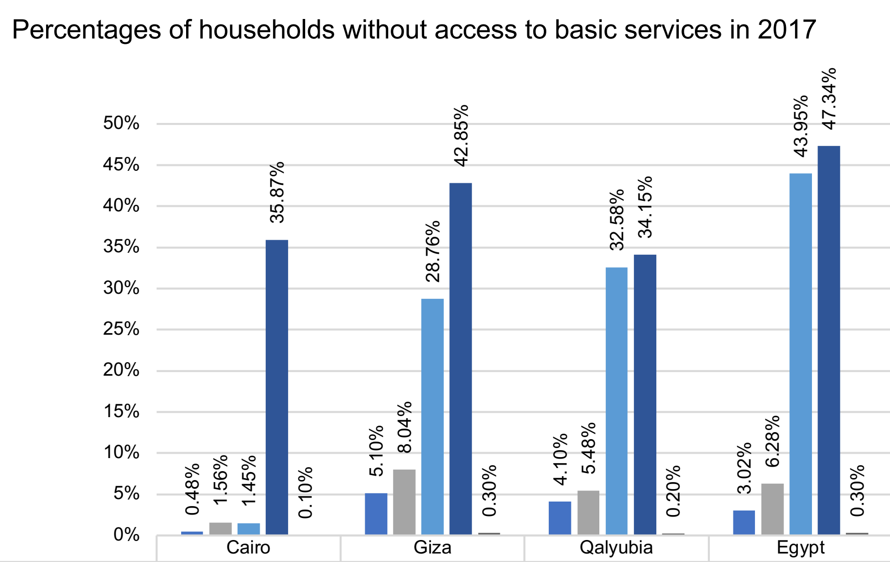
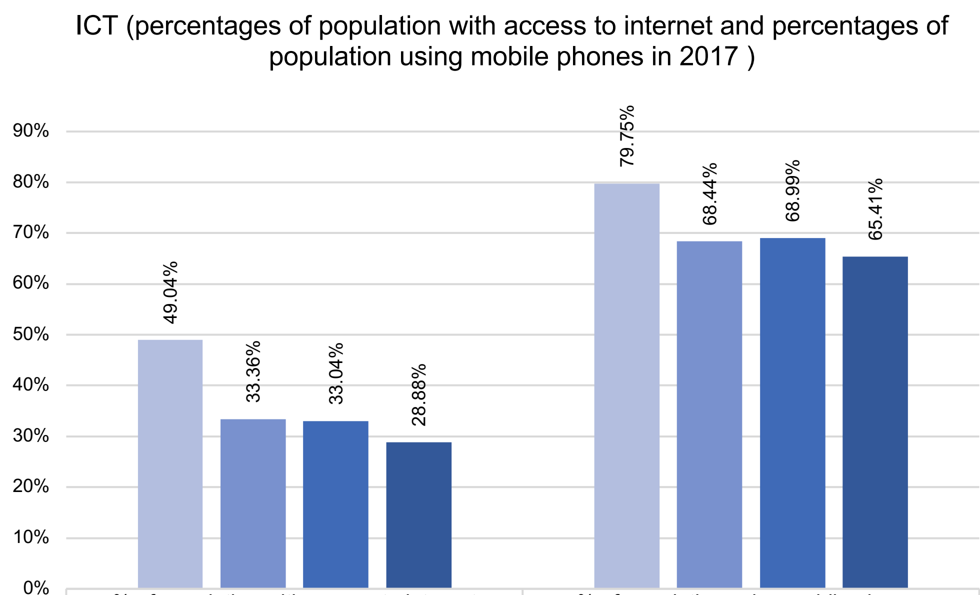


Figure 5-45: Percentages of households without grid electricity connection in Egypt, Cairo, Giza and Qalyubia Governorates.



	Cairo	Giza	Qalyubia	Egypt
% of households without direct access to water	0.48%	5.10%	4.10%	3.02%
% of households without direct access to drinkable water	1.56%	8.04%	5.48%	6.28%
% of households without sanitation	1.45%	28.76%	32.58%	43.95%
% of households living in areas without public waste collection	35.87%	42.85%	34.15%	47.34%
% of households without grid electricity connection	0.10%	0.30%	0.20%	0.30%

Figure 5-46: Percentages of households without access to basic services in 2017.



	% of population with access to internet	% of population using mobile phones
Cairo	49.04%	79.75%
Giza	33.36%	68.44%
Qalyubia	33.04%	68.99%
Egypt	28.88%	65.41%

Figure 5-47: Percentages of population with access to internet and percentages of population using mobile phones in 2017.

5.5 Conclusion:

This chapter presented the current situation and the future targets of the energy and electricity sectors in Egypt, Cairo, Giza and Qalyubia Governorates. The existing situation of the energy and electricity sectors shows that Egypt mainly relies on non-renewable energy resources (natural gas and crude oil) and the share of renewable energy (hydropower, solar and wind) is extremely low. The electricity production and consumption have been significantly increasing between 2002 and 2016 in Egypt and the three governorates. The electricity consumption of Cairo Governorate exceeded its production between 2000 and 2012. The government increased the electricity production of Cairo Governorate as the average annual growth rate reached 24.5% between 2000 and 2016 to meet its increasing demands. The average annual electricity losses (technical and commercial) of Egypt is 15% to 18% of the total electricity production. It is expected that the electricity losses will be higher in Cairo Governorate due to the illegal connections in informal settlements, ageing infrastructure and metering systems.

The government set a target to increase the share of renewable energy resources to reach 20% by 2022. Many actions have been taken by the government to ensure the achievement of this target and to enhance the use of renewable energy resources. Additionally, the energy strategy of Egypt focuses on energy efficiency rather than energy conservation to increase electricity production that is required to increase per capita electricity consumption. The government's plan is to increase the GDP by focusing on sectors that require less energy and electricity to provide more job opportunities.

Although there is a huge potential for renewable energy resources in Egypt and the three governorates (see Chapter 4), there are major challenges to convert these resources into energy. The lack of technical knowledge and the lack of the experience of biding, contracting and financing complicates the process and the development of such projects. Moreover, due to the high-density settlements in Cairo Governorate, this could prevent the development of the distributed systems. However, the distributed systems could be suitable for the new satellite cities surrounding Cairo and Giza Governorates. Wind energy is not suitable for inner cities, while waste-to-energy and sludge-to-energy technologies could be better options for medium and high-density settlements in the three governorates (Cairo, Giza and Qalyubia) which do not produce energy themselves and rely on other cities or governorates to meet the increasing demand of energy. To remove the barriers to the development of waste-to-energy technologies in Egypt several steps need to be taken: first, the energy and electricity sectors should be willing to invest in this sector rather than focusing on the wind and solar energy only; second, the government should reform and actively reshape the governance of the waste management sector and improve the institutional setup to establish an integrated sustainable waste management system; and finally, improve the sanitation coverage to develop sludge-to-energy technologies. Despite that the capacity factor of the solar and wind energy is higher than waste-to-energy, the potential of upgrading the organic waste to produce biogas refers to the effective handling of organic waste, reducing the amount of waste going to landfills or untreated and thrown in the streets, and reducing its environmental impacts.

6 Chapter Six: The current and future projections of the water and wastewater sectors in Cairo, Giza and Qalyubia Governorates and Egypt

6.1 Introduction

This chapter presents the current situation of, and future projections for, the water and wastewater sectors in Egypt and Cairo, Giza and Qalyubia Governorates. The data of the water sector was collected for more than 14 years to identify patterns of production and consumption. The data of the wastewater sector was based on the year 2011 only due to the lack of reliable data. To target the most important quantitative data to measure and assess the water and wastewater sectors, I used the third layer of the multi-layered indicator set that was developed by Kennedy et al. (2014). Additionally, the semi-structured interview that was conducted with the representative of the Holding Company for Drinking Water and Wastewater (Interviewee 4) in Egypt was critically analysed to better understand how the water and wastewater sectors are being managed. The quantitative and qualitative data of the water sector (see section 6.3) and wastewater sector (see section 6.4) in Cairo, Giza and Qalyubia Governorates and Egypt are merged and explained in depth.

6.2 Layer 3-2: water and wastewater sectors in Cairo, Giza and Qalyubia Governorates and Egypt

The third layer of the original multi-layered indicator set includes: the consumption of energy (all types); electricity sources; consumption of water;

consumption of food; building materials; generation of solid waste and wastewater (Kennedy et al., 2014). The focus of this study is on the energy, electricity and water sectors as examples of the inputs of cities and the solid waste and wastewater as examples of the outputs of cities. The energy and electricity sectors (Layer 3-1) were presented in Chapter 5, the water and wastewater sectors (Layer 3-2) are presented in this chapter, while the solid waste sector (Layer 3-3) is presented in Chapter 7. This chapter includes the following data:

c) <u>The water sector:</u>

- Water resources of Egypt and quantities (billion cubic metres/year) from 2006-2007 to 2014-2015.
- Percentages of water resources in Egypt from 2006-2007 and 2014-2015.
- Percentages of water consumption in Egypt by sector from 2006-2007 to 2015-2016.
- Drinking water production (surface and groundwater) of Egypt from 2012-2013 to 2016-2017.
- Percentages of drinking water production (surface and groundwater) of Egypt in 2012-2013 and 2016-2017.
- Drinking water production (surface and groundwater) of Cairo, Giza and Qalyubia Governorates from 2012-2013 to 2016-2017.
- Percentages of surface water production of Cairo, Giza and Qalyubia Governorates and the rest of Egypt in 2012-2013 and 2016-2017.
- Percentages of groundwater production of Cairo, Giza and Qalyubia Governorates and the rest of Egypt in 2012-2013 and 2016-2017.

- Drinking water production, consumption and losses of Egypt from 2001-2002 to 2015-2016.
- Drinking water production, consumption and losses of Cairo, Giza and Qalyubia Governorates from 2002-2003 to 2015-2016.
- Drinking water consumption of Cairo, Giza and Qalyubia Governorates and the rest of Egypt from 2002-2003 to 2015-2016.
- Percentages of drinking water consumption of Cairo, Giza and Qalyubia Governorates and the rest of Egypt in 2002-2003 and 2015-2016.
- Drinking water losses (million cubic metres) of Cairo, Giza and Qalyubia Governorates and the rest of Egypt from 2002-2003 to 2015-2016.
- Percentages of drinking water losses of Cairo, Giza and Qalyubia Governorates in 2002-2003 and 2015-2016.
- Percentages of the drinking water losses (of the production) of Egypt, Cairo, Giza and Qalyubia Governorates from 2002-2003 to 2015-2016.
- Percentages of households without direct access to water and without direct access to drinkable water in 2017.

d) <u>The wastewater sector:</u>

- Total production and untreated wastewater of Egypt, Cairo, Giza and Qalyubia Governorates in 2011.
- Percentages of wastewater production of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2011.
- Types of wastewater treatment (primary, secondary and tertiary treatment, and untreated wastewater) in Egypt, Cairo, Giza and Qalyubia Governorates in 2011.

- Percentages of households without direct access to sanitation services in 2017.

Sources of secondary data are presented in Chapter 3 Table 3-1 and the criteria of including and excluding reports is presented in Appendix 12.

6.3 The water sector in Egypt, Cairo, Giza and Qalyubia Governorates

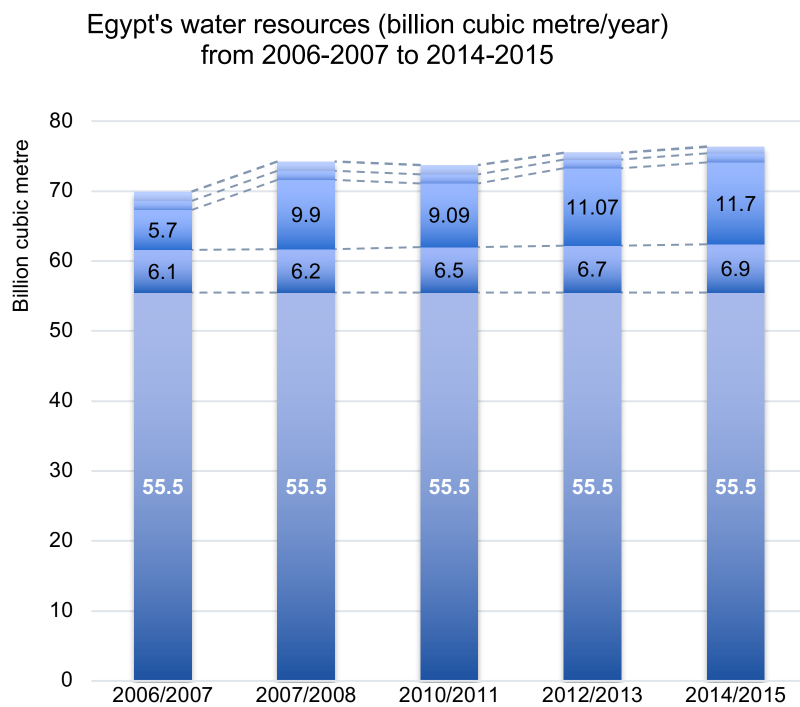
6.3.1 Water resources

There are two ministries managing the water sector in Egypt: The Ministry of Water Resources and the Ministry of Housing and Utilities. The Ministry of Water Resources is responsible for the management of water resources and the irrigation of the agricultural land. The Ministry of Housing and Utilities is responsible for providing drinking water and sanitation services for more than 100 million inhabitants.

> *"The Holding Company for Drinking Water and Wastewater is a separate entity, under the 2003 law that separates the ownership from the management. This means that the government owns all the drinking water and sanitation facilities, which includes the treatment plants and networks. The Holding Company is responsible for the management, operation and maintenance of the drinking water and sanitation facilities"* (Interviewee 4).

The River Nile is the main source of renewable surface water in Egypt (Figure 6-1). The share of Egypt is 55.5 billion m^3y^{-1}, this share has been fixed since 1959 when the High Dam was constructed (Wahba et al., 2018). The share of groundwater in the Nile Valley and Delta was also fixed between 2006-2007 and 2014-2015. Agricultural drainage reuse doubled over a period of 9 years. Rainfall levels, already low, are decreasing further as discussed previously in

Chapter 4 with the average annual rainfall of Egypt at 12mm (Abdel-Shafy et al., 2010). The share of wastewater reuse and seawater desalination is low compared to the rest of the resources.



	2006/2007	2007/2008	2010/2011	2012/2013	2014/2015
Sea water desalination	0.06	0.06	0.06	0.06	0.1
Rainfall	1.3	1.3	1.3	0.93	0.9
Wastewater reuse	1.3	1.3	1.3	1.24	1.3
Agricultural drainage reuse	5.7	9.9	9.09	11.07	11.7
Underground water in the Nile Valley & Delta	6.1	6.2	6.5	6.7	6.9
River Nile	55.5	55.5	55.5	55.5	55.5

Figure 6-1: Egypt's water resources (billion cubic metre/year) from 2006-2007 to 2014-2015.

The percentages of Egypt's water resources in Figures 6-2 and 6-3 show that the share of the River Nile has relatively decreased between 2006-2007 and 2014-2015 from 79% to 73%. The share of agricultural drainage reuse increased from 8% to 15%. The share of other resources remained almost the same over the same period of time. This indicates that water resources in Egypt are either fixed or limited. Water shortage is a critical challenge in Egypt. The annual share of renewable water per capita reached 1000m^3 in 1997, and this is the baseline of the water scarcity according to the Falkenmark Water Stress Indicator (NWRP, 2017).

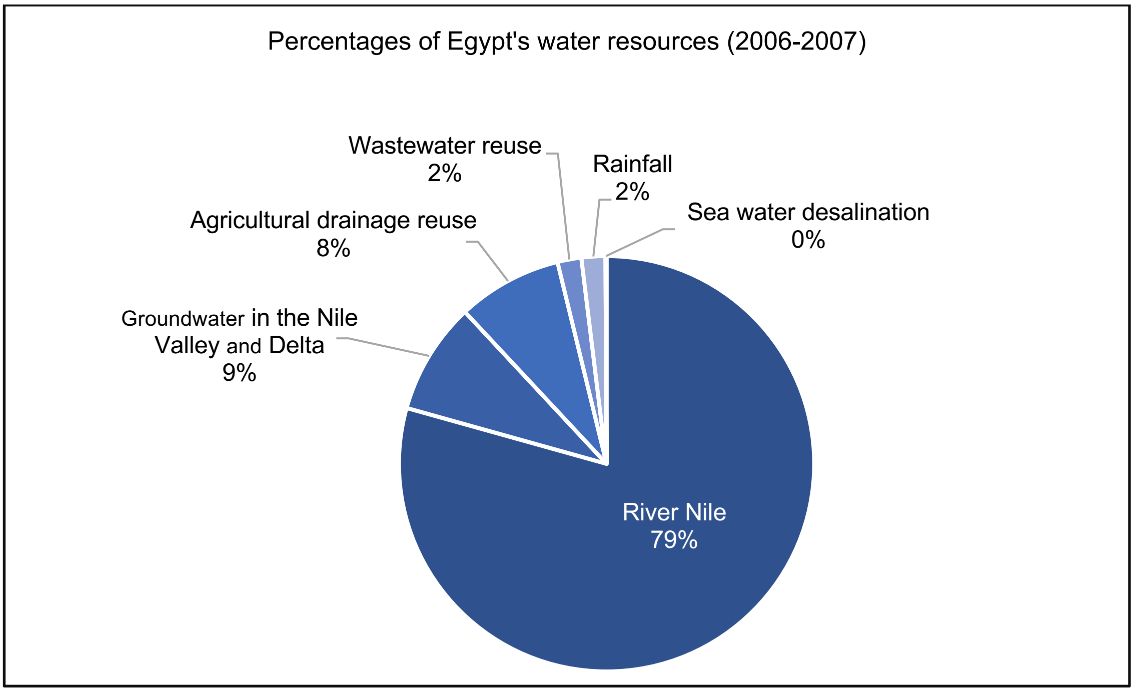


Figure 6-2: Percentages of Egypt's water resources in 2006-2007.

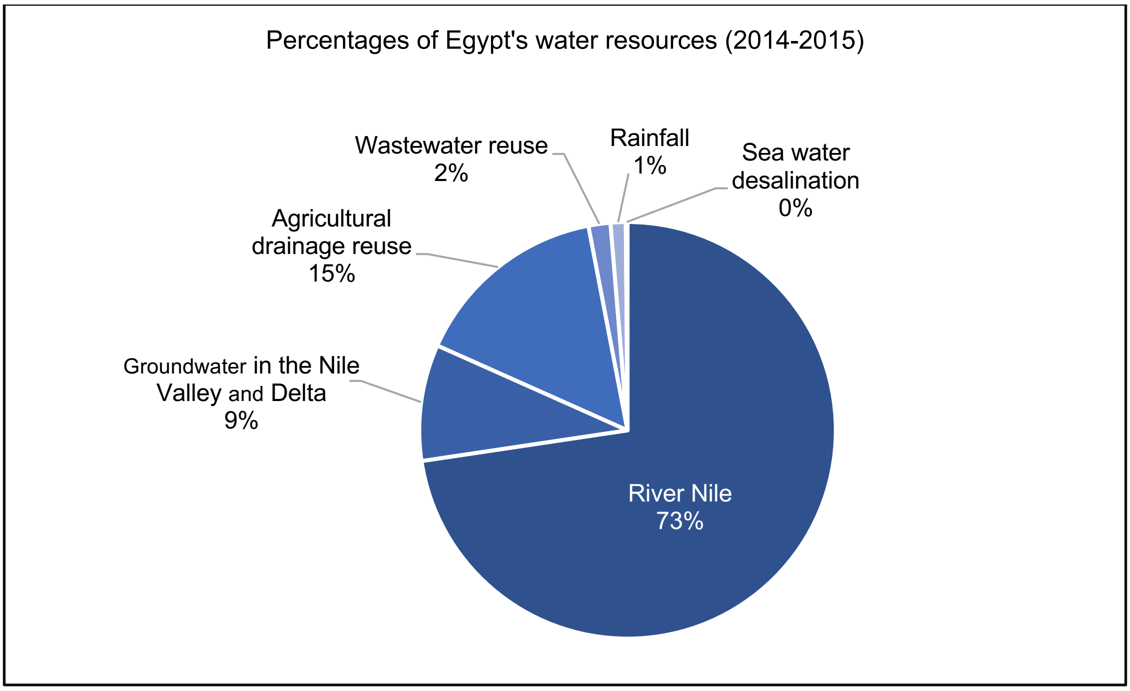


Figure 6-3: Percentages of Egypt's water resources in 2014-2015.

In 2015, the annual share of renewable water per capita dropped to 658m^3 due to rapid population growth and water scarcity (NWRP, 2017). The gap between supply and demand of water resources is increasing; the amount of freshwater is fixed, and the population is rapidly growing. By 2037, the annual share of renewable water per capita is expected to fall by 35% compared to 2015 (NWRP, 2017). Moreover, existing water resources are expected to decrease due to the impacts of the climate change and the Grand Ethiopian Renaissance Dam that will specifically affect the share of Egypt from the River Nile.

> Author: *"Is the Grand Ethiopian Renaissance Dam in Ethiopia going to affect the main source of water in Egypt, the River Nile?"*
>
> Interviewee 4: *"Yes, of course, but if we reduce the water consumption of the agriculture sector (irrigation) and increased the desalination plants to provide the Mediterranean and the Red Sea cities with drinking water, the saving from such actions will cover the potential water loss from the Ethiopian dam."*

The government established a strategy to meet the increasing water demand, and to overcome the challenges of the water sector in Egypt. This strategy is called "National Water Resources Plan 2017-2030-2037 (NWRP)" (NWRP, 2017). The main goals of the strategy are:

- Providing the appropriate environment for integrated water management, planning and implementing the plan.
- Developing water resources.
- Improving the quality of water.
- Rationalizing water use and improving the efficiency of water resource management.

To achieve these goals the government set the following objectives:

- Issuing the necessary laws and legislations for the water quality and management that reflect the principles of integrated water resource management.
- Raising public awareness of water scarcity and the importance of rationalizing the use of water.
- Adding 1.05 billion cubic metre of freshwater resources to the water balance by 2030 and 4.45 billion cubic metres by 2037. This will be achieved by:
    a. Increasing Egypt's share from the River Nile.
    b. Harvesting rainwater and floods.
    c. Increasing the number of sea water desalination plants to provide all the Mediterranean and Red Sea cities with water and reduce the pressure on the River Nile. These projects require a huge budget that will be covered by reducing drinking water subsidies[10]. Since 2004, water subsidies have been gradually reduced and residents are now expected to pay 100% of the actual cost by 2020. This includes the operation and maintenance expenses and the water tariff is expected to increase in the future to cover the new investments as well.

       "First of all, we have a ministerial decree that all the Mediterranean and the Red Sea cities should use desalinated water. This action was taken to reduce the pressure from the River Nile, our main source of water." (Interviewee 4)

[10] Water was heavily subsidized before the establishment of the Holding Company for Drinking Water and Wastewater in 2004.

“10 to 15 years ago the drinking water was heavily subsidized. Residents used to pay 10% to 15% of the actual cost of water services. Since 2004, when the Holding Company for Drinking Water and Wastewater was established, we started to increase the tariff and remove the subsidies gradually.” (Interviewee 4)

d. Maximizing the sustainable use of groundwater.

- Reducing the pollution of water resources by:
  a. Increasing the sanitation coverage to reach 90% by 2037 to reduce the direct drainage of wastewater into water streams, specifically in rural areas. Based on the “2030 Strategic Vision for Treated Wastewater Reuse in Egypt” (AbuZeid and Elrawady, 2014) sanitation coverage will reach 100% by 2030 that is higher than the percentage mentioned in the “National Water Resources Plan 2017-2030-2037” (NWRP, 2017). However, this indicates that increasing sanitation coverage became a top priority for Egypt’s government.
  b. Preventing solid waste from being disposed in water streams. This could not be achieved without developing an integrated sustainable solid waste management system (see Chapter 7).
  c. Reducing industrial and agricultural pollution.
- Increasing the share of agricultural drainage reuse to reach 50% by 2037.
- Rationalizing water use in the agricultural, industrial and residential sectors.
- Increasing agricultural production by using less water. This will be achieved by changing the type of crops.
- Improving drinking water networks to reduce the water losses.

- Reducing the use of drinking water in irrigating public parks and private gardens.

The government's NWRP strategy considered many aspects to overcome the challenges of water scarcity and to increase the efficient use of water resources. However, the strategy did not mention the effect of illegal water connections in informal settlements and the lack of sanitation services in these areas that have a great impact on the water losses and the pollution of the water resources, specifically the main source of water, the River Nile and groundwater as shown in Figures 6-4, 6-5 and 6-6. To reduce water losses and the pollution of water resources these areas should be upgraded or demolished and replaced by new formal settlements and provided by adequate infrastructure. Currently, the government's priority is to upgrade unsafe and then unplanned settlements, but it is not clear yet when this will be achieved. A huge amount of resources is wasted in these areas and illegal connections in informal settlements weaken the existing infrastructure.

Figure 6-4: Informal settlements near the River Nile (Source: author's site visits).

Figure 6-5: Informal settlements near the River Nile (Source: author's site visits).

Figure 6-6: Informal settlements near an agricultural drainage (Source: author's site visits).

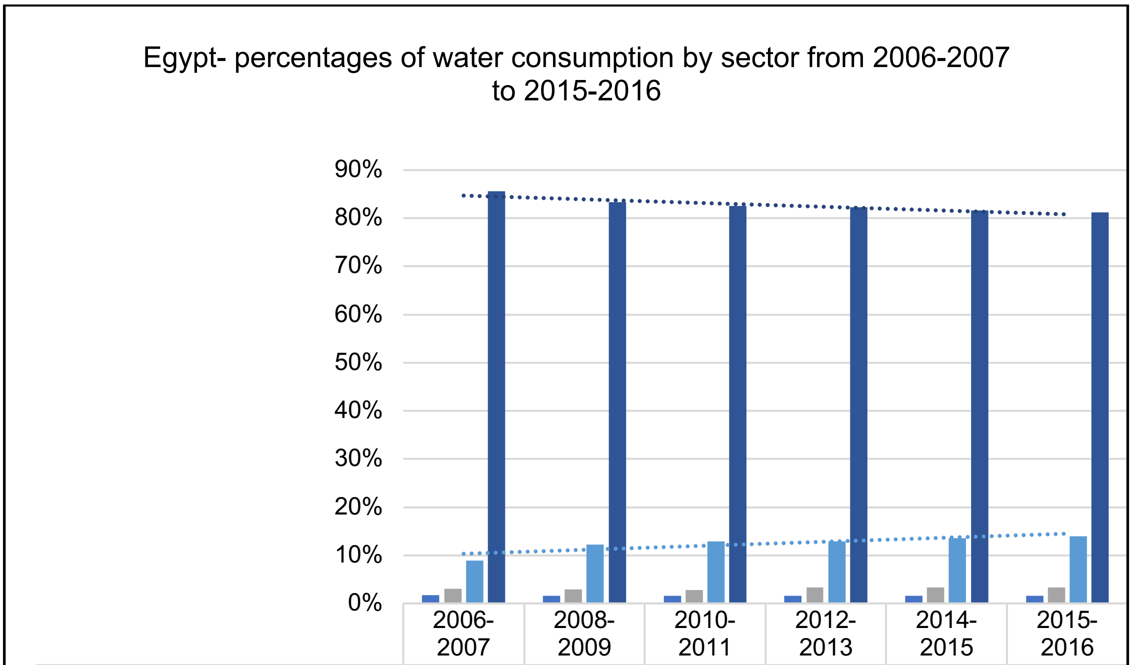
There is another problem (elaborated in Chapter 7): the lack of a proper waste management system, which has a massive impact on Egypt's existing water resources as solid waste enters water streams and increases pollution levels. The representative of the Holding Company for Drinking Water and

Wastewater outlined that there are laws that were issued to protect water resources in Egypt, but he described the implementation of these laws is *"very difficult"*. He also clarified that the government should increase public awareness campaigns so people can understand how their actions affect the quality of Egypt's water resources.

> *"There are laws to protect the water resources, but it is very difficult to apply them. People are not aware enough to understand the effect of water pollution on their health. Public awareness programmes are required to protect our water resources. People should understand the link between their actions and its impact on the environment. We do not have the capacity to follow each one to see whether they are applying the law or not"* (Interviewee 4).

6.3.2 Percentages of water consumption by sector

The agricultural sector has the highest percentage of water consumption compared to other sectors. The percentage of water consumption in the agricultural sector relatively decreased between 2006-2007 and 2014-2015 as it reached 81% in 2014-2015. This is part of the government's strategy to increase agricultural production to meet increasing food demand and for economic growth by using less water. This will be achieved by replacing existing crops with other types that can grow with less water and in high temperature due to the impacts of climate change. This is followed by the water consumption of the drinking water sector that has been increasing over the same period of time, reaching almost 14% in 2014-2015 and is expected to increase in the future due to rapid population growth and economic growth. The percentage of the losses of the River Nile and canals evaporation is around 3% and this percentage is expected to increase with climate change. Water consumption of the industrial sector is the lowest as it is around 1.6%, but this is not the actual consumption level as the industrial sector receives water from various sources and sometimes directly from the River Nile.



	2006-2007	2008-2009	2010-2011	2012-2013	2014-2015	2015-2016
Industrial	1.70%	1.60%	1.63%	1.59%	1.57%	1.56%
Losses by evaporation from the River Nile & canals	3.10%	2.90%	2.85%	3.30%	3.27%	3.25%
Drinking water	8.90%	12.20%	12.95%	12.85%	13.55%	13.97%
Agriculture	85.60%	83.30%	82.58%	82.25%	81.61%	81.22%

Figure 6-7: Percentages of water consumption by sector from 2006-2007 to 2015-2016 in Egypt.

6.3.3 Drinking water production (surface and groundwater)

6.3.3.1 Drinking water production (surface and groundwater) in Egypt

Drinking water in Egypt is mostly produced from surface water (90% in 2016-2017), largely from the River Nile (Figures 6-8 and 6-9). Surface water was almost stable from 2012-2013 to 2016-2017. The production of surface water was stable because Egypt receives 55.5 billion m^3y^{-1} from the River Nile, the main source of surface water, and this share has been fixed since 1959. However, part of the government's strategy is to increase this share in the future that is still under negotiations with the Nile Basin countries. The share of groundwater (10% in 2016-2017) is extremely low and has been decreasing over the same period of time (5 years) (Figures 6-8 and 6-9). The government's strategy to increase the share of groundwater in the future is focused on maximizing the sustainable use of groundwater and increasing sanitation coverage to improve groundwater quality.

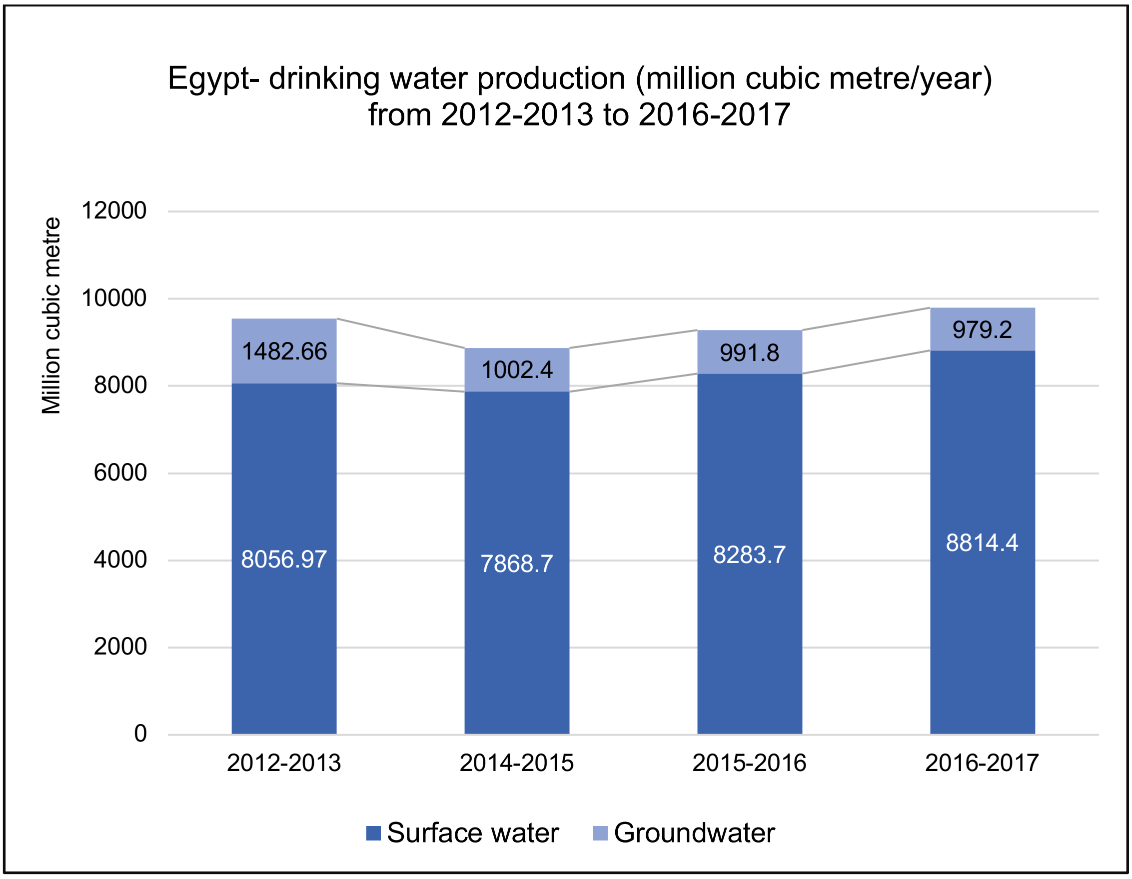


Figure 6-8: Egypt's drinking water production (million cubic metre/year) from 2012-2013 to 2016-2017 (surface and groundwater).

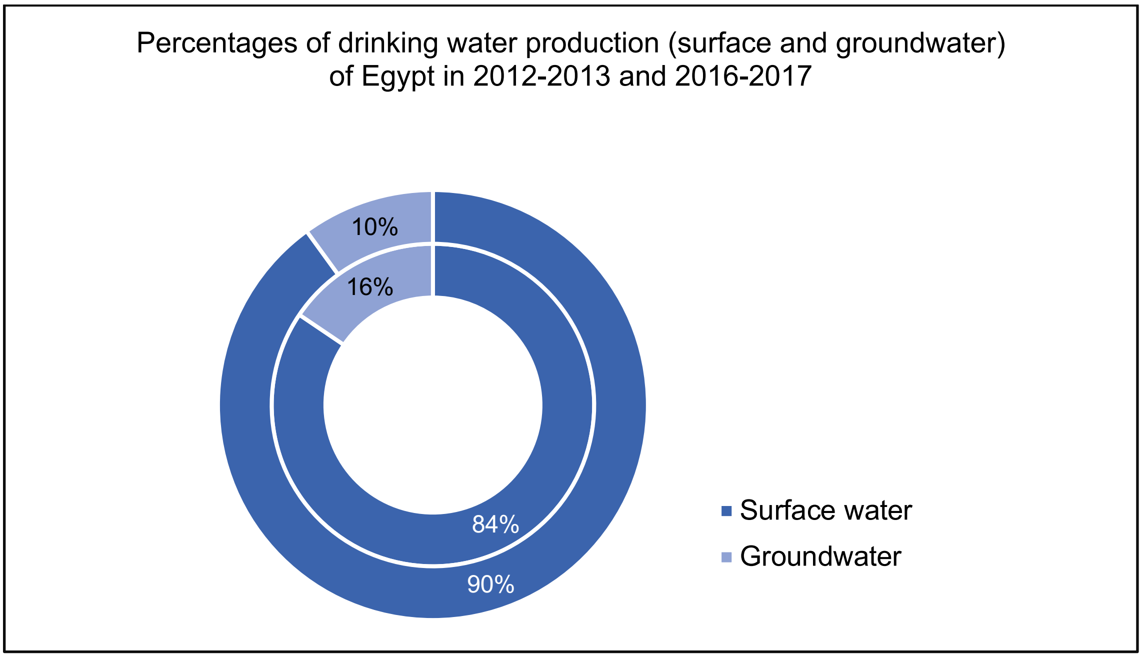
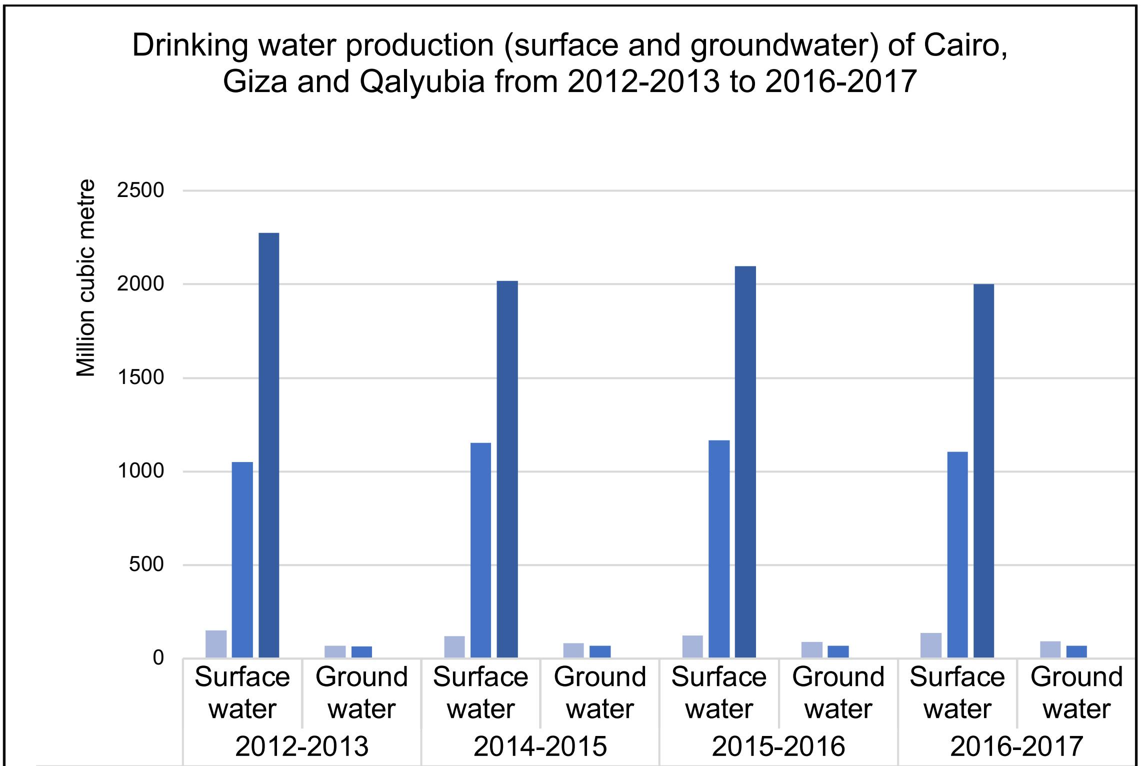


Figure 6-9: Percentages of drinking water production (surface and groundwater) of Egypt in 2012-2013 and 2016-2017.

6.3.3.2 Drinking water production (surface and groundwater) in Cairo, Giza and Qalyubia Governorates

The situation in Cairo, Giza and Qalyubia Governorates is similar to the situation in Egypt. Drinking water production in the three governorates from surface and groundwater was almost stable from 2012-2013 to 2016-2017, although the population is rapidly increasing as presented in Chapter 4. Drinking water production in the three governorates relies mainly on surface water rather than groundwater (Figure 6-10).



	2012-2013 Surface water	2012-2013 Ground water	2014-2015 Surface water	2014-2015 Ground water	2015-2016 Surface water	2015-2016 Ground water	2016-2017 Surface water	2016-2017 Ground water
Qalyubia	149.18	68.82	121.1	82.9	123.9	90.7	138.1	91
Giza	1051.56	63.62	1154.3	70.1	1165.5	69.4	1103.6	69.3
Cairo	2276.36	0	2019.4	1.8	2096.5	1.8	2002.5	1.8

Figure 6-10: Drinking water production (surface and groundwater) of Cairo, Giza and Qalyubia Governorates from 2012-2013 to 2016-2017.

However, the percentage of drinking water production from surface water in Qalyubia Governorate was 60% and groundwater was 40% in 2016-2017 (Figure 6-11). The percentage of drinking water production from groundwater in Qalyubia Governorate is considered high compared to drinking water production in Cairo and Giza Governorates. Cairo Governorate mostly relies on surface water (99.9% in 2016-2017) for the production of drinking water. The percentage of drinking water production from surface water in Giza Governorate is 94% in 2016-2017 and the share of groundwater is only 6% (Figure 6-12).

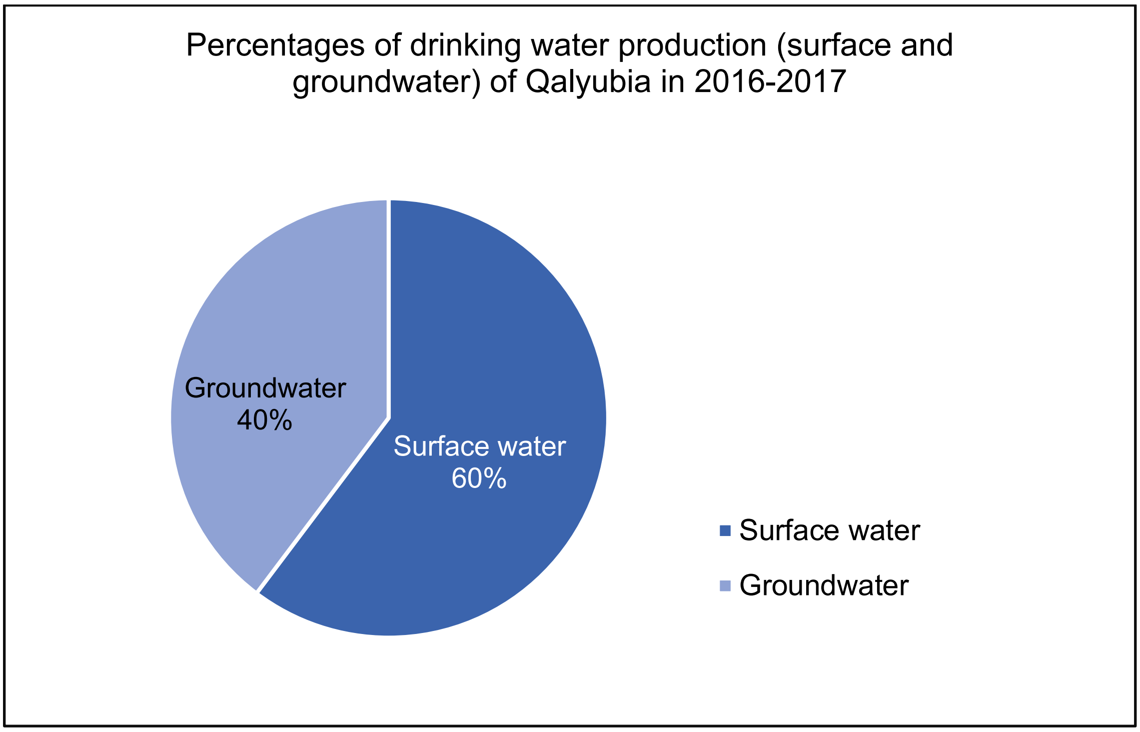


Figure 6-11: Percentages of drinking water production (surface and groundwater) of Qalyubia Governorate in 2016-2017.

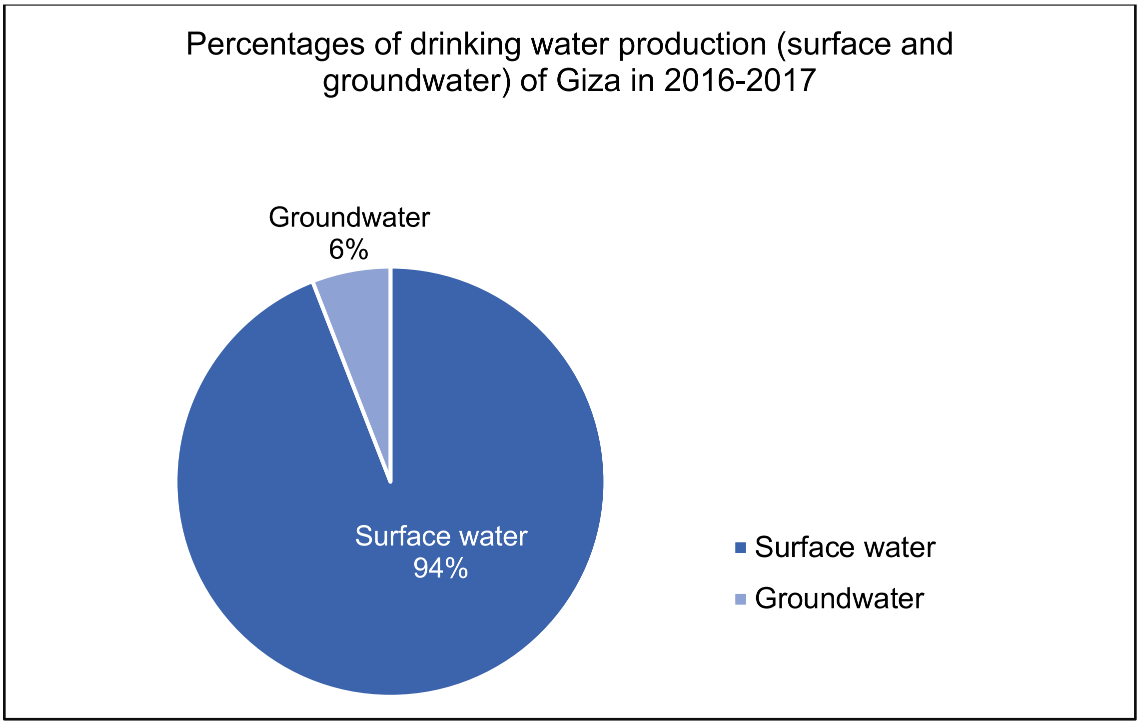


Figure 6-12: Percentages of drinking water production (surface and groundwater) of Giza Governorate in 2016-2017.

6.3.4 Percentages of drinking water production from surface water in Cairo, Giza and Qalyubia Governorates compared to the rest Egypt

The total percentages of drinking water production from surface water of Cairo, Giza and Qalyubia was 43% of total Egyptian production in 2012-2013 (Figure 6-13). This percentage relatively decreased in 2016-2017 as it reached 37% (Figure 6-14). These percentages are considered high if compared to the rest of Egypt. The population in the three governorates represents 25% of the population of Egypt. This explains the high percentage of drinking water production from surface water specifically in Cairo and Giza Governorates to meet the increasing water demand.

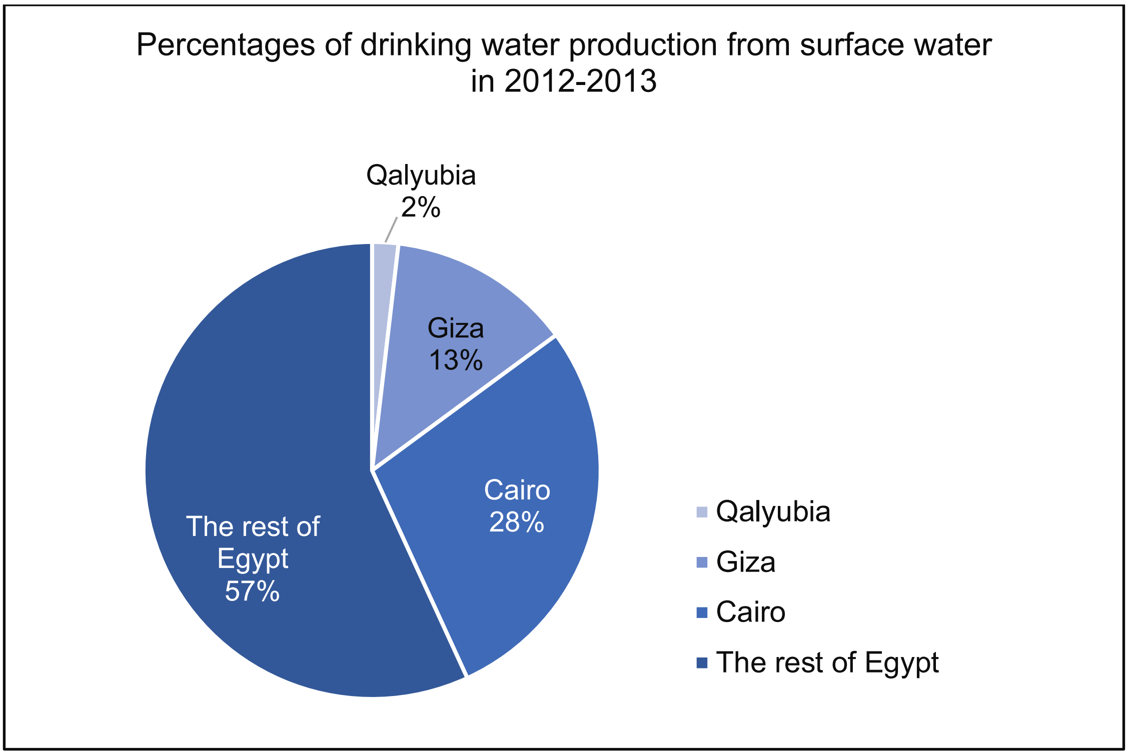


Figure 6-13: Percentages of drinking water production from surface water of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2012-2013.

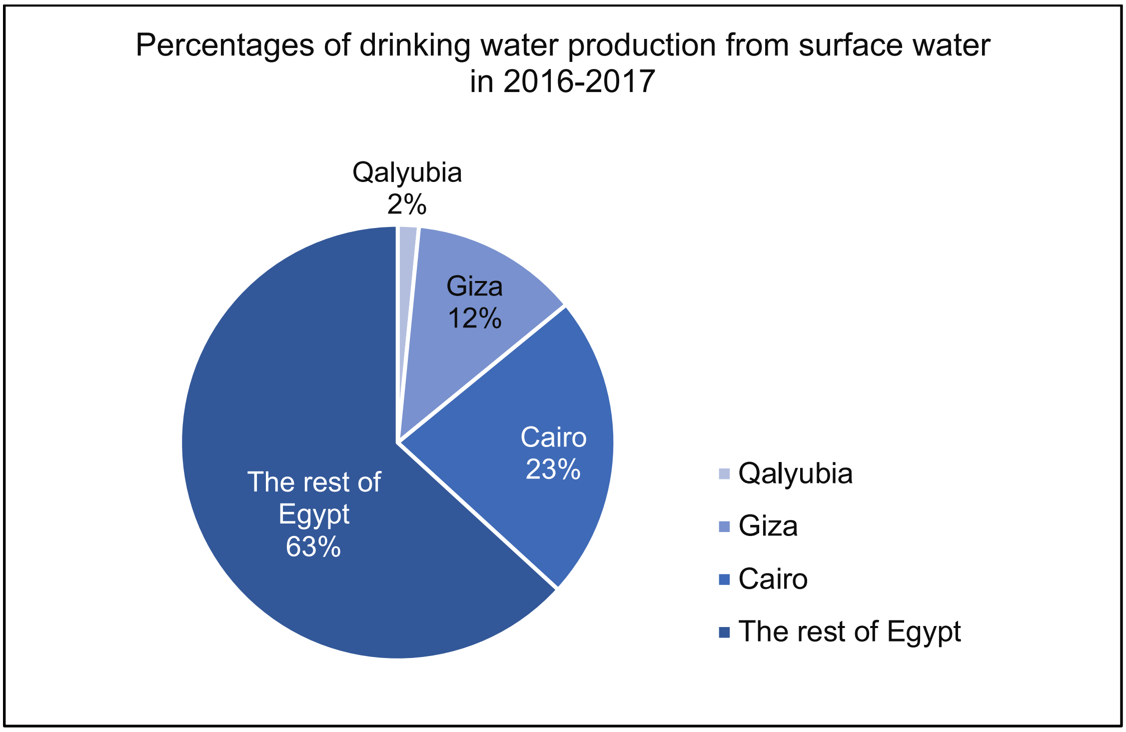


Figure 6-14: Percentages of drinking water production from surface water of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2016-2017.

6.3.5 Percentages of drinking water production from groundwater in Cairo, Giza and Qalyubia Governorates compared to the rest Egypt

Drinking water production from groundwater is limited in Cairo Governorate because groundwater is highly polluted due to the environmental impacts of urban growth (Ellis, 1999). In addition, leakages of sewage networks due to ageing infrastructure in Cairo Governorate has a great impact on the quality of groundwater. The situation might improve in the future if informal settlements were developed and upgraded, and sanitation networks were better maintained to prevent wastewater from reaching the groundwater. The percentage of drinking water production from groundwater in Giza and Qalyubia Governorates increased between 2012-2013 and 2016-2017 (Figures 6-15 and 6-16). This is part of the government's strategy to increase the production of groundwater to meet the increased water demand and reduce the pressure from the River Nile.

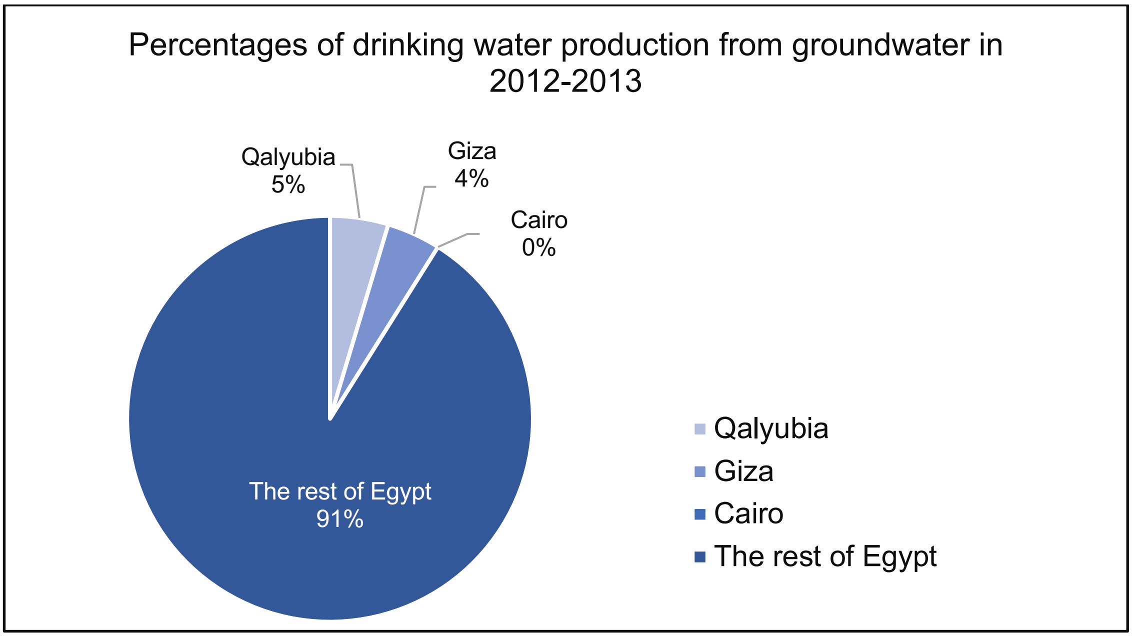


Figure 6-15: Percentages of drinking water production from groundwater of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2012-2013.

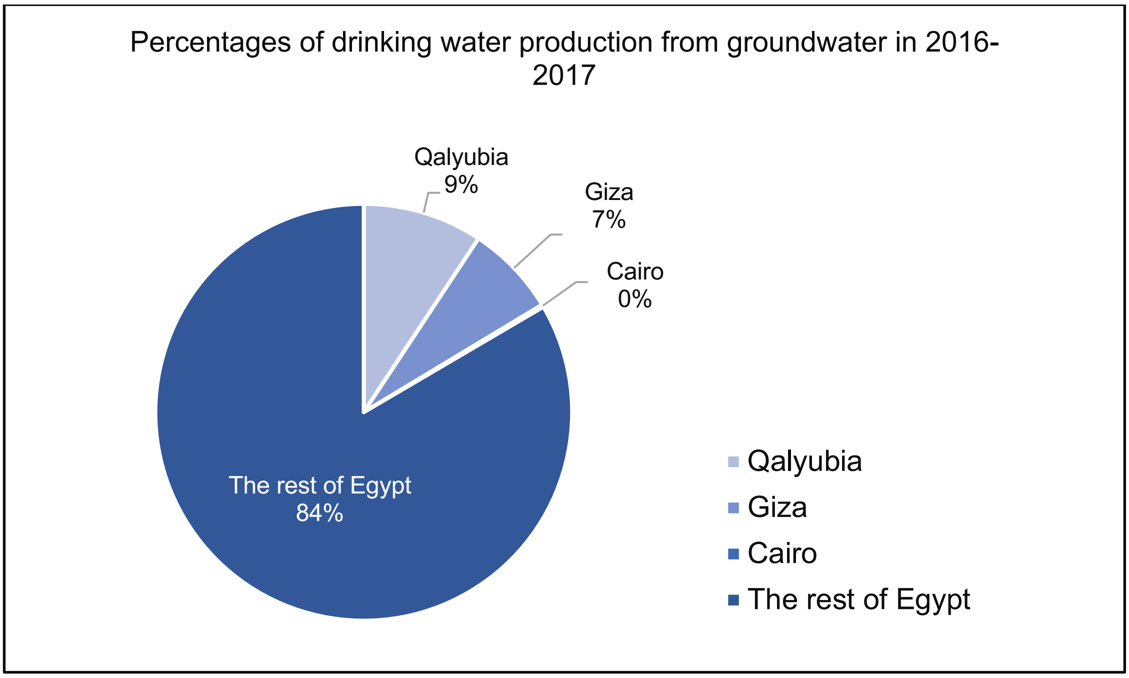


Figure 6-16: Percentages of drinking water production from groundwater of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2016-2017.

6.3.6 Drinking water production, consumption and losses

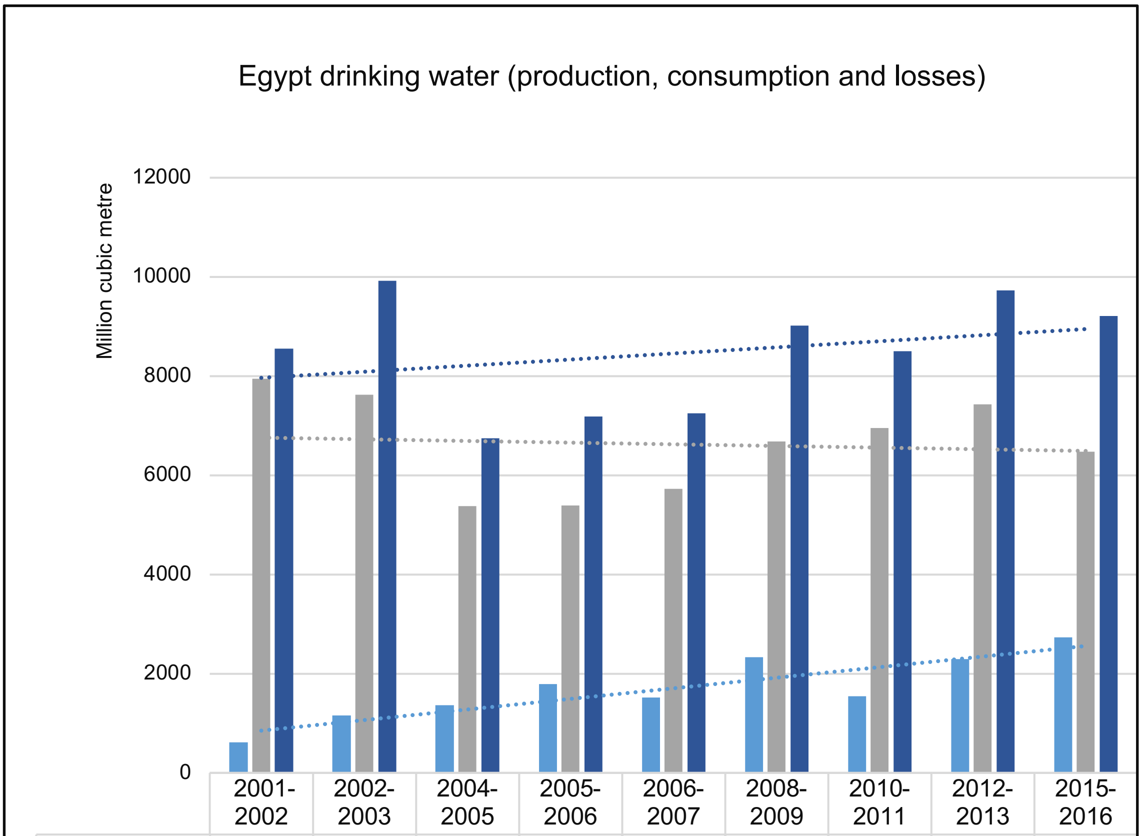
6.3.6.1 Drinking water production, consumption and losses of Egypt

Drinking water production of Egypt increased slightly over a period of 15 years (Figure 6-17). This reflects the limited production and scarcity of water resources in Egypt. The Holding Company for Drinking Water and Wastewater in Egypt developed a masterplan in 2009 to organize the production of drinking water that was based on the annual growth rate of population. However, the political situation of the country during the revolution delayed the implementation of some projects of the masterplan. Additionally, drinking water was heavily subsidized and that affected the availability of the required budget for these projects. The current political situation in the country is improving and the government increased the water tariff to cover the actual cost of water production, operation and maintenance.

> *"Before 2009 we did not have a masterplan so, this increase or decrease in the water production was expected because we did not have a system to organize the water production and distribution. Between 2011 and 2015-2016, the water sector was affected by the political situation in the country during and after the revolution. Nowadays, the water sector started to catch up and follow the masterplan again. The number of new investments, replacement and renewal projects will increase, too. The water production should increase because the masterplan was designed based on the annual growth rate of population and the availability of water resources. The Holding Company upgrades the masterplan every year"* (Interviewee 4).

Drinking water consumption has been decreasing over the same period of time. This indicates drinking water consumption per capita is decreasing as mentioned previously due to the rapid population growth that is not associated with an equal increase in water production. Moreover, water losses increased significantly between 2001-2002 and 2015-2016 (Figure 6-17). Interviewee 4 clarified that these losses include the following:

- Physical losses due to the ageing infrastructure.
- Commercial losses due to the illegal connections in informal settlements and inaccurate readings from water meters.



	2001-2002	2002-2003	2004-2005	2005-2006	2006-2007	2008-2009	2010-2011	2012-2013	2015-2016
Losses	610.35	1161.1	1363.6	1785	1518	2335	1549	2292	2733.24
Consumption	7944.65	7622.82	5383.9	5396	5728.8	6684.9	6956	7434	6474.2
Production	8555	9923	6747.5	7181	7247	9020	8505	9727	9207.44

Figure 6-17: Egypt's drinking water production, consumption and losses from 2001-2002 to 2015-2016.

Furthermore, drinking water is used for other purposes like the irrigation of public parks and private gardens, commercial and touristic activities (NWRP, 2017). This indicates that the drinking water network in Egypt is designed to provide all the activities with the highest quality of water. However, the required quality of resources (water) differs from one activity to another (Agudelo-Vera et al., 2012). Providing the highest quality of resources for all activities means that some activities receive higher quality than what is actually required. A huge amount of resources is wasted or, as mentioned by Agudelo-Vera et al. (2012, p.4), the *"quality losses in the system"*. To reduce these losses, Agudelo-Vera et al. (2012) suggested that the quality of resources should fit the required activities. The quality losses in the drinking water system in Egypt should be considered in designing the drinking water networks with a variety of water quality levels to provide each activity with a suitable quality of water. This will save a huge amount of water and enhance the efficient use of water resources.

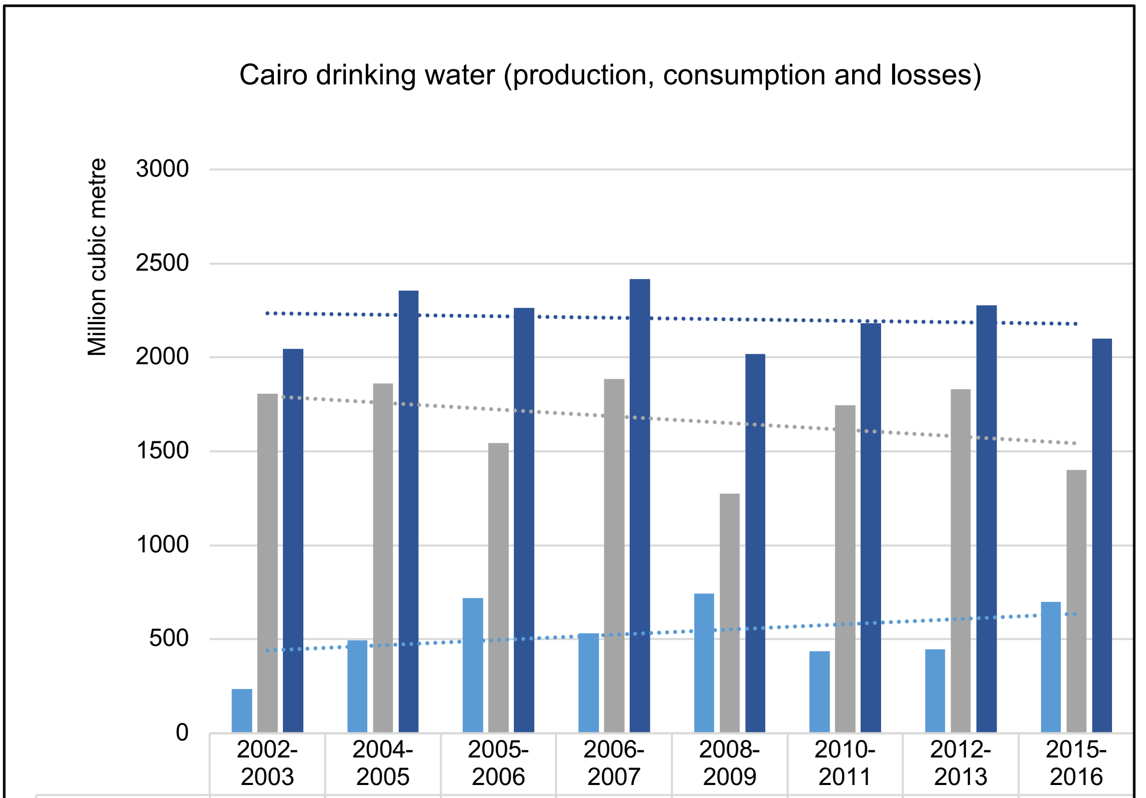
6.3.6.2 Drinking water production, consumption and losses of Cairo Governorate

The situation in Cairo Governorate is similar to drinking water production, consumption and losses of Egypt. The linear trendline in Figure 6-18 shows that drinking water production in Cairo Governorate is almost stable over a period of 13-14 years. Drinking water consumption decreased and the losses have been increasing significantly (Figure 6-18). This reflects the major challenges of the drinking water sector in Cairo Governorate:

- water resources are limited and it mostly relies on surface water and there is no potential to increase it;

- the groundwater is highly affected by the environmental impacts of urbanization and leakages of sewage networks;
- water losses due to illegal connections of informal areas represent a high percentage of urban settlements in Cairo Governorate and the ageing infrastructure;
- and rapid population growth – the average annual growth rate in Cairo Governorate was 1.91% from 2001 to 2016.

Furthermore, the situation might get worse in future due to the impacts of climate change and water demand will increase for all activities.

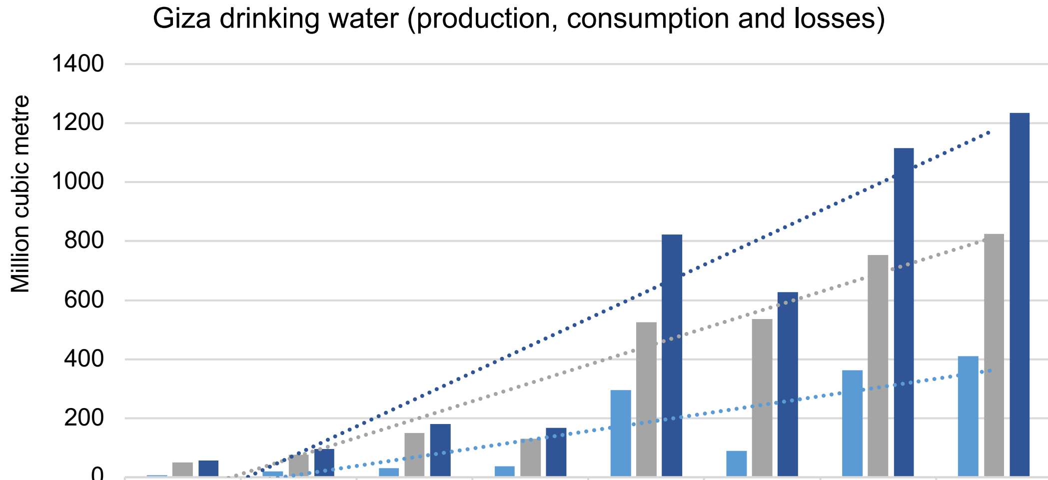


	2002-2003	2004-2005	2005-2006	2006-2007	2008-2009	2010-2011	2012-2013	2015-2016
Losses	236.98	494.83	720.37	530.96	742.5	435.97	446.33	698.7
Consumption	1806.95	1861.5	1544.3	1885.04	1275.46	1743.9	1830.03	1399.6
Production	2043.93	2356.3	2264.7	2416	2017.46	2179.9	2276.36	2098.3

Figure 6-18: Cairo's drinking water production, consumption and losses from 2002-2003 to 2015-2016.

6.3.6.3 Drinking water production, consumption and losses of Giza Governorate

There was a substantial increase in drinking water production in Giza Governorate between 2002-2003 and 2015-2016 (Figure 6-19). Drinking water production is expected to increase as the average annual population growth in Giza Governorate during that time was 3.17%, swelling it from 5.3 million to 7.8 million. The government increased drinking water production plants in Giza Governorate to meet the increasing demand for water. Drinking water consumption also increased significantly over the same period of time (13 years) as this was part of the government's plan to divert the growth towards Giza Governorate (south-west towards the desert) to reduce the pressure from Cairo Governorate. However, the government failed to prevent the growth of informal settlements and illegal connections that increased drinking water losses in Giza Governorate.

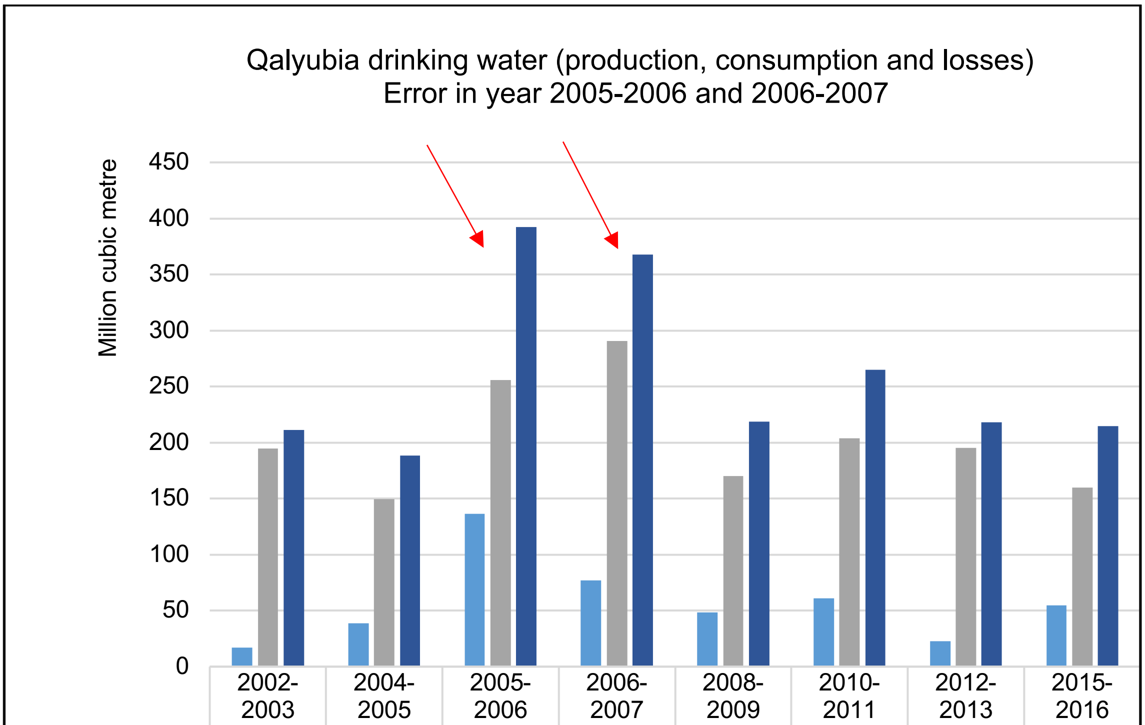


	2002-2003	2004-2005	2005-2006	2006-2007	2008-2009	2010-2011	2012-2013	2015-2016
Losses	7.4	20.54	29.74	36.35	296.136	89.7	361.76	409.9
Consumption	49.51	75.22	150.32	131.16	526.24	536.8	753.43	825
Production	56.98	95.75	180.1	167.5	822.37	626.6	1115.18	1234.9

Figure 6-19: Giza's drinking water production, consumption and losses from 2002-2003 to 2015-2016.

6.3.6.4 Drinking water production, consumption and losses of Qalyubia Governorate

The data presented in Figure 6-20 shows that drinking water production, consumption and losses of Qalyubia Governorate in years 2005-2006 and 2006-2007 are inaccurate. The values of drinking water production, consumption and losses are higher than the previous years and the following years. In Figure 6-21, these years are excluded, and the data is presented without 2005-2006 and 2006-2007.

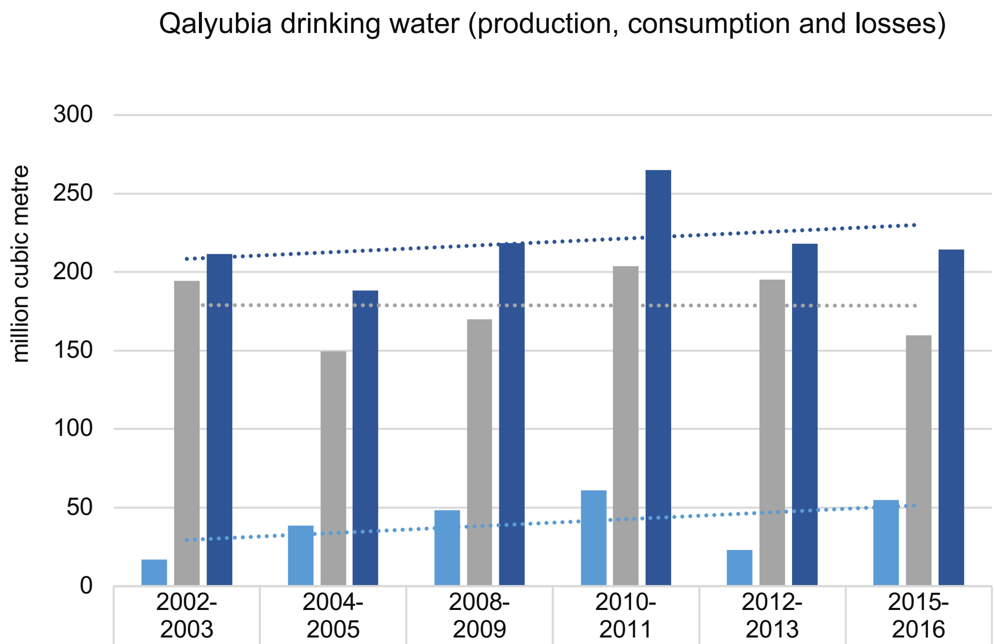


	2002-2003	2004-2005	2005-2006	2006-2007	2008-2009	2010-2011	2012-2013	2015-2016
Losses	16.9	38.76	136.63	77.18	48.46	60.9	22.96	54.7
Consumption	194.5	149.47	255.63	290.34	169.99	203.9	195.04	159.9
Production	211.41	188.23	392.3	367.5	218.44	264.8	218	214.6

Figure 6-20: Qalyubia's drinking water production, consumption and losses from 2002-2003 to 2015-2016 (Error in year 2005-2006 and 2006-2007).

The linear trendlines in Figure 6-21 show that drinking water production in Qalyubia Governorate was almost stable and consumption slightly decreased between 2002-2003 and 2015-2016. Drinking water losses in Qalyubia

Governorate is similar to Cairo and Giza. Water losses increased as the quantity of water losses tripled in 2015-2016 when compared to the quantity of water losses in 2002-2003.



	2002-2003	2004-2005	2008-2009	2010-2011	2012-2013	2015-2016
Losses	16.9	38.76	48.46	60.9	22.96	54.7
Consumption	194.5	149.47	169.99	203.9	195.04	159.9
Production	211.41	188.23	218.44	264.8	218	214.6

Figure 6-21: Qalyubia's drinking water production, consumption and losses from 2002-2003 to 2015-2016 (excluding 2005-2006 and 2006-2007 to avoid the error).

6.3.7 Comparing the percentages of drinking water production of Cairo, Giza and Qalyubia Governorates to the rest of Egypt

The total production of drinking water in Egypt was 9923 million cubic metres in 2002-2003. The total percentage of the drinking water production of the three governorates (Cairo, Giza and Qalyubia) was 23% of the total production of Egypt in 2002-2003 (Figure 6-22). The percentage of drinking water production of Cairo

Governorate was the highest (21%), followed by Qalyubia (2%) and the percentage of Giza was the lowest.

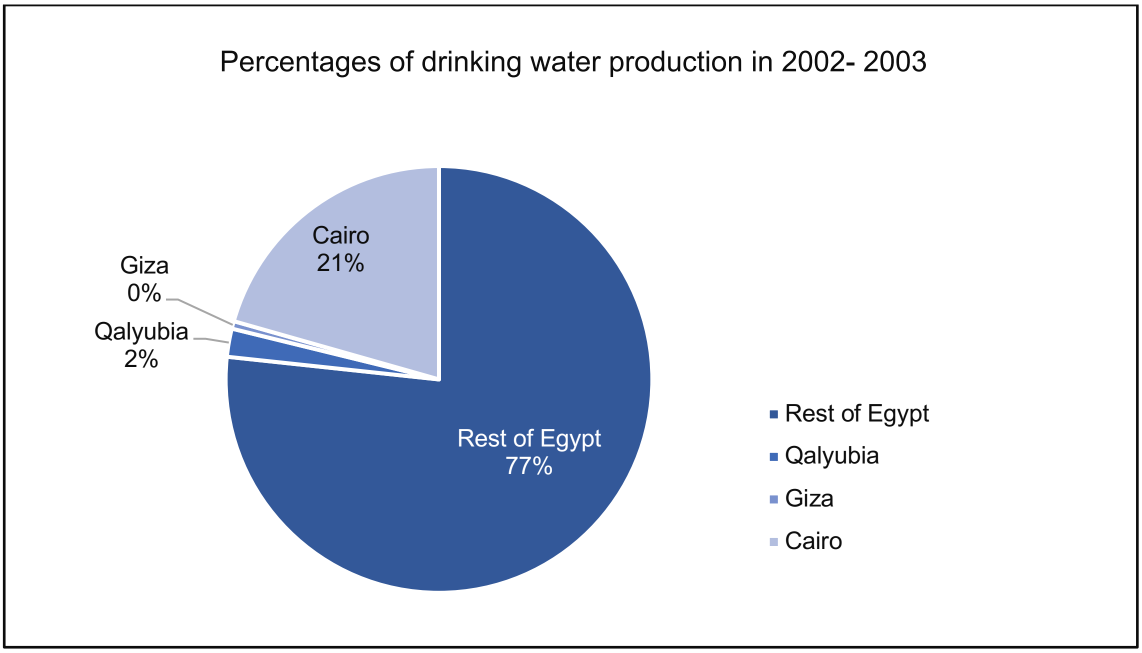


Figure 6-22: Percentages of drinking water production of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2002-2003.

In 2015-2016, drinking water production of Egypt slightly decreased as it reached 9207 million cubic metres, which remained almost the same in Cairo and Qalyubia. However, there was a considerable increase in the percentage of the drinking water production of Giza Governorate (see above) as it reached 13% of the total production of Egypt. This increased the total percentage of the drinking water of the three governorates as it reached 38% of the total production of Egypt. This indicates that most drinking water production is intensively concentrated in the three governorates, specifically Cairo and Giza Governorates. This also shows that drinking water production in the rest of Egypt is decreasing and this will have a great impact on the government's plan to reduce the pressure from Cairo and the Greater Cairo Region. The government should provide the basic services for the inhabitants of the rest of the governorates to prevent internal migration to urban areas that have better services.

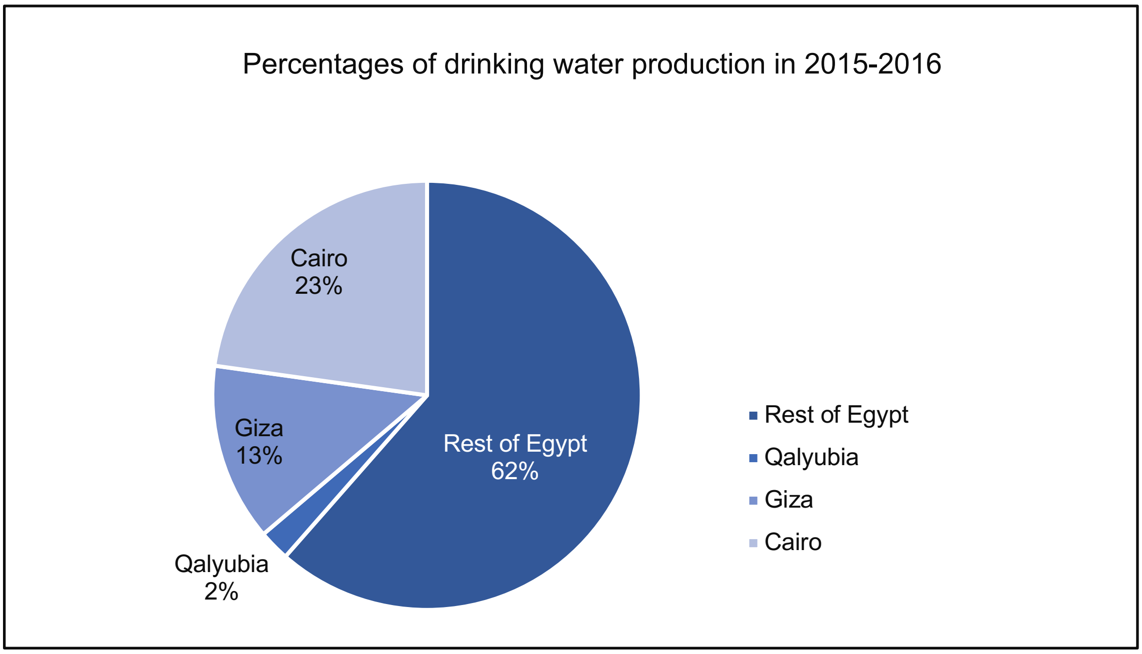


Figure 6-23: The percentages of drinking water production of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2015-2016.

6.3.8 Comparing drinking water consumption of Cairo, Giza and Qalyubia Governorates to the rest of Egypt

The total consumption of drinking water in Egypt was 7623 million cubic metre in 2002-2003. The total percentage of drinking water consumption for the three governorates (Cairo, Giza and Qalyubia) was 27% of the total consumption of Egypt, as shown in Figure 6-24. The percentage of drinking water consumption for Cairo Governorate was higher than Giza and Qalyubia Governorates. Cairo Governorate, being the capital of Egypt, is expected to have the highest coverage of basic services (such as drinking water). This situation is similar to most African countries as governments usually focus on providing better services in urban areas rather than the rural settlements. Giza and Qalyubia Governorates are not as urban as Cairo Governorate. Both governorates, Giza and Qalyubia, include rural areas so the drinking water coverage is not high as Cairo Governorate.

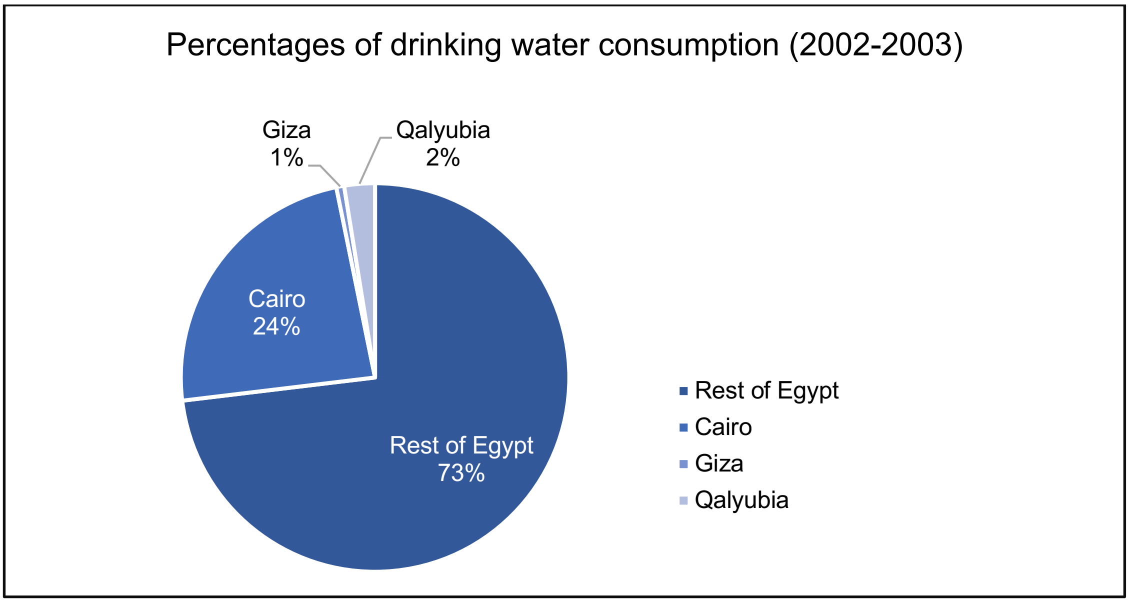


Figure 6-24: Percentages of drinking water consumption of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2002-2003.

However, the situation changed after the establishment of the Holding Company for Drinking Water and Wastewater in 2004. The Holding Company for Drinking Water and Wastewater developed a masterplan to increase drinking water coverage in Egypt, based on the available water resources and the annual population growth rates. This coverage includes both urban and rural areas equally. In 2015-2016, the total drinking water consumption of Egypt was 6474 million cubic metre (note: less than the total consumption in 2002-2003). The total percentage of drinking water consumption of the three governorates (Cairo, Giza and Qalyubia) reached 37% (Figure 6-25). Most of the increase was in Giza Governorate, which, as mentioned above, has seen the highest population growth compared to other governorates. The percentage of drinking water production of Qalyubia Governorate also increased, but not as much as Giza

Governorate. The percentage of drinking water consumption of Cairo Governorate relatively decreased, although it remained significantly higher than the other governorates. Indeed, while water consumption overall decreased in Egypt, and the total consumption of the three governorates still accounts for 37% of Egypt's total consumption. This indicates that the drinking water is unequally distributed across the country. Per capita consumption differs from one place to another, despite the government's efforts to reach 100% of drinking water coverage.

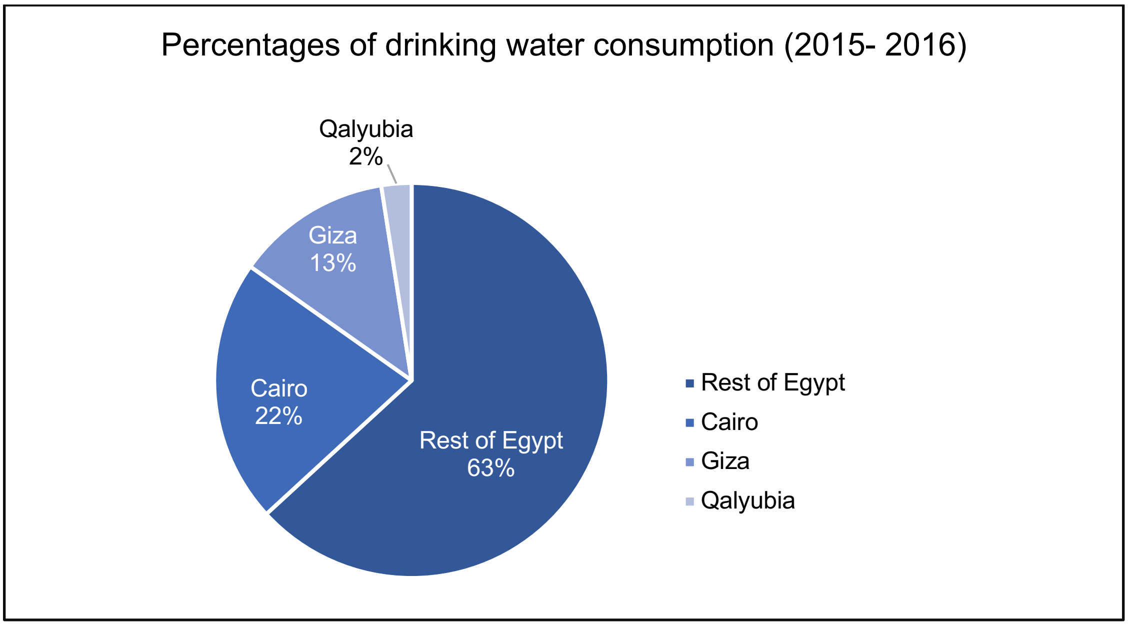
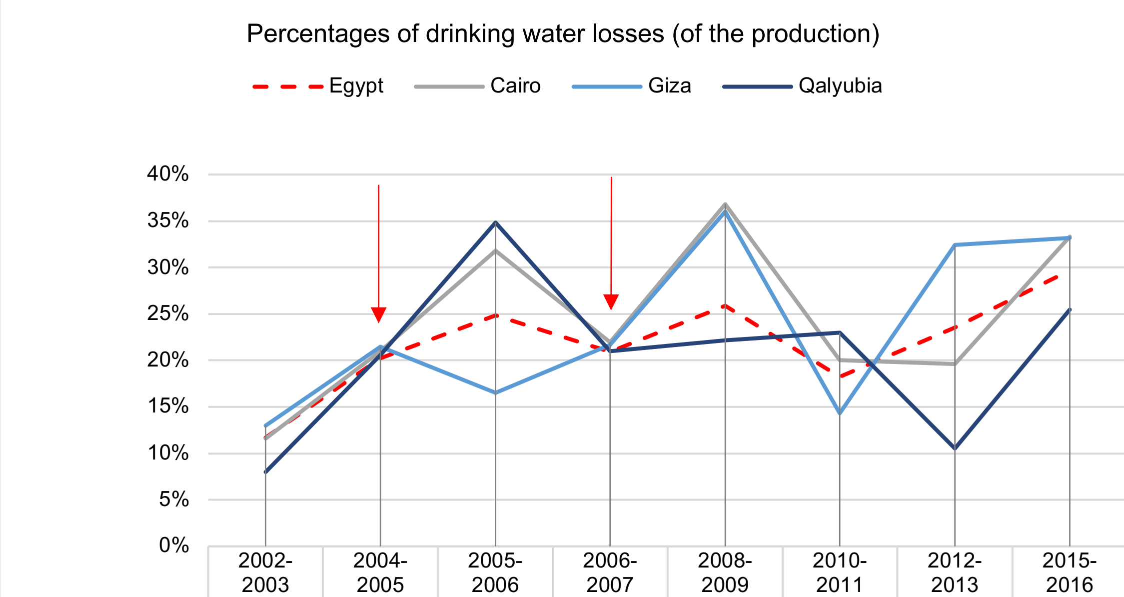


Figure 6-25: Percentages of drinking water consumption of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2015-2016.

6.3.9 Drinking water losses in Cairo, Giza and Qalyubia Governorates and Egypt

The data of the percentages of the drinking water losses in the three governorates (Cairo, Giza and Qalyubia) and Egypt is inaccurate. The red arrows in Figure 6-26 show that during these years the losses were calculated at a fixed rate (approximately 20%) of the drinking water production. The data for the rest of the years is inconsistent.



	2002-2003	2004-2005	2005-2006	2006-2007	2008-2009	2010-2011	2012-2013	2015-2016
Egypt	11.7%	20.2%	24.9%	20.9%	25.9%	18.2%	23.6%	29.7%
Cairo	11.6%	21.0%	31.8%	22.0%	36.8%	20.0%	19.6%	33.3%
Giza	13.0%	21.5%	16.5%	21.7%	36.0%	14.3%	32.4%	33.2%
Qalyubia	8.0%	20.6%	34.8%	21.0%	22.2%	23.0%	10.5%	25.5%

Figure 6-26: The percentages of the drinking water losses in Cairo, Giza and Qalyubia Governorates and Egypt from 2002-2003 to 2015-2016.

Despite inaccurate data in official statistics, the representative of the Holding Company for Drinking Water and Wastewater (Interviewee 4) stated that the average of drinking water loss is 30% in some areas and could even be as high as 40% in informal areas. Such drinking water losses are high, and is an indicator of the ageing infrastructure and metering systems in place. Before the establishment of the Holding Company for Drinking Water and Wastewater, the government did not allocate a budget for replacement and renewal projects; most investments were directed towards the new expansions of drinking water and sanitation projects. This affected the quality of the existing infrastructure and metering systems.

> *"Before the establishment of the Holding Company for the Drinking Water and the Wastewater, the government's budget did not include replacement and renewal projects. All the available budget was for the new investments only. When the Holding Company was established in 2004, a budget became available for replacement and renewal projects. Two separate budgets became available: one for the new projects and another one for the replacement and renewal projects. But it is not enough, and this is due to the economic situation of the country."* (Interviewee 4)

As noted above, illegal connections in informal settlements play a significant role in accounting for such water losses (Figure 6-27). Even if the residents of the informal settlements pay a fine, these illegal connections still weaken the existing infrastructure and increase water losses.

> *"Yes, it is the government's responsibility to provide the informal settlements with drinking water and sanitation services even if they are illegal settlements. They have to pay for the service (water consumption) and pay fines for the illegal connections. Because if we do not provide these services, they will connect illegally to the main network. So, at least we force them to pay fines for the illegal connections and pay for the drinking water service. This is a temporary solution until the government replaces these settlements with other formal settlements or relocates the residents to other planned areas."* (Interviewee 4)

Figure 6-27: An unplanned settlement in Cairo Governorate. This photo shows the urban forms in these areas, the poor quality of the infrastructure and the narrow streets that prevent the efficient flow of resources in and out these settlements (Source: author’s site visits).

Drinking water losses are also associated with a huge amount of energy losses. The production and distribution of drinking water require a huge amount of energy, so when water losses increase, the percentage of the energy used in the production and distribution of the drinking water is wasted. In addition, all these water losses enter the water cycle again as treated or untreated wastewater (NWRP, 2017). This adds the amount of energy that is required for the treatment of wastewater.

6.3.10 Comparing the drinking water losses of Cairo, Giza and Qalyubia Governorate to the rest of Egypt

The total drinking water losses of Egypt in 2002-2003 was 1161 million cubic metre and the production was 9923 million cubic metre. The percentage of drinking water losses of Cairo Governorate was 20% in the same year. The percentages of drinking water losses in Giza and Qalyubia were low, as shown in Figure (6-28).

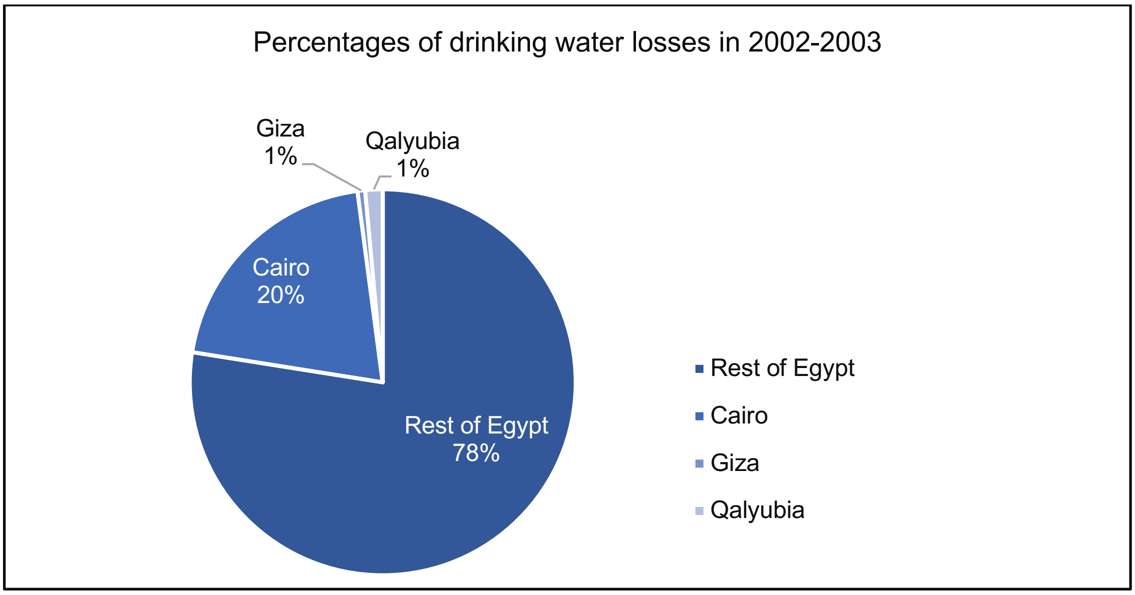


Figure 6-28: The percentages of the drinking water losses in Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2002-2003.

In 2015-2016, drinking water production in Egypt decreased (9207 million cubic metre) and the losses increased (2733 million cubic metre). The losses of Cairo Governorate also increased significantly as the percentage of the drinking water losses reached 26% of the total losses of Egypt (Figure 6-29), this at a time when drinking water production did not increase at the same rate as the losses. In 2002-2003, the drinking water production of Cairo Governorate was 2043 million cubic metre, with losses of 237 million cubic metre. In 2015-2016, production slightly increased (2098 million cubic metre) while losses almost tripled (699 million cubic metre). There was a substantial increase in the drinking water production of Giza Governorate between 2002-2003 (57 million cubic metre) and 2015-2016 (1235 million cubic metre). This increase was associated with a significant increase in water losses from 2002-2003 (7.4 million cubic metre) to 2015-2016 (410 million cubic metre). Additionally, the percentage of drinking water losses of Giza Governorate reached 15% of the total of Egypt. The percentage of the drinking water losses of Qalyubia Governorate increased in 2015-2016, although water production remained almost stable from 2002-2003 to 2015-2016. The total percentage of the drinking water losses of the three governorates (Cairo, Giza and Qalyubia) was 22% of the total losses of Egypt in 2002-2003. In 2015-2016, the percentage of the three governorates reached 43% of the total losses of Egypt.

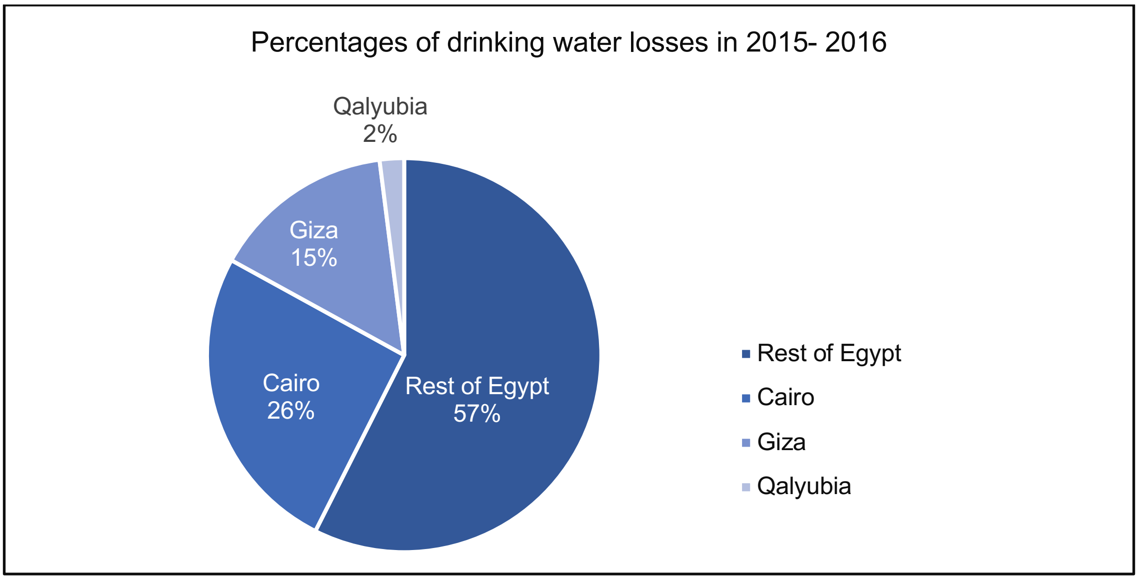


Figure 6-29: The percentages of the drinking water losses in Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2015-2016.

The percentage of drinking water production, consumption and losses are extremely high in Cairo and Giza Governorate compared to the rest of Egypt. These two governorates are draining most of the water resources of Egypt due to their rapid population growth and urbanization. Furthermore, a huge amount of these water resources is wasted because of ageing infrastructure (networks and metering systems) and the poor and illegal connections in informal settlements.

6.3.11 Percentages of households without access to water and without direct access to drinkable water in 2017

Cairo Governorate has the lowest percentage of households without direct access to water and drinkable water, being the capital of Egypt, so it receives the best services (Figure 6-30). This is followed by Qalyubia Governorate, while Giza Governorate had the highest percentage of households without direct access to water and drinkable water, largely due to the size of its unplanned settlements.

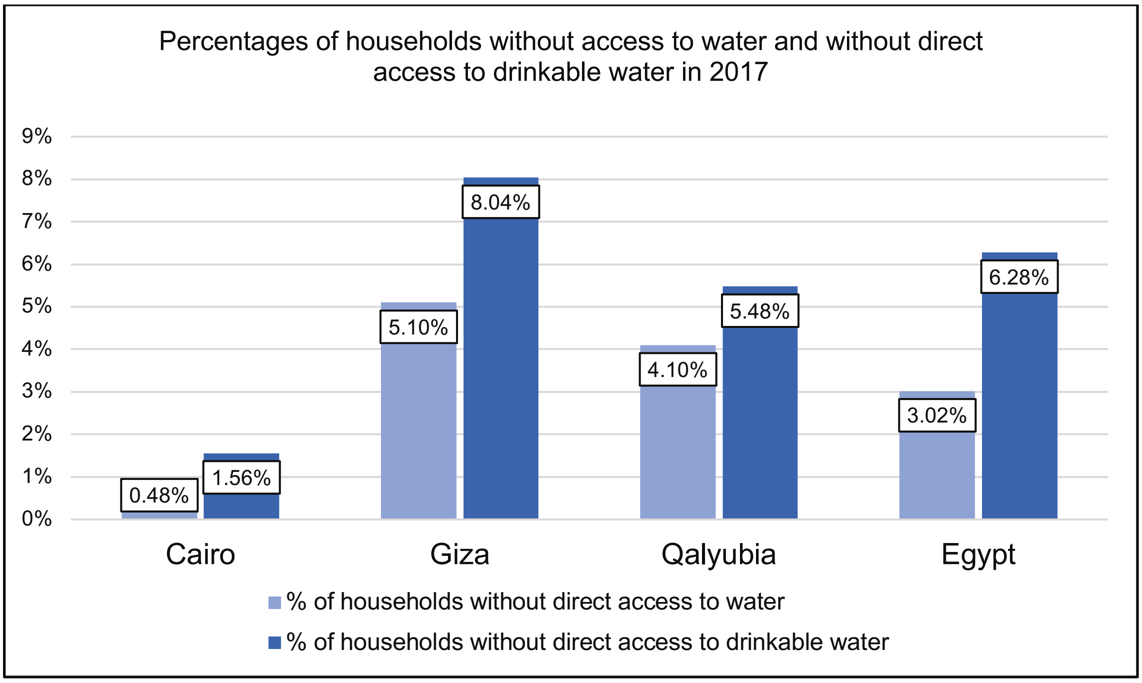


Figure 6-30: The percentages of households without direct access to water and without direct access to drinkable water in 2017.

In general, the drinking water coverage in Egypt was 95% to 96% in 2017-2018, as the representative of the Holding Company for Drinking Water and Wastewater mentioned. Drinking water coverage reached 100% in 2010, but due to the rapid population growth, the country's political situation and the lack of investment, finance, the masterplan's projects were delayed.

> *"The coverage of drinking water services all over Egypt is 95% to 96%. During 2010 we reached 100% coverage. From 2010 to 2018 percentage of drinking water coverage decreased to 95% to 96%, due to the rapid population growth. The annual population growth rate is 10 times the rate of the implementation of the water projects. The projects are not being implemented as the masterplan, there is some delay. Due to the political situation in the country"* (Interviewee 4).
>
> *"There is a delay in the projects and the budget is not always available"* (Interviewee 4).
>
> *"The political situation of the country, the available budget, and the lack of public participation and engagement"* (Interviewee 4).
>
> *"Between 2011 and 2015-2016, the water sector was affected by the political situation in the country during and after the revolution"* (Interviewee 4).

This indicates that the government cannot cope with the rapid population growth in Egypt, absorb this growth and provide the basic services for its inhabitants. However, the representative of the Holding Company for Drinking Water and Wastewater clarified that the country started to recover from the impacts of the revolution and accordingly the water sector will improve by following the masterplan.

> *"Between 2011 and 2015-2016, the water sector was affected by the political situation in the country during and after the revolution. Nowadays,*

the water sector started to catch up and follow the masterplan again. The number of new investments, replacement and renewal projects will increase, too." (Interviewee 4).

6.4 The wastewater sector in Egypt, Cairo, Giza and Qalyubia Governorates

The available data for the wastewater sector in the Central Agency for Public Mobilization and Statistics of Egypt was reviewed from 2000-2001 to 2016-2017. All the reports do not include the actual quantities of wastewater production. The available data is only for the quantities of collected wastewater and the types of treatment. Unfortunately, this data is not suitable for this study because I will not be able to identify the trends of wastewater production growth over time. The data for Egypt's wastewater production and the rest of the governorates is available in the "2030 Strategic Vision for Treated Wastewater Reuse in Egypt" (AbuZeid and Elrawady, 2014). Egypt's wastewater production and all the governorates in 2011 were used as a baseline to develop the 2030 strategy. Therefore, the data of the wastewater production of Egypt, Cairo, Giza and Qalyubia is obtained from the 2030 strategy, being the most accurate and available data.

6.4.1 Wastewater production and percentages of the untreated wastewater of Egypt, Cairo, Giza and Qalyubia Governorates

In 2011, the total wastewater production of Egypt was 7048 million cubic metre and 52% of the generated wastewater was untreated (Figure 6-31). The situation of Cairo Governorate was better with the percentage of the wastewater treatment is higher than the rest of the governorates. The total wastewater production of Cairo Governorate was 1818 million cubic metre in 2011 and 29% of the generated wastewater was untreated (Figure 6-31). Giza Governorate's percentage of untreated wastewater is higher than Cairo's, but lower than the average of Egypt. Giza Governorate's figures are reflective of the larger size of its rural population (41%) and the tendency to have fewer wastewater treatment plants in non-urban areas. Qalyubia Governorate had a higher percentage of untreated wastewater in 2011 compared to Cairo and Giza, and is also above the average of Egypt. Qalyubia Governorate's reflectively large (55%) rural population means that it has fewer wastewater treatment plants.

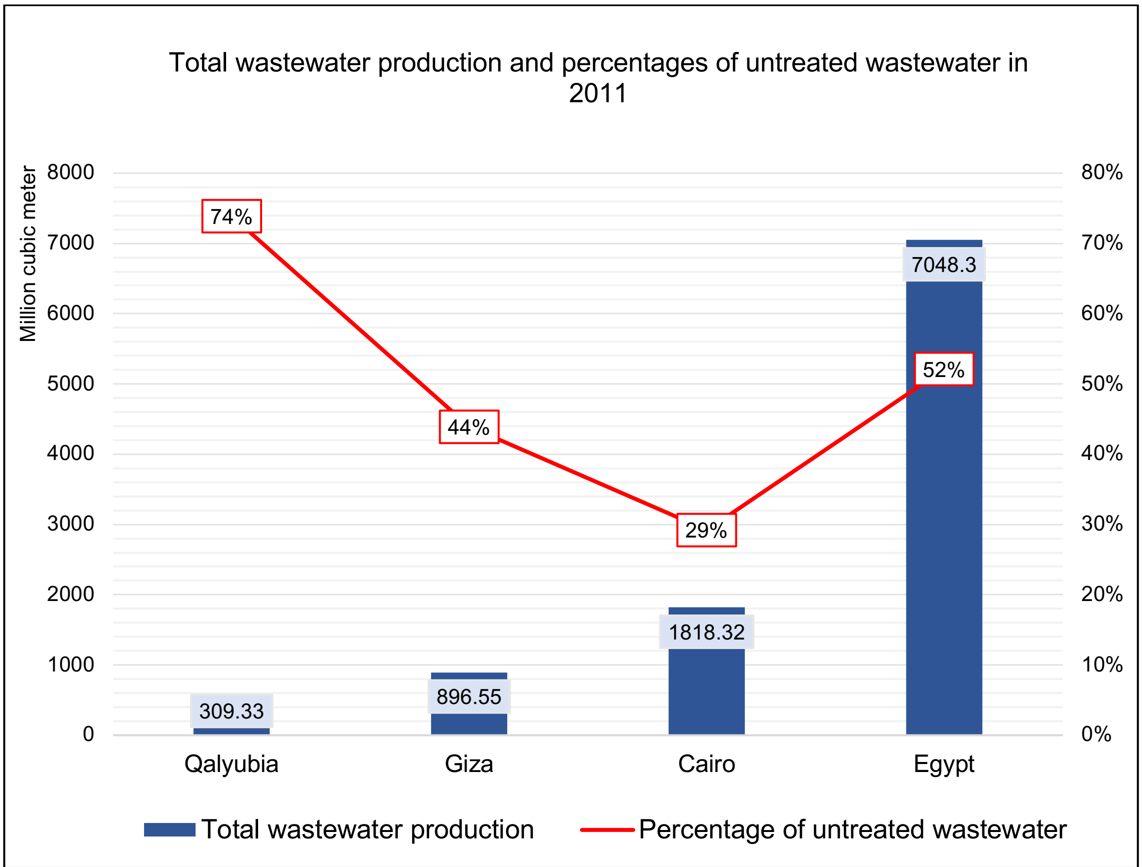


Figure 6-31: The total wastewater production and the percentages of untreated wastewater of Egypt, Cairo, Giza and Qalyubia Governorates in 2011.

However, the coverage of the sanitation services is not an indicator to the percentage of treated or untreated wastewater. The representative of the Holding Company for Drinking Water and Wastewater (Interviewee 4) explained that the average coverage of sanitation services is 50%, reaching up to 95% in urban settlements and as low as 15% in rural settlements. In rural areas the sewage is pumped into septic tanks and these tanks are drained every two weeks. The sewage is then transferred to a wastewater treatment plant or to any other water body without treatment. According to Interviewee 4, septic tanks have become ineffective due to the rapid population growth and the government developed a 2030 strategy to increase the sanitation coverage to reach 100% that includes both rural and urban settlements.

> *"The coverage of the drinking water services is 95%, and the sanitation services only is 50%. The coverage of the sanitation services in cities is 95%, but in rural settlements and villages is 15%. This means that 85% of rural settlements are without sanitation services. However, the coverage of the drinking water services in rural settlements is 95%"* (Interviewee 4).
> *"In the rural settlements and villages, if they are not connected to a sanitation network and treatment plant, they usually have a septic tank for each house. The average capacity of the septic tank is from 10 to 15 cubic metre. The sewage is pumped into these tanks and then it is sucked every two weeks. The sewage is then transferred to a treatment plant or to any water body. I mean canals, lakes, in some areas they dump it in the desert and agriculture land"* (Interviewee 4).
>
> Author*: "Without treatment!"*
>
> Interviewee 4: *"Yes, without treatment."*
>
> Author*: "Does these activities affect the water resources in Egypt? The River Nile and the groundwater".*

Interviewee 4: *"It affects the water resources and it has a major impact on public health and productivity. Therefore, the government established a strategy to provide 100% sanitation coverage within 5 to 10 years. To achieve this target, 200 billion Egyptian pounds are required."*

In general, the percentages of the untreated wastewater in Egypt, Cairo, Giza and Qalyubia governorates are all considered high. The lack of wastewater treatment and access to sanitation services is a common problem worldwide, specifically in the Global South. According to United Nations statistics, 6 in 10 people lack access to adequate sanitation services and more than 80% of wastewater is discharged into water bodies without treatment (United Nations, 2016c).

The total wastewater production of Egypt was 7048 million cubic metres in 2011 and the total population was 81 million inhabitants. By 2030, the total population of Egypt is expected to reach 112 million inhabitants, and this will be associated with a substantial increase in the production of wastewater as it is expected to be 11673 million cubic metres. This is based on the estimates of the "2030 Strategic Vision for Treated Wastewater Reuse in Egypt" (AbuZeid and Elrawady, 2014) which considered the annual population growth of each governorate in Egypt and how to provide the 100% coverage of sanitation services and wastewater treatment. This target is a top government's priority, although the lack of financing is one of the major challenges to achieve it. The water tariff is insufficient to provide the budget required for sanitation and wastewater treatment, even if it increased and covered 100% of the cost of drinking water production, distribution, operation and maintenance.

"I think nowadays, 80% of the actual cost is covered. Next year (2019) the tariff will cover 100% of the actual cost of drinking water. We expect to move to another stage to cover the operation, maintenance and new investments. To cover the new investments, it might take some time, because we have a big gap in the sanitation services. As previously mentioned, 200 billion Egyptian pounds are required to reach 100% sanitation coverage. It will be difficult to cover this amount of money from the tariff. If the government was able to cover this gap, then all the new investments that are required to meet the increasing population can be covered from the drinking water tariff" (Interviewee 4).

"After we reach 100% sanitation coverage, all the investments will be directed towards the expansions of the drinking water and sanitation projects to meet the increasing demand due to the rapid population growth. So, we need to increase the water tariff to cover the expenses of the operation, maintenance and the new investments. The new investments include; water and sanitation treatment plants, and networks. The government can finance the sanitation and wastewater projects by applying for grants and loans from the World Bank, African Bank and the European Bank" (Interviewee 4).

This indicates that increasing the coverage of sanitation services and wastewater treatment, as well as reducing the amount of pollution arising from the release of untreated wastewater, are considerable challenges for the Egyptian government. To overcome these challenges, wastewater should be considered as a secondary renewable resource that could be a source of income if it was managed efficiently. The production of wastewater is expected to increase due to Egypt’s rapid population growth. There is a huge potential to develop sludge-to-energy technology if sanitation coverage is increased. This could provide Egypt with a renewable source of energy that would reduce its reliance on fossil fuels and the amount of untreated wastewater that is dumped into the water bodies. Reducing the consumption of fossil fuels could increase Egypt’s exports of natural gas to other countries that will maintain the flow of foreign currency, which is required to import other important products. As mentioned earlier in this chapter, water scarcity in Egypt is increasing and has a massive impact on food production. The government is banning the production of many crops that require a huge amount of water to grow. These crops are replaced by others that can grow with less water. The government will need foreign currency to import other crops and products to meet the increasing demand for food due to the rapid population growth. This shows that improving the sanitation coverage and developing the sludge-to-energy technology in Egypt could have a significant impact on other sectors, not just the wastewater sector. The efficient management of resources requires understanding the condition of each resource separately and then collectively to develop strategies and make better decisions for integrated resource management.

6.4.2 Comparing the percentages of wastewater production of Cairo, Giza and Qalyubia Governorates to the rest of Egypt

The total percentage of wastewater production in Cairo, Giza and Qalyubia governorates was 43% of the total production of Egypt in 2011 (Figure 6-32). Unfortunately, I could not compare this percentage with previous and subsequent years due to the lack of reliable data. However, the average annual population growth rates of the three governorates, as presented in Chapter 4, indicate that this percentage is expected to increase in the future.

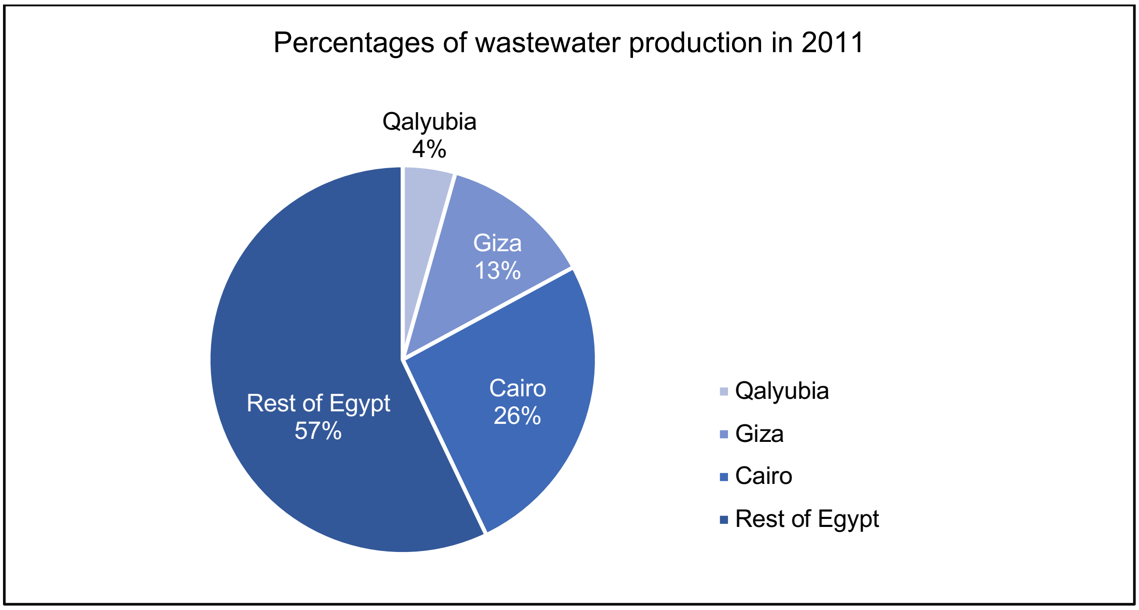


Figure 6-32: The percentages of wastewater production of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2011.

The generated wastewater could hold huge potential for Cairo, Giza and Qalyubia Governorates if it was considered as a secondary resource and was transformed into a source of income instead of being a burden. This requires increasing the coverage of sanitation services, the percentage of wastewater treatment and the quality of treatment to:

- maximize the use of treated wastewater to reduce the consumption of primary water resources and reduce the pollution levels,
- maximize the use of sludge-to-energy technology to provide these governorates with a renewable source of energy and reduce the imports and consumption of non-renewable energy resources (as mentioned in Chapter 5, none of these governorates produce energy). The representative of the Holding Company for Drinking Water and Wastewater mentioned the

significant potential of such projects in Egypt and that the government is already encouraging the private sector to get involved in these projects.

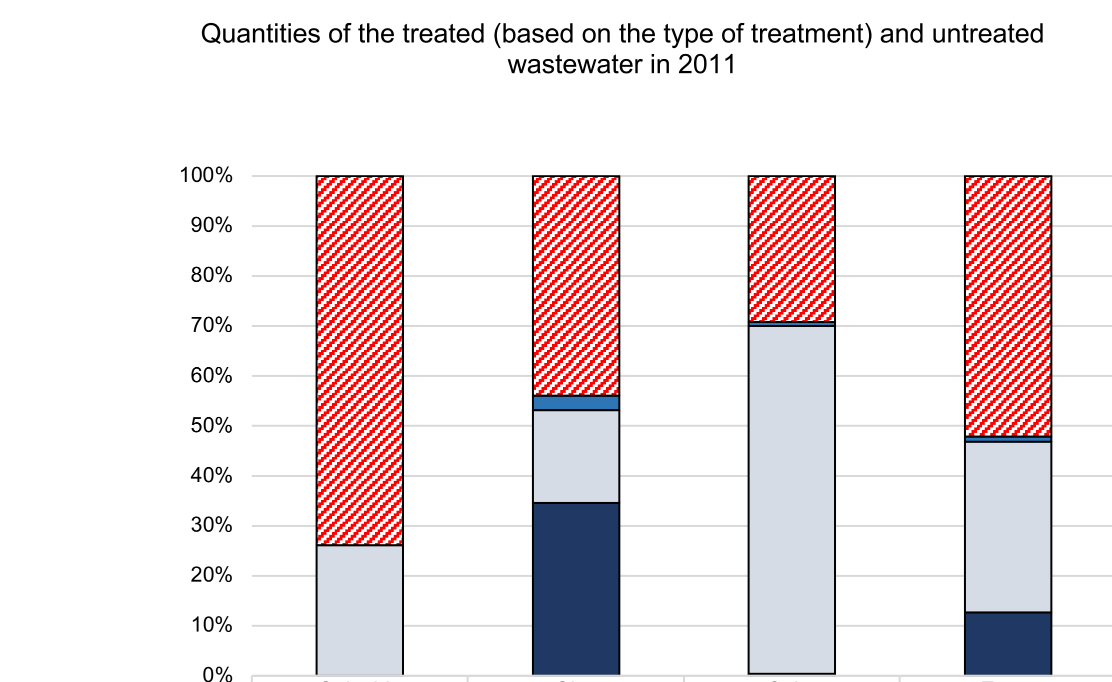
> *"There are new ideas to add sludge treatment plants to new sanitation projects to generate electricity. The government is encouraging the private sector to participate in such projects by selling and transmitting directly to the electricity grid. On the other hand, the government will take 2% of the produced electricity and the private sector will provide the required electricity to operate the treatment plants. There are already existing projects in Kafer El Sheikh and will be ready to transmit electricity within one or two months"* (Interviewee 4)

- and finally, to improve public health; this will save part of the allocated budget for the health sector.

6.4.3 Types of wastewater treatment in Egypt, Cairo, Giza and Qalyubia Governorates

Wastewater treatment in Egypt varies from one place to another as shown in Figure 6-33. For example, the wastewater treatment in Qalyubia relies on secondary treatment. In Giza Governorate, the majority of wastewater treatment relies on primary treatment, followed by secondary treatment and a small percentage of tertiary treatment. Most of wastewater treatment in Cairo Governorate relies on secondary treatment. In general, the majority of wastewater treatment in Egypt relies on secondary treatment followed by the primary treatment and a small percentage rely on tertiary treatment. This explains the target of the government's 2030 strategy to focus on the following:

- increasing wastewater treatment to reach 100% all over the country by providing secondary wastewater treatment plants,
- upgrading the existing wastewater primary treatment plants to secondary treatment plants,
- and keep the existing tertiary wastewater treatment plants in operation.



	Qalyubia	Giza	Cairo	Egypt
Untreated wastewater	228.53	393.54	530.92	3674
Tertiary treatment	0	27.01	14.6	67.6
Secondary treatment	80.8	165.7	1266.6	2416.7
Primary treatment	0	310.3	6.2	889.9

Figure 6-33: Quantities of the treated (based on the type of treatment) and untreated wastewater in 2011.

6.4.4 The percentage of households without sanitation services in Egypt, Cairo, Giza and Qalyubia Governorates in 2017

This data was available in a recent report for the Central Agency for Public Mobilization and Statistics (CAPMAS, 2017f). Cairo Governorate has the lowest percentage of households without direct access to sanitation services compared to Giza, Qalyubia and the average of Egypt (Figure 6-34). As explained earlier, as Cairo Governorate is 100% urban and the capital of Egypt, usually the percentage of direct access to basic services is higher in urban areas and cities rather than the rural settlements. This is common in developing countries, most services and investments are concentrated in the capital and big cities. To reduce internal migration, the government should provide adequate services for the inhabitants in all governorates to reduce the pressure from Cairo Governorate.

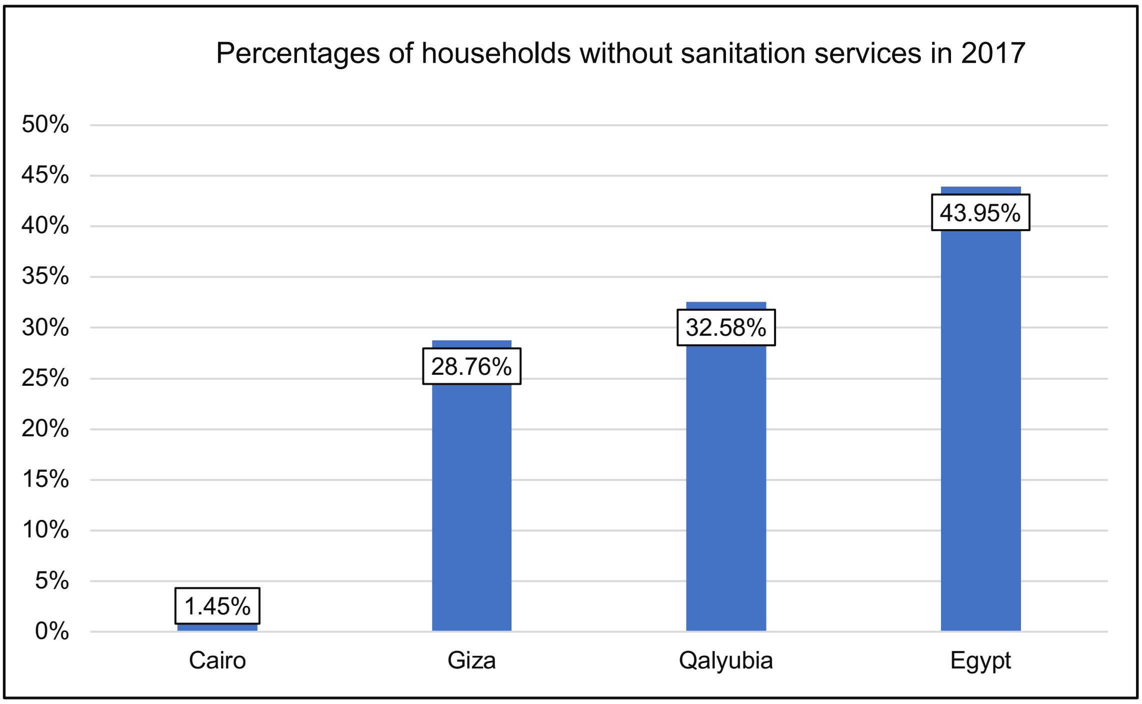
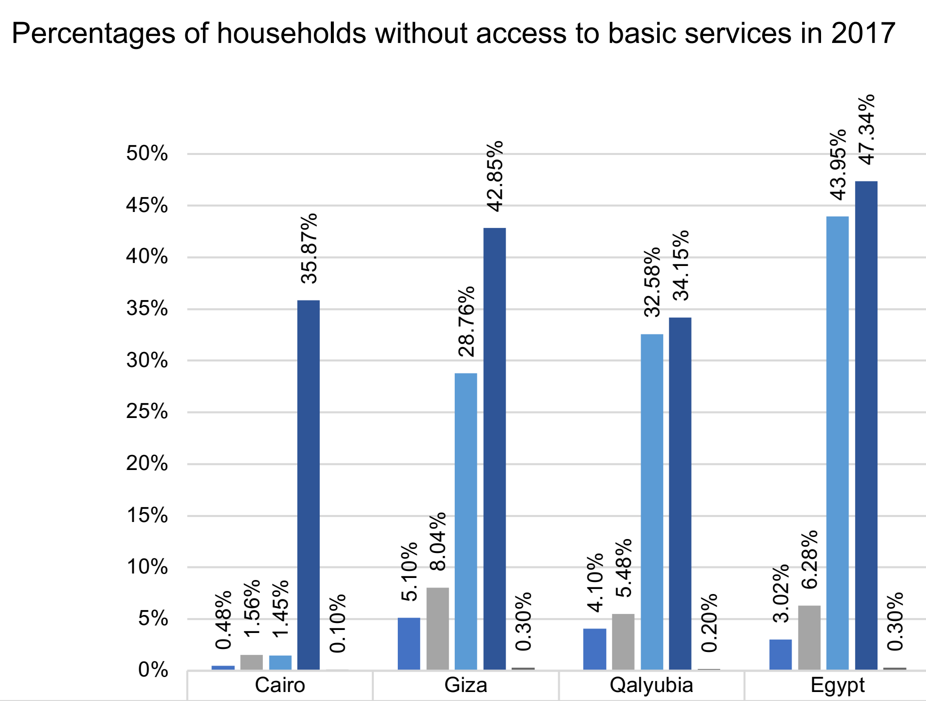


Figure 6-34: The percentages of households without sanitation services in Egypt, Cairo, Giza and Qalyubia Governorates in 2017.

The percentage of households without direct access to sanitation services is extremely high in Giza, Qalyubia and Egypt in general compared to the rest of the services apart from the solid waste collection (Figure 6-35).



	Cairo	Giza	Qalyubia	Egypt
% of households without direct access to water	0.48%	5.10%	4.10%	3.02%
% of households without direct access to drinkable water	1.56%	8.04%	5.48%	6.28%
% of households without sanitation	1.45%	28.76%	32.58%	43.95%
% of households living in areas without public waste collection	35.87%	42.85%	34.15%	47.34%
% of households without grid electricity connection	0.10%	0.30%	0.20%	0.30%

Figure 6-35: Percentages of households without access to basic services in 2017.

6.5 Conclusion:

This chapter presented the current situation of the water and wastewater sectors in Egypt. Both sectors are creating considerable challenges. Water resources are limited, the population is rapidly increasing and water losses are increasing due to ageing infrastructure, water meters and illegal connections in informal settlements that weaken the existing infrastructure. The lack of financing, public awareness and the political situation of the country delayed the expansion of the drinking water projects to meet the increasing demand for water. The government established a strategy to overcome water resources scarcity that considered many aspects but did not include improving the infrastructure of informal settlements even though these areas have a massive impact on the consumption of all the resources, not just the drinking water.

The available data for the wastewater sector in Egypt is limited and mainly focuses on the quantities of collected and the types of treatment rather than the total production. This is a common problem for both wastewater and solid waste (the outputs of cities) or secondary resources; the data is rare and the available data is inaccurate. This is due to the low percentage of sanitation coverage, so it is difficult to quantify the actual wastewater production. However, the government’s 2030 strategy for wastewater treatment is to increase the sanitation coverage to reach 100%. This will improve the quality of wastewater data; meanwhile, pilot studies can provide better data and then the total production could be estimated.

The current situation of the sanitation coverage in Egypt is low, particularly in rural areas where it can be as low as 15%. This has a massive impact on the environment as it increases the pollution levels of existing water resources and causes health problems that reduce human productivity. It is crucial to transform the wastewater into a source of income by upgrading it and feeding it back into the urban and rural systems. This will not be achieved without increasing sanitation coverage, the quality of treatment and developing sludge-to-energy projects.

The situation of water resources and drinking water production and consumption of the three governorates (Cairo, Giza and Qalyubia) is similar to the situation of all Egypt. The percentage of drinking water production and consumption of the three governorates is extremely high compared to the rest of

Egypt (reaching 37% in 2015-2016), particularly in Giza governorate as there was a substantial increase in the drinking water production and consumption during 2002 to 2016. The amount of drinking water losses of the three governorates reflects the ageing infrastructure and the illegal connections of informal settlements that represent a high percentage of the urban settlements.

The percentage of the wastewater production of the three governorates was 43% in 2011. This is the most recent available data. However, this percentage is expected to increase in the future due to the rapid population growth. The following steps should be considered in the future to better manage the available water resources and wastewater in Cairo, Giza and Qalyubia:

- upgrade unsafe and the unplanned areas, provide adequate infrastructure and metering systems,
- improve the existing infrastructure and metering systems all over the country to reduce the water losses,
- improve the sanitation coverage and sludge-to-energy projects to provide the three governorates with a source of renewable energy, and reduce the pollution levels of available water resources,
- improve the quality of wastewater treatment to maximize the use of treated wastewater and reduce the use of primary water resources,
- and establish an integrated solid waste management system to prevent and reduce the environmental impacts of waste entering water streams.

7 Chapter Seven: The current and future projections of the municipal solid waste sector in Cairo, Giza and Qalyubia Governorates and the whole country Egypt

7.1 Introduction

This chapter presents the current situation and the future projections of the municipal solid waste sector in Cairo, Giza and Qalyubia Governorates and all Egypt. The quantitative and qualitative data of the municipal solid waste in Cairo, Giza and Qalyubia Governorates and Egypt are merged and explained in depth. To target the most important quantitative data to measure and assess municipal solid waste I used the third layer of the multi-layered indicator set that was developed by (Kennedy et al., 2014). The available data for solid waste in Egypt at different scales (national and local levels) is limited, inaccurate and the methods of data collection are inconsistent. Therefore, to address this knowledge gap, two semi-structured interviews were conducted with:

- A representative of the Ministry of Environment (Interviewee 1) as it is responsible for Egypt's solid waste sector. This interview was conducted to better understand the strategic level of managing the solid waste sector.
- A representative of the Public Authority of Cleaning and Beautification of Cairo Governorate (Interviewee 3). This department is responsible for the day-to-day collection of municipal solid waste in Cairo Governorate. This interview was conducted to better understand the challenges of the day-to-day collection of solid waste in Cairo Governorate.

Both interviews were critically analysed, using NVivo, and presented in this chapter. The study also included site visits to different settlements (low, medium and high-density settlements including formal and informal settlements) in Cairo Governorate to identify the challenges of the waste management sector according to the characteristics of each settlement.

The data in this chapter is different from the previous chapters as the amount of qualitative data (from the semi-structured interviews) is larger than the quantitative data. This is due to the lack of reliable data for the actual quantities of generated solid waste. This is a common problem in many cities worldwide, as quantitative data of solid waste is unreliable (Koop and Leeuwen, 2017).

7.2 Layer 3-3: Municipal solid waste in Cairo, Giza and Qalyubia Governorates and Egypt

The third layer of the original multi-layered indicator set includes: the consumption of energy (all types); electricity sources; consumption of water; consumption of food; building materials; generation of solid waste and wastewater (Kennedy et al., 2014). The focus of this study is on the energy, electricity and water sectors as examples of the inputs of cities and the solid waste and wastewater as examples of the outputs of cities. The energy and electricity sectors (Layer 3-1) were presented in Chapter 5, the water and wastewater sectors (Layer 3-2) were presented in Chapter 6 and solid waste sector (Layer 3-3) is presented in this chapter (Chapter 7). This chapter includes the following data:

- The total collected solid waste, waste composition and the percentage of organic waste of Egypt, Cairo, Giza and Qalyubia Governorates in 2010.

- The total collected solid waste of Egypt, Cairo, Giza and Qalyubia Governorates based on the entity that collected and disposed of it between 2006 and 2016.
- The total generated municipal solid waste of Egypt from 2001 to 2012.
- The daily generation of municipal solid waste of Egypt, Cairo, Giza and Qalyubia Governorates in 2012.
- Percentages of the daily generated municipal solid waste in Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2012.
- Municipal solid waste composition of Egypt in 2012.
- Percentages of the municipal solid waste collection coverage of Egypt, Cairo, Giza and Qalyubia Governorates in 2012.
- Percentages of households without public waste collection of Egypt, Cairo, Giza and Qalyubia in 2017.

Sources of secondary data are presented in Chapter 3 Table 3-1 and the criteria of including or excluding reports are presented in Appendix 12.

7.3 The total collected municipal solid waste for Egypt Cairo, Giza and Qalyubia Governorates

While reviewing official reports to collect municipal solid waste data like the previous resources in this study, I noticed that most of the available data is for collected solid waste and not for generated waste. This is expected because solid waste collection coverage is less than 100%. In urban areas, the average of solid waste collection is 50-65% and in rural areas is 0-30% (SWEEP-Net, 2014). In addition, the methods of data collection are inconsistent and inaccurate. For example, the Egypt in Figures 2012 Report (CAPMAS, 2012) includes the following:

- The total collected solid waste in Egypt and all the governorates in 2010.
- The waste composition (cardboard, plastic, glass and metal, and organic waste is added to the metal) in 2010.
- The percentage of organic in each governorate in 2010 and the average of Egypt is missing.

Egypt in Figures reports for previous years did not include similar data for solid waste collection or any other data for solid waste. The total collected solid waste, composition and the percentage of organic waste for Egypt, Cairo, Giza and Qalyubia Governorates in 2010 are presented in Table 7-1. It is noted that the quantities of plastic and glass waste in Giza Governorate are equal. This strongly indicates that these quantities are estimated rather than being accurately measured. Similarly, the quantities of cardboard, plastic and glass waste in Qalyubia Governorate are equal. This also shows that all these quantities are estimated and are not accurately measured.

Table 7-1: The total collected solid waste (tonnes/year) of Egypt, Cairo, Giza and Qalyubia Governorates in 2010.

The total collected solid waste (tonnes/year) in 2010							
	Cardboard	Plastic	Glass	Metal/other (includes organic waste	Total	Percentage of organic waste	units
Cairo	535,711	309,864	164,834	3,111,241	4,121,650	40%	tonnes/year
Giza	73,562	30,651	30,651	600,757	735,621	43%	tonnes/year
Qalyubia	36,024	36,024	36,024	492,353	600,425	40%	tonnes/year
Egypt	1,321,852	855,591	489,438	11,139,388	13,806,269	N/A	tonnes/year

The percentages of organic waste in each governorate are also lower than the percentages that the interviewees mentioned during interviews (Table 7-1). The representative of the Ministry of the Environment (Interviewee 1) mentioned that the percentage of organic waste is 60% in rural areas and 50% in urban areas.

> *"No, I am talking about the municipal solid waste. If each person produced one kilogram of waste every day, then organic waste will be 50 grams"* (Interviewee 1).
>
> *"50% in urban areas and 60% in rural areas. Because in rural areas they do not have cans and plastics like the urban areas. Usually they use glass bottles and exchange them"* (Interviewee 1).

The representative of the Public Authority of Cleaning and Beautification of Cairo Governorate (Interviewee 3) clarified that the percentage of organic waste in informal areas and low-income settlements is higher than the percentage of organic waste in high-income settlements.

> *"In low-income settlements the solid waste is higher. In low-income settlements (such as Ain Shams and Mataria) the content of organic waste is higher because they buy the raw vegetables and clean it at home. In high-income settlements (such as Maadi and Zamalek) they buy clean vegetables, so organic waste is less"* (Interviewee 3).
>
> *"It* (organic waste) *differs from one place to another, but the average is 60%. As I mentioned in informal settlements the percentage of organic waste is higher than other high-income settlements. Organic waste*

represents 60% of the solid waste and 40% of other types of waste such as cans, plastics, glass and cardboard" (Interviewee 3).

The above data shows that the available data of the percentage of organic waste is unreliable. It is important to accurately measure the exact quantities of the solid waste generation and the quantities of each type of waste to maximize the use of solid waste as a secondary resource.

Another example highlighting that existing methods of data collection for solid waste are inconsistent is that the available data from 2006 to 2016 in official reports is different from the methods of data collection in 2010. The total collected solid waste from 2006 to 2016 are presented based on the entity that collected and disposed of it. Furthermore, solid waste is divided into two different types: the first is presented in tonnes, and the second in cubic metres. The data does not show the composition of collected waste and the percentage of organic waste, as in the data for 2010. The total collected solid waste from 2006 to 2016 is presented in Table 7-2. The total quantities of the collected solid waste for example, in Cairo Governorate (highlighted in red) and Egypt (highlighted in green) indicate that these quantities are incomparable. For example, the total collected solid waste in Cairo Governorate in 2006 was 3 million cubic metre, in 2012 was 49 million cubic metre, in 2014 more than 15 million cubic metre and in 2016 less than 2 million cubic metre. Although this data (presented in Table 7-2) was obtained from official statistics, the unexplained variation meant that it could not be used to generate reliable graphs or charts to identify the trends of solid waste generation in each governorate and Egypt as a whole.

Table 7-2: The total collected solid waste from 2006 to 2016 of Egypt, Cairo, Giza and Qalyubia Governorates.

Total amount of collected solid waste									
Year		City council		Waste collection companies		Informal sector		Total	
		Ton	cubic metre	Ton	cubic metre	Ton	cubic metre	Ton	cubic metre
2006	Cairo	400,470	66,913	2,164,178	2,496,237	697,849	568,353	3,262,497	3,131,503
	Giza	2,139,410	2,323,390	524,840	887,645	36,000	600	2,700,250	3,211,635
	Qalyubia	173,510	390,993	38,600	10,800	_	26,745	212,110	428,538
	Egypt	19,973,069	18,048,739	5,373,712	5,912,239	1,368,362	1,136,070	26,715,143	25,097,048
2012	Cairo	1,138,250	1,750,377	2,958,557	1,675,575	968,468	45,894,795	5,065,275	49,320,747
	Giza	1,052,640	478,973	1,516,660	1,186,474	11,469,300	5,734,717	14,038,600	7,400,164
	Qalyubia	762,255	283,587	262,800	82,826	40	127,750	1,025,095	494,163
	Egypt	57,930,175	56,175,216	7,210,677	6,236,348	14,396,907	51,975,412	79,537,759	114,386,976
2014	Cairo	144,550	554,895	1,500,662	806,306	1,077,847	14,415,274	2,723,059	15,776,475
	Giza	722,129	531,324	735,563	178,177	245,490	6,000	1,703,182	715,501
	Qalyubia	590,295	1,057,476	248,200	197,100	182,500	109,500	1,020,995	1,364,076
	Egypt	5,981,285	28,060,651	4,455,251	1,263,230	1,697,321	14,621,352	12,133,857	43,945,233
2016	Cairo	2,331,000	406,000	264,000	1,140,000	1,065,000	208,000	3,660,000	1,754,000
	Giza	587,000	338,000	199,000	_	282,000	228,000	1,068,000	566,000
	Qalyubia	870,000	414,000	485,000	394,000	163,000	2,000	1,518,000	810,000
	Egypt	12,932,000	10,535,000	2,355,000	1,703,000	2,296,000	1,659,000	17,583,000	13,897,000

The above data for solid waste generation indicates inconsistencies and raise concerns around the accuracy of available data in official reports. These reports were reviewed before I conducted the semi-structured interviews with the representative of the Ministry of Environment and the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate. Therefore, I had the chance to ask them during the interviews whether this data is accurate, and if not, where the most accurate data for the solid waste generation could be obtained. The representative of the Ministry of Environment (Interviewee 1) revealed that they do not have full control of the solid waste sector. This is due to the involvement of many sectors (formal and informal) in the solid waste collection, specifically the informal sector (such as Cairo's informal garbage collectors El-Zabbaleen). He suggested that the most accurate data would be in the reports that were prepared by the collaboration of the Egyptian government and the German Agency for International Cooperation (GIZ) such as the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014).

> *"As long as we do not have full control on the system, we will never have accurate data for the quantities of the solid waste"* (Interviewee 1).
>
> *"No, do not use these reports* (official statistics)*; use the GIZ reports if you want to find accurate data. Most of the municipal solid waste data are inaccurate due to the informal sector as mentioned previously"* (Interviewee 1).

The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate explained how they measure the total amount of the solid waste production in Cairo Governorate. This is based on the average generated solid waste by each household (estimated 1.5 to 2kg/day) multiplied by the number of residential units in each neighbourhood.

> *"Cairo is divided into 38 neighbourhoods. We calculate the number of residential units in each neighbourhood. Then we calculate the average of generated solid waste by each household which is 1.5 to 2kg/day"* (Interviewee 3).

Although the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate is involved in the day-to-day collection of municipal solid waste in Cairo Governorate, the quantities that he mentioned for household generation does not match the quantities that are mentioned in the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014). The average municipal solid waste per capita in urban areas is 0.7- 1.0

kg/day and in rural areas is 0.4 - 0.5 kg/day (SWEEP-Net, 2014). The average members in each household in Cairo Governorate is 3.64 based on Egypt Census 2017 (the total population of Cairo Governorate 9,461,246 divided by the total number of households 2,595,977 in 2017). If the average members in each household was multiplied by the average waste generation per capita as mentioned in the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014), then the average generation per household should be (0.7×3.64= 2.55 kg/day to 1×3.64= 3.64 Kg/day). This quantity of solid waste generation per household is higher than the average generation per household that the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate stated. Again, this conflicting data indicate that the quantities of solid waste generation are inaccurate and unreliable. This misleading data will have a massive impact on establishing an integrated sustainable waste management system.

Flowing from the qualitative and quantitative data that are presented above, I then decided to use the data of the Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013) and the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014), being the most accurate and reliable data that is available.

7.4 Municipal solid waste generation of Egypt, Cairo, Giza and Qalyubia Governorates

Municipal solid waste generation in Egypt has been consistently increasing over a period of 11 years - as shown in Figure 7-1 - and it is expected to continue increasing in the future due to the rapid urbanization and population growth.

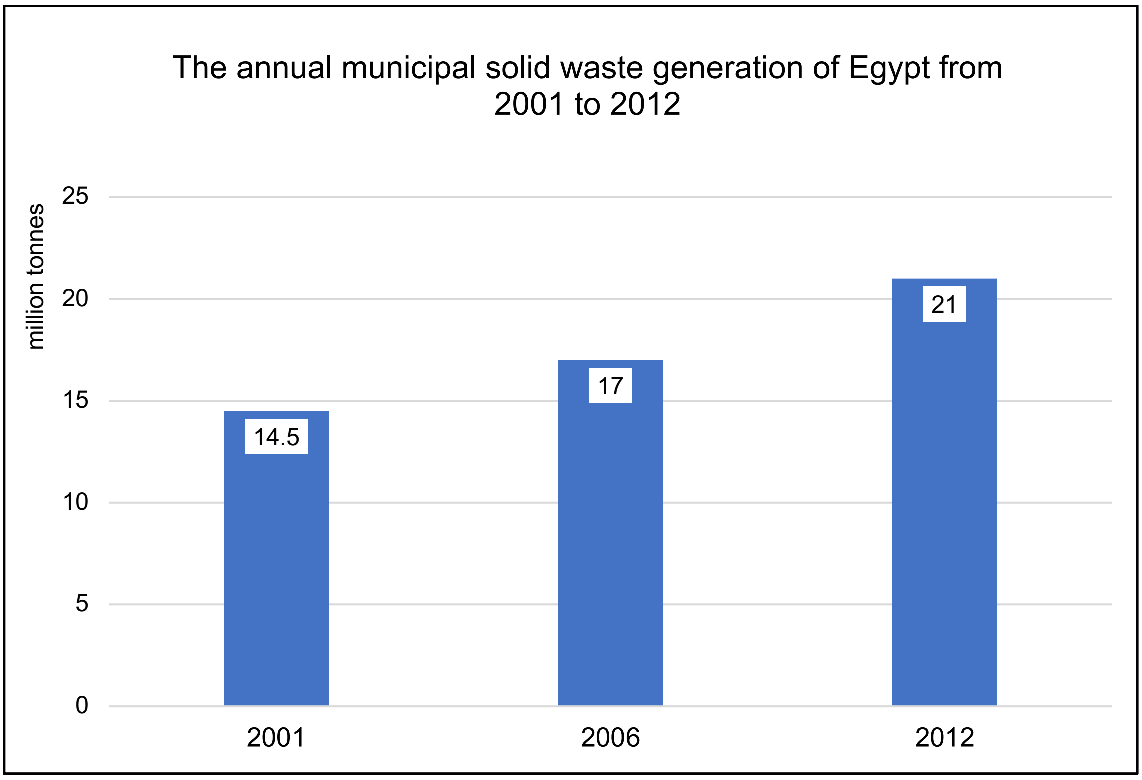


Figure 7-1: The annual municipal solid waste generation of Egypt from 2001 to 2012. (Source: The Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013)

In 2012, the municipal solid waste production per capita was 0.7-1.0 kg/day in urban areas and 0.4-0.5 kg/day in rural areas (SWEEP-Net, 2014). These quantities are almost similar to the waste generation per capita in 2018 based on the world bank report "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050" (Silpa Kaza et al., 2018) as the waste generation per capita of Egypt is 0.50 to 0.99 kg/day (Figure 7-2). This indicates that the waste generation per capita in both reports are most likely to be accurate.

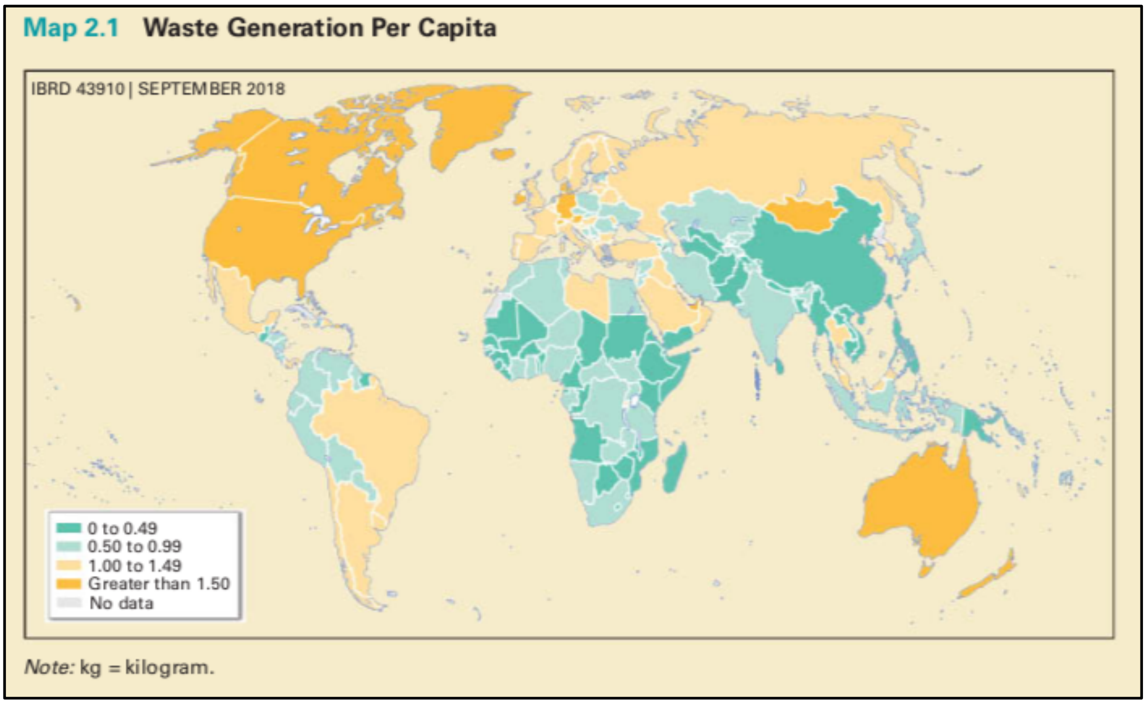


Figure 7-2: World map: waste generation per capita in 2018. (Source: The World Bank report “What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050” (Silpa Kaza et al., 2018).

The data of the annual municipal solid waste generation of Cairo, Giza and Qalyubia Governorates is unavailable in the Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013) and the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014). However, the data of the daily municipal solid waste generation of Cairo, Giza and Qalyubia Governorates and Egypt in 2012 was available in both reports (presented in Figure 7-3). The daily municipal solid waste generation of Cairo Governorate is higher than Giza and Qalyubia as it has the highest population. It is expected that Giza Governorate’s municipal solid waste will increase due to its rapid growth in population, having a high average annual growth rate than Cairo and Qalyubia (see Chapter 4).

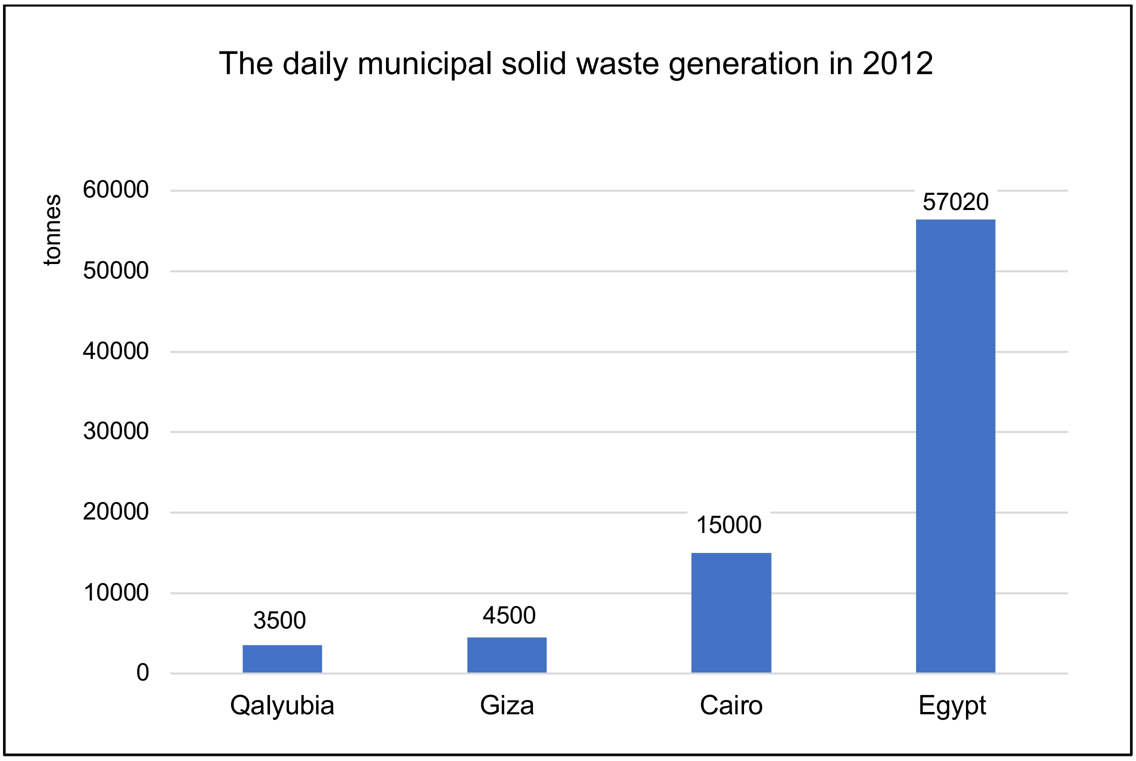


Figure 7-3: The daily municipal solid waste generation of Egypt, Cairo, Giza, and Qalyubia Governorates in 2012. Source: The Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013).

The total percentage of the daily municipal solid waste generation of the three governorates (Cairo, Giza and Qalyubia) was 40% of the total generation of Egypt in 2012, which is considered extremely high (Figure 7-4). The highest percentage was Cairo Governorate (26%), followed by Giza Governorate (9%) and finally Qalyubia Governorate (6%). These percentages were not compared with the previous and following years due to the lack of data.

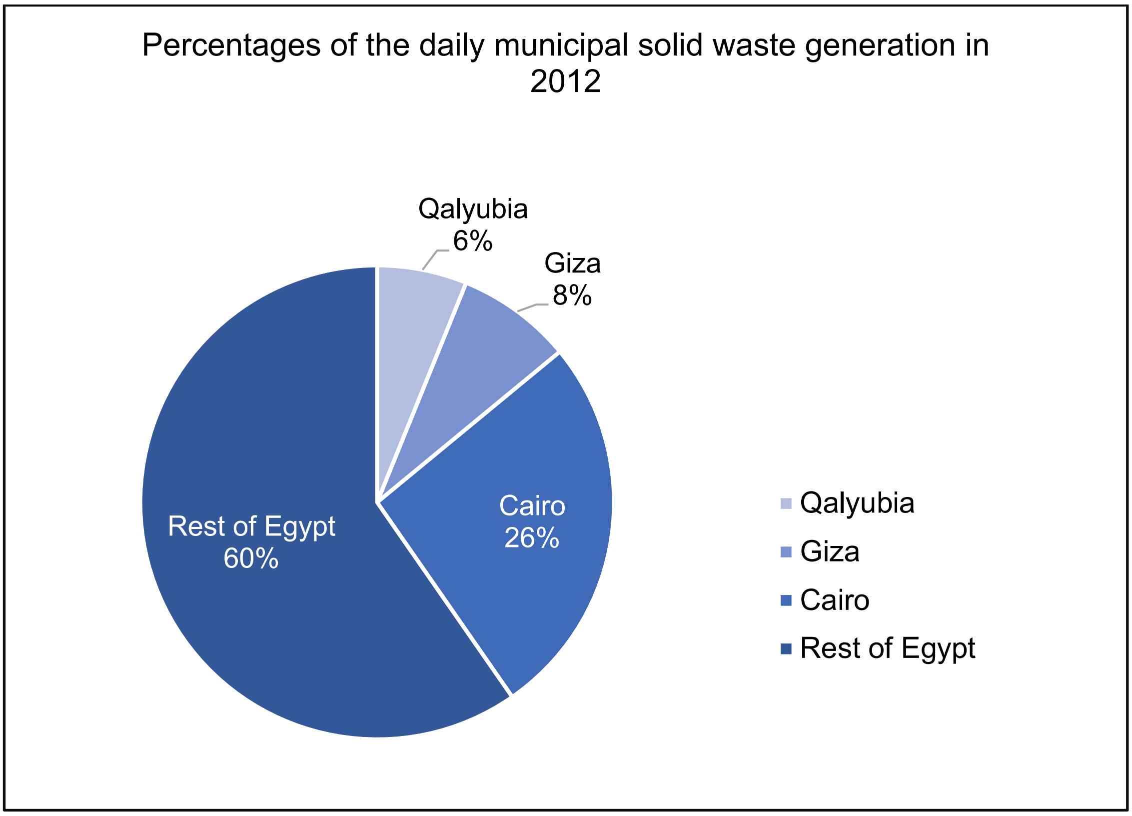


Figure 7-4: Percentages of the daily municipal solid waste generation of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2012.

However, the solid waste is strongly correlated with the population growth and urbanization, both are rapidly increasing in Cairo, Giza and Qalyubia Governorates, so it is projected that the municipal solid waste generation will continue to increase in the future. For example, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) mentioned that the daily municipal solid waste generation of Cairo Governorate was approximately 6000 tonnes in 1983 and reached 17000 tonnes in 2018.

"The Cleaning Authority for Cairo Governorate was established in 1983. In 1983, there was 16 neighbourhoods in Cairo Governorate. Nowadays (2018), there is 38 neighbourhoods. The total number of neighbourhoods is more than the double. Of course, the quantity of the generated waste increased. The total generated solid waste in 1983 did not exceed 6000

tonnes/day. Due to the rapid population growth and the internal migration the quantity of solid waste increased and reached 17000 tonnes/day. In the 60s the total population of Egypt was 23 million inhabitants, but now it reached almost 100 million inhabitants. So, the growth of the generated solid waste is a normal growth due to the increased population" (Interviewee 3).

Furthermore, based on the world classification by income, Egypt is considered a lower-middle-income country (Figure 7-5) and it is projected that by 2050 the total waste generation of the lower-middle-income countries will significantly increase compared to the waste generation in 2016 (Figure 7-6).

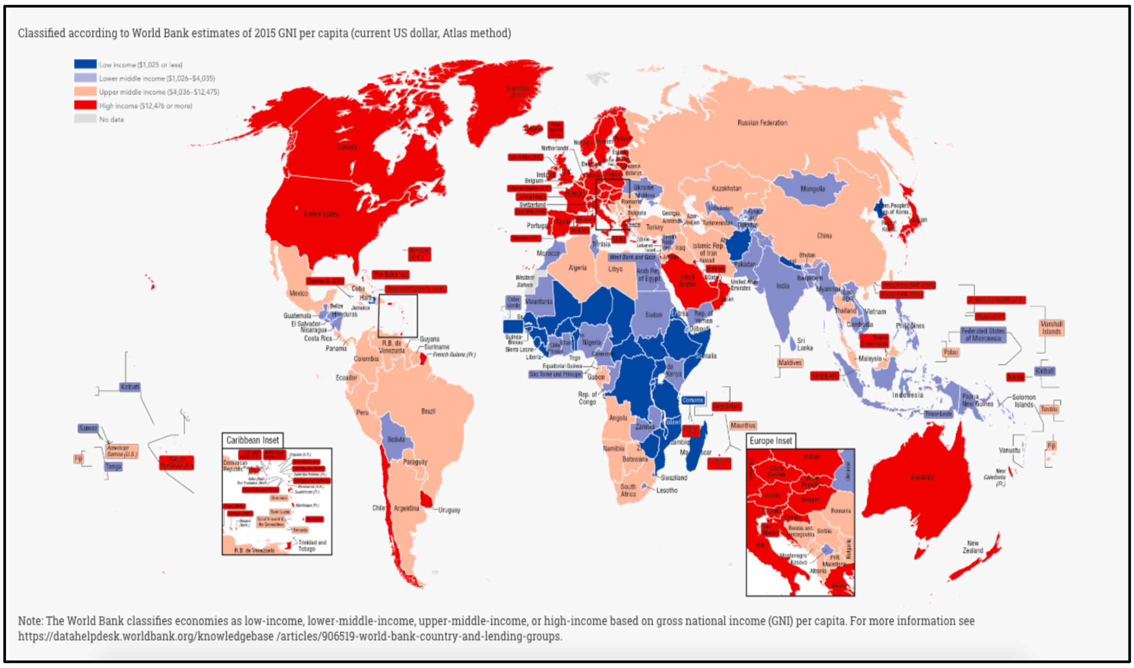


Figure 7-5: The world by income, FY2017. (Source: The World Bank Group 2017, the world by income, FY2017 (The World Bank Group, 2017).

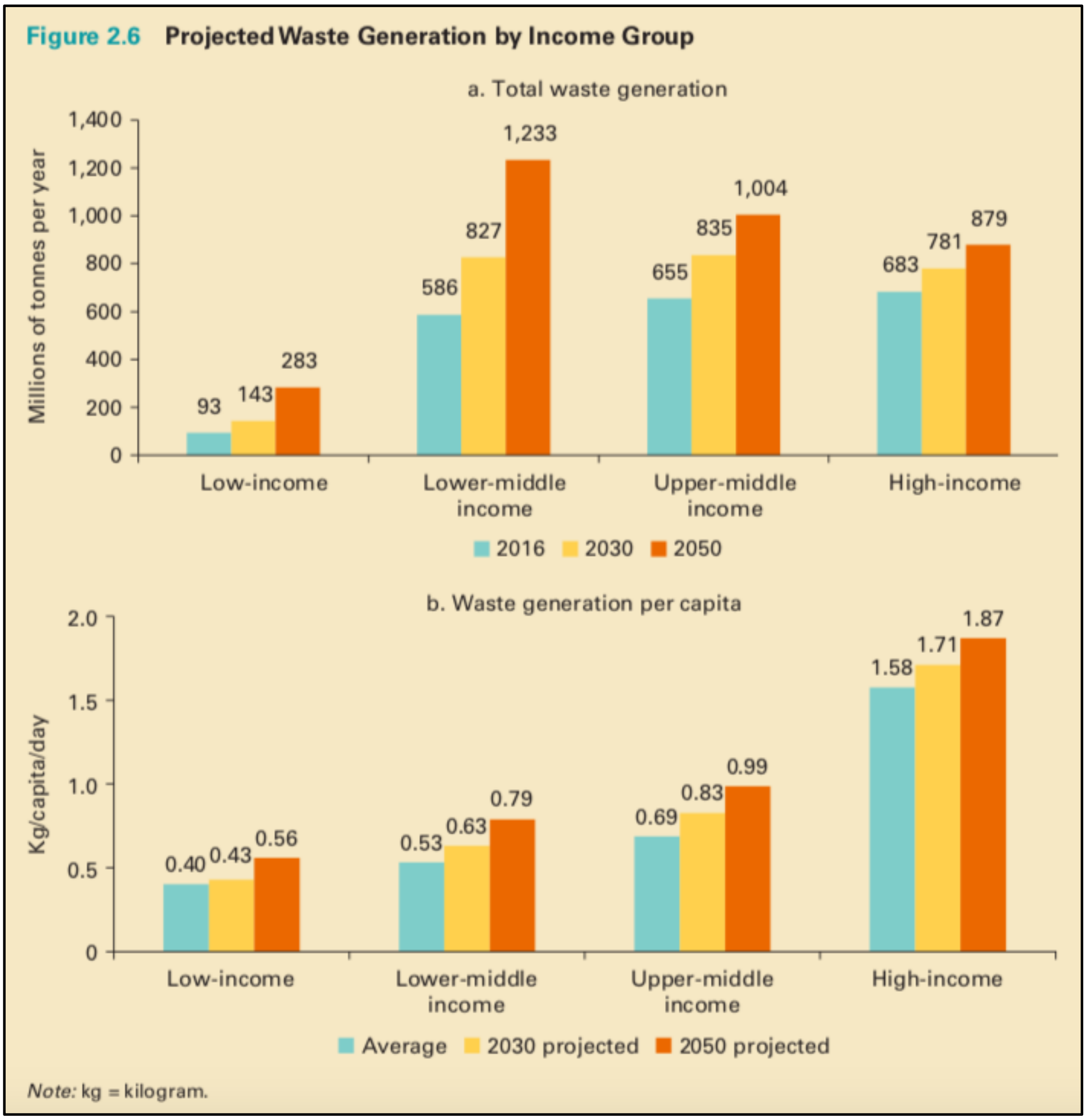


Figure 7-6: Projected waste generation by income group. (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Silpa Kaza et al., 2018).

It is crucial to establish an integrated sustainable waste management system to:

- increase waste collection coverage,
- maximize the use of solid waste as a secondary resource such as upgrading organic waste to produce biogas that is a clean and renewable source of energy that could be used as an alternative to traditional energy resources (primary resources), and

- reduce the massive environmental impacts of municipal solid waste if left without collection and sustainable treatment.

7.5 Municipal solid waste composition of Egypt

The waste composition is the classification of the types of materials found in municipal solid waste (Silpa Kaza et al., 2018). Organic waste represents the highest percentage (56%), as shown in Figure 7-7. This is followed by plastics, paper, cardboard, a small percentage of glass and metal, and 15 % of other unspecified waste.

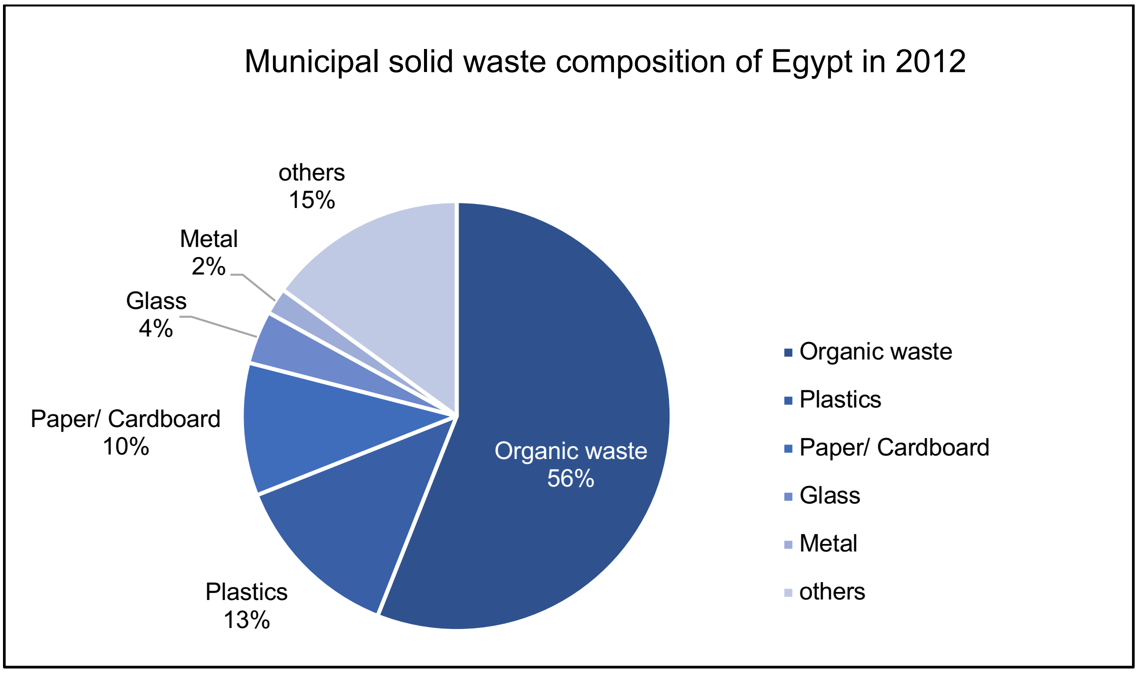


Figure 7-7: Municipal solid waste composition of Egypt in 2012. (Sources: The Country Report on Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014) and What a Waste: A Global Review of Solid Waste Management (Hoornweg and Bhada-Tata, 2012).

The municipal solid waste composition of Egypt is similar to the waste composition of other lower-middle-income countries (Figure 7-8). Municipal solid waste composition varies according to the income level as shown in Figure 7-8. As the percentage of organic waste (food and green) is higher than other types of waste (dry waste such as glass, paper, cardboard, plastics and metal) in lower-middle-income countries. The percentage of dry waste is higher than the percentage of organic waste in high-income countries (Silpa Kaza et al., 2018).

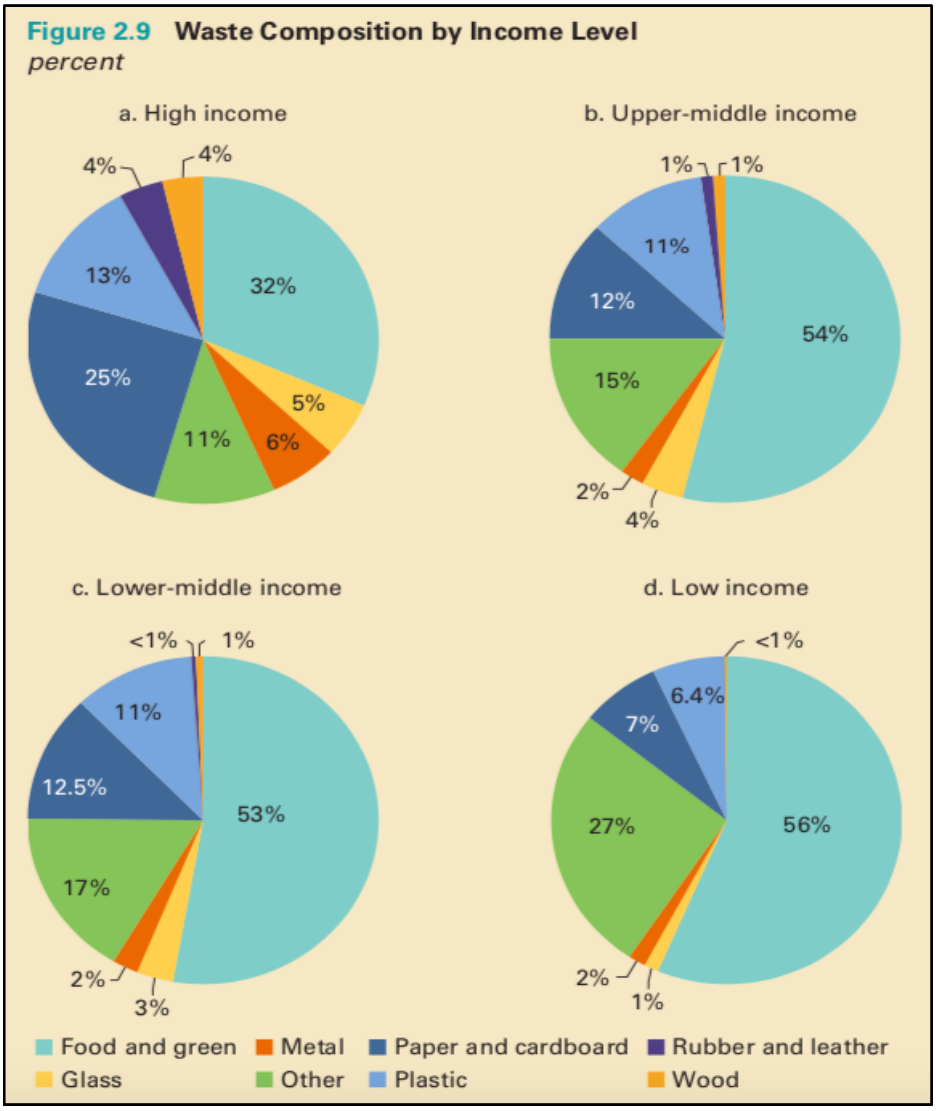


Figure 7-8: Waste composition by income level. (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Silpa Kaza et al., 2018).

The municipal solid waste composition also varies in Egypt. In rural settlements, the percentage of organic waste is around 60%, which is higher than other types of waste. In urban settlements, organic waste is less than rural settlements, as it represents 50% of the total waste and the rest is dry waste (such as glass, paper, plastics, metal and cardboard).

Author: *"Is the percentage of organic waste 50% or 60%, because the data that I have collected shows that it is 56%?"*

Representative of the Ministry of Environment (Interviewee 1): *"50% in urban areas and 60% in rural areas."*

Author: *"Why?"*

Representative of the Ministry of Environment (Interviewee 1): *"Because in rural areas they do not have cans and plastics like in urban areas. Usually they use glass bottles and exchange them."*

In addition, municipal solid waste composition differs in Egypt from one place to another. For example, in Cairo Governorate, municipal solid waste composition varies from one settlement to another based on the income level. In high-income settlements, the percentage of dry waste is higher than low-income settlements and the percentage of organic waste is higher in low-income settlements than in high-income settlements.

Representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3): *"No, the average is 1 to 1.5 kg per household. It varies from one place to another. The solid waste in high-income settlements is not too much. In other low-income settlements the solid waste is higher. In low-income settlements (such as Ain Shams and Mataria) the content of organic waste is higher because they buy the raw vegetables and clean it at home. In high-income settlements (such as Maadi and Zamalek) they buy clean vegetables, so organic waste is less."*

Author: *"But high-income settlements (such as Zamalek) will have other types of waste such as cans, plastics and cardboard."*

Representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3): *"Yes, of course they have other types of waste such as cans, cardboard, but they are all included in the solid waste."*

Author: *"Official statistics show that organic waste is 56% of the total generated solid waste."*

Representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3): *"It differs from one place to another, but the average is 60%. As I mentioned in the informal settlements the percentage of organic waste is higher than other high-income settlements."*

The above data shows the high percentage (up to 56%) of organic waste compared to other types of municipal solid waste in Egypt. This sheds light on the huge potential of upgrading organic waste (secondary resource) by anaerobic digestion to produce biogas. Biogas is a renewable source of energy that could be an alternative energy source instead of relying on traditional fuels (natural gas and oil). This potential was explored further in Chapter 5 (particularly Figure 5-11). Most of the urban settlements (Cairo, urban areas in Giza and Qalyubia) rely on natural gas as a source of energy for cooking that could be replaced by biogas.

The data of the municipal solid waste composition of Cairo, Giza and Qalyubia Governorates is unavailable in all the official statistics and published reports that were reviewed. This information is important to make better decisions in the future for integrated sustainable solid waste management and resource management. Measuring the actual quantities of organic waste and tracking the locations (settlements) of high generation of organic waste is essential to maximize the use of organic waste to produce biogas and to identify the best locations to build anaerobic digestion plants. Measuring other types of waste is also important to provide suitable treatment to prevent the environmental impacts of the dry and organic waste if left without treatment.

7.6 Municipal solid waste collection of Egypt, Cairo, Giza and Qalyubia Governorates

The percentage of the municipal solid waste collection coverage in Egypt is between 50-60% in urban areas and 0-30% in rural areas (SWEEP-Net, 2014). These percentages show the massive gap between urban and rural areas in terms of accessibility to basic services such as the solid waste collection. As mentioned previously, specifically in the water and wastewater sectors (Chapter 6), the percentage of households without direct access to drinking water and sanitation services is higher in rural areas than urban areas. This is common in developing countries, most of the services and investments are concentrated in urban areas and cities rather than rural settlements.

In general, waste collection rates in both urban and rural areas in Egypt are considered low compared to high-income countries (Figure 7-9). However, the average percentage of waste collection in lower-middle-income countries is 51%, that is almost similar to the collection rates in Egypt. Moreover, the percentage of waste collection coverage is higher in urban areas than rural areas in lower-middle income countries (as shown in Figure 7-10) that is similar to the situation in Egypt. In contrast, in high-income countries waste collection coverage is higher than other income group levels and the urban and rural collection coverage rates are almost equal (Figures 7-9 and 7-10). This goes some way to explaining low levels of pollution in high-income countries compared to lower-middle and low-income countries. Municipal solid waste has a massive impact on the environment if left without collection, sustainable management, and treatment. Additionally, the low rates of waste collection hinder the development of new sustainable technologies to maximize the use of solid waste as a secondary resource that could be upgraded and fed back into the city.

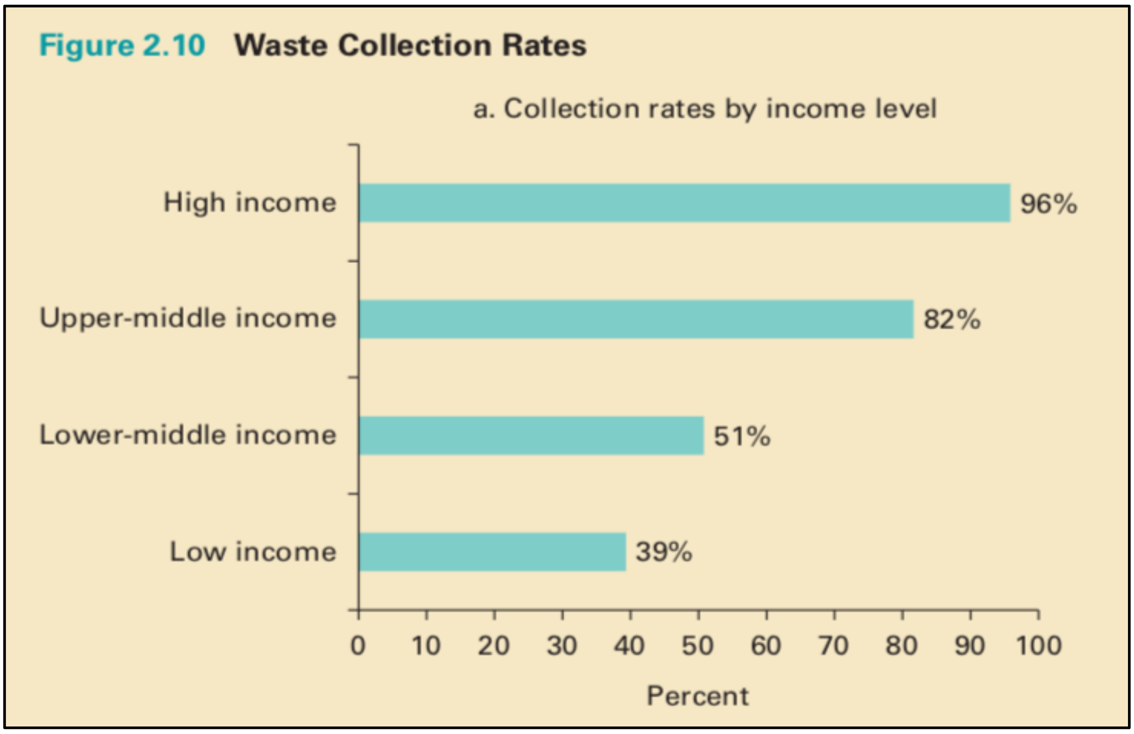


Figure 7-9: Municipal waste collection rates by income level. (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Silpa Kaza et al., 2018).

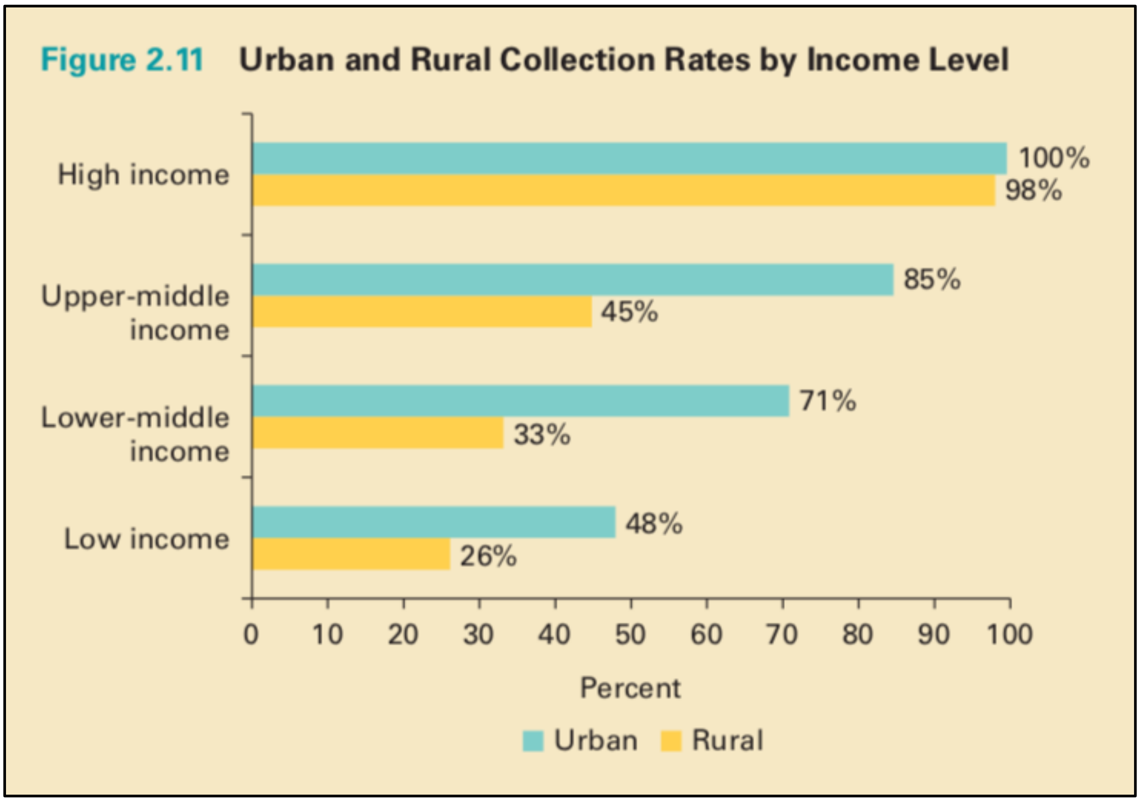


Figure 7-10: Urban and rural collection rates by income level. (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Silpa Kaza et al., 2018).

In 2012, the municipal solid waste collection rates in Cairo Governorate was 70%, Giza 60% and Qalyubia 60% (Zaki et al., 2013). Unsurprisingly, the waste collection rates in Cairo Governorate, being the capital of Egypt and 100% urban, is the highest compared to Giza and Qalyubia Governorates. The waste collection rates in Giza and Qalyubia Governorates are less than Cairo Governorate because both include rural areas (see Chapter 4), and the waste collection rate in rural areas is less than urban areas.

The percentages of households living without public waste collection in 2017 are presented in Figure 7-11. The percentages of households living without waste collection in Cairo, Giza and Qalyubia Governorates are less than the average collection of Egypt. Yet, the overall collection coverage rates of the three governorates and Egypt are still considered low and did not improve between 2012 and 2017 causing massive environmental impacts. Most of the uncollected waste is usually thrown in the streets or water bodies, polluting the limited water resources of Egypt and causing health problems.

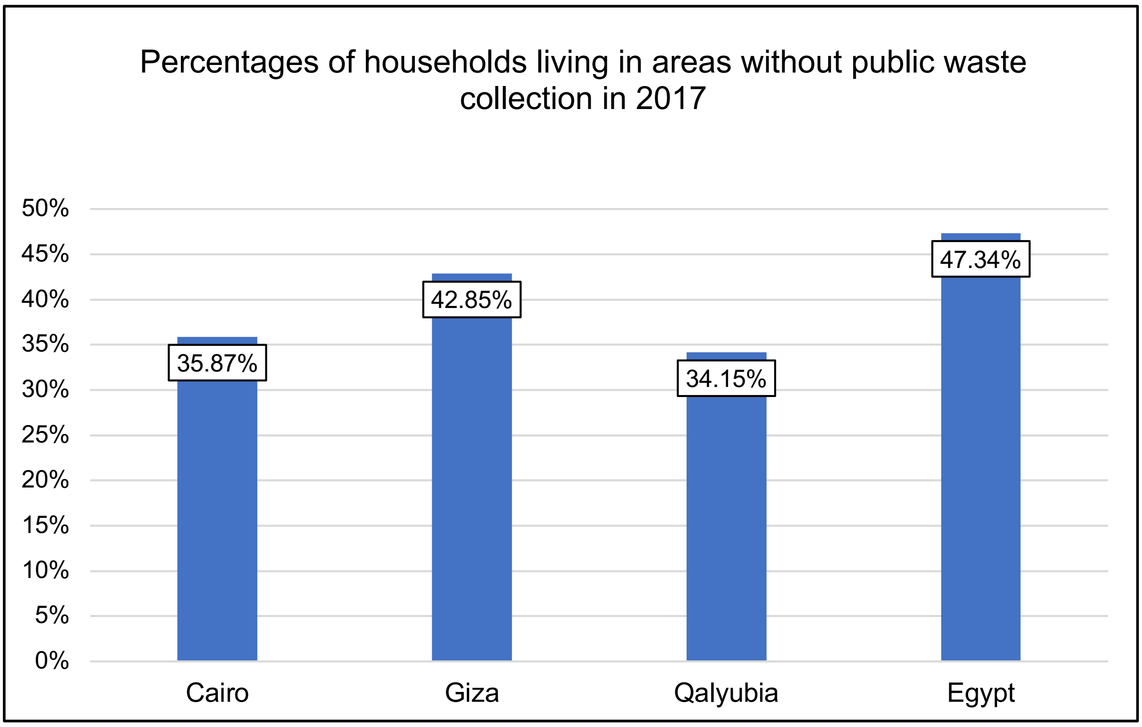
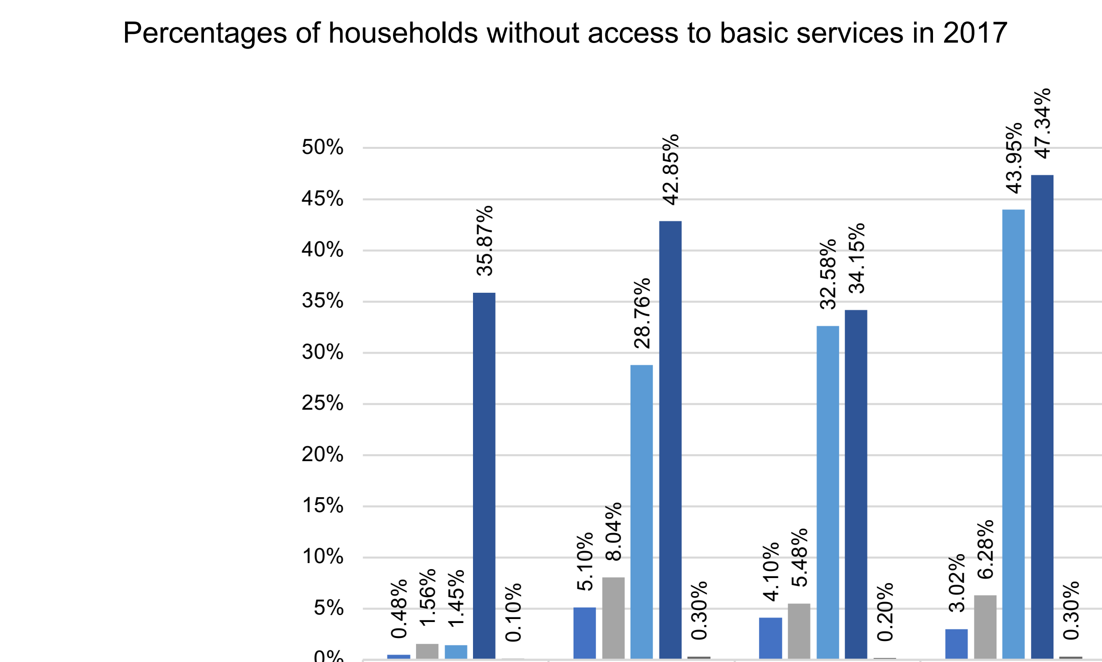


Figure 7-11: Percentages of households living in areas without public waste collection in 2017.

The percentages of households living in areas without public waste collection and sanitation services are the highest compared to the rest of the basic services as shown in Figure 7-12. This indicates that most of the government's development plans and investments are directed towards increasing access to primary resources (such as the electricity and drinking water) rather than upgrading the secondary resources (output of cities such as the solid waste and wastewater) and maximizing their uses. Driven by climate change and the scarcity of resources, it is essential the percentages of waste collection coverage and sanitation services are increased to reduce their environmental impacts and to upgrade these secondary resources and feed them back into the city. Furthermore, it became a global concern to increase waste collection coverage and sustainable management, and sanitation coverage to achieve the Sustainable Development Goals (SDGs) developed by the United Nations, specifically Goal 3 ‘Ensure healthy lives and promote well-being for all at all ages’ and Goal 6 ‘Ensure availability and sustainable management of water and sanitation for all’ (United Nations, 2015a).



	Cairo	Giza	Qalyubia	Egypt
% of households without direct access to water	0.48%	5.10%	4.10%	3.02%
% of households without direct access to drinkable water	1.56%	8.04%	5.48%	6.28%
% of households without sanitation	1.45%	28.76%	32.58%	43.95%
% of households living in areas without public waste collection	35.87%	42.85%	34.15%	47.34%
% of households without grid electricity connection	0.10%	0.30%	0.20%	0.30%

Figure 7-12: Percentages of households without access to basic services in 2017.

7.7 Municipal solid waste treatment and disposal methods in Egypt

The data of the municipal solid waste treatment and disposal methods is available for Egypt only and the data for the three governorates is unavailable in existing official statistics and reports. The missing data should be considered in the future to develop an integrated sustainable waste management system that is based on the quantity and composition of the generated waste.

Most of the generated waste in Egypt is openly dumped, and the rest is either composted, landfilled or recycled Table 7-3. The percentages of solid waste treatment that are presented in Table 7-3 are for the collected solid waste because the uncollected solid waste is usually thrown in the streets, desert and water bodies.

Table 7-3: Municipal solid waste treatment and disposal methods in Egypt (SWEEP-Net, 2014).

Municipal solid waste treatment and disposal methods in Egypt	Percentage
Composted	7%
Recycled	10-15%
Landfilled	7%
Openly dumped	80-88%

The percentage of the openly dumped solid waste in Egypt is higher than the average of lower-middle-income countries as shown in Figure 7-13. Moreover, the percentages of landfilled and composted solid waste in Egypt are less than the average for lower-middle-income countries. The percentage of recycled waste in Egypt is higher than the average of lower-middle-income countries. The overall performance of the solid waste management in Egypt is weak compared to other countries specifically if compared by region as shown in

Figure 7-13. The percentages of solid waste disposal methods in the Middle East and North Africa are much better than the percentages of Egypt. The challenges of solid waste management in Egypt that are presented below explain the failure and weaknesses of the solid waste sector in Egypt and how they massively affect the overall performance of the sector.

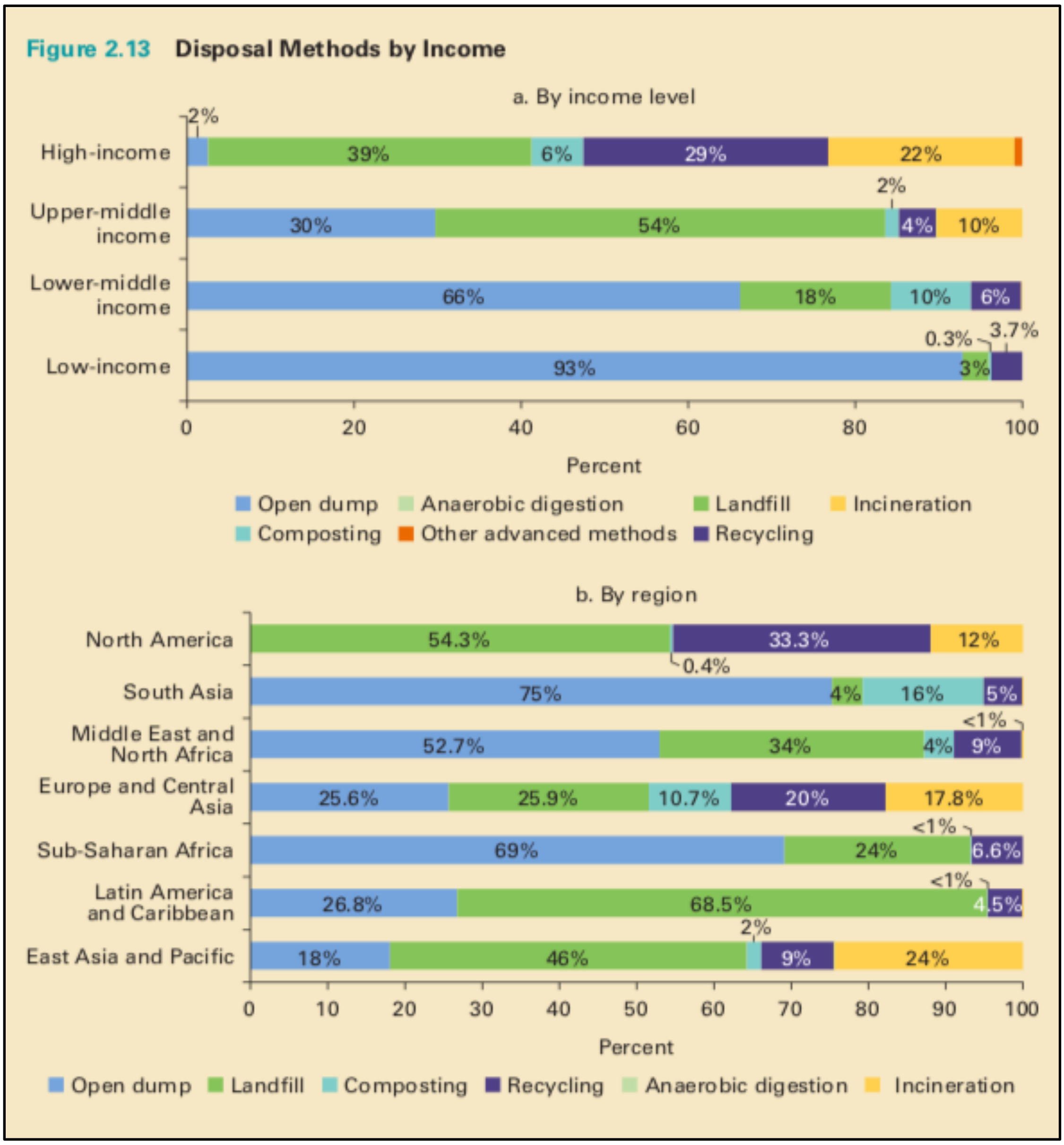


Figure 7-13: World waste disposal methods by income level and region. (Source: What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Silpa Kaza et al., 2018).

7.8 Challenges of the municipal solid waste management in Egypt

- The lack of effective governance is one of the major challenges of the solid waste sector in Egypt as it is not well defined as many partners are involved including the Ministry of Environment, the Ministry of Local Development and the municipalities.

  "The cabinet has issued a feed-in tariff for the waste and some activities, but still the governance of this sector (solid waste) *is not well defined"* (Interviewee 2, the representative of the Ministry of Electricity and Renewable Energy).

  "A number of ministries are part of it; the Ministry of Electricity, the Ministry of Environment, the Ministry of Local Development if we are talking about solid waste and the Ministry of Housing and if we are talking about sludge and sanitary plants like anaerobic digestion. I think we have many partners, which complicates the process and the lack of governance" (Interviewee 2, the representative of the Ministry of Electricity and Renewable Energy).

  "The potential of organic waste is limited. The potential of 1000 megawatt compared to other resources, lack of governance of the sector, which is complicated because many partners are involved and the cost is still high" (Interviewee 2, the representative of the Ministry of Electricity and Renewable Energy).

- The lack of an integrated sustainable waste management system and appropriate infrastructure and governance for the solid waste sector.

“This means that first you need a proper waste management system. In addition, you have a problem with the disposal places that should be well designed where you can generate not just biogas from anaerobic digestion, you can also generate gas from landfills, too. So, we need a proper infrastructure and governance for the waste sector. It is a very promising source of energy. It will also solve an environmental problem specifically in large cities like Cairo and Alexandria in the country” (Interviewee 2, the representative of the Ministry of Electricity and Renewable Energy).

- The government does not have full control of the solid waste sector in Egypt. This is due to the involvement of many sectors in the solid waste management (collection, recycling and disposal) that includes the formal sector (such as the councils (municipals), non-governmental organizations NGOs and the private companies) and the informal sector (such as El-Zabbaleen in Cairo Governorate).

“There is a major flaw in the waste management system in Egypt and we do not have full control on it. A large percentage of our waste is collected by El-Zabbaleen (informal sector) *and transferred to El- Mokkatam where they live, sort, recycle, reuse and sell the waste”* (Interviewee 1, the representative of the Ministry of the Environment).

- The government failed to integrate the informal and formal sectors to produce better outcomes on solid waste in Egypt. This failure is largely due to resistance from the informal sector because waste collection is often its only source of income, which it does not want to share with other sectors or the government.

> *"It* (informal sector, Zabbaleen) *is a closed community. There were many attempts to integrate the informal sector with the formal sector to form an effective and powerful waste management system, but they were unsuccessful. Some of them create small companies and work as subcontractors for bigger companies or with foreign companies. Others make direct deals with small neighbourhoods to collect the solid waste"* (Interviewee 1, the representative of the Ministry of the Environment).

- The lack of reliable data to identify the actual quantities of the generated solid waste for better management.

> *"However, there is a large number of the informal sector not included within the waste management system and this has a negative impact on the system. As long as we do not have full control on the system, we will never have accurate data for the quantities of the solid waste"* (Interviewee 1, the representative of the Ministry of the Environment).

- The lack of financial resources to develop an adequate integrated sustainable waste management system as there is a wide gap in the cost of solid waste collection and the actual cost to develop a sustainable solid waste management system. The existing waste collection fees do not meet the required finances for developing a sustainable waste management system.

> *"For the economic aspect, for example, we have a problem in the waste collection cost we did not decide yet whether the residents or the recycling*

companies would pay it. Nowadays, the cost of the waste collection is added to the electricity bills and it is from 4 to 10 Egyptian Pounds, but the actual cost is 24 Egyptian Pounds. This problem is not properly managed" (Interviewee 1, the representative of the Ministry of the Environment).

- Existing recycling factories do not properly recycle solid waste. Rather, they just split organic waste from other types of waste. The informal sector has primitive technologies to recycle cans, plastics, glass and cardboard and none of these stages is monitored or controlled by public bodies.

"No, all our recycling factories, we call them recycling, but actually they split organic waste from other types of waste. Then they use organic waste as compost and windrows in most of the governorates" (Interviewee 1, the representative of the Ministry of the Environment).

"In Manshiyat Nasr and Esbat El Nakhel (informal areas) *50% of the projects there are primitive projects such as cans and cardboard compactors, and paper recycling factories (very small factories). In addition, they export some types of non-organic waste to China"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"The informal sector has primitive equipment to crush glass and plastics then sell it to other recycling plants or factories" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

- The stages of the recycling process are not monitored that have a massive impact on the environment and public health.

  "We do not have a national system to monitor the recycling and the reuse stages, but we have pilot projects" (Interviewee 1, the representative of the Ministry of the Environment).

- Organic waste, that represents 56% of the solid waste in Egypt, is causing massive environmental problems as most of the recycling companies refuse to take organic waste and prefer other types of recyclable waste. Only 30%-40% of organic waste is recycled and the rest are openly dumped. The informal sector was interested in collecting organic waste to feed pigs, but the government ordered the slaughter of all these pigs after the spread of the swine flu. In recent few years, the informal sector started to raise pigs illegally, though few than before swine flu.

  "We always have a problem in organic waste. Most of the recycling companies refuse to collect organic waste, but they collect other types of recyclable waste (cans, glass, and cardboard). Organic waste is the milestone of the waste management system because organic waste in Egypt should be collected on daily basis due to the high temperature that increases the growth of bacteria, if organic waste was left without collection, it will have a major effect on the environment and the spread of diseases. We need a daily transportation system to collect organic waste, but for other types of waste for example; cans they can be collected once a week they will not cause any problems" (Interviewee 1, the representative of the Ministry of the Environment).

"No, this is the illegal way to get rid of organic waste, we have other formal ways "we dump it" we do not use it at all. We only recycle 30% to 40% maximum of our organic waste" (Interviewee 1, the representative of the Ministry of the Environment).

"Yes, the garbage collectors (scavengers) who collect the garbage from the residential units are interested in the non-organic waste because they sell it, but for organic waste no one is interested in it" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"For organic waste, the garbage collectors (Zabbaleen) used organic waste to feed pigs, but the government ordered to slaughter all the pigs due to the swine flu. So, they used to take both organic and the non-organic waste, but nowadays, organic waste became a burden no one wants it" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

While there are some pilot projects to produce biogas from organic waste in Egypt, the lack of maintenance and knowledge of operating such projects prevent their expansion and the lack of a proper waste management system to ensure the daily collection of organic waste. Moreover, the lack of financing and land availability specifically in high-density settlements hinders the development of anaerobic digestion projects. The representative of the Ministry of Environment clarified that anaerobic digestion projects might be more suitable in rural areas where land is available. However, he suggested that the government could build anaerobic digesters near to existing landfills in high-density urban settlements as the solid waste is already transferred there, and it would be easy to sort organic waste from other types of waste and use it to produce biogas.

"Although most of those projects are successful, they are not widely spread. Even the existing pilot projects stop working due to the lack of maintenance and knowledge to operate such projects" (Interviewee 1, the representative of the Ministry of the Environment).

"The problem is the price of the electricity. The government subsidizes the electricity, so the price of the electricity is always less than the other alternatives. When the government removes the subsidies- (it actually started to remove the subsidies gradually)*, the price of the electricity will increase and will be higher than other alternatives"* (Interviewee 1, the representative of the Ministry of the Environment).

"There are many offers presented by companies, these projects (anaerobic digesters) *depend on the availability of land and financing"* (Interviewee 1, the representative of the Ministry of the Environment).

"I think biogas will be better and beneficial for rural areas. It will be difficult to build digesters in Cairo due to the high-density" (Interviewee 1, the representative of the Ministry of the Environment).

"Alternatively, we can build the digesters beside the existing landfills; the waste is already transferred there so we can get rid of organic waste by building anaerobic digesters or any other suitable technology" (Interviewee 1, the representative of the Ministry of the Environment).

The above data indicates that there is huge potential to maximize the use of organic waste in Egypt in both urban and rural settlements to produce biogas. Despite, the barriers to the implementation of waste-to-energy technologies presented above, specifically upgrading organic waste to produce energy, the amount of renewable energy that could be produced is worth removing these barriers. Moreover, the drivers of upgrading organic waste is not only to produce energy but ensuring the daily collection and the treatment of organic waste. This is also important to reduce the environmental impacts of organic waste if left without treatment as it emits methane (CH_4) that is worse than the carbon dioxide (CO_2) emissions as 1 ton of methane is equivalent to 25 tons of carbon dioxide (Eurostat, 2020). Furthermore, transforming organic waste from a burden that no one is interested in, to a secondary resource (to produce biogas that is a renewable source of energy) that has a value, could increase the financial resources of the solid waste sector in Egypt and enable the government to establish an integrated sustainable solid waste management system. But the governance of the solid waste sector should be defined, and the institutional setup should be improved before establishing a solid waste management system. Measuring the actual quantities of the generated solid waste is essential to provide better collection services, to upgrade this secondary resource and maximize its uses and improve the environmental and health conditions.

Additionally, the above data shows that the informal sector plays an important role in the waste management sector and there were many unsuccessful attempts to integrate the informal sector within the formal waste management system. Despite these unsuccessful attempts, it is essential to integrate the informal sector within the formal framework of the waste management sector to enable the government to better coordinate the actions of the sector. This would improve the government's strategy and planning for establishing an integrated sustainable waste management system. This integration could be achieved by explaining the advantages of being part of the formal framework of the waste management system (such as better working and living conditions, transforming the informal economy and illegal practices into formal and legal practices, which secure a better future).

7.9 Municipal solid waste in Cairo Governorate

7.9.1 Pre-privatization of the municipal solid waste sector in Cairo Governorate

The Public Authority for Cleaning and Beautification of Cairo Governorate was established in 1983. At that time, there were 16 neighbourhoods in Cairo Governorate which generated approximately 6000 tonnes of solid waste per day. The Cleaning Authority was responsible for the waste collection of Cairo Governorate. The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) described the waste management system during that time as *"an integrated system"* that included waste collection, recycling and disposal, in addition to street sweeping.

The Cleaning Authority used to deal directly with the garbage collectors (scavengers) to provide a door-to-door waste collection service for the residents of Cairo Governorate. The Cleaning Authority gave the garbage collectors (scavengers) coupons to collect the required fees for the waste collection service from the residents. The Cleaning Authority stamped these coupons for 30 piasters per slip and the garbage collectors took 3 Egyptian pounds per slip from the residents. The service covered 25% to 30% of the total number of residents. This was an attempt to organize the work of the garbage collectors (scavengers) to assign an area for each one to avoid problems between them.

The recycling process at that time included the separation of organic waste from other types of waste to produce compost. The garbage collectors (scavengers) took most of the non-organic waste to sell it as this was their source of income. This problem still exists today as the Cleaning Authority receives only 5% of the non-organic waste and the garbage collectors take the rest. The waste disposal during that time was mostly openly dumped.

> *"No projects have been implemented to make use of solid waste instead of dumping it without treatment. We only use organic waste to produce compost. The garbage collectors take most of the non-organic waste (cans, cardboard, paper and glass), they make use of it or sell it to other recycling factories. We receive only 5% of the non-organic waste"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

This shows that the main targets of the Public Authority for Cleaning and Beautification of Cairo Governorate was to collect the waste and keep Cairo Governorate clean lacking an integrated sustainable waste management system. Additionally, the percentage of municipal waste collection coverage was extremely low (25% to 30% of the total number of residents). This indicates that managing the solid waste sector exceeded the technical and financial capacity of the Public Authority for Cleaning and Beautification of Cairo Governorate.

7.9.2 Privatization of the municipal solid waste sector in Cairo Governorate

In 1999, a decision was made to privatize the municipal solid waste sector in Cairo Governorate to increase the waste collection coverage and to improve the performance of the waste management system. The role of the Cleaning Authority changed at that time. Foreign companies (Spanish and Italian) and the private sector were responsible for three areas in Cairo Governorate: The Northern, Eastern and Western regions of Cairo Governorate except El-Marg neighbourhood. The Cleaning Authority was responsible for the Southern region of Cairo Governorate and El-Marg, which is an informal area. Based on the contracts with foreign companies were responsible for the solid waste management in the three regions of Cairo Governorate (Northern, Eastern and Western).

The system included door-to-door waste collection from residential units, transfer of the collected waste to intermediate handling stations and from the handling stations to the recycling factories than to the final disposal areas. These companies also dealt with garbage collectors (scavengers), but this system was changed when the companies placed large containers in the streets. The garbage collectors (scavengers) were responsible to collect the waste from the residential units to the containers then the companies collected these containers. The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (interviewee 3) thought that the companies paid the garbage collectors (scavengers) less money compared to the amount of money that the Cleaning Authority used to pay. This could be one of the major reasons for the failure of integrating the informal sector in the municipal solid waste management system.

In addition, the government established the “Contract Control Unit” to monitor the performance and the quality of the service provided by foreign companies, revise the contracts and apply fines whenever required. This unit was under the supervision of the Cleaning Authority. However, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (interviewee 3) mentioned that the Cleaning Authority was working *“hand in hand”* with foreign companies for 15 years during the duration of the contract, allowing the foreign companies to provide an inadequate level of service.

The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) explained that there were two companies: a Spanish company and an Italian company. Based on the contracts, the companies were responsible to collect all the generated waste, even for the new urban expansions. The companies collected a certain amount of waste and left whatever exceeded that amount. They said that the contracts include action plans that they must abide by. Interviewee 3 denounced how the government approved these contracts.

> *“I do not know how these contracts were approved!”* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

The overall performance of the foreign companies and the participation of the private sector in the municipal solid waste management was “less than adequate” (SWEEP-Net, 2014). This was due to various reasons, starting with the Government's lack of experience related to the technical specifications required for such contracts and bidding procedures. This led to weak contracts in terms of technical, commercial and legislation aspects. Furthermore, the foreign companies failed to integrate the informal sector within the waste management system. This led to unsuccessful implementation and failures in the solid waste sector. In addition, the deficiencies in the contracts were compounded by the failure of the government to include provisions for re-negotiating the contracts or to include sanctions for failure to meet specified standards.

7.9.3 The current situation of the municipal solid waste sector in Cairo Governorate

The contracts of these foreign companies have expired, and they have withdrawn from 12 of Cairo Governorate's 28 neighbourhoods, replaced by the Public Authority of Cleaning and Beautification. The representative of the latter organization (Interviewee 3) noted that the authority was prepared to replace foreign companies by increasing the number of labours, drivers and the required equipment.

> *"After the foreign companies left, it is our responsibility (The Cleaning Authority) to find solutions for these problems. We are trying to provide the new and suitable equipment, training and raising the efficiency of the labours and drivers. Moreover, we are focusing now to replace the foreign companies without causing any drop to the existing situation. This transformation requires a lot of investments"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

> *"Yes, we are aiming to provide better or higher level of service. We developed a new waste management plan for the neighbourhoods, which the foreign companies left. We bought new equipment and provided an adequate number of labours"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

However, he described the responsibility of the municipal solid waste sector as a *"burden",* due to the following reasons:

- The solid waste sector exceeds the technical and financial capacity of the cleaning authority.

  > *"As a Cleaning Authority we do not have time to think. The most important thing for us is to collect the generated waste every day and keep the streets clean. Waste collection is a huge responsibility, it should include other sectors to distribute the load"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).
  > *"The waste management system requires huge investments that exceeds the budget of the Cleaning Authority as it is not an independent ministry"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

- Public behaviour is considered one of the major challenges for the cleaning authority as the public throws garbage at any time during the day without respecting the specific dates of waste collection. With 10 million inhabitants of Cairo Governorate, behaviour change is an important part of any future strategy for successful waste management.

"Residents throw the garbage at any time during the day. To avoid a crisis in Cairo, the Cleaning Authority has to collect the garbage every day. If we leave it without collection for one or two days, it will cause serious problems" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"We tell the residents that we will collect the garbage every other day instead of every day. There are more than 4 million residential units in Cairo Governorate, which capacity can provide a daily collection!" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"Where are the garbage collectors (scavengers) that can collect all this amount of waste from 4 million residential units? That is impossible!" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"Therefore, we decided that the collection would be every other day, but public behaviour is challenging" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"Now, we have to sweep the streets twice or thrice a day, one is not enough due to public behaviour. People throw anything in the streets all the time" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"We sweep the streets early in the morning, but university and school students' litter on their way back during the afternoon. So, we need to sweep the streets once more. This behaviour is not accepted from the students. Continuous public awareness campaigns are required"

(Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

The behaviour of Cairo Governorate's inhabitants requires developing a schedule for waste collection and the government should strictly enforce the law and apply penalties on lawbreakers. However, this would not be achieved without improving the governance of the solid waste sector and establishing an integrated sustainable waste management system, both are still under development. In addition, increasing public participation and awareness campaigns to increase the sense of responsibility and draw attention to the consequences of this behaviour such as the environmental impacts and health problems.

- The Public Authority for Cleaning and Beautification of Cairo Governorate has three recycling sites. The first site is on 15th of May[11] and it receives 1600 tonnes/day of solid waste. The second site is in El-Kattamya and it receives 640 tonnes/day of solid waste. The third site is in El- Salam and it receives 260 tonnes/day of solid waste. The total quantity of the three sites is around 2500 tonnes/day. This shows that the recycling sites receive only 14.7% of the total generated solid waste (17000 tonnes/day). The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) also clarified that the collection coverage is less than 100%. Additionally, the main purpose of the recycling sites is to split organic waste from the non-organic waste to produce compost and RDF (Refused Derived Fuel) from the rejected waste only without any further treatment.

[11] (15th of May) is the name of a city located in Cairo Governorate.

“Actually, we (The Public Authority for Cleaning and Beautification of Cairo Governorate) do not collect the 17000 tonnes of solid waste that are generated every day. The 17000 tonnes include all types of waste” (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

“In the Cleaning Authority recycling plants, we produce compost from organic waste and the rejected waste is used to produce RDF. Then the cement factories use it as a fuel instead of the oil for the cement burners (or kilns)” (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

This indicates that the technical and financial capacity of the Public Authority for Cleaning and Beautification of Cairo Governorate is insufficient to provide an adequate waste management service and a sustainable treatment for the generated waste. Future restructuring of the waste section should consider redistributing responsibility of waste management and encouraging the participation of the private sector. It is also important to improve the terms and conditions of the waste management contracts based on the previous experience with the foreign companies (private sector) to avoid any failures in the future. Contracts should be with clear targets, proper monitoring systems, and sanctions (including immediate termination or financial penalties) for failure to keep to agreements.

- There are seven dumpsites in Cairo Governorate. The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate explained that each site has its own characteristics; one or two sites are authorized landfills and the rest are dumpsites. These sites have been there for more than 50 years, and, due to urbanization, they are now located within the boundaries of Cairo Governorate and have an impact on environmental quality and public health. Interviewee 3 clarified that the government could not relocate these sites for the last 15 years before the contracts of the foreign companies expired. Part of the government's plan after the foreign companies leave is to close all the existing dumpsites and provide new sustainable landfills based on the Egyptian National Solid Waste Management Programme. This is considered a massive challenge for the Public Authority for Cleaning and Beautification of Cairo Governorate, closing and relocating the existing dumpsites is a huge responsibility that exceeds the capacity of the cleaning authority that could not be achieved without the participation of other sectors.

> *"There are seven dumpsites in Cairo Governorate. These sites are in 15th of May, El- Wafaa and El-Amel, Shaq El-Teaban, El-Nahda, El-Katamaya and Helwan. One or two sites of them are authorized landfills. Part of the El-Wafaa and El- Amel site, around 100 feddan are manged by FCC Company. Although, this part is an authorized landfill, the released gas is not collected, so it produces an unpleasant smell. The 15th of May site is an authorized landfill. El-Katamaya site is a controlled dumpsite, but it is not a proper landfill"* (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

> *"These sites have been there for more than 50 years. 50 years ago, the urban mass was far away from these dumpsites, but due to urbanization they became closer. Urban planners should consider the existing dumpsites and the landfills before the urban expansions"* (Interviewee 3,

the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

"Due to the contracts with the foreign companies in the last 15 years the contracts' duration we could not relocate these sites. We did not want to change the contracts to avoid problems. After the foreign companies leave, all these sites will be relocated. The government will close these sites and will provide new sustainable landfills based on the solid waste management strategy. So, the new landfills will be part of the Egyptian National Solid Waste Management Programme" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

One of these dumpsites that are located within the boundaries of Cairo Governorate is shown in Figures (7-14 to 7-17). These Figures explain the huge challenges of relocating these dumpsites outside the boundaries of Cairo Governorate. This requires the participation of many sectors to relocate these dumpsites and to provide alternative sustainable landfills.

Figure 7-14: A dumpsite located within the boundaries of Cairo Governorate (Source: author's site visits).

Figure 7-15: A dumpsite located within the boundaries of Cairo Governorate (Source: author's site visits).

Figure 7-16: A dumpsite located within the boundaries of Cairo Governorate (Source: author's site visits).

Figure 7-17: A dumpsite located within the boundaries of Cairo Governorate (Source: author's site visits).

- The Public Authority for Cleaning and Beautification of Cairo Governorate is facing another challenge: providing intermediate handling stations in most of Cairo Governorate's neighbourhoods, due to the high density and the shortage of land. The main purpose of these stations is to enable waste collectors (scavengers) to collect waste from the residential units and transfer it to these intermediate handling stations using small vehicles, and this enables them to do more trips using less fuel. Large trucks then transfer the waste from the intermediate handling stations to dumpsites or landfills. This is an example of the challenges that faces the Public Authority for Cleaning and Beautification in Cairo Governorate. Although, the cleaning authority is trying to improve the waste management system (specifically the efficiency of the collection system) within the limited capacity of the authority, there are challenges related to the characteristics of the urban settlements (related to the high density and the availability of land to provide intermediate handling stations) that hinders their efforts to improve the waste management system (Figures 7-18 to 7-20 show the challenges that are related to the characteristics of the urban settlements).

  "The intermediate handling stations, in Cairo Governorate, we wanted to provide intermediate handling stations in the neighbourhoods. We wanted the waste collectors (scavengers) to use small waste vehicles to collect the waste for the residential units and transfer it the intermediate handling stations. Then the large waste trucks with bigger capacity transfer the waste from the intermediate handling stations to the dumpsites or the landfills. The waste collectors (scavengers) will be able to make several trips within a residential area. In addition, it will reduce the fuel used to transfer the waste by small vehicles that have limited capacity to the

dumpsites and landfills, which could be far from the residential areas. We found out that it was very difficult to provide intermediate handling stations within the neighbourhoods of Cairo Governorate" (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

Figure 7-18: An example of a high-density settlement located in the centre of Cairo Governorate. This photo shows the difficulty of providing intermediate handling stations to improve the solid waste collection process due to the lack of land (Source: author's site visits).

Figure 7-19: This is an example of an informal settlement in Cairo Governorate. This photo shows the difficulty of accessing (by vehicles) these settlements to provide waste collection services (Source: author’s site visits).

Figure 7-20: This is another example of an informal settlement in Cairo Governorate. This photo shows the difficulty of accessing (by vehicles) these settlements to provide waste collection services (Source: author's site visits).

- As noted above, the failure to properly coordinate the actions of the informal sector is a major challenge to the waste management system in Cairo Governorate. The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate outlined that the informal sector is behind the failure of many projects, which disrupts the development of the waste management sector.

  “There were several trails, but they all failed. We proposed a new project in Cairo Governorate. We distributed some kiosks to buy cans, paper, plastics, glass and cardboard. The garbage collectors (scavengers) were behind the failure of this project. They do not want to share their source of income with anyone” (Interviewee 3, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate).

The challenges that are presented above are part of the challenges of the waste management sector in Cairo Governorate. Some of these challenges are due to the characteristics of Cairo Governorate, while other challenges are due to the limited capacity - institutional, financial and technical - of the Public Authority of the Cleaning and Beautification of Cairo Governorate.

Despite these challenges, the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) clarified that the aim of the cleaning authority during this stage is to provide a comparable level of service to that provided by the foreign companies, although the percentage of the waste collection coverage was not 100%. He explained that they are trying to maintain the existing level of service in Cairo Governorate with the limited capacity of the cleaning authority and they do not want the situation to get worse.

This is a temporary solution until the government establishes a holding company for waste management as there are many attempts, but unfortunately, no actions have been taken yet. However, the Ministry of Environment established a new department for waste management that receives funds from the GIZ. The Waste Management department is currently working closely with the GIZ to prepare the "Egyptian National Solid Waste Management Programme." It is responsible to prepare an integrated waste management strategy for Egypt that includes all the governorates.

The representative of the Public Authority for Cleaning and Beautification of Cairo Governorate (Interviewee 3) has been working in the waste management sector for more than 50 years and he explained that the Ministry of Environment was not involved in the waste management sector during that time (the Ministry of Environment was only established in 1997). Moreover, the Ministry of Environment was not involved when the government was signing the contracts with foreign companies, although it had been established by that time. This indicates that the Ministry of Environment will be taking over the responsibility of the waste management sector without having the practical experience and the required understanding of the major challenges and the day-to-day challenges of managing this sector. Additionally, the Ministry of Environment is not an implementing entity, accordingly, this will limit its role in achieving the objectives of the strategy.

> *"The Ministry of Environment might act as a champion, but it is not an implementing entity"* (Interviewee 2, the representative of the Ministry of Electricity and Renewable Energy).

Despite the efforts of the Public Authority for Cleaning and Beautification of Cairo Governorate to maintain the existing situation of the solid waste sector in Cairo, the overall performance is less than adequate. The Cleaning Authority is facing huge challenges that exceed its capacity. The situation is deteriorating and solid waste generation is increasing rapidly causing massive environmental impacts. This was concluded from the site visits that were part of this research as the low rates of waste collection is a common problem in all types of settlements, but it is worse in informal settlements. The site visits included settlements of different densities (low, medium, and high-density), formal and informal settlements in Cairo Governorate, and near the ring road in 2018. The low rates of waste collection force the inhabitants to throw the solid waste illegally in the streets because of the lack of alternatives. This is a common behaviour all over Cairo Governorate (Figures 7-21 to 7-40 show the piles of garbage thrown illegally in the streets in different areas and settlements in Cairo Governorate).

Figure 7- 21: Dumped waste near the ring road in Cairo Governorate (Source: author’s site visits).

Figure 7- 22: Dumped waste near the ring road in Cairo Governorate (Source: author's site visits).

Figure 7- 23: Dumped waste near the ring road and an informal settlement in Cairo Governorate (Source: author's site visits).

Figure 7- 24: Dumped waste near the ring road and an informal settlement in Cairo Governorate (Source: author's site visits).

Figure 7- 25: Dumped waste near the ring road and an informal settlement in Cairo Governorate. This photo shows the difficulty of accessing narrow streets in informal settlements in order to provide waste collection services. The residents of these areas usually throw the garbage in the streets (Source: author's site visits).

Figure 7- 26: A dumpsite near the ring road and an informal settlement in Cairo Governorate. This photo shows that residents use this area as a dumpsite, creating an environmental and public health hazard (Source: author's site visits).

Figure 7- 27: Dumped waste near the ring road in Cairo Governorate (Source: author's site visits).

Figure 7- 28: Dumped waste on both sides of the ring road (Source: author’s site visits).

Figure 7- 29: Dumped waste near an agricultural drainage (Source: author’s site visits).

Figure 7- 30: Dumped waste under a bridge in Cairo Governorate (Source: author's site visits).

Figure 7- 31: A dumpsite near the entrance of an informal settlement in Cairo Governorate (Source: author's site visits).

Figure 7- 32: Dumped waste near the entrance of an informal settlement in Cairo Governorate or the residents consider it as a dumpsite to get rid of the garbage (Source: author’s site visits).

Figure 7- 33: Dumped waste in a medium-density settlement in Cairo Governorate. This photo shows that residents use this area as a dumpsite due to the low rates of waste collection (Source: author’s site visits).

Figure 7- 34: Dumped waste in a medium-density settlement in Cairo Governorate. This photo shows that residents throw waste in the streets due to the low rates of waste collection (Source: author's site visits).

Figure 7- 35: Dumped waste in a medium-density settlement in Cairo Governorate. This photo shows that residents throw waste in the streets due to the low rates of waste collection (Source: author's site visits).

Figure 7- 36: Dumped waste in a low-density settlement located in a new satellite city, the New Cairo. This photo shows that residents throw waste in the streets due to the low rates of waste collection (Source: author's site visits).

Figure 7- 37: A dumpsite in a low-density settlement located in a new satellite city, the New Cairo. This photo shows that residents use this area as a dumpsite due to the low rates of waste collection and the quantity of the garbage exceeds the capacity of the available containers (Source: author's site visits).

Figure 7-38: A dumpsite in a low-density settlement located in a new satellite city, the New Cairo. This photo shows that residents use this area as a dumpsite due to the low rates of waste collection and the quantity of the garbage exceeds the capacity of the available containers (Source: author’s site visits).

Figure 7- 39: Dumped waste in a low-density settlement located in a new satellite city, the New Cairo. This photo shows that residents use this area as a dumpsite due to the low rates of waste collection and the quantity of the garbage exceeds the capacity of the available containers (Source: author’s site visits).

Figure 7- 40: Dumped waste in a low-density settlement located in a new satellite city, the New Cairo. This photo shows that residents use this area as a dumpsite due to the low rates of waste collection and the quantity of the garbage exceeds the capacity of the available containers (Source: author's site visits).

7.10 Conclusion:

This chapter presented the current and future projections of the municipal solid waste sector in Cairo, Giza and Qalyubia Governorates and Egypt. The solid waste sector is creating considerable challenges for the government of Egypt. The major challenges of the solid waste sector in Egypt are:

- Solid waste generation is rapidly increasing, particularly in Cairo Governorate, due to rapid population growth and urbanization. It is also projected that solid waste generation will increase in Giza Governorate due to high rates of average annual population growth.

- The governance and institutional framework for the solid waste sector in Egypt is not well defined due to the involvement of many partners.
- The lack of a proper waste management system that includes source separation, collection, recycling and reusing, and sustainable landfills.
- The government is unable to properly coordinate the solid waste sector due to the involvement of many sectors in solid waste management (collection, recycling and disposal) that includes the formal sector (such as the councils, non-governmental organizations, and the private companies) and the informal sector (such as El-Zabbaleen in Cairo Governorate).
- The lack of reliable data for the generated solid waste, and the inconsistency of data collection methods. This includes the official statistics.
- Public attitudes and behaviour towards waste disposal.
- The difficulty of accessing the informal and high-density settlements to provide waste collection services, such as in Cairo Governorate's informal settlements.
- The financial and technical challenges of the solid waste sector exceed the capacity of the municipalities that replaced the private companies.

8 Chapter Eight: Discussion

8.1 Introduction

This chapter summarises the findings of the study and how the research aim, objectives and questions are addressed. It discusses the potential and limitations of employing the urban metabolism framework and the customized tool to gain a better understanding of the characteristics of Cairo Governorate, drivers and barriers to sustainable resource management. The chapter evaluates the potential of measuring and understanding the complex interconnections of the flow of resources of cities to enhance the efficient use of local resources, reduce resources importation from the surrounding environment and reduce the environmental impacts of existing flows. Finally, it clarifies the limitations of the study, largely the lack of accurate and reliable data that affected the study's findings, such as data of primary resources at the city level and secondary resources (such as solid waste and wastewater).

8.2 Employing the urban metabolism framework to understand the flow of resources in Cairo Governorate

Holistic approaches are required to address sustainability challenges and up-to-date none of the existing frameworks provide an ultimate solution to address these challenges including the urban metabolism framework (see Chapter 2). Each framework or approach has its advantages and disadvantages and is used for a specific purpose based on the scope of study and influenced by the researcher's field of study or expertise. However, several authors from different disciplines highlighted that the analysis of urban metabolism is an important step towards sustainable urban development and resource management (Kennedy and Hoornweg, 2012; Kennedy et al., 2014; Pincetl and Bunje, 2009).

As previously mentioned in Chapter 2 (section 2.3.4), urban metabolism is a metaphor derived from industrial ecology (Ferrão and Fernández, 2013) that developed and became a well-established framework in existing literature (Céspedes Restrepo and Morales-Pinzón, 2018; Kennedy et al., 2014). The urban metabolism provides a variety of methods, tools and metrics to understand and examine the metabolism of urban systems (John et al., 2019), and it also assesses the level of circularity of resource streams to identify deficiencies in urban systems and opportunities for sustainable improvement (Ferrão and Fernández, 2013). The urban metabolism analysis provides the basic information required to conduct ecological footprint assessment (Pincetl and Bunje, 2009), for circular economy implementation (Kalmykova et al., 2018; Kalmykova and Rosado, 2015; Williams 2019) and for nexus approaches (Hülsmann et al., 2019) (see Chapter 2, section 2.3.4). Furthermore, the urban metabolism framework enables researchers to understand the conditions that created sustainability challenges in urban areas. Jerneck et al. (2010) suggested that understanding these conditions is key for shifting research from problem identification to problem-solving research in sustainability science (see Chapter 2, section 2.3.1).

Therefore, this study employed the urban metabolism framework to explore the challenges of resource management in Cairo Governorate as a first step to understand causes of urban sustainability challenges (such as water scarcity, environmental degradation, inadequate urban services and natural resources shortage). This study is considered a contribution to the field of sustainability science as it employs a holistic approach to identify complex issues regarding resource management and suggests opportunities for sustainable development improvement based on scientific evidence. Additionally, this study contributes to urban metabolism studies as existing literature shows a huge gap for such studies in the Global South (see Chapter 2). It also customizes an urban metabolism tool to overcome the limitations of conducting urban metabolism studies in developing countries (see Chapter 2) and tests its applicability in this context.

Employing the urban metabolism framework and testing an existing urban metabolism tool, the multi-layered indicator set that was developed by Kennedy et al. (2014) in this study, enabled me to better understand the key challenges of resource management in Cairo Governorate, an example of a rapidly urbanizing city in the Global South. The existing multi-layered indicator set was customized in this study to fit in the context of Cairo Governorate (see Chapter 3, section 3.2.2). Although Kennedy et al. (2014) used the multi-layered indicator set to explore the flow of materials of the world's megacities and the Greater Cairo Region was included, Kennedy et al. (2015) mentioned that some of the data of the Greater Cairo Region were unavailable. This study focused on Cairo Governorate rather than the Greater Cairo Region because it is difficult to identify the exact population of megacities as their political boundaries are always changing (Kennedy et al., 2014). Population growth and urbanization are key factors in urban metabolism and help to identify evolving patterns of resource consumption. Assumptions were made in this study that given it is the capital city, the available secondary data of Cairo Governorate will be the most accurate and available data compared to other governorates and the Greater Cairo Region.

This is common in developing countries as access to basic services in urban areas is higher than rural areas and this has a great impact on the quantity and quality of the available data.

Cairo Governorate is considered an appropriate case study for this research because it is a complex case study. Cairo Governorate is the capital of Egypt, a developing country, which is facing massive environmental, social, economic and political challenges. Cairo Governorate includes different types of settlements: 1) planned and unplanned settlements; 2) low, medium and high-density settlements; 3) low, middle and high-income settlements. The urban nature of Cairo and the variety of settlements alongside the difficulty of obtaining data for resources flows complicate the process of conducting urban metabolism studies. Identifying the challenges of resource management in Cairo Governorate requires an integrated approach rather than conventional urban metabolism accounting approaches. The findings of this study reveal that the characteristics of Cairo Governorate have a huge impact on its metabolism. These characteristics would not have been identified with focusing only on the physical dimensions of the flow of resources. Customizing and testing an existing urban metabolism tool in the complex context of Cairo could provide insightful information for conducting such studies in developing countries. Although the results and findings of a single case study do not provide the basis for generalization, there are common features (specifically, the lack of reliable data and informal settlements) in developing countries that could enable the replication of this study in other contexts. However, this study suggests that researchers should adopt the integrated tool that has been used in this study to fit in the specific characteristics of other case studies and to overcome the limitations of this tool that have been identified (these limitations are discussed later in this section). Furthermore, the findings of this study shed light on the importance of including the unmeasurable dimensions of cities' metabolism to better understand the unique characteristics of individual cities, specifically in developing countries.

To better understand the challenges of resource management in Cairo Governorate and its impacts on the surrounding environment, the same data was collected for Giza and Qalyubia Governorates to fill in the customized multi-layered indicator set. Additionally, Cairo Governorate, the urban parts of Giza and Qalyubia are the constituent cities of Greater Cairo Region that are considered one of the largest megacities in Africa (Kennedy et al., 2015). Broto et al. (2012) outlined the importance of conducting comparative urban metabolism studies to identify deficiencies in resource management; however, in this study, the purpose of collecting the same data for Giza and Qalyubia Governorates was not limited to understand the impacts of Cairo Governorate on the surrounding environment, but also to broaden the understandings of the challenges of resource management in the constituent cities of the Greater Cairo Region. The same data were also collected for all Egypt to fill in the customized multi-layered indicator set. This was important to identify the share of resource consumption and production, waste generation, percentage of the population and other layers of information of Cairo Governorate compared to the total of the whole country. This provides a better understanding of the impacts of the flow of resources of Cairo Governorate on a larger scale. Despite that this study considered the integration of top-down and bottom-up approaches by gathering data of the national level (Egypt) and the city level (Cairo) and the surrounding governorates, the study did not consider bottom-up approaches to identify the metabolism of Cairo's 38 neighbourhoods. This is considered one of the limitations of this study because understanding the metabolism of these neighbourhoods is significantly important to improve the metabolism of Cairo Governorate.

Data was collected to fill in the customized multi-layered indicator set from 2000-2001 to 2016-2017. The data was collected for more than 15 years to identify patterns of resource consumption and production over the years and to overcome the lack of accurate data in some situations. It was assumed that the available data on Cairo Governorate would be the most accurate data compared to other governorates. Surprisingly, the major challenges that were identified while filling in the multi-layered indicator set in this study were the lack of accurate data and that the methods of data collection in official statistics and published reports were inconsistent. For example, in some situations the data was missing, and in others data had to be excluded if it was inaccurate. For this reason, the reports for specific years were excluded and replaced by data of other years. The lack of reliable data is explained in depth in the empirical chapters (Chapters 4, 5, 6 and 7 and Appendix 12) of this thesis. In general, collecting data for urban metabolism studies that cover a number of years is better than studies that focus only on one year (Hoekman and Blottnitz, 2017). This enables researchers to identify patterns and changes of resource consumption and production over the years due to population growth, urbanization, economic growth and the availability of resources. In addition, collecting data for urban metabolism studies that cover a number of years in the Global South is also important because it enables researchers to determine the most accurate data that they can use in their studies and exclude misleading data. The purpose of explaining the process of data collection in detail (Chapter 3) and the criteria of including or excluding the available data (Appendix 12), and highlighting the errors in the published reports (Chapters 4, 5 ,6 and 7) were to shed light on the challenges of conducting urban metabolism studies in the Global South. Sharing this information is important to encourage more researchers to overcome the lack of reliable data and to use the existing and most accurate data that is available to provide a baseline for urban metabolism case studies, specifically for cities in the Global South. There is a huge gap in urban metabolism studies for cities in the Global South as identified in Chapter 2 and it is important to fill this gap. Furthermore, pilot studies on smaller scales can be conducted to obtain more accurate data for the flow of resources (Attia and Khalil 2015).

As explained above, the temporal dimension has been considered in the urban metabolism analysis of Cairo Governorate and the changes of consumption and production patterns over the years were identified in this study (see Chapter 8, section 8.4). Although, the spatial dimension was also considered in this study and it was mostly collected from secondary data and site visits (see Chapter 4 and Chapter 8, section 8.3), the use of the geographic information system (GIS) would have been more suitable to provide accurate data on land-use changes, specifically in a rapidly urbanizing city like Cairo. These changes have further implications on the urban infrastructure and resources flows that should be considered. A recent study highlighted the importance of spatiotemporal dimensions for urban metabolism analysis and suggested the use of geographic information system (GIS) to integrate metabolic processes with spatiotemporal information (Tang et al., 2021). In addition, Tang et al. (2021) and Shahrokni et al. (2015) shed light on the effective role of technology and the potential of smart-city technologies in providing real-time and high-resolution data for tracking resources flows in cities and providing more accurate data for urban metabolism studies. Despite the effective role of technology in urban metabolism studies, the access and use of these technologies are still limited in developing countries. The findings of this study show that the percentages of the population with access to the internet in Cairo is considered low if compared to cities in developed nations and should be increased in the future, specifically for the deployment of smart meters (see Chapter 5, Figure 5-47).

The original multi-layered indicator set includes four layers of qualitative and quantitative information (see Chapter 2, Table 2-5). This tool was developed to assess the flow of materials of the world's megacities, which are located in developed countries and developing countries so the tool was designed to fit in different contexts. However, the actual implementation of this tool in Kennedy's et al. (2015) study shows that some areas were excluded such as the food production for all megacities. The original study also shows that megacities in developing countries were excluded from some charts due to the lack of reliable data. In this study, some of these data were excluded or replaced by other data due to different reasons. For example, this study focused on five major sectors (energy, electricity, water, wastewater and solid waste) and excluded the food production because it was already omitted from the original study and the decision was also influenced by my field of study and previous experience. This is another limitation that should have been addressed especially that the findings of this study show that the water scarcity is increasing in Egypt and has a massive impact on food production.

The original multi-layered indicator set included the building gross floor areas for residential, commercial and institutional buildings, but in this study, this data is unavailable so it is replaced by the number of buildings. The total number of buildings might not be important as the building gross floor areas because the latter could identify, for example, the energy required for heating or cooling and the construction materials. However, one of the objectives of this study is to highlight the importance of the missing data that could be considered in the future by the Central Agency for Public Mobilization and Statistics or researchers. The unemployment rate was not included in the original multi-layered indicator set. In this study, the unemployment rates for Cairo, Giza and Qalyubia Governorates and Egypt are included. The unemployment rate is an important indicator of resource management. It shows the job opportunities that could be provided, for example, from the development of renewable energy projects and the establishment of an integrated sustainable waste management system.

Layer 4 in the original multi-layered indicator set mainly focuses on the role of utilities. In this study, data for Layer 4 was collected by conducting semi-structured interviews with members from local authorities to better understand the role of utilities and the quality of services. Access to basic services and access to the internet and mobile phones were collected from secondary data (see Chapter 5, Figures 5-46 and 5-47). Kennedy's et al. (2014) indicator set included other areas such as the number of buildings with photovoltaic panels (PV), number of electric vehicles and number of electric vehicle charging points. These areas are important for developed nations, but for developing countries, they are still in the very early stages of the development of such technologies so these data were excluded from this study.

In this study, conducting semi-structured interviews with representatives from public authorities and site visits to different settlements in Cairo Governorate (low, medium and high-density settlements including formal and informal settlements) transformed the original tool into an urban metabolism multi-dimensional tool. This transformation enabled an in-depth understanding of the unique characteristics and challenges of resource management in Cairo Governorate, particularly the intangible dimensions of resource flows that would not have been identified by relying on quantitative data alone. This study included only four interviews due to the difficulty of accessing decision-makers. None of the interviewees responded to my invitation emails to participate in this study and I had to rely entirely on finding direct connections to reach them. The initial target was to invite more interviewees to assess and compare their responses to provide more accurate and reliable data. However, the four interviews were conducted with high-level key stakeholders; they all come from an academic background (they are all PhD holders and university professors apart from the representative of the Public Authority for Cleaning and Beautification of Cairo Governorate), which made their responses based on scientific information. The data that they have provided was based on their practical experience in public authorities and their academic experience. The average experience of the interviewees is between 30 to 40 years, which makes them experts in their fields. Despite that the data that they have provided included many topics guided by open-ended questions (such as the government's strategies, initiatives and targets, governance, social and economic aspects, technical and institutional capacities, and human behaviour), the political context was rarely discussed. The political situation largely affects the metabolism of cities and the findings of this study (mainly from quantitative data) show that the Egyptian revolution in 2011 had direct and indirect impact on the metabolism of Cairo and the whole country. The data that the interviewees have provided is highly dependent on their personal experience, their level of access to information and what they decide to include or exclude from the discussion. The data that they have provided is also influenced by the lens that they use to discuss specific topics to respond to the open-ended questions. Researchers could overcome these limitations by increasing the number of interviews with interviewees from similar and different sectors and with different level of responsibilities to assess and compare their responses. Despite these limitations, the semi-structured interviews provided a better understanding of the drivers and barriers of resource management for major sectors (energy, electricity, water, wastewater and solid waste).

The data that was collected from the site visits also added another dimension to the study that would not have been achieved by focusing on quantitative (numerical) data only. For example, Figures 4-39 and 4-40 in Chapter 4 show the huge potential for solar energy in Cairo but Figure 5-7 in Chapter 5 shows that the nature of urban form in Cairo hinders the development of distributed systems. Figures 4-11 to 4-18 in Chapter 4 show the growth of informal settlements in different areas in Cairo Governorate and the surrounding governorates, these photos provide a better understanding of the characteristics of such areas and the challenges that they create. The inequality of resources consumption and access to basic services is highly affected by the government's decisions and the characteristics of these informal settlements (see Chapter 4, Figures 4-29 and 4-30). The narrow streets, the quality of buildings, the lack of adequate infrastructure impedes the government's initiatives to increase the percentage of access to basic services. The findings of this study show the importance of site visits in understanding the metabolism of cities, specifically to provide sustainable interventions that fit in the context of individual cities and urban areas.

This study shows that the available data on population, biophysical characteristics and primary resources (energy, electricity and water) at the national level were better than the available data on secondary resources (solid waste and wastewater). This is due to the low percentages of sanitation and waste collection coverage compared to other services at the national level (Chapter 5, section 5.4.10; Chapter 6, section 6.4.4; and Chapter 7, section 7.6). At the city level, the quality of the available data on population growth, biophysical characteristics, electricity and water are better than the available data on primary energy production and consumption (Chapter 5, section 5.3.6) and secondary resources (such as solid waste and wastewater). The lack of reliable data for secondary resources such as solid waste generation and composition is due to the lack of a proper waste management system. Many partners are involved (formal and informal) in the solid waste sector so the government cannot properly coordinate the governance of this sector and it is difficult to exchange the data between partners. The low percentage of waste collection coverage in Cairo, Giza and Qalyubia Governorates, at the city level, provides misleading data on actual solid waste generation (Chapter 5, section 5.4.10; Chapter 6, section 6.4.4; and Chapter 7, section 7.6). One of the major problems of solid waste management in developing countries is the difficulty of obtaining reliable data and the low coverage of waste collection (Wilson et al., 2013).

The illegal connections to the national grid and water networks of informal settlements in Cairo, Giza and Qalyubia Governorates have a great impact on the quality of available data because these connections are uncontrolled. Additionally, the lack of mechanical or smart metering systems in informal settlements to accurately measure water and electricity consumption also creates problems of both governance and data gathering. The quality and the percentage of the sanitation and waste collection services are extremely low in informal settlements, which complicates the process of data collection for urban metabolism studies.

The lack of reliable data at the city level, data collection methods that are inconsistent and the complexity of tracking the flow of resources in informal settlements are common challenges for urban metabolism studies in Africa (Currie and Musango, 2017). Despite, these challenges Currie and Musango (2017) highlighted the importance of conducting urban metabolism studies for African cities to explore resource flows as these studies provide a better understanding of local characteristics and promote sustainable development strategies that fit in the African context (referring to informal settlements and informal economy) rather than following the same approaches of developed nations. In this study, the challenges of the lack of reliable data were identified in the empirical chapters (Chapters 4, 5, 6 and 7 and Appendix 12) and explained in depth the importance of missing or inaccurate data that should be considered in the future to enhance urban metabolism studies and enable policy and decision-makers to identify suitable pathways for sustainable urban strategies (see Chapter 8, section 8.5 and Table 8-1). Quantifying and measuring secondary resources, such as the solid waste generation and composition, and the exact quantities of wastewater can have a great impact on planning for future infrastructure and increasing the use of secondary resources by upgrading them and feeding them back into the city, as well as reducing the environmental impacts of the wastewater and solid waste.

Despite the advantages of employing the urban metabolism framework to understand sustainability challenges of cities and urban areas, the majority of urban metabolism studies and practical approaches largely focus on quantifiable elements of urban systems (such as the physical flows of resources) with minimal consideration of unquantifiable dimensions (such as social, cultural, institutional and political context) (Céspedes Restrepo and Morales-Pinzón, 2018). The findings of this study show that omitting these factors from the urban metabolism studies weakens the analysis of cities' metabolism. Human behaviour, cultural characteristics and practices, institutional capacities and the political context are considered key aspects in shaping the unique characteristics of urban areas and they have a huge impact on the metabolism of cities and resources flows. These unmeasurable factors should be considered in urban metabolism studies to enable sustainability-transitions and tailor sustainable development strategies that fit in the context of individual cities or urban areas. The integration of top-down and bottom-up approaches is important not just to enable researchers to collect data for informal settlements and overcome the lack of reliable data at the city level in developing countries (Musango et al., 2020) but also to enable researchers to collect data on the social, cultural and political context.

Although there is an increasing interest in the field of urban metabolism studies, it is still lacking a unifying framework that could be applied worldwide to conduct comparative studies. Researchers use different tools and approaches to assess the metabolism of cities, the selection criteria are based on the scope of the study, the timeframe of the research and the researchers' field of study and previous experience. Moreover, urban metabolism analysis is significantly influenced by the researcher's field of study and the quality and quantity of the available data. Accordingly, the outcomes of urban metabolism studies are incomparable even when researchers use the same approach or tool the findings of these studies are influenced by the researchers' fields of study and their scientific background. Developing a unifying urban metabolism framework is required to conduct comparative studies worldwide. The engagement of interdisciplinary groups of researchers in constructing a unifying framework is also important to enable individual researchers from different disciplines to add measurable and unmeasurable indicators that consider physical flows of materials and unquantifiable aspects. This study suggests that the engagement of interdisciplinary groups of researchers in urban metabolism studies is also important in the phase of data analysis and interpretation to prevent biases. Cities are complex systems that need to be seen with different perspectives to address sustainability challenges and to understand their causes, and provide integrated and suitable solutions.

The findings of this study confirm the importance of studying the changes of urban metabolism in the context of climate change (Céspedes Restrepo and Morales-Pinzón, 2018). This is another dimension that should be added to the urban metabolism framework. Climate change is expected to affect cities, regions and countries all over the world and in different ways. Understanding the impacts of climate change on the metabolism of cities and different areas is crucial to identify future challenges and develop suitable mitigation and adaptation strategies.

The findings of this study show that the urban metabolism framework enables researchers to identify sustainable development interventions that suit the characteristics of individual cities. However, the environmental impacts of these interventions are considered in most urban metabolism studies while the social impacts are rarely considered. To provide tailored sustainable development interventions that fit with the social and cultural characteristics of different settlements, this study suggests the integration of other methods with the urban metabolism framework such as the Social Life Cycle Assessment (SLCA) participatory approach developed by Mathe (2014). The SLCA participatory approach differs from other social impact assessment approaches as it considers various factors that are important for assessing the value of non-market social impacts. It considers the engagement of multiple stakeholders and the integration of opinions not only of those affected by the impacts but also of those such as public decision-makers who affect the evolution of these impacts through regulatory measures (Mathe, 2014). It also considers the local context and impact categories that make sense for stakeholders in different contexts (Mathe, 2014).

Furthermore, this study identified the challenges of individual sectors and the findings show that resources flows are interconnected, which confirms Currie's et al. (2017) suggestions that any changes occurring in the flow of one of the resources will have impacts on other flows and an integrated approach (integrated analysis of resource nexuses) is required for resource management and infrastructure development. As mentioned in Chapter 2 (section 2.3.4), the scope of urban nexus is on the dynamic interactions, uses systematic approaches to increase the efficiency of these interconnections within the whole urban system to ensure the sustainability of cities overtime (Chen, B. and Chen, 2015). The nexus approach seeks to understand and assess interdependencies across different sectors at different scales to mitigate trade-offs and promote synergies in resource management (Hülsmann and Jampani, 2020). The urban metabolism framework does not explore this dimension although it provides the basic information that is required for the analysis of resource nexuses. Chen, B. and Chen (2015) suggest the integration of urban nexus in the urban metabolism framework to provide more practical approaches for sustainable urban planning and management, and to address challenges of urbanization and environmental changes.

Despite, the limitations of the urban metabolism framework and the customized tool (as explained above) and the challenges of data availability, employing the urban metabolism framework and testing the customised multi-layered indicator set on Cairo Governorate, the surrounding environment (Giza and Qalyubia Governorates) and on a larger scale (the whole country Egypt) provided a baseline for urban metabolism studies in the Global South. It provided a better understanding of the characteristics and conditions that created sustainability challenges in the selected case study (see Chapter 8, section 8-3). It also identified the key challenges of resource management in Cairo Governorate, Egypt and some of the common challenges of resource management and urban metabolism studies in the Global South (see Chapter 8, section 8-4, and Chapter 9, sections 9.2 and 9.3). Employing the urban metabolism framework in this study shifted this research from problem identification to problem-solving research as the findings of this study enabled the identification of the most suitable sustainable development interventions that fit in the context of the case study (see Chapter 8, section 8.5). There is a huge potential to use the urban metabolism framework to explore the future challenges of cities, especially in the Global South where most future urbanization growth is projected (see Chapter 2, section 2.2.2). The urban metabolism framework combines and arranges different types of data including the social, economic, environmental and biophysical characteristics of cities. Organizing these data removes the difficulty of assessing the flow of materials and the environmental impacts of cities that lead to a better understanding of future challenges (Decker et al., 2002).

Section 8.3 discusses the main characteristics of the Cairo Governorate that affect the flow of materials. Section 8.4 discusses the impacts of the flow of resources on the performance of Cairo Governorate towards sustainable development. Challenges of resource management in Cairo Governorate at the end of Chapter 5 (energy and electricity sectors), Chapter 6 (water and wastewater sectors) and Chapter 7 (solid waste sector) are summarized, combined and discussed in Section 8.4 to identify the impacts of the flow of materials on the performance of Cairo Governorate towards sustainable development and its urban carrying capacity. Section 8.5 provides proposals for sustainable development interventions for policymakers in Cairo Governorate.

8.3 The main characteristics of Cairo Governorate (case study) that affect the flow of materials

From 2001 to 2016 the total population of Egypt increased by 25 million inhabitants of which 15 million inhabitants in rural areas and 10 million inhabitants in urban areas. The total population of Egypt reached 98 million inhabitants in 2019 and is projected to reach almost 122 million in 2050 (United Nations, 2014; CAPMAS, 2019). By 2050 it is expected that the urban population will reach 56.5% of the total population of Egypt, adding more than 30 million inhabitants to the urban population of 2016. This shows that the urban population will reach more than 68 million inhabitants by 2050. More pressure will be added to existing cities and infrastructure. Moreover, to absorb this growth a huge amount of resources will be required to build new cities and for the expansion of existing urban areas, and to provide the necessary infrastructure.

The total population of Cairo, Giza and Qalyubia Governorates represents 25% of the total population of Egypt; they live in approximately 3.6% of the total inhabited area of Egypt in 2016 (Chapter 4, Figure 4-27). From 2001 to 2016 the total population of Cairo Giza and Qalyubia Governorates remained 25% of the total population of Egypt (Figures 4-5 and 4-6). The total population of Cairo Governorate reached 9.4 million inhabitants in 2016 (Chapter 4, Figure 4-4). The United Nations defines a megacity as a city that has 10 million inhabitants or more (United Nations, 2016d). If the population of Cairo Governorate continues to grow at the same rate it will become a megacity within the next few years (Chapter 4, Figure 4-9). But Cairo Governorate will be a megacity within an existing megacity, the Greater Cairo Region. The population of Greater Cairo Region was above 19 million inhabitants in 2016 (United Nations, 2016d). The population of Cairo and the surrounding Governorates Giza and Qalyubia have been consistently increasing from 2001 to 2016 (Chapter 4, Figure 4-4). Unfortunately, a huge percentage of the population growth of Cairo, Giza and Qalyubia Governorates was unplanned and spread on the agricultural land in Giza and Qalyubia. Despite, the government's efforts to reduce the density of the Greater Cairo Region by diverting urban growth towards new satellite cities and removing or upgrading informal areas, they failed to prevent the growth of informal settlements (Chapter 4, Figures 4-11 to 4-18).

The highest population increase from 2001 to 2016 was the population of Giza Governorate that was 2.5 million inhabitants, followed by Cairo Governorate 2.1 million inhabitants, with the lowest population increase of 1.6 million in Qalyubia Governorate. Giza Governorate had the highest average annual population growth rates between 2001 and 2016 (Chapter 4, Figure 4-9), the inhabited density of Cairo Governorate consistently increased between 2003 and 2017 (Chapter 4, Figure 4-28). The inhabited density of Egypt reveals the uneven distribution of Egypt's population as it reached more than 50,000 inhabitants per square kilometres in Cairo Governorate, with an inhabited density of all Egypt being less than 1400 inhabitants per square kilometres (Chapter 4, Figure 4-28). Cairo Governorate has the highest inhabited density compared to Giza and Qalyubia Governorates (Chapter 4, Figure 4-28). Cairo Governorate is considered one of the world's most densely cities to the extent that residents, apart from the new satellite cities, occupy most of the roofs of residential buildings. This is considered one of the major challenges that prevent the installation of solar panels on the roofs of residential buildings in Cairo Governorate. Additionally, in high-density settlements in Cairo Governorate, in unplanned settlements, the streets are so narrow that they hinder the flow of resources in and out these areas to provide basic services (Chapter 4, Figures 4-11 to 4-13, Figures 4-29 and 4-30). The growth of informal settlements hampers the ability of the government to achieve the Sustainable Development Goals, specifically:

- Goal 6: clean water and sanitation,
- Goal 7: affordable and clean energy, and
- Goal 11: sustainable cities and communities (United Nations, 2015a).

The population growth of Cairo Governorate has a huge impact on the surrounding governorates as the population of Giza and Qalyubia Governorates consistently increased between 2001 and 2016 (Chapter 4, Figure 4-4) and their average annual population growth rates are higher than the average annual population growth rates of Cairo Governorate and the average of Egypt (Chapter 4, Figure 4-9). Despite that the inhabited density of Cairo Governorate is higher than the inhabited density of Giza and Qalyubia Governorates, the inhabited density of Giza and Qalyubia consistently increased between 2003 and 2017 (Chapter 4, Figure 4-28). Even though a huge amount of this growth was unplanned and spread on the agricultural land of Giza and Qalyubia Governorates, there was also a significant increase in the number of residential, commercial and institutional buildings in both governorates compared to Cairo Governorate from 2006 to 2017 (Chapter 4, Figures 4-32 and 4-36). This shows that the government's efforts to reduce the density of Cairo Governorate had a huge impact on diverting growth towards Giza and Qalyubia Governorates, although, the inhabited density of Cairo Governorate has been consistently increasing over time. Some of the old buildings of Cairo Governorate have been demolished and replaced with multi-storey buildings to absorb more residents. In other cases, if the structure of existing buildings is suitable, more levels are added instead of replacing them with new ones. Accordingly, the number of residential buildings of Cairo Governorate slightly increased from 2006 to 2017 as shown in (Chapter 4, Figure 4-32), but the capacity of these buildings increased to absorb more residents. The problem is that usually increasing the capacity of these buildings is not associated with an equal increase in the capacity of the infrastructure and networks. This adds more pressure and weakens the existing infrastructure and networks, which were designed to meet specific demand of electricity, drinking water and other services; when the demand exceeds their capacity, this leads to the failure of the whole system.

The unemployment rate of Cairo Governorate is considered high compared to the average rates of Egypt and the surrounding governorates Giza and Qalyubia (Chapter 4, Figure 4-23). The overall unemployment rates of the three governorates and the average of Egypt are considered high compared to the world's advanced economies (Chapter 4, Figure 4-24). This was due to the political instability in Egypt arising from the revolution in 2011, which had a massive impact on the social and economic stability of the country. This made the country unattractive for new investments and businesses and it also affected the existing ones. As the centre of political power, Cairo Governorate was the most affected governorate. By 2014, the unemployment rate of Cairo Governorate decreased gradually when the country started to recover from the impacts of the revolution. Additionally, recent reports show that the unemployment rate of Egypt reached 8.6% in 2019 (IMF, 2019). This indicates that the unemployment rate of Egypt is decreasing gradually, and the country started to become more stable. However, the government should provide more job opportunities in Cairo, Giza and Qalyubia Governorates to reduce the unemployment rates and achieve the Sustainable development Goal 8: 'decent work and economic growth' (United Nations, 2015a). This could be achieved by establishing an integrated sustainable waste management system and investing in renewable energy projects. Both sectors require a huge number of labourers, technicians, engineers and a range of skills.

The next section explains the impacts of population growth and urbanization in Cairo Governorate on the flow of resources (energy, electricity, water, solid waste and wastewater) and how these flows affected the performance of Cairo Governorate towards sustainable development and achieving the Sustainable Development Goals (SDGs).

8.4 The impacts of the flow of resources on the performance of Cairo Governorate towards sustainable development

The flow of materials (energy, electricity, water, solid waste and wastewater) indicate that the urban metabolism of Cairo Governorate has been changing over the years and it also has a huge impact on changing the urban metabolism of the surrounding environment (Giza and Qalyubia Governorates). The urban metabolism of Cairo Governorate and the surrounding environment has been changing over the years in different ways based on population growth rates, urbanization, economy, biophysical characteristics, resources production and consumption, quality of infrastructure and access to basic services (Chapters 4, 5, 6 and 7). This supports Kennedy et al.'s findings (2007) that the metabolism of cities is changing and increasing over the years, differing from one place to another based on the climate, energy cost and consumption, age of the city, and stage of development (Chapter 2, section 2.3.4). The metabolism of cities also differs from one place to another based on the percentage of informal settlements (safe and unsafe) in urban areas, the urban form and the density of urban settlements (low, medium and high-density). The ageing infrastructure and metering systems extremely affect the efficient flow of resources of cities. The illegal connections in informal settlements to the national electricity grid and the drinking water networks have a massive impact on the existing infrastructure and the quality of the flow of resources of cities. Moreover, the low percentages of sanitation services and types of treatment, and the low percentages of solid waste collection and the lack of a proper solid waste management system hinder the sustainable flow of resources of cities.

The energy balance of Egypt in 2018 shows that natural gas and crude oil represent 95% of the primary energy production and only 5% of all renewables (Chapter 5, section 5.3.1), despite the huge potential of solar and wind power (see Chapter 4, sections 4.3.4.3 and 4.3.4.4). Data shows that the production and consumption of natural gas from 2013-2014 to 2015-2016 decreased and natural gas consumption exceeded its production (Chapter 5, Figure 5-3). Recent data indicates that the production of natural gas will increase and exceed the level of consumption due to new discoveries. The production of crude oil was almost stable during the same period, but consumption exceeded production (Chapter 5, Figure 5-4). It is expected that the demand for primary energy resources will increase in the future due to the rapid population growth, urbanization and economic growth (see Chapter 4, section 4.2.1). The current energy situation in

Egypt is similar to most other African countries, specifically Northern African countries. Most African countries rely on traditional fuels: oil, natural gas in Northern Africa; biofuels and waste in Middle, Eastern and Western Africa; and oil and biofuels in Southern Africa. Most Northern African countries are resource-driven economies as their economies rely on exporting oil and natural gas (Mandelli et al., 2014). Better use of energy resources is required instead of relying on one or two types of energy (Mandelli et al., 2014). In South Africa, there is a mixed-use of traditional resources, but in general, the majority of African countries depend on fossil fuels with minimal exploitation of renewable resources, despite their huge potential and availability (Mandelli et al., 2014).

Despite the availability of natural gas in Egypt due to the new discoveries, the Egyptian government set a target to increase the share of renewable energy to reach 20% by 2022 and 35% by 2030 of which 5% is targeted to come from hydropower, 16% solar and 14% wind power (Cabinet of Ministers - Arab Republic of Egypt, 2016). By 2035, the share of renewable energy might reach 42%, but this is under revision as the representative of the Ministry of Electricity and Renewable Energy revealed. This shows that the government will focus on solar and wind power to achieve these targets rather than the hydropower as the sources of hydropower are limited in Egypt and there is no potential to increase it (Chapter 5, section 5.3.2). Data shows that the government will be able to achieve the solar power target, but some of the wind projects will be delayed as they are still under negotiations (Chapter 5, section 5.3.3). Additionally, the objective of the energy strategy of Egypt is to reduce the energy intensity of the country by focusing on energy efficiency rather than energy conservation (Chapter 5, section 5.3.10). This will be achieved by developing sectors that provide more job opportunities with less energy consumption (Chapter 5 section 5.4.9.1).

The electricity sector has the highest primary energy consumption compared to other sectors and consistently increased from 2009-2010 to 2016-2017 and is projected to continue increasing due to population growth, urbanization and the change in usage patterns (Chapter 5, section 5.3.7). Currently, the electricity sector is highly subsidized, but the government is gradually removing these subsidies. This will increase future electricity bills. The government aims to change customers’ practices and consumption through price signalling.

The electricity production mix of Egypt between 2002-2003 and 2015-2016 shows that Egypt has been relying on two types of non-renewable energy resources: natural gas and oil with a small share of renewable energy (Chapter 5, section 5.4.1). The electricity production mix of Egypt in 2018 consists of natural gas (82%), oil (8%) with all renewables only making up 10%, of which 7-8% is hydropower and 2-3% other renewable energy resources, mostly wind. The residential sector has the highest electricity consumption (Chapter 5, Figure 5-35). The electricity production mix of Egypt is similar to most of the developing countries that rely on one or two types of non-renewable energy resources for the electricity production that is mainly used in the residential sector (Facchini et al., 2017; Khoury et al., 2016). While in developed countries, the electricity production mix usually includes different types of energy resources rather than relying on one or two types (Facchini et al., 2017) (Chapter 5, section 5.4.1).

The electricity sector has the highest carbon dioxide (CO_2) emissions in Egypt and has been increasing since 2009-2010, reaching 43% by 2016-2017 (Chapter 5, Figures 5-18 and 5-19). The electricity sector has the highest CO_2 emissions in Egypt because the electricity generation mix mainly relies on traditional fuels (natural gas and oil). Given future population and economic growth, the percentage of the CO_2 emissions of the electricity sector will increase significantly in the future if renewable energy resources do not replace conventional fuels and the government does not remove energy subsidies (Chapter 5, section 5.3.9).

It is notable that the government's target to increase the share of renewable energy-focused only on increasing the share of solar and wind power and did not include any targets to increase the development of waste-to-energy and sludge-to-energy projects even though there is a huge potential for such projects in Egypt. Solid waste generation (Chapter 7), wastewater generation (Chapter 6), the average annual population growth rates and urbanization growth (Chapter 4) show that organic waste and wastewater are expected to increase significantly in the future. Waste-to-energy and sludge-to-energy projects are also more suitable in medium and high-density settlements in Egypt as there are many other challenges for distributed renewable energy systems that were explained in Chapter 5 (section 5.3.4). Despite, the challenges of waste-to-energy and sludge-to-energy projects in Egypt were identified and presented in Chapters 6 and 7, there is still a huge potential to increase solid waste collection coverage and sanitation services to maximize the use of these secondary resources, reduce the use of primary resources and reduce the environmental impacts of untreated solid waste and wastewater (Chapter 7, Figures 7-21 to 7-40). Despite that, the capacity factor of waste-to-energy is limited compared to solar and wind energy, the potential of developing these projects refers to the sustainability benefits of effective handling of organic waste and its use as an energy source rather than a quantified potential for energy generation (see Chapter 5, Table 5-2).

Cairo Governorate mainly relies on natural gas and LPG to meet its energy demands (Chapter 5, Table 5-3). Natural gas is mostly used as a cooking fuel in Cairo Governorate (Chapter 5, Figure 5-11). Results of Chapter 5 indicate that Cairo Governorate does not produce any type of energy and relies on other governorates to meet its energy demands. The electricity generation mix of Cairo Governorate is not available, but Egypt's electricity generation mix indicates that Cairo Governorate mainly relies on traditional fuels and the share of renewable energy resources is very low (Chapter 5, Figure 5-23). The average annual growth rate of electricity production and consumption of Cairo Governorate increased significantly over a period of 16 years. However, production was less than consumption. To fill the supply and demand gap Cairo Governorate imports electricity from the surrounding governorates (Chapter 5, section 5.4.8 and Figure 5-32). The average electricity consumption of Cairo Governorate from 1999-2000 to 2015-2016 was 19% of the total electricity consumption of Egypt. This shows that 10% of the total population of Egypt (that live in Cairo Governorate) consume 19% of the total electricity consumption of Egypt over the 16-year period. The average percentage of electricity losses of Egypt is 15-18% (Chapter 5, section 5.4.4); this data is not available for Cairo Governorate. However, the percentage of electricity losses in Cairo Governorate might exceed the average electricity losses of Egypt due to the illegal connections in informal settlements, in addition to the technical and commercial losses (Chapter 5, sections 5.4.4 and 5.4.5).

The residential sector has the highest rates of electricity consumption in Cairo Governorate compared to other sectors (Chapter 5, section 5.4.9.2). Most electricity consumption is required for cooling purposes, as mentioned in Chapter 4 section 4.3.4.1. It is projected that electricity consumption will increase due to the rapid population growth, urbanization, economic growth and climate change. Adapting energy efficiency strategies could reduce the electricity consumption of the residential sector (Krarti and Dubey, 2018; Mirrahimi et al., 2016). Promoting energy efficiency strategies is also important to achieve Sustainable Development Goal 7: 'Ensure access to affordable, reliable, sustainable and modern energy,' Target 7.3: 'By 2030, double the global rate of improvement in energy efficiency' (United Nations, 2015a). Cairo Governorate has the lowest percentage of households without grid connection compared to the average of Egypt (Chapter 5, Figure 5-45). The electricity coverage in Cairo Governorate is considered high compared to the rest of the basic services (see Chapter 5, section 5.4.10 and Figure 5-46).

The patterns of the electricity production and consumption of Cairo Governorates indicate that both will significantly increase in the future and the government has started to gradually remove electricity and energy subsidies. This means that the price of traditional energy will increase. This makes it crucial to maximize the use of renewable energy resources, especially now that their prices are almost equal or less than traditional fuels. Replacing traditional fuels with renewable energy resources is also important to reduce carbon dioxide emissions. Furthermore, Cairo Governorate imports electricity from the surrounding environment to fill the supply and demand gap; providing alternative local resources is fundamental to reduce imports from other ecosystems. Preventing the growth of informal settlements is essential to reduce electricity losses. Upgrading and developing the existing infrastructure and replacing the ageing metering systems with smart metering systems will reduce electricity losses and will enable the government to have better control over the national grid. This will also improve the quality of data on electricity consumption and patterns of electricity usages for future planning and development.

There is a huge potential for solar and wind energy in Cairo Governorate (see Chapter 4, Figures 4-39 and 4-43). However, the process of converting these renewable energy resources into energy is complicated due to the difficulty of resources identification, project identification, technology challenges, biding and financing. The lack of finances, poor regulations, clear policies and legal frameworks, and corruption in some governments prevent the development of renewable energy projects (Khoury et al., 2016). The difficulty of operating the existing electricity national grid with a high share of renewable energy resources (such as hybrid systems) is considered another problem for the expansion of renewable energy projects in Cairo Governorate. The existing grid is not suitable for receiving and transmitting different types of renewable energy resources. The government is currently upgrading the national grid to receive different types of energy resources.

In addition, the urban form and the density of settlements has a huge impact on the development of distributed renewable energy systems, specifically in Cairo Governorate. Wind power is not suitable for inner cities and solar panels are not suitable for medium and high-density settlements in Cairo Governorate.

High buildings beside short buildings create shaded areas that reduce the efficiency of solar panels (Chapter 5, Figure 5-7). The ownership patterns of roofs are also not identified and most of the existing roofs are occupied by the inhabitants of Cairo Governorate due to the high inhabited density (Chapter 4, Figure 4-28).

Moreover, prices of distributed systems are more expensive than the utility size in Egypt. The weak connections in informal settlements are not suitable for distributed systems. The lack of developed banking systems to finance such businesses for high-income households who are able to install solar panels is a problem, as is the absence of financial guarantees that could be provided by customers, particularly households of informal settlements most of them do not have bank accounts. Solar panels can be more efficient in new satellite cities (low-density settlements) that surround Cairo Governorate as urban planning is better and the ownership patterns of roofs are identifiable (Chapter 5, Figure 5-8).

The data for solid waste and wastewater is limited, and it is difficult to identify the patterns of generation over time for Cairo Governorate. However, the existing data of the flow of wastewater in Chapter 6 and the flow of solid waste in Chapter 7 show that there is a huge potential to upgrade organic waste to produce biogas and to develop sludge-to-energy projects. It is predicted that the generation of solid waste and wastewater will increase based on future population growth in Cairo Governorate (Chapter 4, Figure 4-4). The municipal solid waste generation of Cairo Governorate was approximately 6000 tonnes/day in 1983 and reached 17000 tonnes/day in 2018 (Chapter 7, section 7.4). Hoornweg and Bhada-Tata (2012) outlined that most of the global waste generation increase will be in lower-middle-income countries where most megacities will be located in the future (Chapter 2, Figure 2-5). Wilson et al. (2013) shed light on the potential of upgrading organic waste by anaerobic digestion to produce biogas in low-income countries.

Upgrading these secondary resources (solid waste and wastewater) to produce energy are better options for Cairo Governorate, including high-density settlements as other distributed renewable energy systems are not suitable (Chapter 5, section 5.3.4). Both will provide a sustainable and renewable source of energy for Cairo Governorate instead of importing its energy and electricity from other governorates. Currently, Cairo Governorate mainly relies on natural gas for cooking purposes (Chapter 5, Figure 5-11) so the existing grid could be upgraded to replace natural gas with biogas. This will change the flow of the solid waste (secondary resource) - specifically organic waste that represents from 50% to 60% of the total generation of municipal solid waste - from a linear flow into a circular flow by upgrading it and feeding it back into the urban system to reduce the use of natural gas (a primary non-renewable resource). Creating circular flows in the city will create resilient urban systems and close the metabolic flows (Broto et al., 2012; Codoban and Kennedy, 2008).

The data of the municipal solid waste composition of Cairo Governorate is unavailable in official statistics and published reports that were reviewed. The results from semi-structured interviews indicated that the municipal solid waste composition in Cairo Governorate varies from one settlement to another based on the income level (Chapter 7, section 7.5). In high-income settlements, the percentage of dry waste is higher than low-income settlements and the percentage of organic waste is higher in low-income settlements than in high-income settlements. Measuring the actual quantities of organic waste and tracking locations (settlements) of high generation of organic waste are essential to maximize the use of organic waste to produce biogas and to identify the best locations to build anaerobic digestion plants. Splitting municipal solid waste into two categories wet (organic waste) and dry (such as glass, metal and cardboard) is recommended for treating organic waste in developing countries (Wilson et al., 2013).

The driver of upgrading organic waste is not only to produce energy but to ensure the daily collection and treatment of organic waste are also important to reduce the environmental impacts of organic waste. Untreated organic waste emits methane that is worse on the environment than carbon dioxide emissions as 1 ton of methane is equivalent to 25 tons of carbon dioxide (Eurostat, 2020). Baklanov et al. (2016) outlined that capturing methane and waste management projects were part of the successful mitigation strategies that were developed in Mexico to reduce emissions. Other cities in the Global South face similar challenges and pursuing such mitigation strategies is important to promote sustainable urban development (Baklanov et al., 2016).

Transforming organic waste from a burden that no one is interested in (see Chapter 7, section 7.8) into a secondary resource (through upgrading it to produce biogas) is important. This could increase the financial capacity of the solid waste sector in Egypt that could enable the government to establish an integrated sustainable solid waste management system. The governance of the solid waste sector should be defined first, and the institutional settings should be improved before establishing a solid waste management system. Measuring other types of waste is also important to provide suitable treatment to prevent negative environmental impacts from dry and wet waste. This information is important to make better decisions for integrated sustainable solid waste management and resource management.

The percentages of households (including Cairo Governorate, Giza Qalyubia and the whole country Egypt) living in areas without public waste collection and sanitation services are high compared to other basic services (see Chapter 6, Figures 6-34 and 6-35 and Chapter 7, Figures 7-11 and 7-12). This indicates that most of the government's development plans and investments are directed towards increasing access to primary resources (such as the electricity and drinking water) rather than upgrading the available secondary resources (output of cities such as the solid waste and wastewater) and maximizing their uses. Driven by climate change and the scarcity of resources, it is crucial to increase the percentages of waste collection coverage and sanitation services to reduce their environmental impacts and to upgrade these secondary resources and to feed them back into the city. It became a global concern to increase the waste collection coverage and sustainable management, and the sanitation coverage to achieve the Sustainable Development Goals (SDGs) developed by the United Nations specifically; Goal 3 'Ensure healthy lives and promote well-being for all at all ages', Goal 6 'Ensure availability and sustainable management of water and sanitation for all' and Goal 11 'Sustainable cities and communities' (United Nations, 2015a).

Like many other developing countries, the informal sector represents massive challenges for the solid waste sector in Cairo Governorate, and Egypt in general. As explained in Chapter 7, there were many unsuccessful attempts to integrate the informal sector within the formal waste management system in Cairo Governorate. Despite these unsuccessful attempts, it is necessary to integrate the informal sector within the formal framework of the waste management sector to enable the government to better coordinate the activities of this sector. This will improve the government's strategy and planning for establishing an integrated sustainable waste management system. The Sustainable Development Goals (SDGs) Goal 11 'Sustainable cities and communities' indicator 11.6.1 'Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated by cities' outlines the importance of integrating the formal and informal sector for the benefit of both (United Nations, 2015a). The integration of the informal sector could provide better working and living conditions, transform the informal economy and its illegal practices into formal and legal practices and produce better outcomes for society and the environment.

The water and wastewater sectors are creating considerable challenges for the government in Egypt. Water resources are limited (mainly sourced from the River Nile's surface water (Chapter 6, section 6.3.1, Figure 6-1), the annual rainfall and average precipitation are extremely low (Chapter 4, section 4.3.4.2, Figure 4-38), the population is rapidly increasing (Chapter 4, section 4.2.1) and water consumption per capita is decreasing. In addition, the water losses are increasing due to the ageing infrastructure and water metering systems and the illegal connections in informal settlements that weaken the existing infrastructure

(Chapter 6, section 6.3.6.1 Figure 6-17). The government established a strategy to overcome the scarcity of water resources in Egypt that considered many aspects apart from improving the infrastructure of informal settlements. Infrastructure is important because these areas have a massive impact on the consumption of all resources, not just the drinking water. The lack of financing, public awareness, and the political situation of the country delayed the expansion of drinking water projects and the implementation of the government's water strategy.

Moreover, drinking water is used in other purposes like the irrigation of public parks and private gardens, commercial and touristic activities (NWRP, 2017). While the drinking water network in Egypt is designed to provide all activities with the highest quality of water, the required quality of resources (water) differs from one activity to another (Agudelo-Vera et al., 2012). Providing the highest quality of resources for all activities means that some activities receive higher quality than what is actually required. A huge amount of resources are wasted or as mentioned in the Agudelo-Vera et al. (2012, p.4) study the 'quality losses in the system'. To reduce these losses Agudelo-Vera et al. (2012) suggested that the quality of resources should fit the required activities. The quality losses in the drinking water system in Egypt should be considered in designing the drinking water networks with a variety of water quality levels to provide each activity with a suitable quality of water. This will save a huge amount of water and will enhance the efficient use of water resources.

The available data for the wastewater sector in Egypt is limited and mainly focuses on the quantities of the collected wastewater and the types of treatment used, rather than the total generation. This is a common problem for both wastewater and the solid waste (the outputs of cities) or the secondary resources - data is rare and the available data is inaccurate (see section 8.2). This is due to the low percentage of sanitation coverage, so it is difficult to quantify actual wastewater production. However, the government's 2030 strategy for wastewater treatment is to increase sanitation coverage to reach 100%. This will improve the quality of wastewater data. Meanwhile, pilot studies can provide better data and then total production could be estimated.

The current situation of sanitation coverage in Egypt is low, specifically in rural areas as it is only 15%. This has a massive impact on the environment as it increases the pollution levels of the existing water resources and causes health problems that reduce human productivity. It is crucial to transform wastewater into a source of income by upgrading it and feeding it back into urban and rural systems. This will not be achieved without increasing sanitation coverage, the quality of treatment and developing sludge-to-energy projects. It is a global concern nowadays to provide adequate sanitation services for all and eliminate the amount of untreated wastewater to reduce pollution levels. To overcome these challenges wastewater should be considered as a secondary renewable resource that could be a source of income if it was managed efficiently.

The production of the wastewater is expected to increase due to the rapid population growth in Egypt. There is considerable potential to develop sludge-to-energy technologies if the sanitation coverage increased. This will provide Egypt with a renewable source of energy that could reduce the use of fossil fuels and the amount of wastewater that is dumped into water bodies without treatment. Reducing the consumption of fossil fuels could increase the exports of natural gas to other countries that would maintain the flow of hard currency. Hard currency is required to import other important products in the future. As mentioned earlier in this chapter, water scarcity is increasing in Egypt and has a massive impact on food production. The government is banning the production of many crops that require a huge amount of water to grow. These crops are replaced by others that can grow with less water. The government will need hard currency to import other crops and products to meet the increasing demand for food due to rapid population growth. This shows that improving the sanitation coverage and developing sludge-to-energy technology in Egypt could have a significant impact on other sectors, not just the wastewater sector. Efficient resource management requires understanding the condition of each resource separately and then collectively in a more holistic way to develop sustainable strategies and make better decisions for integrated resource management.

Multi-sourcing is vital to secure the stability of urban metabolic systems and water-saving technologies have a great impact on reducing the water demand (Agudelo-Vera et al., 2012; Agudelo-Vera, Mels et al., 2012). Splitting the wastewater network into two different networks sewage and greywater (secondary resources) should be considered in the future to maximize the use of greywater for activities that do not require high-quality water and personal contact, and to limit the use of drinking water (primary resource) for activities that require high-quality water. Greywater is defined as wastewater without any contributions from toilet water (Casanova et al., 2001; Oteng-Peprah et al., 2018; Ottoson and Stenström, 2003).

The situation in Cairo Governorate is similar to drinking water production, consumption and losses of Egypt. The drinking water production of Cairo Governorate was almost stable over a period of 14 years (Chapter 6, Figure 6-18). Drinking water consumption has been decreasing and the losses have been significantly increasing (Chapter 6, Figure 6-18). While water consumption levels have been decreasing over recent years, the total percentage of drinking water consumption of Cairo Governorate and the surrounding governorates (Giza and Qalyubia) still reached 37% of the total consumption of Egypt in 2015-2016 (Chapter 6, Figure 6-25). Most of the increase was in Giza Governorate. This is expected as the average annual population growth of Giza Governorate (3.17%) was the highest compared to other governorates. The total percentage of the drinking water production, consumption and losses are extremely high in Cairo and Giza Governorate compared to the rest of Egypt. The average drinking water losses in Cairo Governorate are 30% in some areas and could even be as high as 40% in informal areas (Chapter 6, section 6.3.9). A huge amount of these water resources is wasted because of the ageing infrastructure (networks and water metering systems) and the poor and illegal connections in informal settlements. The high percentage of drinking water consumption of Cairo Governorate and the surrounding governorates (specifically Giza Governorate) indicates that the drinking water is not equally distributed all over the country. Despite the government’s efforts to reach 100% of drinking water coverage, drinking water consumption per capita differs from one place to another.

Drinking water losses are also associated with a huge amount of energy losses. The production and distribution of drinking water require a huge amount of energy. So, when water losses increase, this means that a percentage of the energy that is used in the production and distribution of the drinking water is also lost. In addition, water losses enter the water cycle again as treated or untreated wastewater (NWRP, 2017). This adds to the amount of energy that is required for wastewater treatment.

The major challenges of the drinking water sector in Cairo Governorate are: the water resources are limited; it mostly relies on surface water with limited potential to increase it; groundwater resources are limited and they are affected by the environmental impacts of urbanization and the leakages of the existing sewage networks; a high percentage of water losses due to illegal connections in informal areas; the ageing infrastructure and metering systems, and the rapid population growth as the average annual growth rate in Cairo Governorate was 1.91% from 2001 to 2016 (Chapter 4, Figure 4-9). Furthermore, the situation might get worse due to the impacts of climate change and water demand is expected to increase for all activities due to economic growth.

Despite the difficulty of identifying the patterns of wastewater generation over a certain period of time due to the lack of data, the most recent available data presented in Chapter 6 shows that in 2011, the total wastewater production of Egypt was 7048 million cubic metre and 52% of the generated wastewater was untreated (Chapter 6, Figure 6-31). The situation of Cairo Governorate was better with the percentage of the wastewater treatment is higher than the rest of the governorates (largely due to more favourable treatment for the nation's capital). The total wastewater production of Cairo Governorate was 1818 million cubic metre in 2011 and 29% of the generated wastewater was untreated (Chapter 6, Figure 6-31). However, sanitation coverage is not an indicator of the percentage of treated or untreated wastewater. In general, the percentages of untreated wastewater in Egypt, Cairo, Giza and Qalyubia Governorates are all considered high. The lack of wastewater treatment and access to sanitation services is a common problem worldwide, especially in the Global South. This evident from the United Nations' statistics that six in ten people lack access to adequate sanitation services and more than 80% of wastewater is discharged into water bodies without treatment (United Nations, 2016c).

The total wastewater production of Egypt was 7048 million cubic metres in 2011 and the total population was 81 million inhabitants. By 2030, the total population of Egypt is expected to reach 112 million inhabitants, and this will be associated with a substantial increase in the production of wastewater as it is expected to be 11673 million cubic metres (AbuZeid and Elrawady, 2014). This is based on the estimates of the "2030 Strategic Vision for Treated Wastewater Reuse in Egypt" (AbuZeid and Elrawady, 2014). The 2030 strategy considered the annual population growth of each governorate in Egypt to provide complete coverage of sanitation services and wastewater treatment. This target is a top governmental priority but is frustrated by the lack of finance available to achieve it. The drinking water tariff does not provide enough funding that is required for extending sanitation services and wastewater treatment.

The percentage of wastewater production of Cairo Governorate and the surrounding governorates (Giza and Qalyubia) was 43% of the total production of Egypt in 2011, of which 26% per cent was in Cairo Governorate (Chapter 6, Figure 6-32). This is the most recent available data. The average annual population growth rates of the three governorates as presented in Chapter 4 (section 4.2.1) indicate that this percentage is expected to increase in the future. The generated wastewater could represent a huge potential for Cairo, Giza and Qalyubia Governorates, if it was considered as a secondary resource and was transformed into a source of income instead of being a burden. This requires increasing sanitation coverage, the percentage of wastewater treatment and the quality of treatment to: maximize the use of treated wastewater that will reduce the consumption of primary water resources and will reduce the pollution levels, maximize the use of sludge-to-energy technology to provide these governorates with a renewable source of energy and reduce the imports and consumption of non-renewable energy resources (see Chapter 5, none of these governorates produces energy) and finally, to improve public health; this will save part of the allocated budget for the health sector. Upgrading the existing sanitation systems to separate sewage and greywater is strongly recommended to maximize the use of greywater in activities that do not require high-quality water and personal contact (Oteng-Peprah et al., 2018).

The outcomes of this study indicate that public behaviour has a huge impact on the flow of resources in Cairo Governorate. For example, public behaviour is considered one of the major challenges for the solid waste sector in Cairo Governorate (Chapter 7, section 7.9.3). The existing financial, technical and institutional capacity of the cleaning authority could not control the behaviour of 10 million inhabitants of Cairo Governorate. Changing public practices could be achieved by developing a schedule for waste collection and the government should strictly enforce the law and apply penalties on lawbreakers. However, this could not be achieved without improving the governance of the solid waste sector and establishing an integrated sustainable waste management system. Both are still under development. Moreover, increasing public participation and awareness campaigns to increase the sense of responsibility and draw attention to the consequences of public behaviour towards solid waste disposal, such as the environmental impacts and health problems, is required.

The study suggests changing household practices to reduce electricity and drinking water consumption is also important, particularly in Cairo Governorate to provide equal distribution of resources all over the country. Yang et al. (2012) outlined that urban household metabolism varies from one place to another and is highly affected by the urban and social context. Yang et al. (2012) indicated that changing the behaviour and lifestyle of households could improve urban sustainability. Urban metabolism describes the interactions between different functions and the environment and human actions are part of these interactions (Broto et al., 2012). Social and economic characteristics of cities affect the metabolism of cities, and governance systems can regulate these relations.

Employing the urban metabolism framework in this study provided a better understanding of the complex interlinkages of the flow of resources in Cairo Governorate. These linkages revealed the impact of inefficient use of resources on the performance of Cairo Governorate towards sustainable development. Previous urban metabolism studies show that researchers were able to determine various dimensions of sustainability within cities and deficiencies in resource management (Broto et al., 2012). Sustainable development should consider finding integrated solutions to provide the most appropriate strategies for all sectors to enhance the effective use of local resources, increase the use of secondary resources and reduce the exploitation of resources from the surrounding environment to build more resilient urban systems (Agudelo-Vera et al., 2012; Broto et al., 2012; Codoban and Kennedy, 2008; Currie et al., 2017).

The outcome of this study supports the findings of Huang and Chen (2009) who explored the impact of urbanization on the urban metabolism of Taipei. The increased demand for energy and other resources exceeded the capacity of the natural ecosystem of Taipei. Most of the energy and material flows of the surrounding areas were directed towards Taipei. Huang and Chen (2009) suggested reducing urban sprawl to improve the performance of the city towards sustainable development. Similarly, the outcome of this study suggests reducing the growth of informal settlements (safe and unsafe) is crucial to improve the performance of Cairo Governorate towards sustainable development and achieving the Sustainable Development Goals (SDGs). The quality of informal settlements and the poor infrastructure – including illegal connections - have a huge impact on the flow of resources in Cairo Governorate. In addition, improving existing informal settlements and providing adequate infrastructure is also important to ensure equal distribution of resources.

Exploring the flow of resources (energy, electricity, water, wastewater and solid waste) of Cairo Governorate, understanding local characteristics and identifying the challenges of each sector indicate that the population growth and urbanization of Cairo Governorate exceed its urban carrying capacity (UCC). Wei et al. (2015, p.65) defined urban carrying capacity as 'the limit of urban development from environmental impacts and natural resources, infrastructure and urban services, public perception, institution setting, and society supporting capacity.' The UCC differs from one place to another because it depends on the interaction between its elements (Chapter 2, Figure 2-9). Cities can improve and increase their capacities in different ways (see Chapter 2 section 2.3.2). This could be achieved by mitigating their environmental footprints (impacts), reducing levels of pollution and reducing the use of natural resources. Providing adequate infrastructure also has a significant impact on the efficiency of resources consumption and the output of cities (González et al., 2013). It is also important devising strategies for improving prospects for residents of rural settlements to reduce internal migration. Increasing financial, technical and institutional capacities of cities are also important, specifically to provide basic services in developing countries.

Furthermore, the findings of this study support Tobbala's (2019) suggestions that the current system of local administration in Egypt relies heavily on centralized decision-making and that the central control leads to policies and strategies that do not meet real local needs (see Chapter 2, section 2.3.2). Top-down administration has created a gap between the central government and the sub-national level (Tobbala, 2019) and the government's initiatives towards decentralization in Egypt are influenced by the idea of central planning that lacks flexibility and adequate response to local needs and public participation (Ibrahim, 2011). The current system lacks transparency in information flows which is essential for effective participation of local communities and accountability of local governments to ensure the efficient and effective use of government resources and delivery of public services (Ibrahim, 2011; Tobbala, 2019; UNDP and INP, 2004). Public participation at local levels is also an indicator of good local governance (UNDP and INP, 2004). Transparency in information flows and accountability of local governments accompanied with good governance reduces information inconsistencies between the government's different institutions as inconsistencies in existing information provides unreliable data for decision-making, planning, setting targets and monitoring (UNDP and INP, 2004). Information flows should be available vertically with central and local governments and horizontally with all sectors and institutions to serve the integrated holistic objectives of sustainable human development (UNDP and INP, 2004) and with Sustainable Development Goal 16, which aims 'to promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels,' Target 16.5 'Substantially reduce corruption and bribery in all their forms', Target 16.6 'Develop effective, accountable and transparent institutions at all levels' and Target 16.7 'Ensure responsive, inclusive, participatory and representative decision-making at all levels' (United Nations, 2015a).

8.5 Sustainable development interventions for Cairo Governorate

Sustainable development requires tailored strategies to fit successfully in a particular place, as each region, country or city has its own characteristics that shape its unique identity. In this study, employing the urban metabolism framework provided a better understanding of the local characteristics and the key challenges of resource management and their impacts on the performance of Cairo Governorate towards sustainable development (section 8.3 and 8.4). This assisted the identification of the most suitable sustainable development interventions for Cairo Governorate as suggested below:

- Developing, upgrading and creating more flexible infrastructure to receive different types of energy resources and increasing the installation of smart metering systems. This will enable the government to have greater control on the flow of resources.

- Preventing the growth of informal settlements and upgrading both safe and unsafe settlements, including their infrastructure. This is vital to reduce the number of illegal connections and losses and to provide better services for all and equal distribution of resources.

- Increasing sanitation and solid waste collection coverage to maximize the development of sludge-to-energy and waste-to-energy projects. This will reduce the use of non-renewable resources (natural gas and oil), carbon dioxide emissions and the environmental impacts of solid waste and wastewater.

- Establishing an integrated sustainable waste management system by redefining the governance of this sector, increasing the financial, technical and institutional capacities of all sectors, and integrating formal and informal sectors. This will enable the government to have full control of the solid waste sector in Cairo Governorate. Accordingly, this will ensure better management and reduce the environmental impacts of the solid waste sector.

- Measuring the actual quantities of organic waste and tracking locations (settlements) of a high generation of organic waste are essential to maximize the use of organic waste to produce biogas and to identify the best locations to build anaerobic digestion plants. Splitting municipal solid waste into two categories, wet (organic waste) and dry (such as glass, metal and cardboard) is recommended for the treatment of organic waste in developing countries (Wilson et al., 2013).

- Splitting the wastewater network into two different networks - sewage and greywater - should be considered to maximize the use of greywater for activities that do not require high-quality water and personal contact, and to limit the use of drinking water for activities that require high-quality of water.
- Continuing the process of removing non-renewable energy, electricity and water subsidies: 1) to increase the financial, institutional and technical capacities of all sectors including wastewater and solid waste to provide better services and to develop the existing infrastructure, and 2) to encourage the use of other alternative renewable energy resources as their prices will be equal or less than non-renewable energy resources after removing the subsidies. Removing subsidies should be accompanied by creating schemes targeted at low-income households to avoid poverty.
- Increasing public engagement and awareness campaigns to encourage behaviour change and alter practices towards solid waste disposal and electricity and water consumption.

Increasing the quality of available data to identify patterns of production and consumption of resources. This could be achieved by conducting pilot studies on smaller scales taking into consideration that resource consumption differs from one settlement to another based on the density and income level. Table 8-1 shows the suggested areas for future data collection.

Table 8-1: Summary of future data collection.

Sector	Future data collection at the *"city level"*
Energy	▪ Primary energy production mix at the city level including renewable and non-renewable energy resources. ▪ Energy consumption by sector at the city level.
Electricity	▪ Electricity production mix at the city level including renewable and non-renewable energy resources. ▪ Electricity consumption per capita.* ▪ Electricity losses (technical and commercial) including planned and unplanned settlements.
Water	▪ Water consumption by sector at city level. ▪ Water consumption per capita.* ▪ Water losses (technical and commercial) including planned and unplanned settlements.
Wastewater	▪ Total wastewater production at city level (the most recent available data was in 2011). ▪ Wastewater methods of treatment at city level (the most recent available data was in 2011). ▪ Sewage and greywater should be split and accurately quantified by conducting pilot projects in different settlements.
Solid waste	▪ Total solid waste generation at the city level. ▪ Solid waste generation per capita.* ▪ Solid waste composition at the city level and in different settlements as it differs from one settlement to another. ▪ Solid waste treatment and disposal methods at city level.

N.B. : * Per capita resources consumption and solid waste generation differ from one settlement to another based on the density and income level, and access to basic services. Data per capita should be accurately measured by conducting pilot studies on a smaller scale in different settlements (low, medium and high-density settlements, formal and informal settlements, and low, middle and high-income settlements).

* Some of the above data are available but the findings of this study show that they are inaccurate and other data are available but need to be updated such as the data of wastewater production and methods of treatment.

9 Chapter Nine: Conclusion

9.1 Introduction

This chapter summarises the conclusion of this study. The potential of employing the urban metabolism framework to identify the challenges of resource management in different contexts is illustrated. The potential of using mixed methods research and multiple sources of data to overcome the lack of reliable data for urban metabolism studies in developing countries is outlined. Recommendations for future studies are presented.

9.2 Summary of findings

Driven by the scarcity of resources and climate change, resource management became crucial for urban sustainability in the Global South, where most future urbanization will take place. A huge amount of resources are required for expanding existing cities and building new cities with sufficient infrastructure where greenhouse gas emissions and all types of waste can be controlled to reduce environmental impacts.

Resource management requires quantifying, assessing, and controlling the flow of materials and energy resources. The major challenges of such studies in the Global South's cities are related to the difficulty of tracking the flow of materials due to the uncontrolled growth of cities, the lack of reliable data at the city level, and inconsistency of data collection methods. (Currie et al., 2017).

The existing literature shows that there is an increasing interest in urban metabolism as a concept, particularly in the Global North and China. A variety of methods and tools have been developed and employed by researchers to assess the flow of materials of urban areas at different scales (levels). Urban metabolism studies identify the deficiencies in urban ecosystems that affect the use and flow of resources that can have a great impact on the directions of future decisions for urban and infrastructure planning.

The existing literature on urban metabolism shows a huge gap for such studies in the Global South. This research addresses this gap by employing the urban metabolism framework to explore the challenges of resource management for urban sustainability in developing countries. An example of a rapidly urbanizing city in the Global South, Cairo Governorate, the capital of Egypt, was selected as a case study for this research. To understand the challenges of Cairo Governorate, the same data was collected for the surrounding Governorates of Giza and Qalyubia. Cairo Governorate and the urban parts of Giza and Qalyubia are the constituent cities of Greater Cairo Region that is considered one of the largest megacities in Africa (Kennedy et al., 2015). Additionally, it was important to compare the data of the three governorates with the whole country to ascertain and quantify, where possible, specific challenges and differences. The data for Cairo, Giza and Qalyubia Governorates and the whole country Egypt was collected from 2000-2001 to 2016-2017.

This study customized an existing urban metabolism tool, the multi-layered indicator set that was developed by Kennedy et al. (2014), to guide the quantitative data collection. Due to the lack of reliable data and the informal context of some areas in the selected case studies, the most suitable tool was the multi-layered indicator set as it targets data that could be practically collected.

It was previously tested in different contexts (the world's megacities). This study was also informed by a number of semi-structured interviews with members from public authorities and site visits (low, medium and high-density settlements) to gain a better understanding of the challenges of resource management.

Based on the qualitative and quantitative data analysis of this study, the key challenges of resource management of Cairo Governorate that were identified are:

- The rates of population growth and urbanization of Cairo Governorate exceeds its urban carrying capacity. Natural resources, environmental impacts, infrastructure and urban services, financial, technical and institutional capacities are considered the most important limits of sustainable urban development in Cairo Governorate.
- The flow of resources of Cairo Governorate are linear flows. Cairo Governorate mainly relies on primary resources (inputs of cities) and secondary resources (outputs of cities) are not efficiently used to feed them back into the city (see Figure 9-1).
- Cairo Governorate mainly relies on primary resources (inputs of cities) including non-renewable energy resources (natural gas and oil), electricity and fresh drinking water. The consumption of these resources has been increasing over a period of more than 15 years (2000-2001 to 2016-2017). The production and consumption of these resources have been changing over time, based on population growth and urbanization, availability of resources, quality of infrastructure, access to basic services and the country's political situation.
- Secondary resources (outputs of cities) of Cairo Governorate such as wastewater and solid waste are rapidly increasing and are expected to

increase in the future. There is a huge potential for the development of sludge-to-energy, waste-to-energy projects and increase in the use of greywater in Cairo Governorate. But major challenges remain: the lack of reliable data; low coverage of solid waste collection; the lack of an integrated solid waste management system; the existing sanitation networks are not designed to split sewage and greywater; limited financial, technical and institutional capacities; and hard to shift public behaviour towards solid waste disposal.

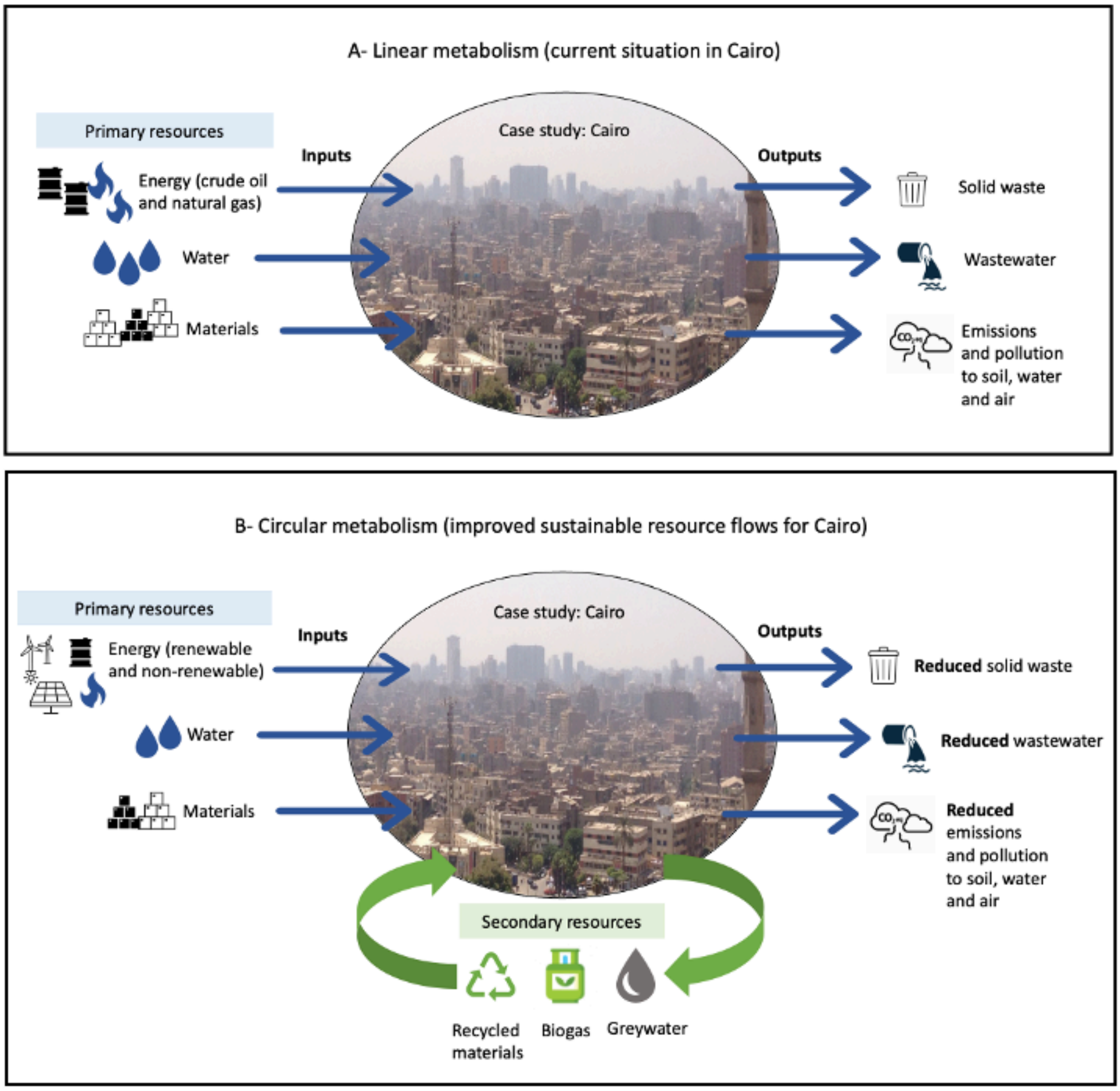


Figure 9-1: This figure shows the linear metabolism in Cairo Governorate (A) and the suggested circular metabolism (B), (Source: this figure is adapted from Agudelo-Vera et al. (2012)).

- Various challenges complicate the process of data collection for measuring the actual consumption and production of resources to assess and control the use of resources. These include: ageing infrastructure and metering systems; the low coverage of waste collection and treatment; the high percentage of informal settlements (safe and unsafe) and illegal connections of informal settlements, which have a huge impact on the quality and losses of the flow of resources in Cairo Governorate.
- The flow of resources of Cairo Governorate differ from one place to another based on the density and income level of the urban settlements.
- Cairo Governorate exploits most of the local resources (mostly primary resources) and imports external resources to meet its increasing demands.
- The population growth and urbanization of Cairo Governorate has a huge impact on the local environment and the surrounding environment. The population growth of Giza and Qalyubia Governorates has been significantly increasing between 2001 and 2016. Their average annual population growth rates are higher than Cairo Governorate and the average of Egypt. The average annual population growth rates and the trends of resources production and consumption of Giza and Qalyubia indicate that a huge amount of resources will be required to meet their future demands. These surrounding governorates will not be able to export resources to Cairo Governorate in the future to meet their own increasing demands.
- There is a huge potential for renewable energy resources in Cairo Governorate. However, they do not fit the local characteristics of Cairo

Governorate. Wind energy is not suitable for inner cities, the high-density of Cairo Governorate, urban forms (high and short buildings create shaded areas that reduce the efficiency of solar panels), most of the buildings' roofs are occupied and the ownership patterns are not identified, the existing infrastructure could not operate with different types of energy resources and a high percentage of informal settlements (safe and unsafe areas) prevent the expansion of distributed renewable energy systems.

- Primary resources (such as energy, electricity and drinking water) have long been highly subsidised. This delayed the development of renewable energy projects and secondary resources (such as solid waste and wastewater or greywater).

Understanding the key challenges of the selected case study for this research, providing a better understanding of the common challenges of resource management in developing countries. Yet, each city should explore its own challenges to provide tailored sustainable urban development strategies that fit in the context where they are being developed.

9.3 The major challenges of resource management in developing countries

The findings of this study suggest that the key challenge of resource management in developing countries is the lack of a comprehensive understanding of the interplay and interdependencies between resources and various flows. This supports the findings of Currie et al. (2017) who employed a simple urban metabolism assessment to explore the resource consumption of Cape Town. The outcome of Currie et al. (2017) study suggests that any changes occurring in the flow of one of the resources will have impacts on other flows and that all resources are interlinked. This leads to the need for an integrated approach (*integrated analysis of resource nexuses*) for resource management and infrastructure development (Currie et al., 2017).

In addition, the lack of understanding of the existing urban carrying capacity of cities and the limits of existing cities from natural resources, institutional settings, the existing infrastructure and other components of the urban carrying capacity that is necessary to identify the sustainable urban development pathways and strategies. As sustainable urban development strategies mainly depend on local conditions and the urban carrying capacity of cities in which they are being developed, cities have to improve and increase their capacities in different ways (see Chapter 2).

An integrated approach is required for resource management in the Global South to better understand the flow of resources (inputs and outputs of cities) within the urban carrying capacity of individual cities and integrating the flow of resources (primary and secondary resources) to reduce the environmental impacts of urban areas, meet the increasing demand of resources and improve cities performance towards sustainable development and achieving Sustainable Development Goals (SDGs). Cities can also improve and increase their capacities in different ways by:

- Reducing the use of non-renewable resources and increasing the use of renewable energy resources.
- Mitigating their environmental impacts.

- Improving and developing their institutional settings to cope with population growth and urbanization.
- Developing and upgrading the existing infrastructure (including grid, networks and metering systems) to be more flexible (such as upgrading the grid to receive different types of renewable energy resources and upgrading water networks to make use of greywater), to monitor and control the flow of resources, and to reduce losses.
- Ensuring the equal distribution of resources and basic services for rural and urban settlements to reduce internal migration.
- Removing non-renewable energy, electricity and water subsidies: 1) to increase the financial, institutional and technical capacities of all sectors, including wastewater and solid waste to provide better services and to develop the existing infrastructure, 2) to encourage the use of other alternative renewable energy resources as their prices will be equal or less than non-renewable energy resources after removing subsidies. Removing subsidies should be accompanied by creating low-income household schemes to avoid poverty.

The lack of reliable and accurate data is also considered a major challenge for resource management and urban metabolism studies in the Global South because resource management requires measuring, assessing and controlling the use of resources that includes primary resources (such as renewable and non-renewable energy resources and water) and secondary resources (such as solid waste and wastewater). The lack of reliable data in the Global South is due to the informal flow of materials as a result of illegal connections in the informal settlements, methods of data collection being inconsistent (including official statistics and published reports) and data at the city level being usually unavailable. This is a common problem in Africa as Currie and Musango (2017) outlined that the major challenges of urban metabolism studies in Africa are the lack of city-level reliable data, the methods of data collection are inconsistent and the complexity of tracking the flow of resources in informal settlements.

Furthermore, the findings of the study indicate that the available data on primary resources (such as energy and water resources) is more accurate than the data on secondary resources (such as solid waste and wastewater); this is due to the low levels of sanitation and waste collection coverage in developing countries specifically in rural areas (covered in Chapters 5, 6 and 7). The scarcity of data also affects the quality and quantity of resource management studies in the Global South (see Chapter 2). The lack of reliable data has a massive impact on the creation of robust urban sustainability strategies tailored to the unique characteristics of urban areas and the availability of primary and secondary resources.

9.4 Recommendations for future research

- The urban metabolism framework provides a better understanding of the flow of resources and the local characteristics of cities and the surrounding environment. This could assist decision-makers to manage available resources efficiently and reduce the environmental impacts of cities. Researchers could conduct urban metabolism studies to identify deficiencies of resource management of cities or at different scales.
- Existing literature on urban metabolism and material flow analysis indicated that most of the case studies are for cities in the Global North and China,

and very few cases are explored in the Global South, specifically in Africa. Filling this gap in the future is recommended to increase the urban metabolism studies in the Global South. This will enable researchers to conduct comparative studies and to exchange knowledge of successful practices for resource management.

- The existing literature on urban metabolism studies shows that many researchers have developed a variety of tools to explore the flow of resources of cities. This study recommends using the multi-layered indicator that was developed by Kennedy et al. (2014) because, it targets data that could be easily collected, was successfully tested in previous studies, suitable for different contexts, arranges and integrates different types of data to assess the flow of resources of cities.
- Mixed methods research design is recommended for urban metabolism studies to gain a better understanding of resource management in different contexts, specifically for cities in the Global South. These cities are facing uncommon challenges because the trends of population and urbanization growth differ from cities in the Global North.
- The findings of this study suggest that it is important when undertaking urban metabolism studies in developing countries to collect data from multiple sources to overcome the lack of accurate data at the city level.
- For future urban metabolism studies, it is recommended to track the flow of resources for a longer period of time to identify patterns of resources production and consumption. This provides policy and decision-makers with more accurate data that enables them to make better decisions for sustainable resource management. It is also important to overcome the lack

of data and to identify the most accurate data that could be used in urban metabolism studies in developing countries (poor data countries).

- Researchers should recognize the importance of the missing data and how it affects the development of sustainable strategies in developing countries and address these gaps in future studies.
- The quality of infrastructure and buildings differs from one place to another and this has a great impact on the flow of resources within the city. Urban metabolism studies, specifically in the Global South should explore the quality of the flow of resources within cities not only measuring and assessing the quantities of the inputs and outputs of cities.
- This study suggests the importance of understanding the existing urban carrying capacity of cities and limits of urban development to enable decision-makers to promote sustainable interventions strategies to increase the capacity of cities without causing environmental impacts and to absorb the projected urbanization growth, specifically cities in the Global South.

References

Abdel Wahaab, R., 2003, Sustainable Development and Environmental Impact Assessment in Egypt: Historical Assessment, *The Environmentalist,* vol. 23, no. 1, pp. 49-70.

Abdel-Shafy, H., El-Saharty, A., Regelsberger, M. & Platzer, C., 2010, Rainwater in Egypt: quantity, distribution and harvesting, *Mediterranean marine science,* vol. 11, no. 2, pp. 245-257.

Abernethy, V.D., 2001, Carrying capacity: the tradition and policy implications of limits, *Ethics in Science and Environmental Politics,* vol. 2001, no. 1, pp. 9-18.

AbuZeid, K.M. & Elrawady, M., 2014, *2030 Strategic Vision for Treated Wastewater Reuse in Egypt*, Water Resources Management Program - CEDARE, Egypt.

Acselrad, H., 1999, Sustainability and the city, *EURE (Santiago),* vol. 25, no. 74, pp. 36-46.

Agudelo, C., Mels, A. & Rovers, R., 2009, "Urban water tissue: Analysing the urban water harvest potential", *3rd CIB International Conference on Smart and Sustainable Built Environments (SASBE), Delft. Available at: http://www. sasbe2009. com/papers. html*.

Agudelo-Vera, C.M., Mels, A.R., Keesman, K.J. & Rijnaarts, H.H.M., 2011, Resource management as a key factor for sustainable urban planning, *Journal of Environmental Management,* vol. 92, no. 10, pp. 2295-2303.

Agudelo-Vera, C., Leduc, Wouter R. W. A., Mels, A.R. & Rijnaarts, H.H.M., 2012, Harvesting urban resources towards more resilient cities, *Resources, Conservation & Recycling,* vol. 64, pp. 3-12.

Agudelo-Vera, C., Mels, A., Keesman, K. & Rijnaarts, H., 2012, The Urban Harvest Approach as an Aid for Sustainable Urban Resource Planning, *Journal of Industrial Ecology,* vol. 16, no. 6, pp. 839-850.

Attia, S. & Khalil, H.A., 2015, "Urban metabolism and quality of life in informal areas", *REAL CORP 2015: Plan Together – Right Now – Overall* Ghent, Belgium, May 2015, pp. 661.

Baklanov, A., Molina, L.T. & Gauss, M., 2016, Megacities, air quality and climate, *Atmospheric Environment,* vol. 126, pp. 235-249.

Barles, S., 2009, Urban Metabolism of Paris and Its Region, *Journal of Industrial Ecology,* vol. 13, no. 6, pp. 898-913.

Beck, M.B. & Villarroel Walker, R., 2013, On water security, sustainability, and the water-food-energy-climate nexus, *Frontiers of Environmental Science & Engineering,* vol. 7, no. 5, pp. 626-639.

Beloin-Saint-Pierre, D., Rugani, B., Lasvaux, S., Mailhac, A., Popovici, E., Sibiude, G., Benetto, E. & Schiopu, N., 2017, A review of urban metabolism studies to identify key methodological choices for future harmonization and implementation, *Journal of Cleaner Production,* vol. 163, pp. S223-S240.

BMI 2015, Egypt Power Report - Q3 2015, Business Monitor International, London.

Boulding, K.E., 1966, The Economics of the Coming Spaceship Earth. Available: http://www.zo.utexas.edu/courses/THOC/Boulding_SpaceshipEarth.pdf [8 December 2020].

Bringezu, S., 2018, "Key Strategies to Achieve the SDGs and Consequences for Monitoring Resource Use" in Managing Water, Soil and Waste Resources to Achieve Sustainable Development Goals, Springer International Publishing, Cham, pp. 11-34.

Broto, V.C., Allen, A. & Rapoport, E., 2012, Interdisciplinary Perspectives on Urban Metabolism, *Journal of Industrial Ecology,* vol. 16, no. 6, pp. 851-861.

Brunner, P.H., 2007, Reshaping Urban Metabolism, *Journal of Industrial Ecology,* vol. 11, no. 2, pp. 11-13.

Butler, T.M., Lawrence, M.G., Gurjar, B.R., van Aardenne, J., Schultz, M. & Lelieveld, J., 2008, The representation of emissions from megacities in global emission inventories, *Atmospheric Environment,* vol. 42, no. 4, pp. 703-719.

Cabinet of Ministers 2016, *Sustainable Development Strategy: Egypt Vision 2030*, Cabinet of Ministers, Egypt.

CAPMAS 2019, *Current Population* [Homepage of Central Agency for Public Mobilization and Statistics] [Online].
Available: https://www.capmas.gov.eg/HomePage.aspx [Accessed: 2 February 2019].

CAPMAS 2018a, *Annual Bulletin of Public Utilities Services at the Level of Cities and Districts Councils 2017 Report*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2018b, *The Annual Bulletin of Pure Water and Sanitation Statistics 2016-2017*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2018c, *Egypt in Figures 2018*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2018d, *Egypt Statistical Yearbook 2018,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017a, *The Annual Bulletin of Drinking Water and Sanitation Statistics 2015-2016*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017b, *Electricity and Energy annual report 2015-2016*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017c, *The Energy Balance 2015-2016 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017d, *Population, Housing and Establishment Census, Egypt Census 2017,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017e, *Statistics of Public Utility Services Supervised by the Local Councils 2016 Report*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2017f, *Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2016a, *Egypt Statistical Yearbook 2016,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2016b, *Electricity and Energy annual report 2014-2015*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2016c, *Statistical Yearbook - Environment 2016,* The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2015a, *The Energy Balance 2014-2015 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2015b, *Statistical Yearbook - Environment 2015,* The Central Agency for Public Mobilization ad Statistics, Egypt.

CAPMAS 2014a, *The Annual Bulletin for Drinking Water Purification, Distribution and Selling 2012-2013*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2014b, *The Energy Balance 2013-2014 Report*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2014c, *The Future of Energy in Egypt 2014 report*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2014d, *Statistical Yearbook - Environment 2014,* The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2013a, *Electricity and Energy annual report 2011-2012*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2013b, *Statistics of Public Utility Services Supervised by the Local Councils 2012 Report*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2012a, *The Annual Bulletin for Drinking Water Purification, Distribution and Selling 2010-2011*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2012b, *Egypt in Figures 2012,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2012c, *Electricity and Energy annual report 2010-2011*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2011a, *Egypt in Figures 2011,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2011b, *Electricity and Energy annual report 2009-2010*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2010, *Statistics of Water Collection, Purification and Distribution 2008-2009*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2009, *Egypt in Figures 2009,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2008a, *Electricity and Energy annual report 2006-2007*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2008b, *Statistics of Public Utility Services Supervised by the Local Councils 2006 Report*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2008c, *Statistics of Water Collection, Purification and Distribution 2006-2007*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2007a, *Egypt in Figures 2007,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2007b, *Electricity and Energy annual report 2005-2006*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2007c, *Statistics of Water Collection, Purification and Distribution 2005-2006*, Central Agency of Public Mobilization and Statistics, Egypt.

CAPMAS 2006a, *Egypt in Figures 2006,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2006b, *Statistics of Water Collection, Purification and Distribution 2004-2005*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2004a, *Electricity and Energy annual report 2002-2003*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2004b, *Statistics of Water Collection, Purification and Distribution 2002-2003*, Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2003a, *Egypt in figures 2002,* Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2003b, *Electricity and Energy annual report 2001-2002*, The Central Agency for Public Mobilization and Statistics, Egypt.

CAPMAS 2003c, *Statistics of Water Collection, Purification and Distribution 2001-2002*, Central Agency of Public Mobilization and Statistics, Egypt.

CAPMAS 2001, *Electricity and Energy annual report 1999-2000*, The Central Agency for Public Mobilization and Statistics, Egypt.

Casanova, L.M., Gerba, C.P. & Karpiscak, M., 2001, Chemical and microbial characterization of household graywater, *Journal of Environmental Science and Health, Part A,* vol. 36, no. 4, pp. 395-401.

Catney, P. & Doyle, T., 2011, The welfare of now and the green (post) politics of the future, *Critical Social Policy,* vol. 31, no. 2, pp. 174-193.

Céspedes Restrepo, J.D. & Morales-Pinzón, T., 2018, Urban metabolism and sustainability: Precedents, genesis and research perspectives, *Resources, Conservation and Recycling,* vol. 131, pp. 216-224.

Chen, B. & Chen, S., 2015, Urban metabolism and nexus, *Ecological Informatics,* vol. 26, pp. 1-2.

Chirisa, I., Bandauko, E., Mazhindu, E., Kwangwama, N.A. & Chikowore, G., 2016, Building Resilient Infrastructure in the Face of Climate Change in African Cities: Scope, Potentiality and Challenges, *Development Southern Africa,* vol. 33, no. 1, pp. 113-127.

Clarke, V. & Braun, V., 2017, Thematic analysis, *The Journal of Positive Psychology,* vol. 12, no. 3, pp. 297-298.

Codoban, N. & Kennedy, C.A., 2008, Metabolism of Neighborhoods, *Journal of Urban Planning & Development,* vol. 134, no. 1, pp. 21-31.

Cooper, W.W., Seiford, L.M. & Tone, K., 2007, *Data Envelopment Analysis : A Comprehensive Text with Models, Applications, References and DEA-Solver Software,* Second Edition edn. Springer, Boston.

Creswell, J.W., 2014, *Research design : qualitative, quantitative, and mixed methods approaches,* 4th edn. SAGE, Los Angeles, Calif.

Creswell, J.W., 2009, *Research design: qualitative, quantitative, and mixed methods approaches,* 3rd edn. Sage, Los Angeles.

Creswell, J.W. & Plano Clark, V.L., 2017, *Designing and conducting mixed methods research,* SAGE, Los Angeles.

Cuddihy, J., Kennedy, C. & Byer, P., 2005, Energy use in Canada: environmental impacts and opportunities in relationship to infrastructure systems1, *Canadian Journal of Civil Engineering,* vol. 32, no. 1, pp. 1-15.

Currie, P.K. & Musango, J.K., 2017, African Urbanization: Assimilating Urban Metabolism into Sustainability Discourse and Practice, *Journal of Industrial Ecology,* vol. 21, no. 5, pp. 1262-1276.

Currie, P.K., Musango, J.K. & May, N.D., 2017, Urban metabolism: A review with reference to Cape Town, *Cities,* vol. 70, pp. 91-110.

Dang, H. & Unger, N., 2015, Contrasting regional versus global radiative forcing by megacity pollution emissions, *Atmospheric Environment,* vol. 119, pp. 322-329.

David, S., Gordon, M. & Cecilia, T., 2010, Urbanization and its implications for food and farming, *Philosophical Transactions: Biological Sciences,* vol. 365, no. 1554, pp. 2809-2820.

Decker, E.H., Elliott, S. & Smith, F.A., 2002, Megacities and the Environment, *The Scientific World Journal,* vol. 2, pp. 374-386.

Decuir-Gunby, J., Marshall, P.L. & Mcculloch, A.W., 2011, Developing and Using a Codebook for the Analysis of Interview Data: An Example from a Professional Development Research Project, *Field Methods,* vol. 23, no. 2, pp. 136-155.

DTU 2018a, *Global Wind Atlas, Arab Republic of Egypt* [Homepage of The World Group Bank] [Online]. Available: https://globalwindatlas.info/en/area/Arab%20Republic%20of%20Egypt?print=true [Accessed: 23 February 2019].

DTU 2018b, *Global Wind Atlas, World* [Homepage of The World Bank Group] [Online]. Available: https://globalwindatlas.info/en/downloads/World [Accessed: 24 February 2019].

EgyptERA 2017, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2015-2016*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt.

EgyptERA 2014, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2012-2013*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt.

EgyptERA 2012, *The Annual Report of the Electricity Consumption Indicators for the Economic Activities 2010-2011*, Egyptian Electricity Utility and Consumer Protection Regulatory Agency, Egypt.

EIA 2015, *Country Analysis Brief: Egypt* [Homepage of U.S. Energy Information Administration] [Online].
Available: https://www.eia.gov/beta/international/analysis.php?iso=EGY
[Accessed: 26 January 2019].

Ellen MacArthur Foundation 2015, Growth within: A circular economy vision for a competitive Europe.
Available: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf [8 December 2020].

Ellen MacArthur Foundation 2013, Towards the Circular Economy : Economic and Business Rationale for an Accelerated Transition.
Available: https://www.werktrends.nl/app/uploads/2015/06/Rapport_McKinsey-Towards_A_Circular_Economy.pdf [8 December 2020].

Ellis, J.B., 1999, "Impacts of urban growth on surface water and groundwater quality", *Proceedings of an international symposium held during IUGG 99, the XXII General Assembly of the International Union of Geodesy and Geophysics, at Birmingham, UK,*IAHS Press, Wallingford, 18-30 July 1999.

Eurostat 2017, *Energy statistics - cooling and heating degree days* [Homepage of Eurostat, the Statistical Office of the European Union] [Online].
Available: https://ec.europa.eu/eurostat/cache/metadata/fr/nrg_chdd_esms.htm
[Accessed: 20 February 2019].

Facchini, A., Kennedy, C., Stewart, I. & Mele, R., 2017, The energy metabolism of megacities, *Applied Energy,* vol. 45, no. 9, pp. 80.

FAO 2016, *AQUASTAT Country Profile- Egypt*, Food and Agriculture Organization of the United Nation (FAO), Rome, Italy.

Ferrão, P. & Fernández, J.E., 2013, Sustainable Urban Metabolism, The MIT Press, Cambridge, Massachusetts; London, England.

Feyerabend, P., 1991, Three dialogues on knowledge*,* Blackwell, Oxford.

Folberth, G.A., Butler, T.M., Collins, W.J. & Rumbold, S.T., 2015, Megacities and climate change – A brief overview, *Environmental Pollution,* vol. 203, pp. 235-242.

Frosch, R.A. & Gallopoulos, N.E., 1989, Strategies for Manufacturing, *Scientific American,* vol. 261, no. 3, pp. 144-153.

Giljum, S. & Hubacek, K., 2009, "Conceptual Foundations and Applications of Physical Input-Output Tables" in *Handbook of Input-Output Economics in Industrial Ecology* Springer, Dordrecht, pp. 61-75.

González, A., Donnelly, A., Jones, M., Chrysoulakis, N. & Lopes, M., 2013, A decision-support system for sustainable urban metabolism in Europe, *Environmental Impact Assessment Review,* vol. 38, pp. 109-119.

Gonzalez-Garcia, S., Manteiga, R., Moreira, M.T. & Feijoo, G., 2018, Assessing the sustainability of Spanish cities considering environmental and socio economic indicators, *Journal of Cleaner Production,* vol. 178, pp. 599-610.

Google Maps, 2019, *Egypt* [Homepage of Google] [Online]. Available: https://www.google.com/maps/place/Egypt/ [Accessed: November 2019].

GOPP 2012, *Greater Cairo Urban Development Strategy, Part 1: Future Vision and Strategic Direction*, The General Organisation for Physical Planning, Egypt.

Goudie, A., 2019, Human Impact on the Natural Environment*,* 8th edn. Wiley Blackwell, Hoboken, NJ.

Guibrunet, L., 2017, The contribution of the informal economy to urban sustainability: case study of waste management in Tepito, Mexico City, ProQuest Dissertations Publishing.

Harris, S., Martin, M. & Diener, D., 2021, Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy. *Sustainable Production and Consumption,* vol. 26, pp. 172-186.

Hector, D.C., Christensen, C.B. & Petrie, J., 2014, Sustainability and Sustainable Development: Philosophical Distinctions and Practical Implications, *Environmental values,* vol. 23, no. 1, pp. 7-28.

Hedeya, R. , 2012, *Egypt Urban Issues* [Homepage of United Nations Habitat] [Online]. Available: https://unhabitat.org/egypt/urban-issues/ [Accessed: 23 January 2019].

Hoekman, P. & Blottnitz, H., 2017, Cape Town's Metabolism: Insights from a Material Flow Analysis, *Journal of Industrial Ecology,* vol. 21, no. 5, pp. 1237-1249.

Hoornweg, D. & Bhada-Tata, P. 2012, *What a Waste: A Global Review of Solid Waste Management*, World Bank, Washington, DC.

Hoornweg, D., Bhada-Tata, P. & Kennedy, C., 2015, Peak Waste: When Is It Likely to Occur? *Journal of Industrial Ecology,* vol. 19, no. 1, pp. 117-128.

Huang, S. & Chen, C., 2009, Urbanization and Socioeconomic Metabolism in Taipei, *Journal of Industrial Ecology,* vol. 13, no. 1, pp. 75-93.

Hülsmann, S. & Jampani, M., 2020, "The Nexus Approach as a Tool for *Resources Management* in Resilient Cities and Multifunctional Land-Use Systems" in *A Nexus Approach for Sustainable Development* Springer International Publishing, Cham, pp. 1-13.

Hülsmann, S., Sušnik, J., Rinke, K., Langan, S., van Wijk, D., Janssen, A.B. & Mooij, W.M., 2019, Integrated modelling and management of water resources: the ecosystem perspective on the nexus approach, *Current Opinion in Environmental Sustainability,* vol. 40, pp. 14-20.

Ibrahim, A., 2012, Renewable energy sources in the Egyptian electricity market: A review, *Renewable and Sustainable Energy Reviews,* vol. 16, no. 1, pp. 216-230.

Ibrahim, A., 2011, Challenging limitations for achieving decentralization in terms of participatory planning in developing countries, Case Study: Egypt, *WIT Transactions on Ecology and the Environment,* vol. 150, pp. 699.

Ibrahim, M.I.M. & Mohamed, Nanis Abd El Monem, 2016, Towards Sustainable Management of Solid Waste in Egypt, *Procedia Environmental Sciences,* vol. 34, pp. 336-347.

IMF 2019, *World Economic Outlook (October 2019) - Unemployment rate* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/external/datamapper/LUR@WEO [Accessed: 30 March 2020].

IMF DataMapper 2018a, *Country Data, Egypt* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/en/Countries/EGY [Accessed: 13 February 2019].

IMF DataMapper 2018b, *World Economic Outlook, People, Unemployment Rate* [Homepage of International Monetary Fund] [Online]. Available: https://www.imf.org/external/datamapper/LUR@WEO/ADVEC/EGY [Accessed: 13 February 2019].

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., Hornborg, A., Kronsell, A., Lövbrand, E. & Persson, J., 2010, Structuring sustainability science, *Sustainability Science,* vol. 6, no. 1, pp. 69-82.

John, B., Luederitz, C., Lang, D.J. & Von Wehrden, H., 2019, Toward Sustainable Urban Metabolisms. From System Understanding to System Transformation, *Ecological Economics,* vol. 157, pp. 402-414.

Johnson, R.B., Onwuegbuzie, A.J. & Turner, L.A., 2007, Toward a Definition of Mixed Methods Research, *Journal of Mixed Methods Research,* vol. 1, no. 2, pp. 112-133.

Kalmykova, Y. & Rosado, L., 2015, "Urban Metabolism as Framework for Circular Economy Design for Cities", *World Resources Forum (2015)*, Davos, 11 – 14 October 2015.

Kalmykova, Y., Sadagopan, M. & Rosado, L., 2018, Circular economy – From review of theories and practices to development of implementation tools, *Resources, Conservation and Recycling,* vol. 135, pp. 190-201.

Kanakidou, M., Mihalopoulos, N., Kindap, T., Im, U., Vrekoussis, M., Gerasopoulos, E., Dermitzaki, E., Unal, A., Koçak, M., Markakis, K., Melas, D., Kouvarakis, G., Youssef, A.F., Richter, A., Hatzianastassiou, N., Hilboll, A., Ebojie, F., Wittrock, F., von Savigny, C. & Burrows, J.P., 2011, Megacities as hot spots of air pollution in the East Mediterranean, *Atmospheric Environment,* vol. 45, no. 6, pp. 1223-1235.

Kates, R.W., 2001, Environment and Development: Sustainability Science, *Science (American Association for the Advancement of Science); Science,* vol. 292, no. 5517, pp. 641-642.

Keirstead, J. & Sivakumar, A., 2012, Using Activity-Based Modelling to Simulate Urban Resource Demands at High Spatial and Temporal Resolutions, *Journal of Industrial Ecology,* vol. 16, no. 6, pp. 889-900.

Kennedy, C., Stewart, I.D., Ibrahim, N., Facchini, A. & Mele, R., 2014, Developing a multi-layered indicator set for urban metabolism studies in megacities, *Ecological Indicators,* vol. 47, pp. 7-15.

Kennedy, C.A., Stewart, I., Facchini, A., Cersosimo, I., Mele, R., Chen, B., Uda, M., Kansal, A., Chiu, A., Kwi-gon Kim, Dubeux, C., La Rovere, E.L., Cunha, B., Pincetl, S., Keirstead, J., Barles, S., Pusaka, S., Gunawan, J., Adegbile, M. & Nazariha, M., 2015, Energy and material flows of megacities, *Proceedings of the National Academy of Sciences of the United States of America,* vol. 112, no. 19, pp. 5985-5990.

Kennedy, C., Cuddihy, J. & Engel-Yan, J., 2007, The Changing Metabolism of Cities, *Journal of Industrial Ecology,* vol. 11, no. 2, pp. 43-59.

Kennedy, C. & Hoornweg, D., 2012, Mainstreaming Urban Metabolism, *Journal of Industrial Ecology,* vol. 16, no. 6, pp. 780-782.

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A. & Mendez, G.V., 2010, Methodology for inventorying greenhouse gas emissions from global cities, *Energy Policy,* vol. 38, no. 9, pp. 4828-4837.

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A. & Villalba Mendez, G., 2009, Greenhouse gas emissions from global cities, *Environmental science & technology,* vol. 43, no. 19, pp. 7297-7302.

Kenway, S.J., Lant, P.A., Priestley, A. & Daniels, P., 2011, The connection between water and energy in cities: a review, *Water science and technology; Water Sci Technol,* vol. 63, no. 9, pp. 1983-1990.

Khalifa, M.A., 2011, Redefining slums in Egypt: Unplanned versus unsafe areas, *Habitat International,* vol. 35, no. 1, pp. 40-49.

Khoury, J., Mbayed, R., Salloum, G., Monmasson, E. & Guerrero, J., 2016, Review on the integration of photovoltaic renewable energy in developing countries—Special attention to the Lebanese case, *Renewable and Sustainable Energy Reviews,* vol. 57, pp. 562-575.

Komiyama, H. & Takeuchi, K., 2006, Sustainability science: building a new discipline, *Sustainability Science,* vol. 1, no. 1, pp. 1-6.

Kool, R., 2013, Limits to Growth, environmental science and the nature of modern prophecy, *Ecological Economics,* vol. 85, pp. 1-5.

Krarti, M. & Dubey, K., 2018, Benefits of energy efficiency programs for residential buildings in Bahrain, *Journal of Building Engineering,* vol. 18, pp. 40-50.

Kuhn, T., 1962, The structure of scientific revolutions, University of Chicago Press.

Lazarevic, D. & Valve, H., 2017, Narrating expectations for the circular economy: Towards a common and contested European transition, *Energy research & social science,* vol. 3, pp. 60-69.

Leduc, Wouter R. W. A. & Van Kann, Ferry M. G., 2013, Spatial planning based on urban energy harvesting toward productive urban regions, *Journal of Cleaner Production,* vol. 39, pp. 180-190.

Lucertini, G. & Musco, F., 2020, Circular Urban Metabolism Framework, *One Earth,* vol. 2, no. 2, pp. 138-142.

Luck, L., Jackson, D. & Usher, K., 2006, Case study: a bridge across the paradigms, *Nursing Inquiry,* vol. 13, no. 2, pp. 103-109.

Lwasa, S., Buyana, K., Kasaija, P. & Mutyaba, J., 2018, Scenarios for adaptation and mitigation in urban Africa under 1.5°C global warming, *Current Opinion in Environmental Sustainability,* vol. 30, pp. 52-58.

Mandelli, S., Barbieri, J., Mattarolo, L. & Colombo, E., 2014, Sustainable energy in Africa: A comprehensive data and policies review. *Renewable and Sustainable Energy Reviews,* vol. 37, pp. 656-686.

Mathe, S., 2014, Integrating participatory approaches into social life cycle assessment: the SLCA participatory approach, *The international journal of life cycle assessment,* vol. 19, no.8, pp. 1506-1514.

Mavropoulos, A., 2010, Megacities sustainable development and waste management in the 21st century*. ISWA working paper.* Available: https://www.iswa.org/uploads/tx_iswaknowledgebase/Mavropoulos.pdf [5 November 2019].

Meadows, D.H., Randers, J. & Meadows, D.L., 2005, The limits to growth: the 30-year update*,* Earthscan, London.

Miller, L.A., Ramaswami, A. & Ranjan, R., 2013a, Contribution of Water and Wastewater Infrastructures to Urban Energy Metabolism and Greenhouse Gas

Emissions in Cities in India, *Journal of Environmental Engineering,* vol. 139, no. 5, pp. 738-745.

Miller, T.R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D. & Loorbach, D., 2013b, The future of sustainability science: a solutions-oriented research agenda, *Sustainability science,* vol. 9, no. 2, pp. 239-246.

Mirrahimi, S., Mohamed, M.F., Haw, L.C., Ibrahim, N.L.N., Yusoff, W.F.M. & Aflaki, A., 2016, The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate, *Renewable and Sustainable Energy Reviews,* vol. 53, pp. 1508-1519.

Moles, R., Foley, W., Morrissey, J. & O'Regan, B., 2008, Practical appraisal of sustainable development—Methodologies for sustainability measurement at settlement level, *Environmental Impact Assessment Review,* vol. 28, no. 2, pp. 144-165.

MPMAR 2019, *Economic Indicators- GDP* [Homepage of Ministry of Planning Monitoring and Administrative Reform] [Online]. Available: http://mpmar.gov.eg/ [Accessed: 8 February 2019].

Musango, J.K., Currie, P. & Robinson, B., 2017, Urban metabolism for resource efficient cities: from theory to implementation, UN Environment., Paris.

Musango, J.K., Currie, P., Smit, S. & Kovacic, Z., 2020, Urban metabolism of the informal city: Probing and measuring the ‘unmeasurable’ to monitor Sustainable Development Goal 11 indicators, *Ecological Indicators,* vol. 119, pp. 106746.

Ness, B., Anderberg, S. & Olsson, L., 2010, Structuring problems in sustainability science: The multi-level DPSIR framework, *Geoforum,* vol. 41, no. 3, pp. 479-488.

Ness, B., Urbel-Piirsalu, E., Anderberg, S. & Olsson, L., 2007, Categorising tools for sustainability assessment, *Ecological Economics,* vol. 60, no. 3, pp. 498-508.

Niza, S., Rosado, L. & Ferrão, P., 2009, Urban Metabolism, *Journal of Industrial Ecology,* vol. 13, no. 3, pp. 384-405.

NWRP 2017, National Water Resources Plan *(2017- 2030- 2037)*, Ministry of Water Resources and Irrigation, Egypt.

Odum, H.T., 1996, Environmental Accounting: Emergy and Environmental Decision *Making,* Wiley, New York.

Oteng-Peprah, M., Acheampong, M. & deVries, N., 2018, Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review, *Water, Air, & Soil Pollution; An International Journal of Environmental Pollution,* vol. 229, no. 8, pp. 1-16.

Ottoson, J. & Stenström, T.A., 2003, Faecal contamination of greywater and associated microbial risks, *Water research,* vol. 37, no. 3, pp. 645-655.

Papaioannou, N., 2013, Environmental Impact Assessment and Optimization of Urban Energy Systems, Imperial College London.

Pincetl, S. & Bunje, P.M.E., 2009, Potential targets and benefits for sustainable communities research, development, and demonstration funded by the pier program*: Prepared for California Energy Commission*, UCLA Institute of the Environment, Los Angeles, CA.

Pinho, P., Oliveira, V., Cruz, S.S. & Barbosa, M., 2013, Metabolic Impact Assessment for urban planning, *Journal of Environmental Planning & Management,* vol. 56, no. 2, pp. 178-193.

Plano Clark, V.L. & Ivankova, N.V., 2016, *Mixed methods research,* SAGE, Los Angeles.

Reymond, P., Abdel Wahaab, R., Moussa, M.S. & Lüthi, C., 2018, Scaling up small scale wastewater treatment systems in low- and middle-income countries: An analysis of challenges and ways forward through the case of Egypt, *Utilities Policy,* vol. 52, pp. 13-21.

Rogers, R.H., 2018, Coding and Writing Analytic Memos on Qualitative Data: A Review of Johnny Saldaña's The Coding Manual for Qualitative Researchers, *The Qualitative Report,* vol. 23, no. 4, pp. 889-892.

Rosado, L., Kalmykova, Y. & Patrício, J., 2017, Reprint of: Urban metabolism profiles. An empirical analysis of the material flow characteristics of three metropolitan areas in Sweden, *Journal of Cleaner Production,* vol. 163, pp. S254-S266.

Rosado, L., Niza, S. & Ferrão, P., 2014, A Material Flow Accounting Case Study of the Lisbon Metropolitan Area using the Urban Metabolism Analyst Model, *Journal of Industrial Ecology,* vol. 18, no. 1, pp. 84-101.

Rossman, G.B. & Wilson, B.L., 1985, Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study, *Evaluation review,* vol. 9, no. 5, pp. 627-643.

Ryan, G.W. & Bernard, H.R., 2003, Techniques to Identify Themes, *Field Methods,* vol. 15, no. 1, pp. 85-109.

Seto, K.C., Golden, J.S., Alberti, M. & Turner, B.L., 2017, Sustainability in an urbanizing planet, *Proceedings of the National Academy of Sciences – PNAS* (Proc. Natl. Acad. Sci. U.S.A.), vol. 114, no. 34, pp. 8935-8938.

Shah, A., 1999, Balance, Accountability, and Responsiveness: Lessons about Decentralization, Policy Research Working Papers 2021, The World Bank, Washington DC.

Shahrokni, H., Lazarevic, D. & Brandt, N., 2015, Smart Urban Metabolism: Towards a Real-Time Understanding of the Energy and Material Flows of a City and Its Citizens, *Journal of Urban Technology,* vol. 22, no. 1, pp. 65-86.

Shi, Y., Wang, H. & Yin, C., 2013, Evaluation method of urban land population carrying capacity based on GIS—A case of Shanghai, China, *Computers, Environment and Urban Systems,* vol. 39, pp. 27-38.

Shouman, E.R. & Khattab, N.M., 2015, Future economic of concentrating solar power (CSP) for electricity generation in Egypt, *Renewable and Sustainable Energy Reviews,* vol. 41, pp. 1119-1127.

Silpa Kaza, Lisa Yao, Perinaz Bhada-Tata & Frank Van Woerden, 2018, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, The World Bank, Washington, DC, USA.

Solargis 2017a, *Global Solar Atlas, Egypt* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/downloads/egypt [Accessed: 23 February 2019].

Solargis 2017b, *Global Solar Atlas, World* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/downloads/world [Accessed: 24 February 2019].

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M. & O'Connell, D., 2017, Integration: the key to implementing the Sustainable Development Goals, *Sustainability Science; Sustain Sci,* vol. 12, no. 6, pp. 911.

Stahel, W.R., 2010, The performance economy, Palgrave Macmillan, Basingstoke, UK.

Stahel, W.R. & Reday-Mulvey, G., 1981, Jobs for Tomorrow: The Potential for Substituting Man-power for Energy, Vantage Press.

Sullivan, A.M., 1985, The Pricing of Urban Services and the Spatial Distribution Residence, *Land Economics,* vol. 61, no. 1, pp. 17.

SWEEP-Net 2014, *Country Report on the Solid Waste Management in Egypt*, GIZ, Egypt.

Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J.K., Ramaswami, A., Robinson, B., Salat, S., Suh, S., Currie, P., Fang, A., Hanson, A., Kruit, K., Reiner, M., Smit, S. & Tabory, S., 2018, The weight of cities, *Our Planet,* vol. 2017, no. 4, pp. 36-37.

Tang, M., Hong, J., Guo, S., Liu, G. & Shen, G.Q., 2021, A bibliometric review of urban energy metabolism: Evolutionary trends and the application of network analytical methods, *Journal of Cleaner Production,* vol. 279, pp. 123403.

Tashakkori, A. & Teddlie, C., 2003, *Handbook of mixed methods in social & behavioral research,* SAGE Publications, Thousand Oaks, Calif.

The General Organization for Physical Planning, (GOPP), the United Nations Human Settlements Programme (UN-Habitat) & the United Nations Development Programme (UNDP) 2012, *Greater Cairo Urban Development strategy, Part 1: Future Vision and Strategic Directions*, GOPP, Egypt.

The World Bank 2019a, *Average precipitation in depth (mm per year)* [Homepage of The World Bank Group] [Online]. Available: https://data.worldbank.org/indicator/ag.lnd.prcp.mm?view=map [Accessed: 22 February 2019].

The World Bank 2019b, *DataBank World Development Indicators* [Homepage of The World Bank Group] [Online]. Available: https://databank.worldbank.org/data/reports.aspx?source=2&series=NY.GDP.PCAP.CD&country=EGY [Accessed: 9 February 2019].

The World Bank 1994, *World Development Report 1994, Infrastructure for Development,* Oxford University Press, New York.

The World Bank Group 2018, *Global Wind Atlas* [Homepage of The World Bank Group] [Online]. Available: https://globalwindatlas.info/ [Accessed: 10 February 2019].

The World Bank Group 2017, *The world by income, FY2017* [Homepage of The World bank Group] [Online]. Available: http://datatopics.worldbank.org/sdgatlas/archive/2017/the-world-by-income.html [Accessed: 1 July 2019].

The World Bank Group 2016a, *Country Income Groups (World Bank Classification)* [Homepage of The World Bank Group] [Online]. Available: http://chartsbin.com/view/2438 [5 November 2019].

The World Bank Group 2016b, *Global Solar Atlas* [Homepage of The World Bank Group] [Online]. Available: https://globalsolaratlas.info/ [Accessed: 10 February 2019].

Tobbala, S., 2019, Towards a Decentralized Governance System in EGYPT. Available: https://www.iprjb.org/journals/index.php/JPPA/article/view/884 [3 November 2020].

UNDP 2003, *Egypt Human Development Report 2003,* United Nations Development Programme and the Institute of National Planning, Cairo, Egypt.

UNDP 1997, *Decentralized Governance Programme: Strengthening Capacity for People Centered Development*, UNDP, Management Development and Governance Division, Bureau for Development Policy, New York.

UNDP 1993, *Human Development Report 1993*, Oxford University Press, New York.

UNDP & INP, 2004, *Egypt Human Development Report Decentralization Choosing Decentralization for Good Governance* [Homepage of UNDP] [Online]. Available: http://hdr.undp.org/en/content/egypt-human-development-report-decentralization [3 November 2020].

UNEP 2011, *Towards a green economy: pathways to sustainable development and poverty eradication* [Homepage of United Nations Environment Programme] [Online].
Available: http://all62.jp/ecoacademy/images/15/green_economy_report.pdf [5 November 2019].

UNESDOC 2017, *Guidelines on sustainability science in research and education*. Available: https://unesdoc.unesco.org/ark:/48223/pf0000260600 [11 November 2020].

UN-Habitat 2020, *World Cities Report 2020: The Value of Sustainable Urbanization* [Homepage of UN- Habitat] [Online].
Available: https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf [13 November 2020].

UN-Habitat 2015, *HABITAT III ISSUE PAPERS: 22 - INFORMAL SETTLEMENTS*, United Nations, New York.

United Cities and Local Governments, UCLG 2014, *Basic Services for All in an Urbanizing World: Third Global Report on Local Democracy and Decentralization*, Routledge, New York.

United Nations 2019, *World Urbanization Prospects 2018*, United Nations, New York.

United Nations 2018, *The World's Cities in 2018,* United Nations, New York.

United Nations 2016a, *The New Urban Agenda - Habitat III* [Homepage of The United Nations] [Online]. Available: http://habitat3.org/the-new-urban-agenda/ [Accessed: 26 January 2019].

United Nations 2016b, *The New Urban Agenda Habitat III Zero Draft Outcome Document (May 2016)*, The United Nations.

United Nations 2016c, *Sustainable Development Goals, Goal 6: Ensure access to water and sanitation for all* [Homepage of The United Nations] [Online]. Available: https://www.un.org/sustainabledevelopment/water-and-sanitation/ [Accessed: 9 June 2019].

United Nations 2016d, *The World's Cities in 2016,* United Nations, New York.

United Nations 2015a, *Sustainable Development Goals* [Homepage of United Nations] [Online]. Available: https://sustainabledevelopment.un.org/sdgs [September 2019].

United Nations 2015b, *Transforming our world: The 2030 Agenda for Sustainable Development* [Homepage of United Nations] [Online]. Available: https://sustainabledevelopment.un.org/post2015/transformingourworld/publication [11 November 2020].

United Nations 2015c, *World Population Prospects, The 2015 Revision*, United Nations, New York.

United Nations 2014, *World Urbanization Prospects, the 2014 Revision,* United Nations, New York.

United Nations 2013a, *World Economic and Social Survey 2013: Sustainable Development Challenges* [Homepage of United Nations] [Online]. Available: https://www.un.org/development/desa/dpad/publication/world-economic-and-social-survey-2013/ [13 November 2020].

United Nations 2013b, *World Population Prospects: The 2012 Revision*, United Nations, New York.

United Nations 2012, *General maps, Egypt* . Available: https://www.un.org/Depts/Cartographic/map/profile/egypt.pdf [Accessed: 22 May 2019].

United Nations 2002, *World urbanization prospects, the 2001 revision,* United Nations, New York.

United Nations, Department of Field Support Cartographic Section, 2012, *Map of Egypt* . Available: http://www.un.org/Depts/Cartographic/map/profile/egypt.pdf [Accessed: 2 March 2019].

United Nations, Economic & Social Affairs, 2016, *The World's Cities in 2016* [Homepage of The United Nations] [Online]. Available: http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf [Accessed: 2 December 2018].

Wackernagel, M. & Rees, W., 1995, Our ecological footprint reducing human impact on the earth, New Society, Canada.

Wahba, S.M., Scott, K. & Steinberger, J.K., 2018, Analyzing Egypt's water footprint based on trade balance and expenditure inequality, *Journal of Cleaner Production,* vol. 198, pp. 1526-1535.

Wallis, J.J. & Oates, W.E., 1988, "Decentralization in the Public Sector: An Empirical Study of State and Local Government" in *Fiscal Federalism:*

Quantitative Studies, National Bureau of Economic Research, ed. H.S. Rosen, University of Chicago Press, Chicago, pp. 5-32.

Wei, Y., Huang, C., Lam, P.T.I. & Yuan, Z., 2015, Sustainable urban development: A review on urban carrying capacity assessment, *Habitat International,* vol. 46, pp. 64-71.

Wei, Y., Huang, C., Li, J. & Xie, L., 2016, An evaluation model for urban carrying capacity: A case study of China's mega-cities, *Habitat International,* vol. 53, pp. 87-96.

Williams, J., 2019, Circular cities, *Urban studies (Edinburgh, Scotland),* vol. 56, no. 13, pp. 2746-2762.

Wilson, D., Velis, C. & Rodic, L., 2013, Integrated sustainable waste management in developing countries, *Proceedings of the Institution of Civil Engineers,* vol. 166, no. 2, pp. 52-68.

Wolman, A., 1965, The Metabolism of Cities, *Scientific American,* vol. 213, no. 3, pp. 178-193.

Wong, S., Tang, B. & van Horen, B., 2006, Strategic urban management in China: A case study of Guangzhou Development District, *Habitat International,* vol. 30, no. 3, pp. 645-667.

World Commission on Environment, and Development (WCED) & Brundtland, G.H., 1987, *Our common future,* Oxford University Press, Oxford.

World Health Organization 2006, *Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulphur dioxide,* WHO Regional Office for Europe, Copenhagen, Denmark.

Yang, D., Gao, L., Xiao, L. & Wang, R., 2012, Cross-boundary environmental effects of urban household metabolism based on an urban spatial conceptual framework: a comparative case of Xiamen, *Journal of Cleaner Production,* vol. 27, pp. 1-10.

Yang, D., Kao, W.T.M., Zhang, G. & Zhang, N., 2014, Evaluating spatiotemporal differences and sustainability of Xiamen urban metabolism using emergy synthesis, *Ecological Modelling,* vol. 272, pp. 40-48.

Zaki, T., Kafafi, A.G., Mina, M.B. & Abd El- Halim, M., 2013, *Annual Report for Solid Waste Management in Egypt, 2013*, Ministry of State for Environmental Affairs, National Solid Waste Management Programme (NSWMP), Egypt.

Zhang, L.X., Chen, B., Yang, Z.F., Chen, G.Q., Jiang, M.M. & Liu, G.Y., 2009a, Comparison of typical mega cities in China using emergy synthesis, *Communications in Nonlinear Science & Numerical Simulation,* vol. 14, no. 6, pp. 2827-2836.

Zhang, Y., 2013, Urban metabolism: A review of research methodologies, *Environmental Pollution,* vol. 178, pp. 463-473.

Zhang, Y., Yang, Z. & Yu, X., 2015, Urban Metabolism: A Review of Current Knowledge and Directions for Future Study, *Environmental Science & Technology,* vol. 49, no. 19, pp. 11247-11263.

Zhang, Y., Yang, Z. & Yu, X., 2009b, Ecological network and emergy analysis of urban metabolic systems: Model development, and a case study of four Chinese cities, *Ecological Modelling,* vol. 220, no. 11, pp. 1431-1442.

Appendices

Appendix 1

Indicator set for metabolism studies in megacities

Name of reporter: e-mail:

Layer 1: definition of megacity.

Name of megacity[1]	
Population (year round residents) 2001[2]	
Population (year round residents) 2006	
Population (year round residents) 2011	
GDP (2001)	
GDP (2006)	
GDP (2011)	
Is there a formal level of government for the metropolitan area?	Yes ○ No ○
Is there one or more coordinating bodies between constituent cities in the megacity? (If yes, give name)	Yes ○ No ○
Names of constituent cities (i.e. local municipalities)	

[1] There is not a universally accepted approach for defining the boundaries of megacities. In practice, availability of data will dictate what area is used. Where there is choice, please try to use a region with a population of similar magnitude to that in Appendix A.

[2] Alternatively use years 2000, 2005 and 2010 throughout (2001, 2006 and 2011 are census years in many countries).

Layer 2: biophysical characteristics.

Land area (sq. kilometres)
Urbanized area (sq. kilometres)
Heating degree days (18 °C base)[1]
Cooling degree days (25 °C base)
Annual precipitation (mm)
Annual solar radiation (kW h/m^2)
Building gross floor areas (m^2)[2]
Residential
Commercial and institutional industrial

[1] HDD and CDD for 2011 can be determined at www.degreedays.net.
[2] Gross floor area includes floor area on all storeys.

Layer 3: urban metabolism.

	2001	2006	2011	Units	Source/comments/assumptions
Energy (stationary)					
Electricity consumption (on-site renewable)				GW h	
Electricity consumption (grid)				GW h	
Electrical line losses (or non-revenue electricity)				GW h	
Natural gas (excluding power generation)				TJ	
Fuel oil (excluding power generation)				TJ	
Coal (excluding power generation)				TJ	
Biomass/biofuels (excluding power generation)				TJ	
〈add fuels as appropriate〉				TJ	
Energy (mobile)					
Gasoline				TJ	
Diesel				TJ	
Jet Fuel[1]				TJ	
Marine Fuel[2]				TJ	
〈add fuels as appropriate〉				TJ	
Water					
Consumption				ML	
Line losses (or non-revenue water)				ML	
Production				ML	
Production (surface water)				ML	
Production (ground water)				ML	
Wastewater					
Wastewater volume				ML	
Wastewater loading				kt BOD	
Waste					
Solid waste disposal on land				Kt	

	2001	2006	2011	Units	Source/comments/assumptions
Waste incineration				Kt	

Electricity sources.		**2001**	**2006**	**2011**
Coal	%			
Oil	%			
Natural Gas	%			
Hydropower	%			
Nuclear	%			
Off-site Wind	%			
Off-site Solar	%			
〈add sources as appropriate〉	%			
GHG emissions factor[1]	t CO_2 e (GW h)			

[1] Emissions factor at source of production, rather than per unit of consumption (i.e., excluding line losses).

[1] Based on fuel loaded onto planes at major airports either within or serving the megacity.

[2] Based on fuel loaded onto ships at major marine ports of the megacity, if applicable.

Electricity consumption (2011).

Residential	%	
Commercial/institutional	%	
Industrial	%	
Transportation	%	

Stationary energy consumption (2011; excluding electricity).

Residential	%	
Commercial/institutional	%	
Industrial	%	

Materials (2011, or indicate if other).

	Net import	Production	Consumption (or Δ stock)	Units	Sources/comments
Building materials					
Cement				Kt	
Steel				Kt	
〈add building materials as available〉					

	Net import	Production	Consumption (or Δ stock)	Units	Sources/comments
Food[1]				Kt	
Other materials					
〈add materials as available〉				Kt	

[1] Exclude packaging (if possible).

Layer 4: role of utilities (regulation; potential to provide new energy-related services).

Electricity			
Number of local distributors	1–2 ○	3–5 ○	>5 ○
Ownership	All public ○	All private ○	Mix○
Is there a dominant distributor (i.e., serving >80% of market)?	Yes ○	No ○	
Number of power suppliers (generators)	1–2 ○	3–5 ○	>5 ○
Ownership	All public ○	All private ○	Mix○
Is there a dominant supplier (i.e., serving >80% of market)?	Yes ○	No ○	
Is there an independent regulator?[1]	Yes ○	No ○	
Feed in tariffs	Yes ○	No ○	
Other incentives for renewables (e.g., tax breaks, cash subsidies, green certificates)	Yes ○	No ○	Type
Number of electric vehicles		Unknown ○	
Number of electric vehicle charging points		Unknown ○	
Number of buildings with PV		Unknown ○	
% of consumption from independent generators		Unknown ○	
Natural gas			
Number of local distributors	1–2 ○	3–5 ○	>5 ○
Ownership	All public ○	All private ○	Mix ○
Is there an independent regulator?	Yes ○	No ○	
Number of natural gas vehicles		unknown ○	
District heating or cooling			
Number of district heating or cooling distributors	1–2 ○	3–5 ○	>5 ○
Ownership	All Public ○	All Private ○	Mix ○

Electricity			
% Of city heating/cooling consumption from district schemes	unknown ○		
Water			
Number of local distributors	1–2 ○	3–5 ○	>5 ○
Ownership	All Public ○	All Private ○	Mix ○
Is there an independent regulator?	Yes ○	No ○	
Quality of service			
% Of households without direct access to water			
% Of households without direct access to drinkable water			
% Of households without sewage			
% Of waste water subject to treatment			
% Of households living in areas without public waste collection			
% Of households without grid electricity connection			
Average number of hours per year without electricity supply, planned or unplanned			
Wastewater (if different from water)			
Number of local collectors	1–2 ○	3–5 ○	>5 ○
Ownership	All public ○	All private ○	Mix ○
ICT			
% Of population with access to internet			
% Of population using mobile phones			
Open format question			
Please identify any significant changes in the regulation, functioning or structure of utilities in the megacity (in the past few years) that supports sustainable urban development?			

[1] Independent from local, state and national government.

Appendix 2

Invitation Letter

Title of Project: Integrated Resource management for Urban Sustainability in the Global South's Megacities (case study: Cairo, Egypt)

Yesmeen Khalifa, y.a.khalifa@keele.ac.uk

Dear Potential Participant,

My name is Yesmeen Khalifa and I am a PhD student at Keele University carrying out research about integrated resource management for urban sustainability in the Global South's megacities (case study: Cairo, Egypt). I'm writing to invite you to participate in a semi-structured interview. You have been contacted because you are either involved in environmental development projects; or the energy sector; renewable or non-renewable energy resources; electricity sector; or the waste management sector.

If you are willing to participate, you will be interviewed by the researcher. The researcher will ask you some questions relevant to your experience of working in the field of environmental development projects; or the energy sector; renewable or non-renewable energy resources; or the waste management sector in Cairo. The interview will be audio recorded. The interview will last approximately 45minutes to 1 hour. The interview will be held at your workplace at a time of your convenience. There are no direct benefits to taking part in this interview. However, your participation will help the researcher to gain a better understanding of the drivers and barriers of resource management in Cairo. You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to complete a consent to sign before the interview. You are free to withdraw from this study at any time and without giving reasons before I send you, the transcription of the interview for approval. Any interview data will be destroyed.

With this email I have attached a copy of the information sheet for the interview and a sample consent form. If you agree to participate, you will receive a similar one to sign before the interview. After you have had time to read these please consider if you would like to participate in the research project. I will follow up by e-mail within two weeks to find out if you would like to take part. I can also answer any questions you may have via e-mail on (y.a.khalifa@keele.ac.uk).

Thank you for your time,

Yesmeen Khalifa

Appendix 3

INFORMATION SHEET
For Semi-structured Interviews

Study Title: Integrated Resource management for Urban Sustainability in the Global South's Megacities (case study: Cairo, Egypt)

Invitation

You are being invited to consider taking part in the research study Integrated Resource management for Urban Sustainability in the Global South's Megacities (case study: Cairo, Egypt). This project is being undertaken by Yesmeen Khalifa.

Before you decide whether or not you wish to take part, it is important for you to understand why this research is being done and what it will involve. Please take time to read this information carefully and discuss it with friends and relatives if you wish. Ask us if there is anything that is unclear or if you would like more information.

Aims of the Research

The focus of research for this study is how to better understand complex issues in resource management in Cairo (Egypt), as an example of a rapidly urbanizing Global South megacity. The increasing demand of energy resources and the growth of solid waste present considerable challenges for sustainability in Cairo. The aim of this study is to outline the potential for measuring the flow of materials for the creation of robust urban sustainability strategies for a fast-growing megacity Cairo.

Why have I been invited?

You have been invited to be interviewed because you are either involved in environmental development projects; or the energy sector; renewable or non-renewable energy resources; electricity sector; or the waste management sector.

Do I have to take part?

You are free to decide whether you wish to take part or not. If you do decide to take part, you will be asked to complete a consent to sign before the interview.

You are free to withdraw from this study at any time and without giving reasons before I send you, the transcription of the interview for approval. Any interview data will be destroyed.

What will happen if I take part?

You will be interviewed by the researcher. The researcher will ask you some questions relevant to your experience of working in the field of environmental development projects; or the energy sector; renewable or non-renewable energy resources; or the waste management sector in Cairo. The interview will be audio recorded. The interview will last approximately 45minutes to 1 hour. The interview will be held at your workplace at a time of your convenience.

What are the benefits (if any) of taking part?

There are no direct benefits to taking part in this interview. However, your participation will help the researcher to gain a better understanding of the drivers and barriers of resource management in Cairo.

What are the risks (if any) of taking part?

There are no risks of taking part. However, you will be able to withdraw from the study by emailing the researcher Yesmeen Khalifa y.a.khalifa@keele.ac.uk or Dr Sharon George the lead supervisor s.m.george@keele.ac.uk at any time before I send you, the transcription of the interview for approval. All participants will not be identified. After the interview, all participants will be asked again if they would like to withdraw and destroy the data or if they are happy with what they have said, and the collected data can be used.

How will information about me be used?

The researcher will use the information from the interview to gain a better understanding of resource management in Cairo specifically drivers and barriers. All participants will not be identified.

Who will have access to information about me?

The researcher Yesmeen Khalifa and research supervisors' Dr Sharon George and Dr Philip Catney will have access to the information collected in this study. However, the data will never be linked to any identifying characteristics and will be anonymous when the data is analysed. The data from this study will be kept on a password protected computer and the audio recording of the interviews will be deleted.

I do however have to work within the confines of current legislation over such matters as privacy and confidentiality, data protection and human rights and so offers of confidentiality may sometimes be overridden by law. For example, in circumstances whereby I am concerned over any actual or potential harm to yourself or others I must pass this information to the relevant authorities.

Who is funding and organising the research?

The research is funded by Keele University in the United Kingdom.

What if there is a problem?

If you have a concern about any aspect of this study, you may wish to speak to the researcher who will do her best to answer your questions. You should contact Yesmeen Khalifa on (y.a.khalifa@keele.ac.uk). Alternatively, if you do not wish to contact the researcher you may contact:

Dr Sharon George MRSC
Course Director for MSc Environmental Sustainability and Green Technology, and Sustainability Hub Manager
Faculty of Natural Sciences PGT Director
Keele University Sustainability Hub
Home Farm
Keele University
ST5 5AA
E-mail: s.m.george@keele.ac.uk
Tel: +44 (0)1782 733986

If you remain unhappy about the research and/or wish to raise a complaint about any aspect of the way that you have been approached or treated during the course of the study please write to Nicola Leighton who is the University's contact for complaints regarding research at the following address:-

Nicola Leighton
Research Governance Officer
Directorate of Engagement and Partnerships

IC2 Building

Keele University

ST5 5NH

E-mail: n.leighton@ keele.ac.uk

Tel: 01782 733306

Contact for further information

Yesmeen Khalifa

PhD Student

Appendix 4

CONSENT FORM

Title of Project: Integrated Resource management for Urban Sustainability in the Global South's Megacities (case study: Cairo, Egypt)

Name and contact details of Principal Investigator:
Yesmeen Khalifa
PhD Student
William Smith Building
Keele University
Staffordshire
ST5 5BG
Tel: 01782 733620
Email: y.a.khalifa@keele.ac.uk

Please initial box if you agree with the statement

1. I confirm that I have read and understood the information sheet dated 19/12/2017 (Version no.2) for the above study and have had the opportunity to ask questions ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time ☐
3. I agree to take part in this study. ☐
4. I agree to allow the dataset collected to be used for future research projects* ☐
5. I agree to be contacted about possible participation in future research project* ☐

Name of participant	Date	Signature
Researcher	Date	Signature

Appendix 5

CONSENT FORM

(For use of quotes)

Title of Project: Integrated Resource management for Urban Sustainability in the Global South's Megacities (case study: Cairo, Egypt)

Name and contact details of Principal Investigator:

Yesmeen Khalifa
PhD Student
William Smith Building
Keele University
Staffordshire
ST5 5BG
Tel: 01782 733620
Email: y.a.khalifa@keele.ac.uk

Please initial box if you agree with the statement

1. I agree for my quotes to be used ☐
2. I do not agree for my quotes to be used ☐

____________________	____________________	____________________
Name of participant	Date	Signature
____________________	____________________	____________________
Researcher	Date	Signature

Appendix 6

Semi-structured Interview Questions
Cairo Governorate
Public Authority of Cleaning and Beautification of Cairo
Department of Waste Collection

1. Cairo Governorate produces about 15,000 tons of solid waste every day. How is this waste being managed within Cairo Governorate?
2. Official statistics show that the amount of waste will increase in the future due to the rapid population growth. What actions have been taken to face this increase in the future?
3. What are the main goals of the Department of Waste Collection in Cairo? Is it focused on waste collection only or treatment and recycling as well?
4. What are the barriers (social, technical, economic aspects) that prevent the implementation of an integrated sustainable waste management system to improve the overall performance of this sector?
5. What kind of actions are taken to overcome these barriers?
6. Have you ever thought that a mega-city like Cairo can be considered as a producer of secondary (output) resources (example: organic waste)?
7. Organic waste represents about 60% of Cairo's total municipal solid waste. Organic waste can be treated by anaerobic digestion to produce biogas, which is a renewable resource of energy. To maximise the use of organic waste, solid waste must be split into two categories wet and dry. Is this an applicable process in Cairo?

Appendix 7

Semi-structured Interview Questions

Cairo Governorate

Department of Environmental Affairs

1. What are the main goals of the Department of Environmental Affairs in Cairo?
2. What are the drivers of these goals?
    - Are they driven by improving the overall environmental conditions in Cairo (Reducing pollution levels, CO_2 emissions etc.)?
    - Or commitment to international and regional agreements?
    - Or resource scarcity and the need to provide alternatives?
3. What kind of actions have been taken to meet these targets in Cairo Governorate? Are they achievable?
4. What are the barriers (social, technical, economic aspects) that prevent the achievement of these targets?
5. What kind of actions are taken to overcome these barriers?
6. Is the Department of Environmental Affairs involved in the waste management process within Cairo Governorate?
7. Methane (CH_4) is worse than the CO_2 emissions, capturing the CH_4 from organic waste which is usually left without treatment can have a great impact on improving the environmental conditions in Cairo, is it one of the targets of the Department of Environmental Affairs?

8. Do you think efficient resource management can participate in the process of improving the sustainability performance of Cairo?
9. Have you ever thought that a mega-city like Cairo can be considered as a producer of secondary (output) resources (example: organic waste)?

Appendix 8

Semi-structured Interview Questions

NREA (New and Renewable Energy Authority)

1. What are the main goals of the NREA (New and Renewable Energy Authority)?
2. In October 2016, the Supreme Council of Energy adopted the Egyptian Energy Strategy, which aims to increasing the share of renewable energy resources to 37.2% by 2035. The share of renewable energy resources will be; nuclear power 8.8%, concentrated solar power 7.6%, photovoltaic cells 11.8%, wind power 14.6% and hydro power 3.2%. Is this target achievable?
3. Do you think we can exceed this target?
4. Do you think the treatment of organic waste by anaerobic digestion to produce biogas, which is a renewable energy resource, can be considered one of the alternatives of natural gas?
5. What are the barriers (social, technical, economic aspects) that prevent the implementation of renewable energy resources projects in Egypt?
6. What kind of actions are taken to overcome these barriers?

Appendix 9

Semi-structured Interview Questions

Holding Company for Water and Wastewater

1. Nowadays, there is an increase in the water demand, due to the rapid population growth and the scarcity of water resources, what decisions have been taken to reduce the water consumption as a first step?
2. What is the role of the Holding Company for Drinking Water and Wastewater?
3. How is the wastewater managed with the lack of sanitation services specifically in the rural settlements?
4. The target of the “2030 Strategic Vision of Treated Wastewater Reuse in Egypt” is to reach 100% sanitation coverage. They will upgrade the existing primary treatment plants to secondary treatment plants, and they will keep the existing tertiary treatment plants. In addition, all the new sanitation treatment plants will be secondary treatment plants. Is this an achievable target?
5. As a long-term vision how is the government going to meet the increasing demand of drinking water?
6. Is there any kind of public awareness to reduce the water consumption?
7. Is the service of drinking water subsidized, if yes, is the government planning to remove these subsidies in the future?
8. How will the government finance the sanitation projects to reach 100% coverage?

9. Does the government have any plans to use the wastewater (sewage) to generate electricity?
10. Does the water sector in Egypt have an effective role to reduce the pollution levels of the water resources that are mainly caused by the untreated solid waste?
11. Are there any laws to protect the water resources in Egypt from pollution?
12. What are the barriers that prevent achieving the targets of the Holding Company?
13. Do the illegal connections in the informal settlements affect the existing drinking water and sanitation networks?
14. Is the government responsible to provide the informal areas with drinking water and sanitation services even if they are illegal areas?
15. What is your vision for the drinking water and wastewater sector in Egypt?

Appendix 10

Keele University

ETHICAL REVIEW PANEL

APPLICATION FORM (STAFF AND PGR STUDENT RESEARCH PROJECTS)

Section A - Applicant's details

A1	**Project title**	**Integrated Resource Management for Urban Sustainability in the Global South's Megacities (Case Study: Cairo-Egypt)**
A2	**Name of researcher**	**Yesmeen Khalifa**
A3	**Research Institute or School**	**School of Geography, Geology and the Environment**
A4	**Correspondence address**	**William Smith Building Keele University Staffordshire ST5 5BG England**
A5	**Keele E-mail address**	**y.a.khalifa@keele.ac.uk**
A6	**Work telephone number**	**Tel: 01782 733620**
A7	**Type of application**	**PGR**
A8	**Please give supervisor name and contact details if PGR application**	**Name: Sharon George School: School of Geography, Geology and the Environment Office: William Smith Building WSF13A Tel: +44 1782 7 33986 Email: s.m.george@keele.ac.uk**
A9	**Project start date**	**19/09/2016**
A10	**Project end date**	**19/09/2020**
A11	**If project is externally funded please provide details of the funder**	**Keele University**

Section B – Applications considered suitable for light touch review.

ERP applications where research activities are limited to the following categories would be considered to have no material ethical issues and would be deemed suitable to be categorised for light touch ethical review. Please indicate if your research activities fit into one more of the following categories by ticking the relevant boxes.

Applications indicating that the research activities fit into one or more of the following categories will be flagged on the ERP agenda 'for light touch review' by the ERP Administrator. The application will receive minimal discussion at the ERP meeting, unless, in preparation for the meeting an ERP member(s) consider the application to be incorrectly categorised. In such circumstances the ERP member(s) must state at the beginning of the meeting that they consider the application to be incorrectly categorised and the reason(s) why and request that the application receives full discussion at the ERP meeting.

Category	Research Type	Tick
1	Research collecting or using human data[12] or human biomaterial[13] that is anonymous to the researcher *(where data/tissue is received from third parties remember to attach relevant documents from/with the third party).*	
2	Research using existing human data[1] or human biomaterial[2] already taken with consent for research (*where data/tissue is received remember to attach relevant documents describing provenance (eg consent, source etc).*	
3	Research using commercially obtained human biomaterial[2] *(remember to attach relevant documents describing provenance (eg consent, source etc)).*	
4	Questionnaire research that does NOT include highly sensitive areas and/or where accidental disclosure would NOT have serious consequence.	
5	Interviews or focus groups that do not include highly sensitive areas and/or where accidental disclosure would NOT have serious consequence.	Yes
6	Minimally invasive science studies involving consenting adult volunteers eg research activities that would not cause participants any more harm or distress (physical or psychological) than would be experienced in the course of everyday life.	
7	Other research which does not have any 'material ethical issues'.	

Section C - Project details

C1	In lay terms provide a brief summary of the project including the background and rationale for the proposed research and the hypotheses or research question(s) **(max 500 words).** • The focus of research for this study is how to better understand complex issues in resource management in Cairo (Egypt), as an example of a rapidly urbanizing Global South megacity. The increasing demand of energy resources and the growth of solid waste present considerable challenges for sustainability in Cairo.

[12] Includes primary data originating from human subjects (eg anonymous questionnaires); and the use of secondary data, which originated from or is about human subjects, which was initially provided for other purposes (eg other research projects or organisational datasets).

[13] Anything that originates from a human subject including:- cells; tissues; organs; bodily fluids (eg blood, plasma, spinal fluid); secretions and excretions (eg breath, urine); outgrowths (eg hair, nail, teeth).

	• The aim of this study is to outline the potential for measuring the flow of materials for the creation of robust urban sustainability strategies for a fast-growing megacity Cairo. The research considers cities both as consumers of primary (input) resources (for example, fossil fuels, renewable and non-renewable resources) and producers of secondary (output) resources (for example, waste and sewage). With the growth of urbanization secondary resources will increase due to the growth of human activities (Agudelo-Vera et al., 2012). These resources will be examined in the proposed study by using an existing “multi-layered indicator set” tool (Kennedy et al., 2014) which will involve collecting and inputting existing published data from government documents and will involve filling gaps and providing context to published data with interviews with appropriate leaders in Egypt. This will test the suitability and applicability of this existing tool to understand the unique characteristics of Cairo, drivers and barriers to sustainable resource management. **Research questions:** 1. What are the main characteristics of Cairo (case study) that affect the flow of materials (energy and waste)? 2. Does the “multi-layered indicator set” developed by Kennedy et al. (2014) work in the context of Cairo? 3. How is the flow of materials (energy and waste) in Cairo related to its sustainability performance? 4. What institutional, economic and social factors explain the nature and quality of Cairo’s sustainability performance?

C2	In lay terms outline the type of procedure(s) and/or research methodology (eg observational, questionnaire, interviews, experimental) to be employed (max 500 words).

	Research design and methods: The research will utilise two principal data gathering methods: 1) a quantitative data collection to fill a multi-layered indicator set; and 2) qualitative interviews with representatives from public authorities to explore the drivers and barriers to resource management. The research is guided by a mixed methods research approach. Specifically, the research will involve collecting and analysing existing published quantitative data and will use social science methods to collect qualitative data through semi-structured interviews. Mixed methods research combines qualitative and quantitative methods in one study to collect multiple forms of data that leads to a better understanding of the research problem and questions (Creswell, 2014). 1. Multi-Layered Indicator Set (linked to answering Research Question 2) The proposed research will use a 'multi-layered' indicator set of material throughput studies in megacities (Appendix 1). The indicator set was developed by Kennedy et al., (2014) to collect data on (spatial boundaries, constituent cities, population, economy), biophysical characteristics (climate, population density, building floor area), and metabolic flows (water, waste, materials, and all types of energy) of megacities. It also addresses the role of utilities in the provision of services and regulatory actions that, along with public governance, may influence (and/or control) the flow of materials. This 'multi-layered' indicator set guides the collection of data that can be used for the comparison of material flows of megacities. Kennedy et al., (2014) showed that there were no available studies of material throughout ("urban metabolism") for most of the megacities located in the Global South. The proposed study will use a quantitative approach to collect numerical data and information relevant to the physical flows of resources and wastes through megacities.

This study will collect the quantitative data from secondary data resources:

- Official statistics (for example, recent reports published by the government that include data about the population in Cairo, GPD, primary energy resources, energy mix, electricity consumption, waste generation, treatment and collection percentages, etc.)
- Previous studies that include the availability and potential of renewable energy resources.

2. Semi-structured Interviews (linked to research questions 1, 3 and 4)

The proposed study will use a qualitative approach to gain a better understanding of the complex factors that affect decision-making and drivers and barriers to the efficient flow of materials in Cairo. The interviews will examine the role of utilities and other public institutions in the provision of services and regulatory actions that may influence resource management in Cairo.

This study will collect the qualitative data from primary data resources: interviews and site visits.

- Semi-structured interviews will be conducted with members of the Ministry of Environment, Egyptian Environment Affairs Agency, the Ministry of Electricity and Renewable Energy, NREA (New and Renewable Energy Authority) and members of local authorities within Cairo Governorate to gain a better understanding of the context in which infrastructure exists and decisions are made. The researcher will conduct semi-structured interviews (face-to-face). Handwritten notes will be taken and the interviews will be audio recorded for transcription. The information letter, interviewees' invitation, consent and the lists of open-ended questions will be translated to Arabic (attached). (Informs answers to Research Questions 1 and 4)
- Site visits (observation without participation) will be also important to study the physical environment that affects and results from the

	flow of materials in Cairo. The selection of site visits will be based on the density of settlements: low, middle and high-density settlements. The researcher will take field notes and photographs. (Informs answers to Research Question 3) If your research project involves a phased approach then each phase can be applied for separately. Please note, each phase will need to be reviewed by the initial reviewing ERP. Diagrams or flow charts that would aid clarification of the research should be attached if appropriate (these attachments will not be included in the word count). Remember to attach questionnaire or interview questions. Remember some questionnaires may need permission for use

C3	Describe the characteristics of the participant group, the inclusion and exclusion criteria, and information about payments to participants if appropriate. Indicate the sample size, with an explanation of how this sample size was decided/calculated. ➢ The participants of the semi-structured interviews were selected by a purposive sampling strategy which targets key policy actors who are representatives of five policy sectors which constitute key elements of the "multi-layered indicator set." It is expected that these individuals can provide insight into relevant strategic and operational factors needed to provide context to published quantitative data. ➢ The researcher will send an invitation to interview potential participants by email with an information sheet attached to explain the project. A consent form will be administrated before the interview commences. Interviews will be undertaken at the workplace of the interviewees. An information letter, interviewee invitation, consent form and a list of open-ended questions are attached. ➢ The semi-structured interviews will be conducted to collect primary data resources with: **1. <u>Ministry of Environment:</u> (technical office)** The ministry's role: - Drawing up the general policy and preparing the necessary plans for the preservation and development of the environment and follow-up implementation in coordination with the administrative authorities. - The national authority for the promotion of environmental relations between Egypt and other countries, international and regional organizations. - Recommending legal measures to join international and regional conventions related to the environment and preparing draft laws and decisions necessary for the implementation of these agreements. **2. <u>Egyptian Environment Affairs Agency</u>: (department of climate change)** The agency's role includes: - Preparation of draft laws and decisions related to the preservation of the environment.

	- Conducting studies and drafting the national plan for protecting the environment and required projects and setting the necessary standards in planning and development. - Setting up and enforcing the standards and requirements for construction. - Follow-up on the field to implement the standards and requirements that the agencies and establishments are committed to implement and take the procedures that the law provides against violators of these standards and conditions. - Establishes the rates, percentages and the specific loads of pollutants and ensure compliance with them. - Environmental planning, monitoring, regulation and enforcement and governance including financial planning, education and training, and international engagement. **3. <u>The Ministry of Electricity and Renewable Energy</u>:** (department of technical planning) The ministry's role: - Sets and implements policies and plans in the fields of electricity generation, transmission and distribution. - Monitors activities to provide electrical power to support government's plans around social and economic development. - Suggests tariff of electrical power to the cabinet. - Supervises study and implementation of important electrical projects. - Provides the technical support, consultancy and experience to Arab countries in the electrical field. **4. <u>NREA (New and Renewable Energy Authority):</u>** The NREA's role: - Quantifies and assesses all types of energy resources. - Conducts R&D studies to develop the use of renewable energy resources. - Implements renewable energy projects.

	- Develops standard specifications, assesses and issues certificates for renewable energy equipment and systems. - Provides technical consultations for all types of renewable energy projects. - Development of local manufacturing capacity for renewable energy equipment. - Provides information services and training in the field of renewable energy resources. 5. **<u>Cairo Governorate:</u>** a) **Department of Environmental Affairs**: The role of the Department of Environmental Affairs: - Participates in the preparation of the national environmental protection and emergency plan. - Prepares the environmental protection plan and environmental report for Cairo Governorate. - Collects environmental information, monitors pollution sources and prepares environmental maps. - Coordinates to regulate hazardous materials in Cairo Governorate. - Deals with complaints from the public regarding environmental problems. - Addressing offenses e.g., related to waste and protection of wildlife and beaches. b) **Public Authority of Cleaning and Beautification of Cairo: (department of waste collection)** The role of the Public Authority of Cleaning and Beautification of Cairo: Provision of cleaning services at the level of Cairo Governorate; - Supervises the companies working in the cleaning sector in different regions. - Carries out direct cleaning works through Al-Fustat National Company, which includes residential and commercial refuse collection. - Monitors and operates landfills in the governorate.

Section D - Issues of risk or of an ethically sensitive or challenging nature

D1	Will the research involve deceased persons, body parts or other human elements such as blood, hair or tissue samples (including saliva and waste products)? Yes ☐ No ☒
D2	**if yes**, please discuss this project with Dr Alan Harper, Human Tissue Officer on 01782 674472 / 734654 or e-mail a.g.s.harper@keele.ac.uk. Please cite the reference number given by Dr Harper for this research project below;- **Reference number**:
D3	**If yes**, please give details with reference to the Human Tissue Act 2004. Human Tissue Act can be accessed via https://www.hta.gov.uk/human-tissue-act-2004

D4	Will the research involve administrative or controlled data that requires permission for access to and use of the dataset(s)? Remember to attach information evidencing the provenance of and consent for the use of the dataset(s) Yes ☐ No ☒
D5	Will the research involve social media as a medium for the research (eg access to posts from discussion forums for research purposes) Yes ☐ No ☒
D6	Will participants or other individuals be identified in the material used or generated (eg visual or vocal methods producing images or sounds, or interviews with elite individuals who may be identifiable)? Yes ☐ No ☒
D7	Will the research involve raising issues of a sensitive nature where individuals are required to reveal personal information about matters such as their personal lives, illegal behaviour, sexual orientation, etc? Yes ☐ No ☒
D8	Will the research involve the administration of substances to participants or involve intrusive or potentially harmful procedures of any kind (eg vigorous exercise that they would not normally undertake in the course of everyday life)? Yes ☐ No ☒
D9	Are there any potential risks to participants and members of the research team that involve more than minimal levels of risk of harm or discomfort (including physical harm, psychological or emotional distress)? Yes ☐ No ☒
D10	Will the research involve access to, collection of, and/or storage of materials that; Are covered by the Official Secrets Act or Terrorism Act? Yes ☐ No ☒ Are commissioned by the military? Yes ☐ No ☒ Are commissioned under an EU security call? Yes ☐ No ☒

	Involve the acquisition of security clearances? Yes ☐ No ☒ Concern terrorist or extreme groups? Yes ☐ No ☒ If you have ticked yes to any question in C10 you are asked to register your project with the University via http://www.keele.ac.uk/researchsupport/researchgovernance/securitysensitiveresearchmaterial/. The University supports its researchers in undertaking research using security sensitive material (ie the above categories) but takes seriously the need to protect them from the misinterpretation of intent by the authorities. Therefore, registration of research enables the University to have oversight and demonstrate to authorities that it is aware of the research being carried out.

D11	Will the research have potential safety risks for members of the research team? Yes ☐ No ☒
D12	Is the research participatory action research? Yes ☐ No ☒
D13	**For all applications,** outline all potential risks to participants and members of the research team and the measures that will be taken to minimise risk; and the procedures that will be adopted in the event of an adverse event. There are no potential risks for researcher or participants. The University's Lone Working Policy can be accessed via http://www.keele.ac.uk/dohs/a2z/loneworking/

D14	Will the research be undertaken overseas? Yes ☒ No ☐
D15	**a)** **If yes,** have you consulted the foreign and commonwealth office website for guidance/travel advice and is it safe to travel there? Yes ☒ No ☐
D16	**b)** **If yes,** have you completed and submitted a risk assessment form? Yes ☐ No ☒ I did not fill the risk assessment form because my travel dates are not confirmed yet. This will be completed when the travel dates are confirmed.
D17	**c)** **If yes**, are you aware of the political sensitives and issues of local practice in the region where the research will be carried out? Yes ☒ No ☐
D18	**If yes**, outline the details and how these issues will be addressed:- There is a heightened threat of terrorist attacks targeting some places in Egypt (North Sinai and South Sinai) https://www.gov.uk/foreign-travel-advice/egypt. These places are far away from Cairo Governorate where I will be conducting the semi-structured interviews and the site visits. However, it is worth mentioning here that I am originally from Egypt, I have an Egyptian passport and I lived there for more than 25 years. I

	visited many informal settlements within Cairo Governorate during my undergraduate and Master degree studies. I also worked there since I graduated in 1999 until 2013 before I move to UK with my family. I worked as an interior designer for the Housing and Developing Bank in Egypt, then as a site engineer and then I moved to the technical office in the same Bank. In 2007, I started a private business for 6 years and finally I worked as an Executive Manager at an International British school in Egypt for two years. Being Egyptian I am totally familiar with the social aspects, traditions and how to deal with people in different situations. In addition, I will review and adhere to Foreign Office advise (https://www.gov.uk/foreign-travel-advice/egypt). Foreign and Commonwealth Office travel advice website: https://www.gov.uk/foreign-travel-advice Overseas Travel Policy and risk assessment form (covers both Staff and PGR students) is available from http://www.keele.ac.uk/finance/insurance/travelinsurance/travellingoverseas-policyriskassessment/

D19 D20	Will the research involve vulnerable groups eg children, or people with a learning disability or cognitive impairment or those in unequal relationships (eg your own students)? Yes ☐ No ☒ **If yes,** explain how you will ensure that appropriate consent to participate in this study will be obtained.
D21	Will participants be deceived in any way as part of the study? Yes ☐ No ☒ **If yes**, describe the nature and extent of deception involved, including how and when this deception will be revealed and who will administer this feedback (debrief).

SECTION E - Recruitment and consent process

E1 E2	Will the co-operation of a gate keeper be required for initial or continued access to participants such as employees recruited through their work place, adult professionals (eg those working with children or the elderly) or research in communities (in UK or overseas) where access to participants is not possible without the permission of another adult (eg parent or spouse of participant) or a community leader. Yes ☒ No ☐ Indicate how potential participants will be identified, approached and recruited and outline any relationship between the researcher and potential participant.

E3	Information sheets will be sent by e-mail to the ministries' and Cairo Governorate's official e-mails to explain my project and ask for contact details of members from the selected departments to participate in the semi-structured interviews. 1. **<u>Ministry of Environment:</u>** Address: 30 Misr Helwan El-Zyrae Road, Maadi, Cairo, Egypt Phone: (202) 25256452 Fax: (202) 25256490 Email: eeaa@eeaa.gov.eg Website: www.eeaa.gov.eg 2. **<u>Egyptian Environment Affairs Agency:</u>** Address: 30 Misr Helwan El-Zyrae Road, Maadi, Cairo, Egypt Phone: (202) 25256452 Fax: (202) 25256490 Email: eeaa@eeaa.gov.eg Website: www.eeaa.gov.eg 3. **<u>The Ministry of Electricity and Renewable Energy:</u>** Address: Ramsis St. Abbassia, Cairo Phone: 22624537 -24032284 Fax: 22624537 -24032284 E-mail: mediadep.moee@gmail.com Website: www.moee.gov.eg 4. **<u>NREA (New and Renewable Energy Authority):</u>** Address: Dr. Ibrahim Abu El-Naga, Abbass El- Aqqad, Elzhour district, Madinat Nasser. Phone: (202) 22713176 Fax: (202) 22717173 Email: reic@nreaeg.com Website: www.nrea.gov.eg 5. **<u>Cairo Governorate:</u>** Address: 7 Gomhoria St, Abdin Square. Post box: 22 Cairo Central Phone: (202) 23907754 E-mail: cairogov@Cairo.gov.eg Website: www.cairo.gov.eg 6. **<u>Department of Environmental Affairs:</u>** Address: 7 Gomhoria St, Abdin Square. Post box: 22 Cairo Central Phone: (202) 23907754 E-mail: cairogov@Cairo.gov.eg Website: www.cairo.gov.eg 7. **<u>Public Authority of Cleaning and Beautification of Cairo:</u>** Address: 23 July buildings, building no 3B, Abbassia

	Phone: (202) 24842031 Fax: (202) 26744646 E-mail: purity@cairo.gov.eg Website: www.cairo.gov.eg Then I will send invitations (e-mails) to approach participants individually, arrange a meeting to conduct the interview and a consent form will be given to the participants to sign before the interview. The information sheet, invitations (e-mails) and the consent forms will be translated to Arabic. If the research is using existing dataset(s) or human biomaterial received from third parties, including commercially obtained biomaterial, please provide information describing the provenance (eg source and consent). Remember to attach information evidencing the provenance of and consent for the use of the dataset(s)/human biomaterial N/A Remember to attach copies of posters, advertisements, invitation letters/e-mails to be used as part of the recruitment process with version numbers included in the footer.

E4	Describe the process that will be used to seek and obtain informed consent. Information sheets will be sent by e-mail to the ministries' and Cairo Governorate's official e-mails to explain my project and ask for contact details of members from the selected departments to participate in the semi-structured interviews. Then I will send invitations (e-mails) to approach participants individually, arrange a meeting to conduct the interview and a consent form will be given to the participants to sign before the interview. The information sheet, invitations (e-mails) and the consent forms will be translated to Arabic. Remember to attach your information sheet and consent form with versions numbers and date included in the footer Templates available from http://www.keele.ac.uk/researchsupport/researchethics/

E5	Will consent be sought to use the data for other research? Yes ☐ No ☒
E6	Will consent be sought to contact the individual to participate in future research? Yes ☐ No ☒

E7	Can participants withdraw from the research? Yes ☒ No ☐
E8	

E9 E10	**If yes**, state up to what point participants are able to withdraw from the research The deadline for participants to withdraw from the research is when I send the interviewees transcriptions of interviews for approval. **If yes**, outline how participants will be informed of their right to withdraw, how they can do this and what will happen to their data if they withdraw. Participants will be informed in the information sheet and will be reminded verbally before the interview if they wish to withdraw from the research. If they choose to withdraw from the study all data will be destroyed. And they can withdraw at any time after the interview by emailing the researcher Yesmeen Khalifa (y.a.khalifa@keele.ac.uk) or the lead supervisor Dr. Sharon George (s.m.george@keele.ac.uk) or Research Governance Officer Nicola Leighton (n.leighton@keele.ac.uk). **If no**, explain why they cannot withdraw (eg anonymous survey).

SECTION F - Confidentiality and anonymity

F1	Outline the procedures that will be used to protect, as far as possible, the anonymity of participants and/or confidentiality of data during the conduct of the research and in the release of its findings. All quotes will be anonymised, participants will not be identified in the transcription and if a name was mentioned during the interview, the transcription will be modified to hide the name. The recordings of the semi-structured interviews will be on an encrypted USB as per university guidance, and kept in a locked place at my home at Cairo. The recordings will be transferred to a password protected computer and in a locked place at my home in Cairo before transcription. After transcription, the recordings will be retained and the transcription will be kept on a password protected computer. To transport data from Cairo to UK a backup on an encrypted USB will be used. The backup copy will be deleted once the data will be transferred to my password protected computer at Keele University. The researcher will translate and transcribe the interviews and all the attached document (information sheet, invitation letter, consent forms and questions).

SECTION G - Storage, access to, management of, and disposal of data

G1	Will the research involve access to records of personal or sensitive confidential information?

	Yes ☐ No ☒
G2	Will the research involve the linking or sharing of data or confidential information beyond the initial consent given? Yes ☐ No ☒
G3	**For all applications,** describe the research data that will be stored; where it will be stored and for how long; the measures that will be put in place to ensure the security of data; who will have access to the data; long term data management plans following completion of the project; and how/when data will be disposed of. The recordings of the semi-structured interviews will be on an encrypted USB as per university guidance, and kept in a locked place at my home at Cairo. The recordings will be transferred to a password protected computer and in a locked place at my home in Cairo before transcription. After transcription, the recordings will be retained and the transcription will be kept on a password protected computer. To transport data from Cairo to UK a backup on an encrypted USB will be used. The backup copy will be deleted once the data will be transferred to my password protected computer at Keele University. Consent forms (signed hard copy) will be kept locked at my home at Cairo and I will keep soft copy on an encrypted USB. Then I will keep the hard copies in my locked chest of drawers at Keele University and transfer the soft copy to my password protected computer at Keele University. If you are accessing or storing research material that is considered to security sensitive you will need to register your project with University. More information about security sensitive research material and the registration process can be accessed via http://www.keele.ac.uk/researchsupport/researchgovernance/securitysensitiveresearchmaterial/

SECTION H - Other ethical issues raised by the research

H1	Are there any other ethical issues that may be raised by the research? Yes ☐ No ☒
H2	If yes, please give details:
H3	Is there any aspect of the research that could potentially have a negative effect on the reputation of the University (such as receiving controversial sources of funding, engaging with issues that may cause offence to groups or individuals, or engaging in areas that might be misconstrued as endorsing illegal practices, etc)? Yes ☐ No ☒
H4	If yes, please give details:

SECTION I - Other approvals required

I1 I2 I3 I4 I5	Does the project require researcher(s) to have a Disclosure and Barring Service (DBS) check? Yes ☐ No ☒ **If yes**, have you attached a confirmation of satisfactory DBS check memo? Yes ☐ No ☒ Does the project require National Offender Management Service (NOMS) approval? Yes ☐ No ☒ Does the project require Health Research Authority (HRA) Approval? Yes ☐ No ☒ Does the project require approval from another organisation? Yes ☐ No ☒

SECTION J - Checklist

J1	**Please list the documents attached to this application**		
	Document	Version number	Date
	Information Sheet	No. 2	19/12/2017
	Consent Form	No. 2	19/12/2017
	Consent Form (for the use of quotes)	No. 2	19/12/2017
	Invitation Letter	No. 2	19/12/2017
	Semi-structured Interview Questions: Cairo Governorate Public Authority of Cleaning and Beautification of Cairo (Department of Waste Collection)	No. 2	19/12/2017
	Semi-structured Interview Questions: Cairo Governorate (Department of Environmental Affairs)	No. 2	19/12/2017
	Semi-structured Interview Questions: Egyptian Environment Affairs Agency (Department of Climate Change)	No. 2	19/12/2017
	Semi-structured Interview Questions: NREA (New and Renewable Energy Authority)	No. 2	19/12/2017
	Semi-structured Interview Questions: Ministry of Environment (Technical Office)	No. 2	19/12/2017
	Semi-structured Interview Questions: The Ministry of Electricity and Renewable Energy (Department of Technical Planning)	No. 2	19/12/2017

SECTION K – Declarations

K1	In preparing this application did you access the on-line Research Governance Tool Kit for information? (https://www.keele.ac.uk/researchsupport/researchtoolkit/) Yes ☒ No ☐
K2	**Declaration by researcher** I confirm that:- • The form is accurate to the best of my knowledge • I will abide by the University's ethical requirements • I will inform the panel of any changes to the project • I am aware of my responsibility to be up to date and comply with the requirements of the law and any relevant professional guidelines
	Researcher name (in capitals) Yesmeen Khalifa
	Researcher signature
	Date 7/11/2017

K3	**Declaration by supervisor (PGR applications only)** I confirm that:- • The application has been appropriately peer reviewed • I have read the application and am happy for it to proceed for ethical review • The application is accurate to the best of my knowledge • The project will comply with the University's ethical requirements • The applicant will inform the panel of any changes to the project • I am aware of my responsibility to ensure that the applicant is familiar with and complies with the requirements of the law and any relevant professional guidelines
	Supervisor name (in capitals) Dr. Sharon George
	Supervisor signature
	Date 7/11/2017

K4	Declaration by Faculty Research Office/Research Institute Director, Centre/Theme Head, or Head of School **(Staff applications only)** I confirm that:- • The application has been appropriately peer reviewed

	- I have read the application and am happy for it to proceed for ethical review - The form is accurate to the best of my knowledge - The project will comply with the University's ethical requirements - The applicant will inform the panel of any changes to the project - I am aware of my responsibility to ensure that the applicant is familiar with and complies with the requirements of the law and any relevant professional guidelines
	Name (in capitals)
	Post
	Signature
	Date

Please e-mail your completed application form and supporting documentation to research.governance@keele.ac.uk

Appendix 11

Ethical Approval Letter

Keele UNIVERSITY

19/01/2018

Dear Yesmeen

PI: Yesmeen Khalifa
Title: Integrated Resource Management for Urban Sustainability in the Global South's Mega-Cities (Case Study: Cairo-Egypt)
Ref: ERP2361

Thank you for submitting your application for review. The proposal was reviewed by the Panel Chair. I am pleased to inform you that your application has been approved by the Ethics Review Panel.

If the fieldwork goes beyond the date stated in your application, or there are any amendments to your study you must submit an 'application to amend study' form to the ERP administrator at research.governance@keele.ac.uk. This form is available via http://www.keele.ac.uk/researchsupport/researchethics/

If you have any queries please do not hesitate to contact me, in writing, via the ERP administrator, at research.governance@keele.ac.uk stating **ERP2361** in the subject line of the e-mail.

Yours sincerely
PP.

Dr Colin Rigby
Chair – Ethical Review Panel

Appendix 12

Sources of secondary data for Chapters 4, 5, 6 and 7

Chapter	**Sources of secondary data**
Chapter 4	**Sources of secondary data for Layer 1:** The population and economy data were collected from the following official statistics and reports: ▪ United Nations Development Programme (UNDP), Egypt Human Development Report 2003. (UNDP, 2003) ▪ United Nations, World Urbanization Prospects, the 2001 Revision. (United Nations, 2002) ▪ United Nations, World Urbanization Prospects, the 2014 Revision. (United Nations, 2014) ▪ Central Agency for Public Mobilization and Statistics, Statistical Yearbook, Population 2016 and 2018 (CAPMAS, 2018d; CAPMAS, 2016c). ▪ Central Agency for Public Mobilization and Statistics, Egypt in Figures 2002, 2006, 2007, 2009, 2011 and 2012. (CAPMAS, 2012b; CAPMAS, 2011a; CAPMAS, 2009; CAPMAS, 2007a; CAPMAS, 2006a; CAPMAS, 2003a). ▪ For the GDP per capita (US \$) and the total GDP (US \$): this data was obtained from the World Bank website (The World Bank, 2019b). ▪ The total GDP (Egyptian pounds) was available at the website of the Ministry of Planning Monitoring and Administrative Reform, (MPMAR, 2019). ▪ The unemployment rates for each Governorate and Egypt were obtained from the Central Agency for

	Public Mobilization and Statistics, Statistical Yearbook 2016 and 2018 (CAPMAS, 2018d; CAPMAS, 2016c).
	Sources of secondary data for Layer 2: The biophysical characteristics of Cairo Governorate, Giza, Qalyubia and Egypt were collected from the following official statistics and reports: ▪ Land area (sq. kilometres): of Egypt, Cairo, Giza and Qalyubia data was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2018 and the land area of Greater Cairo Region was obtained from the General Organization for Physical Planning, Strategic Development of Greater Cairo Region 2012 report (CAPMAS, 2018d; GOPP, 2012). ▪ Inhabited area (sq. kilometres): of Egypt, Cairo, Giza and Qalyubia data was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2018 (CAPMAS, 2018d). ▪ Percentages of the inhabited area to the total area: for Egypt, Cairo, Giza and Qalyubia data was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2018 (CAPMAS, 2018d). ▪ Inhabited density (population/sq.kilometres): of Egypt, Cairo, Giza and Qalyubia was obtained from: 1. Year 2003: Central Agency for Public Mobilization and Statistics, Egypt in Figures 2002 (CAPMAS, 2003a).

	2. Year 2011: Central Agency for Public Mobilization and Statistics, Egypt in Figures 2012 (CAPMAS, 2012b). 3. Year 2015: Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2016 (CAPMAS, 2016a). 4. Year 2017: Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2018 (CAPMAS, 2018d). ▪ Population of Cairo, Giza and Qalyubia residing within the Greater Cairo Region: this data was available in one report from the General Organization for Physical Planning, Strategic Development of Greater Cairo Region, 2012 report and it was not updated since 2012 (GOPP, 2012). ▪ Area of Cairo, Giza, and Qalyubia within the boundaries of Greater Cairo Region: this data was available in one report from the General Organization for Physical Planning, Strategic Development of Greater Cairo Region, 2012 report and it was not updated since 2012 (GOPP, 2012). ▪ The share of each Governorate (Cairo, Giza and Qalyubia) to the total area of Greater Cairo Region: this data was obtained from the General Organization for Physical Planning, Strategic Development of Greater Cairo Region 2012 report (GOPP, 2012). ▪ The percentage of the share of Cairo, Giza, and Qalyubia within the Greater Cairo Region to the total area of each Governorate: Central Agency for Public Mobilization and Statistics, Egypt Statistical Yearbook 2016 report and the General Organization for Physical

	Planning, Strategic Development of Greater Cairo Region, 2012 report. I calculated the percentage of the area of each Governorate within GCR boundaries to the total area of each Governorate (CAPMAS, 2016a; GOPP, 2012). ▪ The total number of residential, commercial, and institutional industrial buildings: this data was not available for the required years (2001 to 2016) it was available for 2006 and 2017 only. The original multi-indicator set gathered the information for the building gross floor areas of all levels, which was not available so the number of buildings in each Governorate and Egypt was gathered as an alternative. The data was obtained from the Central Agency for Public Mobilization and Statistics, Tables of the most important characteristics and indicators of the General Census of Population, Housing, and Establishments 2017 and the results for the General Census of Population, Housing, and Establishments 2017 (CAPMAS, 2017d; CAPMAS, 2017f). ▪ The total number of residential units: this data was available only in the Central Agency for Public Mobilization and Statistics recent report, the results for the General Census of Population, Housing, and Establishments 2017. It was not available in the previous reports (CAPMAS, 2017d). ▪ Climate: 1. Heating degree-days (HDD) and cooling degree-days (CDD); data was obtained from (http://www.degreedays.net). This website was used by (Kennedy et al., 2015). It provides the heating degree-days (HDD) and cooling degree-

	days (CDD) according to the selected location. I chose the same location (Cairo International airport) for Cairo, Giza and Qalyubia, it was the nearest available station for all Governorates. 2. Annual precipitation (mm) and rainfall; for Cairo Governorate and Egypt was obtained from Abdel-Shafy et al. (2010) and The World Bank (2019a). 3. Annual solar radiation; data for Egypt, Cairo, Giza and Qalyubia was obtained from the Global Solar Atlas (The World Bank Group, 2016b). 4. Wind speed; data for Egypt, Cairo, Giza and Qalyubia was obtained from the Global Wind Atlas (The World Bank Group, 2018).
Chapter 5	**Sources of secondary data for the Layer (3-1)** The energy and electricity data were collected from the following official statistics and reports: ▪ The data of the primary energy production and consumption of Egypt was obtained from the Central Agency for Public Mobilization and Statistics, the Energy Balance 2013-2014 report, 2014-2015 report and 2015-2016 report (CAPMAS, 2017c; CAPMAS, 2015a; CAPMAS, 2014b). The energy balance reports were unavailable for previous years. The data of the primary energy production and consumption for each governorate is not available in these reports. ▪ The Central Agency for Public Mobilization and Statistics publishes an annual Energy and Electricity report that includes the primary energy production and consumption for Egypt and each governorate. All the reports are available since 1999 to 2016. The use of these reports is limited in this study because:

	1. the primary energy consumption of some governorates is added together such as the natural gas consumption of Cairo and Giza Governorates are added together that made it difficult to quantify the consumption of each governorate on its own, 2. the methods of data collection are different from the Energy Balance reports (mentioned above), 3. in some cases, the quality of the reports was poor, so they were unreadable, 4. and the Energy Balance reports that are recently published are more reliable than the Energy and Electricity reports because the methods of data collection are consistent in the three reports (2013-2014, 2014-2015 and 2015-2016) (CAPMAS, 2017c; CAPMAS, 2015a; CAPMAS, 2014b) and the quality of the reports are better than the Energy and Electricity reports. However, the Energy Balance reports do not include the data of the primary energy production and consumption of each governorate. ▪ The renewable energy production from 2002-2003 to 2015-2016 is obtained from the following reports: 1. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the Annual Report of the Electricity Consumption Indicators for the Economic Activities 2010-2011 (EgyptERA, 2012). 2. The Central Agency for Public Mobilization and Statistics, The Future of Energy in Egypt 2014 report (CAPMAS, 2014c). 3. The Central Agency for Public Mobilization and Statistics, Energy Balance report 2013-2014 (CAPMAS, 2014b).

	4. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the Annual Report of the Electricity Consumption Indicators for the Economic Activities 2015-2016 (EgyptERA, 2017). ▪ Percentages of households according to the type of fuel used in cooking: the number of households according to the fuel used in cooking for each governorate and the total of Egypt was available for the first time in the Central Agency for Public Mobilization and Statistics, Egypt Census 2017 report. The percentages of households according to the type of fuel used in cooking is calculated and presented (CAPMAS, 2017d). ▪ Energy consumption and CO_2 emissions by sector (percentages) of Egypt: this data was available from (2009-2010 to 2016-2017) in the following official reports: 1. Central Agency for Public Mobilization and Statistics, Egypt in Figures, 2011 report (CAPMAS, 2011a). 2. Central Agency for Public Mobilization and Statistics, Egypt in Figures, 2012 report (CAPMAS, 2012b). 3. Central Agency for Public Mobilization and Statistics, Statistical Yearbook - Environment 2014 (CAPMAS, 2014d). 4. Central Agency for Public Mobilization and Statistics, Egypt in Figures 2018 report and the Statistical Yearbook- Environment 2015 (CAPMAS, 2018c; CAPMAS 2015b). ▪ Central Agency for Public Mobilization and Statistics, Environment Statistical Yearbook 2016 (CAPMAS, 2016c).

	▪ The energy consumption of Cairo, Giza and Qalyuibia Governorates by sector in 2015-2016 is obtained from the Central Agency for Public Mobilization and Statistics, Energy and Electricity report 2015-2016 (CAPMAS, 2017c). ▪ The electricity production mix (renewable and non-renewable energy resources) of Egypt from 2002-2003 to 2015-2016 is obtained from the following official reports: 1. The Central Agency for Public Mobilization and Statistics, The Future of Energy in Egypt 2014 report (CAPMAS, 2014c). 2. The Central Agency for Public Mobilization Statistics, the Energy Balance report 2013- 2014 (CAPMAS, 2014b). 3. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the Annual Report of the Electricity Consumption Indicators for the Economic Activities 2010-2011 (EgyptERA, 2012). 4. The Central Agency for Public Mobilization and Statistics, Electricity and Energy annual report 2014-2015 (CAPMAS, 2016b). ▪ Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the Annual Report of the Electricity Consumption Indicators for the Economic Activities 2015-2016 (EgyptERA, 2017). ▪ The electricity production mix of Cairo, Giza and Qalyubia Governorates includes non-renewable energy resources only and there is no evidence for the use of renewable energy resources in the three governorates. (All the Electricity and Energy reports from 1999-2000 to 2015-2016).

	▪ The percentages of electricity sources of Egypt from 2002-2003 to 2015-2016, this data is calculated from the electricity production mix of Egypt. ▪ The total electricity consumption of Cairo, Giza and Qalyubia Governorates and Egypt from 1999-2000 to 2015-2016 this data was available in the following reports: 1. The Central Agency for Public Mobilization and Statistics, the Electricity and Energy annual report 1999-2000 (CAPMAS, 2001). 2. The Central Agency for Public Mobilization and Statistics, the Electricity and Energy annual report 2001-2002 (CAPMAS, 2003b). 3. The Central Agency for Public Mobilization and Statistics, the Electricity and Energy annual report 2005-2006 (CAPMAS, 2007b). 4. The Central Agency for Public Mobilization and Statistics, the Electricity and Energy 2009- 2010 annual report (CAPMAS, 2011b). 5. Central Agency for Public Mobilization and Statistics, the Electricity and Energy annual report 2011-2012 (CAPMAS, 2013a). 6. Central Agency for Public Mobilization and Statistics, the Electricity and Energy 2014-2015 annual report (CAPMAS, 2016b). 7. Central Agency for Public Mobilization and Statistics, the Electricity and Energy 2015-2016 annual report (CAPMAS, 2017c). 8. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the annual report of the Electricity Consumption Indicators for the Economic Activities 2015-2016 (EgyptERA, 2017).

	▪ The data of the electrical line losses (the line losses include the losses of the grid, the non-revenue losses and the self-consumption of the power plants) of Egypt from 2005-2006 to 2015-2016 is obtained from the following reports: 1. Central Agency for Public Mobilization and Statistics, Electricity and Energy annual report 2005-2006 (CAPMAS, 2007b). 2. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the annual report of the Electricity Consumption Indicators for the Economic Activities 2010-2011 (EgyptERA, 2012). 3. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the annual report of the Electricity Consumption Indicators for the Economic Activities 2012-2013 (EgyptERA, 2014). 4. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the annual report of the Electricity Consumption Indicators for the Economic Activities 2015-2016 (EgyptERA, 2017). ▪ The data of the electricity consumption by sector (percentages) of Cairo, Giza and Qalyubia Governorates from 1999-2000 to 2014-2015 and Egypt from 1999-2000 to 2016 is obtained from the following official reports: 1. Central Agency for Public Mobilization and Statistics, Electricity and Energy annual report 1999-2000 (CAPMAS, 2001). 2. Central Agency for Public Mobilization and Statistics, Electricity and Energy 2001-2002 annual report (CAPMAS, 2003b).

	3. Central Agency for Public Mobilization and Statistics, Electricity and Energy 2005-2006 annual report (CAPMAS, 2007b). 4. Central Agency for Public Mobilization and Statistics, Electricity and Energy 2009- 2010 annual report (CAPMAS, 2011b). 5. Central Agency for Public Mobilization and Statistics, Electricity and Energy annual report 2010- 2011 (CAPMAS, 2012c). 6. Egyptian Electricity Utility and Consumer Protection Regulatory Agency, the annual report of the Electricity Consumption Indicators for the Economic Activities 2010-2011 (EgyptERA, 2012). 7. Central Agency for Public Mobilization and Statistics, Electricity and Energy 2011-2012 annual report (CAPMAS, 2013a). 8. Central Agency for Public Mobilization and Statistics, the Future of Energy in Egypt 2014 report (CAPMAS, 2014c). 9. Central Agency for Public Mobilization and Statistics, Electricity and Energy annual report 2014- 2015 (CAPMAS, 2016b). ▪ Central Agency for Public Mobilization and Statistics, Energy Balance report 2015-2016 (CAPMAS, 2017c). ▪ The percentages of households without grid electricity connection was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Census 2017 report and tables of the most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017 report. First, I calculated the percentages of direct access to

	electricity public network, and then I calculated the percentages without direct access.
Chapter 6	**Sources of secondary data for the Layer (3-2)** The water and wastewater data were collected from the following official statistics and reports: ▪ The data of the water resources of Egypt and quantities (billion cubic metres/year) from 2006-2007 to 2014-2015 was obtained from the Central Agency for Public Mobilization and Statistics, Egypt in Figures 2011 report and Egypt in Figures 2018 report (CAPMAS, 2018c; CAPMAS, 2011a). ▪ The percentages of water resources in Egypt from 2006-2007 and 2014-2015 were calculated. ▪ The percentages of water consumption in Egypt by sector from 2006-2007 to 2015-2016 were obtained from the from the Central Agency for Public Mobilization and Statistics, Egypt in Figures 2011 report and Egypt in Figures 2018 report (CAPMAS, 2018c; CAPMAS, 2011a). ▪ The data of the drinking water production (surface and groundwater) of Egypt and Cairo, Giza and Qalyubia Governorates from 2012-2013 to 2016-2017 was obtained from the Central Agency for Pubic Mobilization and Statistics, the Annual Bulletin for the Purification, Distribution and Selling Drinking Water 2012-2013 report, the Annual Bulletin of Drinking Water and Sanitation Statistics 2015-2016 report and the Annual Bulletin of Pure Water and Sanitation Statistics 2016-2017 (CAPMAS, 2018b; CAPMAS, 2017a; CAPMAS, 2014a).

	▪ The percentages of drinking water production (surface and groundwater) of Egypt in 2012-2013 and 2016-2017 were calculated. ▪ The percentages of surface water and groundwater production of Cairo, Giza and Qalyubia Governorates and the rest of Egypt in 2012-2013 and 2016-2017 were calculated. ▪ The drinking water production, consumption and losses of Egypt from 2001-2002 to 2015-2016 (CAPMAS, 2018b; CAPMAS, 2017a; CAPMAS, 2014a; CAPMAS, 2012a; CAPMAS, 2010; CAPMAS, 2008c; CAPMAS, 2007c; CAPMAS, 2006b; CAPMAS, 2004b; CAPMAS, 2003c). ▪ Drinking water production, consumption and losses of Cairo, Giza and Qalyubia Governorates from 2002-2003 to 2015-2016 (CAPMAS, 2018b; CAPMAS, 2017a; CAPMAS, 2014a; CAPMAS, 2012a; CAPMAS, 2010; CAPMAS, 2008c; CAPMAS, 2007c; CAPMAS, 2006b; CAPMAS, 2004b; CAPMAS, 2003c). ▪ Drinking water consumption of Cairo, Giza and Qalyubia Governorates and the rest of Egypt from 2002-2003 to 2015-2016 were calculated. ▪ Percentages of drinking water consumption of Cairo, Giza and Qalyubia Governorates and the rest of Egypt in 2002-2003 and 2015-2016 were calculated. ▪ Drinking water losses (million cubic metres) of Cairo, Giza and Qalyubia Governorates and the rest of Egypt from 2002-2003 to 2015-2016 (CAPMAS, 2018b; CAPMAS, 2017a; CAPMAS, 2014a; CAPMAS, 2012a; CAPMAS, 2010; CAPMAS, 2008c; CAPMAS,

	2007c; CAPMAS, 2006b; CAPMAS, 2004b; CAPMAS, 2003c). ▪ Percentages of drinking water losses of Cairo, Giza and Qalyubia Governorates in 2002-2003 and 2015-2016 were calculated. ▪ Percentages of the drinking water losses (of the production) of Egypt, Cairo, Giza and Qalyubia Governorates from 2002-2003 to 2015-2016 were calculated. ▪ The percentages of households without direct access to water and without direct access to drinkable water in 2017 was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Census 2017 report and Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017 report. First, I calculated the percentages of direct access to water and drinkable water, and then I calculated the percentages without direct access. ▪ Total production and untreated wastewater of Egypt, Cairo, Giza and Qalyubia Governorates in 2011. (AbuZeid and Elrawady, 2014) ▪ Percentages of wastewater production of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2011 were calculated. ▪ Percentages of wastewater treatment (primary, secondary and tertiary treatment, and untreated wastewater) in Egypt, Cairo, Giza and Qalyubia Governorates in 2011. (AbuZeid and Elrawady, 2014)

	▪ Total wastewater production and percentages of untreated wastewater for Egypt, Cairo, Giza and Qalyubia Governorates in 2011 were calculated. ▪ The percentages of households without sanitation services in 2017 was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Census 2017 report and Tables of the Most Important Characteristics and Indicators of the General Census of Population, Housing and Establishments 2017 report. First, I calculated the percentages of direct access to sanitation, and then I calculated the percentages without direct access (CAPMAS, 2017d; CAPMAS, 2017f).
Chapter 7	**Sources of secondary data for the Layer (3-3)** The solid waste data was collected from the following official statistics and reports: ▪ The total collected solid waste, composition and percentages of organic waste in 2010 was obtained from the Central Agency for Public Mobilization and Statistics, Egypt in Figures 2012 report (CAPMAS, 2012b). ▪ The total collected solid waste of Egypt, Cairo, Giza and Qalyubia Governorates based on the entity that collected and disposed it from 2006 to 2016 was obtained from Central Agency for Public Mobilization and Statistics, Public Utility 2006, 2012, 2016 and 2017 reports (CAPMAS, 2018a; CAPMAS, 2017e; CAPMAS, 2013b; CAPMAS, 2008b). ▪ The total generated municipal solid waste of Egypt from 2001 to 2012, this data was obtained from the Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013) and the Country Report on the

	Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014). ▪ The daily generated solid waste of Egypt, Cairo, Giza and Qalyubia Governorates in 2012, this data was obtained from the Annual Report for Solid Waste Management in Egypt, 2013 (Zaki et al., 2013) and the Country Report on the Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014). ▪ Percentages of the daily generated solid waste of Cairo, Giza and Qalyubia Governorates compared to the rest of Egypt in 2012 were calculated based on the available data. ▪ Municipal solid waste composition of Egypt in 2012 was obtained from the Country Report on Solid Waste Management in Egypt 2014 (SWEEP-Net, 2014) and (Hoornweg and Bhada-Tata, 2012). ▪ Percentages of waste collection coverage of Egypt, Cairo, Giza and Qalyubia Governorates in 2012, this data was obtained from the Country Report on Solid Waste Management in Egypt 2014. (SWEEP-Net, 2014) ▪ Percentages of households without waste collection coverage in 2017 was obtained from the Central Agency for Public Mobilization and Statistics, Egypt Census 2017 report (CAPMAS, 2017d).