**The Socio-Economic Impact of Decarbonising Geographical Islands’ Energy Systems**

Nkiru Lilian Agu1, Gobind Pillai1, Dana Abi Ghanem1, Stergios Vakalis2, Tracey Crosbie1, Dias Haralambopoulos2, and Xihui Haviour Chen3

1 Centre for Sustainable Engineering, Teesside University, Middlesbrough, TS1 3BA, UK.

2 Department of Environment, University of the Aegean, GR - 81100 Mytilini, Greece.

3 Edinburgh Business School, Heriot-Watt University, Edinburgh, UK

\* Correspondence: n.agu@tees.ac.uk

# ABSTRACT

The impact of the transition to energy autonomy on two geographical island’s local economies, through maximising renewable energy generation and storage, is assessed. The different sectors and activities that impact employment and income generation in the local economies of each of the islands are described. An empirical assessment approach based on the Keynesian Income Multiplier (KIM) is developed and applied using Analytical Hierarchy Process (AHP). Data for AHP was collated through interviews with local experts and stakeholders on each island. Gender employment and wage data was used to calculate the impact on female waged employment within the islands’ economic sectors. The analysis conducted showed that the induced local economic impact per unit of electrical energy due to the new RES-based autonomy in all sectors for male waged employment for both islands, exceeds its unit cost (LCOE). While the profits from per unit of electrical energy for the female waged employment only exceeded the unit cost (LCOE) in tourism for La Graciosa, and three other sectors in Gotland. The local economic impact from decarbonisation and 100% energy autonomy is significantly influenced by how the income from this renewable energy is recirculated within the island’s economic sectors, most essentially, tourism. Our findings suggest that strategies for community ownership and training local people to manage renewable energy facilities is necessary to maximise the benefits of the transition to energy autonomy on local communities.

**Keywords:** Socio-Economic Impact; Decarbonisation; Geographical Islands; Renewable Energy; Keynesian Income Multiplier.

# INTRODUCTION

Geographical islands suffer significant energy challenges. Those with mainland energy connections are highly dependent on the mainland energy market, while the transmission of energy is costly and inefficient. This affects energy security and increases the energy costs on geographically dispersed islands, which are up to 400% higher than those on the mainland [1, 2].

The high cost of energy, instability, and insecurity in supply increases the vulnerability of island communities to power outages adversely affecting residents’ welfare [3]. A self-sustainable energy strategy on geographical islands could alleviate energy poverty and insecurity and help reduce GHG (Green House Gas) emissions. Energy independence can be achieved by providing islands with self-sustainable energy systems that utilise renewable energy resources, energy storage, as well as optimise energy supply by managing demand [4].

According to existing studies [5, 6], energy autonomy results in socio-economic benefits for communities. These include local employment opportunities as well as direct financial rewards through increased independence and lower energy costs for different economic sectors. In addition, energy autonomy can lead to improved living standards resulting from lower energy costs due to decentralised energy sources. Also, energy autonomy can lead to better health arising from reduced GHG emissions, creation of job opportunities and fostering of social bonds by the renewable energy industry, as well as broader community development. At a country level, there is also a suggestion that Renewable Energy Systems (RES) on geographical islands provide economic benefits from saved fuel – oil purchases and carbon levies [5]. Marczinkowski [7] in his study concluded that the energy of islands contributes to the understanding of smart energy and sustainable energy planning, and this is achieved by islands playing a well-represented part in energy planning.

However, the investment in RES facilities and decarbonisation processes necessary for energy autonomy involves high costs [8]. To justify these costs, it is necessary to measure the socio-economic impact of such investment.

This study investigates the socio-economic impact of renewable energy generation, storage, and Information Communication Technologies (ICT) solution deployment for the facilitation of those RES on geographical islands. Specifically, a measurement of the local economic impact is developed for geographical islands.

Many argue that renewable energy/smart grid projects impact significantly on electricity consumers’ behaviour patterns, culture, and lifestyle [9-12]. Earlier studies have conducted impact assessments of RES on geographical regions, using different approaches to conduct a post installation assessment of the socio-economic benefits of the local community energy projects, and most utilised more than 12 months of data from local businesses and services [13-15]. However, there is a lack of evidence for assessing the benefits of community energy projects [16].

As far as the authors are aware, no studies have used methods for assessing the socio-economic impacts of self-sustaining energy system projects based on hypothetical future scenarios of RES installation and smart grid technologies. For geographical islands, RES-based energy systems projects require estimations or forecasts of their local economic effects for scenario evaluation.

We propose a novel approach for computing the forecasted value of socio-economic impact on energy autonomous geographical islands. This involves assessing the induced effects of renewable energy on the economy and various activities influencing employment and income generation in local economies. The approach is based on the Keynesian income multiplier (KIM) method, levelised cost of energy (LCOE) and involves the use of Analytical Hierarchy Process (AHP). REACT (Renewable Energy for self-sustAinable island CommuniTies) is an EU Horizon 2020 research and innovation project investigating the propensity of enabling the decarbonisation and 100% energy autonomy of geographical islands’ energy systems transitioning from a conventional fossil fuel-based island generation system (without information and communication technology interventions) to an autonomous energy system based on RES, storage, intelligent monitoring techniques and advanced energy management measures. Out of the eight geographical islands of different sizes focussed on in REACT, two islands have been used as case studies to demonstrate the utility of the proposed approach. The islands are La Graciosa, Canary Islands, Spain, and Gotland, Sweden.

The remainder of the paper is structured as follows; Section 2 reviews the common approaches to socio-economic impact assessment and introduces KIM as an economic multiplier concept based on AHP. Section 3 describes the case study islands and their energy scenarios based on previous research. In Section 4, we discuss the proposed approach for the socio-economic impact analysis, while results and discussions are presented in Section 5. Finally, conclusions are drawn in Section 6.

# EMPIRICAL SOCIO-ECONOMIC IMPACT ASSESSMENT

Investment in any project involves high costs, therefore, an overall economic impact assessment is required to ascertain a balance of capital investment in its economic gain. For a project’s continuous improvement, there is a critical need to measure its economic impact on the geographical region because it links performance to the principles of sustainability [17]. The assessment of economic impact is an intrinsically complex multi-dimensional process that is usually challenging as its sustainability impacts are often seen as intangible and somewhat difficult to measure but must be integrated into crucial decision making. Economic impact analysis is an inexact process because at different points in the analysis, different procedures are deployed, and underlying assumptions are made that can substantially affect the result.

In measuring the local economic impacts of community energy projects, it is important to distinguish between direct and indirect effects. Direct effects are the employment opportunities created for local employees at the RES facilities. Indirect effects are jobs in industries supplying the RES facilities in the local area. Additionally, induced economic effects on the local economy can be described as those resulting from energy autonomy and RES energy benefits accruing to the island community through RES installation [18 - 20].

For this research, the following assumptions were made for the socio-economic impact analysis.

1. In terms of direct effects, the impact of 100% RES-based energy autonomy negatively impacts on employment in the conventional energy sector on the island. It is assumed that the new local employment created by the RES installation would offer a vis-a-vis replacement for employment lost in the conventional energy sector. This is reasonable as employees in the conventional energy sector are familiar with the electrical power systems on the island.
2. In terms of indirect effects, La Graciosa have fewer inhabitants and fewer industries that can sub-contract elements of the installation of the RES facility. The construction of the RES facility will be sub-contracted and will be a one-off economic influx happening in one snapshot of time rather than being continuous. For these reasons the indirect effects of the construction of RES facilities on this island are not explored in detail in this paper.
3. Induced effects are the primary means by which RES-based autonomous energy systems on geographical islands bring about positive socio-economic changes in geographical islands. Therefore, they are the most important focus of the socio-economic impact assessments of the implementation of RES-based autonomous energy systems on geographical islands.

There are several indicators by which economic impact assessment is expressed, but almost all use the multiplier concept. Economic Base Multiplier, Input-output and Keynesian Income Multiplier (KIM) are techniques/models commonly employed in the analysis of the impact of the additional income and employment in the local economy generated by a major new project [21]. KIM, which is an economic theory, states that an increase in income (private consumption expenditures, investment expenditures, or government expenditures) will cause an increase in the total Gross Domestic Product (GDP), proportionately greater than the original change in income. The value of the multiplier depends on the Marginal Propensity to Consume (MPC) which is the change in total consumption caused by a change in total income as represented in Equation (1) [22]. KIM is based on money re-spent in the economy and measures how consumer spending changes with a change in income, mathematically represented as in Equation (2):

$MPC={∆C}/{∆Y}$ (1)

where *Y* is Income, and *C* is Consumption.

Therefore, KIM can be written as in Equation (2):

$KIM={1}/{(1-MPC)}$ (2)

The marginal propensity to consume (MPC) measures how consumer spending changes with income. The Keynesian Theory states that an increase in production leads to a rise in income and consequently, an increase in spending. The value of MPC allows us to calculate the size of the multiplier using the formula as shown in Equation (2)

In estimating the impacts on the local economy, the KIM can be tailored to focus on the local economic product, such as New Economic Foundation’s Local Multiplier 3 (LM3) [23]. However, as explained by Sacks [23], LM3 needs 9 to 12 months’ worth of data from local businesses and services after the installation of the RES facility to calculate its socio-economic impact on the local economy. In our case, we are investigating pre-installed projects in geographical islands. Hence, there was a need to estimate or forecast the induced effects of hypothetical RES scenarios, so a new method was developed based on the KIM technique.

# CASE STUDY ISLANDS

Two geographical islands which are in different climatic zones, with different underlying energy system requirements and population densities provide the case studies in this research. Depending on their environmental characteristics and national regulatory policies, the islands have different energy generation potentials for different RES technologies. As part of their work in the REACT project Barney, et al [24] identified renewable energy (and electricity storage – where needed) mix scenarios for the islands to attain energy autonomy.

Socio-economic impacts are the outcome of the interaction between the characteristics of the project and development actions i.e., the RES facility and the characteristics of the ‘host’ environment which is the local economy composed of the different business/service sectors active in the economy [21]. In terms of Marginal Propensities to Consume (MPCs), the strength of different sectors in instigating re-spending varies from island to island. This variation in MPCs should be captured by the new method of assessment proposed.

## 3.1 La Graciosa Island

La Graciosa is a volcanic island in the Canary Islands of Spain with an area of 29km2. It has two population centres, Caleta del Sebo and Pedro Barba. In 2018, the population registered was 734 inhabitants, of which 730 were for Caleta del Sebo. It’s electricity consumption, as recorded in 2017 by Fenie Energia, the electricity retailer in Spain, was 1,861MWh. The major economic sectors in La Graciosa are tourism and fishing. The 100% RES energy autonomy scenario best suited for it based on previous research [24] was a solar capacity of 0.5MWp at Levelised Cost of Energy (LCOE) of 0.12€/kWh, which is shown in columns 5 and 6 of Table 1.

## 3.2 Gotland Island

Gotland Island is a very large island in Sweden, located in the Baltic Sea with a population of 59,249 as recorded in 2015 and covers an area of about 3,183km2. Its electricity consumption recorded in 2015 was 984GWh. The major economic sector in Gotland is tourism followed by agriculture. The best suited RES energy autonomy scenarios for the island based on previous research [24] was a wind energy capacity of 310MW at LCOE of 0.12€/kWh, as shown in Table 1.

Table 1: REACT islands summary information.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Island** | **Population** | **Area (km2)** | **Economic Sectors** | **Electricity Demand** | **Energy Scenario**  | **LCOE (€/kWh)** |
| La Graciosa, Canary Island (Spain) | 734 | 29 | Tourism, Fishing, Services, Food processing, Health and social, Education, Arts and Craft[[1]](#footnote-2). | 1,861 (MWh) | PV – 0.5 MWp | 0.12 |
| Gotland (Sweden) | 59,249 | 3,183 | Tourism, Agriculture, Food processing, Mining, Construction, Education, Services, Manufacturing, Health & Social Work[[2]](#footnote-3).  | 984 (GWh) | Wind – 310MW | 0.12 |

Note: PV is photovoltaic; GWh is gigawatt hours; MWh is megawatt-hour; kWh is kilowatt hours.

# PROPOSED EMPIRICAL APPROACH FOR SOCIO-ECONOMIC IMPACT ANALYSIS

The proposed method focuses on capturing the induced effects of RES energy and 100% energy autonomy. The four main elements considered in the approach are:

1. Capturing sectoral MPCs using Analytical Hierarch Process (AHP).
2. RES scenario selection.
3. Capturing effects of capital investments based on LCOE.
4. Capturing decarbonisation and 100% energy autonomy.
5. Capturing gender income differentials.

## 4.1 Capturing Sectoral MPCs Using Analytical Hierarch Process (AHP)

We sought help of expert stakeholders on each island to capture their economic sector information. Their opinions were processed using the AHP method with the aid of an online software (AHP Priority Calculator) that converted these opinions into numeric weights. AHP is a multicriteria decision-making tool that relies on a heterogeneous data-based model building approach to calculate the weights of a given set of criteria [25]. For a detailed mathematical model of AHP, including calculation of relative weights and a consistency index please see [26]. The AHP method recognises that, though there can be several criteria, their magnitudes will differ. Therefore, weights are assigned to the criteria, and their alternatives are evaluated. It derives priorities among criteria and alternatives in a multicriteria decision-making problem [27]. Considering the MPCs for different sectors as Criteria, AHP can arrive at the sector MPCs by ranking them using pair-wise comparisons. The main steps in AHP are as follows:

1. Decompose the decision-making problem into a hierarchy.
2. Make pair-wise comparisons and establish priorities among the elements in the hierarchy.
3. Synthesise judgments (weights for sector MPCs).
4. Evaluate and check the consistency of judgements.

Meetings were arranged with 2 experts each one representing a case study island to obtain relevant information on the local economy. These experts are the members of REACT project team and have detailed knowledge of the local economy of the islands. The socio-economic assessment approach was explained to them, and the economic sectors specific to their respective islands were outlined and discussed. The experts then completed pair-wise comparison of these sectors based on their knowledge of the relative strength of the relevant local economic sectors in the island using the AHP priority calculator. The software tool also checked for consistency in the comparison and then assigned weights to the economic sectors considered finally as the MPCs of the islands economic sectors. With these MPCs, the KIM of each sector was calculated using Equation (2).

## RES Scenario Selection

Previous research [24, 28] assessed the generation potential and limitations of RES sources in the islands, namely wind, solar, biomass, geothermal, wave, tidal, and hydroelectric harvesting. Based on the assessments, a set of feasible RES technologies and potential storage options for each island were determined. Using the results from the assessment of RES potential at the sites and the findings from RES/storage enabled infrastructure planning (which involves legislative, economic, and technical limitations) undertaken as part of the Horizon 2020 project REACT, energy system scenarios were created. The REACT project also conducted a multi-criteria assessment of the lifecycle environmental impacts, economic, technical, and social indicators of the scenarios. Those scenarios which were identified as the most favourable for each island were selected for this study (shown in column 5 of Table1).

## Capturing Effects of Capital Investments Based on LCOE

Levelised cost of energy/electricity (LCOE) is the most frequently used metric to compare electricity generation technologies (whether conventional or renewable) [29]. It is often linked with ‘grid parity’, i.e., whether the cost of a unit of electricity generated by a particular generation technology, cost the same as a unit supplied by the grid [30]. While grid parity is more relevant to mainland grids, for geographical islands, a comparison of LCOEs between generators of different technologies can inform which technology or technology combination is to be deployed on the island.

The LCOE for a generator is calculated based on its energy over its operational lifetime and life-cycle costs. LCOE determines the minimum per-unit energy price a generator must receive to cover its lifetime costs. In simple terms, it can be represented in Equation (3) below:

$LCOE=\frac{Lifetime costs of the generator}{Lifetime energy production} $ (3)

A central concept in financial analysis is that money received today is more valuable than money received in the future due to its earning (growth) potential. An interest rate on the investment normally represents this growth. Equation (4) details a basic LCOE that can be used, including the time value of money in determining costs and production [31].

$LCOE=\frac{Investment Cost+\sum\_{t=1}^{n}\frac{Total annual cost at year t}{(1+interest rate)^{t}} }{\sum\_{t=1}^{n}\frac{Annual electricity generation}{(1+interest rate)^{t}}} $ (4)

where *t* is a given year in the technology’s lifetime, and *n* is technology’s total lifetime in years.

A technology’s investment cost is the total cost to construct it, while the total annual cost can include fuel, operations, and maintenance costs. In Equation (4), the total annual costs and the annual electricity generation are discounted to their present values for each year to make them comparable. Inherently, the cost of capital investment is captured in Equation (3), the LCOE formulation.

## 4.4. Capturing Decarbonisation and 100% Energy Autonomy

### 4.4.1. RES Energy

The energy from RES is the economic stimulus that induces positive socio-economic benefits under 100% energy autonomy. Recent literature suggests that mainland electricity companies would be better off transferring the RES facility ownership and energy generated from it to the community at no cost [5, 32, 33]. This is because significant transmission losses occur during energy importation from the mainland to the geographical islands. A transfer of ownership to the community will redirect RES energy’s cost which corresponds to the LCOE back into the local economy resulting in positive socio-economic benefits to the island community. This paper will focus on the 100% LCOE re-spent situation.

Based on each of the island’s recorded annual energy demand and the energy generated annually by the RES technologies under the hypothetical scenarios selected (column 5 of Table 1), the Office of Statistics databases can then be used to determine whether the RES facility’s size needs to be scaled up for 100% energy autonomy. However, as construction and other costs are almost a linear function of the RES facility’s size, the LCOE for the scenarios – even if they need to be scaled up – would roughly be the same.

### 4.4.2. ICT Platform and its Costing

For enabling the decarbonisation and 100% energy autonomy of geographical islands' they need autonomous energy systems based on renewable energy sources, storage, intelligent monitoring techniques, and advanced energy management techniques. An ICT (Information and Communications Technology) platform is needed for optimised energy dispatching using intelligent monitoring and advanced energy management. The platform needs to integrate algorithms to plan and manage the RES and storage assets by developing a holistic cooperative energy management and demand response (DR) system at the community level on geographical islands. Some of the benefits of energy storage optimisation are, utilising local renewable generation, taking advantage of variable energy prices, responding to custom demand increase/decrease requests, or utilising end-user flexibility in electric load.

Such an ICT platform while integral for autonomous energy management, also adds a cost of between 10% and 50% to the lifetime cost of the RES configurations selected on the geographical islands. This means an increase in the LCOE by a factor between 1.1 and 1.5 based on cost figures observed in the literature [34]. We call this an ICT scale-up factor. Owing to uncertainties around the complexities of the ICT platform, we have considered an ICT scale-up factor of 1.2 for individual scenario analysis. A sensitivity analysis of ICT factors ranging from 1.1 to 1.5 is then performed to evaluate the impact of ICT costs on social and economic benefits.

## Capturing Gender Income Differentials

As there is a focus on technology and policies to drive sustainability in the energy transition to RES, it is also important to ensure that there are equal economic opportunities and employment accessibility across gender, and the benefits this might have will be equitably distributed. Adopting a gender aware approach to assessing the impacts and benefits of sustainable energy interventions is crucial to ensure that women’s contributions – their skills and perspectives – are represented. Increasing women’s engagement will expand the available talent pool for the renewables sector. Other benefits of furthering gender diversity include the varied views women bring to the workplace. Studies have shown that women tend to be more collaborative at work [35]. Whilst increasing the representation of women has shown improved business performance [36].

Labour force participation and wage equality are the two principal parameters related to gender impact on waged employment that will be relevant for socio-economic impact assessment in this paper. Table 2 lists the values of these parameters for the geographical islands that are available from national and international sources [37]. We assume that the national impact is reflected in the islands unless specific sector data is available. Gotland was the only case study island where specific sector data was available [38]. Table 3 shows Gotland’s sectoral labour force participation and the gender representation Female to Male (F/M) in labour income using the national wage equality ratio. The Gender Representation F/M in Labour Income (GRLI) parameter values are considered for socio-economic impact analysis.

Table 2: Gender impact on waged employment parameters values among the geographical islands

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Geographical Island** | **Labour force participation (%)** | **Wage equality score (1-7)** | **Wage equality** | **Gender representation F/M in labour income** |
| **F** | **M** | **F/M ratio (1)** | **F/M** | **F/M ratio (2)** | **= (1) x (2)** |
| La Graciosa, Canary Island (Spain)  | 69.2 | 79.1 | 0.88 | 4.18 | 0.60 | 0.53 |
| Gotland (Sweden)  | 81.3 | 85 | 0.96 | 4.88 | 0.70 | 0.67 |

Note: F for female, M for male

Table 3: Sectoral labour force participation in Gotland Island

|  |  |  |  |
| --- | --- | --- | --- |
| **Industry sector** | **Numbers employed** | **F/M ratio** | **Gender representation F/M in labour income** |
| **F** | **M** |
| Farming, forestry, hunting, fishing | 360 | 1269 | 0.28 | 0.19 |
| Manufacturing and extraction | 352 | 1314 | 0.27 | 0.18 |
| Energy supply; environmental activities | 53 | 182 | 0.29 | 0.20 |
| Construction | 194 | 2290 | 0.08 | 0.06 |
| Sales | 1226 | 1369 | 0.90 | 0.60 |
| Transport and warehousing | 251 | 878 | 0.29 | 0.19 |
| Hotels and restaurants | 651 | 585 | 1.11 | 0.75 |
| Information and communication | 100 | 233 | 0.43 | 0.29 |
| Finance | 345 | 299 | 1.15 | 0.77 |
| Real estate | 152 | 306 | 0.50 | 0.33 |
| Business services | 799 | 1018 | 0.78 | 0.53 |
| Government and military | 1856 | 1360 | 1.36 | 0.91 |
| Education | 2159 | 752 | 2.87 | 1.92 |
| Health and welfare; social services | 4010 | 1050 | 3.82 | 2.56 |
| Cultural and personal services | 848 | 816 | 1.04 | 0.70 |

Note: F for female, M for male

The induced local economic impact per unit of energy due to the new autonomous sustainable energy infrastructure (SEI) on a particular sector in a particular island, can be calculated using Equation (5) as follows:

$SEI\_{n,m}=LCOEm×ICTSFm×KIMn,m$ (5)

where *n* indicates the sector concerned, *m* indicates the island concerned, *LCOEm* is the Levelized Cost of Energy for the island, *ICTSFm* is the ICT scale up factor for the island, and *KIMn,m* is the KIM for the sector on the island.

The impact on female waged employment can be calculated by multiplying the Equation (5) by the GRLI for the islands.

$SEI\_{n,m}(F)=LCOEm×ICTSFm×KIMn,m$ $×GRLIm$ (6)

where *GRLI* is the Gender Representation in Labour Income ratio for the island concerned.

# RESULTS AND DISCUSSION

The basic description of the islands and their key characteristics have been captured in Table 1. The data available for GRLI in Table 2 collated from different national and international sources may have skewed some of the results of these analyses if they are not entirely representative.

## 5.1 La Graciosa, Spain

The key characteristics and preferred energy scenario of this island is as shown in Table 1. Due to the size and low population of the island, specialist contractors from outside the local economy will be required to construct and install the RES facility. The construction phase does not produce direct employment effect as stated in assumption 1, but the operation of the phase which involves PV plant maintenance, and the management of the local control centre will only offer a vis-à-vis replacement of conventional energy sectors. There is a temporary increase in the local cash flow due to the slight increase in population during site development and plant construction which lasts for just the duration of the installation. It is difficult to predict how the land for the site will be arranged at this juncture. If it is leased from local landowners, there is potential for the lease income to be re-distributed within the economy. However, community ownership of the RES facility is better for the local economy from a socio-economic point of view. Therefore, leasing should not be considered only as a means to re-distribute income within the local economy.

With respect to the indirect employment effects, because there are not many industries on the island, elements of the installation cannot be sub-contracted. Therefore, the construction phase will only result in more hours and higher wages which are temporary for those locally on land and marine transportation.

In terms of calculating the induced effects, the new approach described in section 4 using AHP was used. Table 4 shows the economic sectors in the local economy highlighted by the local economy expert, the MPC and the corresponding KIMs for those sectors. Tourism is the economic sector with the highest potential for realising positive economic benefits in the local economy via re-spent income. The second largest economic sector is the service sector, followed by the fishing sector.

Table 4: Economic Sectors, MPC, KIM, and the induced local economic impact per unit of electrical energy for La Graciosa, Spain

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Economic Sectors** | **MPC** | **KIM** | **SEI** | **SEI (F)** |
| Tourism | 0.45 | 1.82 | 0.26 | 0.14 |
| Fishing | 0.14 | 1.16 | 0.17 | 0.09 |
| Food processing | 0.1 | 1.11 | 0.16 | 0.08 |
| Services | 0.21 | 1.27 | 0.18 | 0.10 |
| Health & Social Work | 0.04 | 1.04 | 0.15 | 0.08 |
| Education | 0.03 | 1.03 | 0.15 | 0.08 |
| Arts & Crafts | 0.02 | 1.02 | 0.15 | 0.08 |

Note: MPC is the marginal propensity to consume; KIM is Keynesian income multiplier; SEI is sustainable energy infrastructure; and F is female.

Using Equations (5) and (6), the induced local economic impact per unit of energy due to the new autonomous renewable energy infrastructure (SEI) and the impact on female waged employment were calculated. The ICT scale-up factor was considered to be 1.2, and the GRLI was taken from Table 2. As seen in Table 1, the LCOE for the RES scenario selected was €0.12/kWh. Table 4 also shows the induced local economic impact per unit of energy for La Graciosa. Column 4 shows the impact on male waged employment and column 5 on female waged employment.

The profits from one unit of electrical energy are more than its unit cost (LCOE of €0.12/kWh) for all sectors in male waged employment (SEI). Meanwhile, tourism is the only sector in which the profit from one unit of energy exceeds its unit cost in terms of female waged employment. The data available for GRLI may have skewed some of the results. Municipalities and councils managing the local economy can control the impact potential of re-spend by each economic sector and devise plans for how income from the sales of energy is to be shared to affect growth and improvements in target sectors. Without such action plans, the local economic impact of different sectors will remain the same. Only the size of the economy would increase based on the share of energy income offered to the community.

##  Gotland Island, Sweden

Key characteristics of Gotland is as shown in Tables 1 and 3. Due to the large population of the island, there is a possibility of specialist sub-contractors from within the local economy as plant/site sub-contractors. To create direct and indirect employment opportunities in the construction phase of wind technology, the main machinery must be manufactured outside of the local economy. Due to an increase in population, the local cash flow will temporarily increase, but will only last for the duration of the installation. Prediction of the land lease is premature at this point, but community ownership is recommended. The analysis of the induced effect is conducted, and the results are summarised in Table 5.

Table 5: Economic sectors, MPC, KIM, and the induced local economic impact per unit of electrical energy for Gotland Island, Sweden

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Economic Sectors** | **MPC** | **KIM** | **SEI** | **GRLI** | **SEI (F)** |
| Agriculture | 0.24 | 1.31 | 0.19 | 0.28 | 0.05 |
| Tourism | 0.29 | 1.41 | 0.20 | 1.11 | 0.23 |
| Construction | 0.08 | 1.09 | 0.16 | 0.08 | 0.01 |
| Mining | 0.03 | 1.03 | 0.15 | 0.27 | 0.04 |
| Manufacturing | 0.03 | 1.03 | 0.15 | 0.27 | 0.04 |
| Health & social Work | 0.12 | 1.14 | 0.16 | 3.82 | 0.63 |
| Services | 0.16 | 1.19 | 0.17 | 0.78 | 0.13 |
| Education | 0.03 | 1.03 | 0.15 | 2.87 | 0.43 |
| Fishing | 0.03 | 1.03 | 0.15 | 0.28 | 0.04 |

Note: MPC is the marginal propensity to consume; KIM is Keynesian income multiplier; SEI is sustainable energy infrastructure; GRLI is the Gender Representation F/M in Labour Income; and F is female.

Table 5 also demonstrates the induced local economic impact per unit of energy for Gotland. The profits from one unit of energy are more than its unit cost (LCOE 0f €0.12/kWh) for all sectors in male waged employment, the tourism, health & social work, services, and education sectors in female waged employment. The advantage for Gotland was that sectoral GRLI data was available, unlike other pilot islands.

## 5.3 Sensitivity Analysis of the Impact of ICT Solution Costs.

A sensitivity analysis was performed to holistically understand the impact of the ICT costs. As tourism was a sector with high induced socio-economic impact across both islands, it was the economic sector selected for use in the analysis. Table 6 presents the population, KIM for the tourism sector, the LCOE, the Gender Representation in Labour Income ratio (GRLI), and the induced local economic impact per unit of energy due to the new autonomous renewable energy infrastructure on female waged employment (SEI(F)). For the two islands, their SEI(F) for the different values of ICTSF is higher than the LCOE, indicating a profit.

The value of the ICT scale-up factor will depend on the size of the RES installation, which is determined by the population. Lower populations may face higher ICT scale-up costs owing to the relatively smaller size of the RES installation. While, in theory, a higher ICT scale-up factor can produce higher induced benefits, especially for female waged employment as it increases the per-unit energy costs, this is not necessarily beneficial since the community must bear the negative effects. Therefore, increasing the per-unit energy costs is never beneficial. This might be in the form of a lower ownership share of the RES facility for the community or lower reciprocal payments depending on the conditions and agreements between the local community and the electricity utility.

Table 12: Sensitivity analysis of the impact of ICT scale-up factor on the tourism sector

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Island** | **Population** | **KIM** | **LCOE** | **GRLI** | **SEI (F) for different values of ICTSF** |
| **1.1** | **1.2** | **1.3** | **1.4** | **1.5** |
| La Graciosa (Spain)  | 734 | 1.82 | 0.12 | 0.53 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 |
| Gotland (Sweden)  | 59,249 | 1.41 | 0.12 | 1.11 | 0.21 | 0.23 | 0.24 | 0.26 | 0.28 |

Note: KIM is Keynesian income multiplier; LCOE is levelized cost of energy; GRLI is the Gender Representation F/M in Labour Income; SEI is sustainable energy infrastructure; F is female; and ICTSF is the ICT scale up factor for the island.

# CONCLUSION AND RECOMMENDATIONS

This paper has introduced a new approach of assessing the socio-economic impact of self-sustaining energy system projects that are based on hypothetical future scenarios of RES installation. Keynesian Income Multiplier has been used to investigate the induced effects of RES-based system on the economy and the various activities that influence employment as well as income generation on two geographic islands within the EU’s Horizon 2020 REACT project. The proposed approach involved the use of AHP to capture the sectoral MPC, the selection of RES scenarios based on previous study forecasted values, capturing of effects of capital investments based on LCOE, capturing decarbonisation and 100% energy autonomy, and lastly capturing gender income differentials. It has been shown that the islands’ main source of income comes from tourism. It is imperative that a holistic approach of RES-based autonomy and decarbonisation with detailed examination of all high-income sectors on each island, including their facilities be developed, to ensure direct benefit from the RE income and that RES development does not affect the sectors adversely. These sector facilities should be prioritized due to their significant economic impact on employment on the islands.

A key factor for energy transition is the adoption and encouragement of community energy. This can be expedited by giving incentives to develop renewable energy projects with community ownership and participation. It is recommended to give community the ownership of the RES facility as well as support the local workforce with skills development and training to maximise benefits to the local economy. This will promote public awareness of sustainable development, and thereby reduce public resistance to any RE plant prior to construction [18, 39]. Therefore, local community ownership should be taken into consideration when assessing a planning application and when considering the economic benefits for a community. The local community should be held accountable for how funds are spent to achieve the intended outcomes, and these conditions or agreements should be tailored to benefit local projects of the highest priority.

The gender aware approach has also shown the importance of closing the gender pay gap and the need to foster gender equity in all economic sectors to have a broader socio-economic benefit.

Finally, RES facilities can offer informal education and information via guided tours and other similar activities [39]. Such initiatives can reinforce the local commitment to RES, particularly on small islands. The operators of the facility should be encouraged to produce information packs and websites sharing plant information for the same objective.

# ACKNOWLEDGMENT

The research presented in this paper is partly financed by the European Union (Horizon 2020 REACT project, Grant Agreement No.: 824395).

# REFERENCES

1. Pacheco, A., Monteiro, J., Santos, J., Sequeira, C., & Nunes, J. (2022). Energy transition process and community engagement on geographic islands: The case of Culatra Island (Ria Formosa, Portugal). *Renewable Energy*, *184*, 700–711. https://doi.org/[10.1016/j.renene.2021.11.115](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.renene.2021.11.115)
2. Niles, K., & Lloyd, B. (2013). Small Island Developing States (SIDS) & energy aid: Impacts on the energy sector in the Caribbean and Pacific. *Energy for Sustainable Development*, *17*(5), 521–530. https://doi.org/[10.1016/j.esd.2013.07.004](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.esd.2013.07.004)
3. Jelić, M., Batić, M., Tomašević, N., Barney, A., Polatidis, H., Crosbie, T., ... & Pillai, G. (2020). Towards self-sustainable island grids through optimal utilization of renewable energy potential and community engagement. *Energies*, *13*(13), 3386
4. Petrakopoulou, F. (2017) ‘The social perspective on the renewal energy autonomy of geographical isolated communities: Evidence from a Mediterranean island’, *Sustainability (Basel, Switzerland)*, 9(3), pp. 327
5. Nassar, I. A., Hossam, K., & Abdella, M. M. (2019). Economic and environmental benefits of increasing the renewable energy sources in the power system. *Energy Reports*, *5*, 1082–1088. https://doi.org/[10.1016/j.egyr.2019.08.006](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.egyr.2019.08.006)
6. Zafeiratou, E., & Spataru, C. (2018). Sustainable island power system – Scenario analysis for Crete under the energy trilemma index. *Sustainable Cities and Society*, *41*, 378–391. https://doi.org/[10.1016/j.scs.2018.05.054](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2018.05.054)
7. Marczinkowski, H. M. (2022). Rethinking islands and their models in sustainable energy planning: How inclusive local perspectives improve energy planning globally. *International Journal of Sustainable Energy Planning and Management*, *33*, 7-18.
8. Abolhosseini, S., & Heshmati, A. (2014). The main support mechanisms to finance renewable energy development. *Renewable and Sustainable Energy Reviews*, *40*, 876-885.
9. Bigerna, S., Bollino, C. A., & Micheli, S. (2016). Socio-economic acceptability for smart grid development–a comprehensive review. *Journal of Cleaner Production*, *131*, 399-409.
10. Al-Marri, W., Al-Habaibeh, A., & Watkins, M. (2018). An investigation into domestic energy consumption behaviour and public awareness of renewable energy in Qatar. *Sustainable cities and society*, *41*, 639-646.
11. Cruz, C., Palomar, E., Bravo, I., & Aleixandre, M. (2021). Behavioural patterns in aggregated demand response developments for communities targeting renewables. *Sustainable Cities and Society*, *72*, 103001. https://doi.org/[10.1016/j.scs.2021.103001](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2021.103001)
12. Novianto, D., Koerniawan, M. D., Munawir, M., & Sekartaji, D. (2022). Impact of lifestyle changes on home energy consumption during pandemic COVID-19 in Indonesia. *Sustainable Cities and Society*, *83*, 103930. https://doi.org/[10.1016/j.scs.2022.103930](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2022.103930)
13. Sastresa, E.L., Usón, A.A., Bribián, I.Z. and Scarpellini, S., 2010. Local impact of renewables on employment: Assessment methodology and case study. *Renewable and sustainable energy reviews*, *14*(2), pp.679-690.
14. Padrón, I., Avila, D., Marichal, G. N., & Rodríguez, J. A. (2019). Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago. *Renewable and Sustainable Energy Reviews*, *101*, 221–230. https://doi.org/[10.1016/j.rser.2018.11.009](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.rser.2018.11.009)
15. Pimentel Da Silva, G.D., Magrini, A. and Branco, D.A.C., 2020. A multicriteria proposal for large-scale solar photovoltaic impact assessment. *Impact Assessment and Project Appraisal*, *38*(1), pp.3-15.
16. Van Der Waal, E.C., 2020. Local impact of community renewable energy: A case study of an Orcadian community-led wind scheme. *Energy Policy*, *138*, p.111193
17. Epstein, M.J. & Buhovac, A.R. 2017, *Making Sustainability Work: Best Practices in Managing and Measuring Corporate Social, Environmental and Economic Impacts,*Taylor and Francis
18. ADAS. (2003). *Renewable Energy and Its Impact on Rural Development and Sustainability in the UK*
19. Breitschopf, B., Nathani, C., & Resch, G. (2012). *Methodological guidelines for estimating the employment impacts of using renewable energies for electricity generation*. Fraunhofer ISI.
20. Foley, L. (2018). *Transmission Reinforcement between the Western Isles and the Scottish Mainland: Cost Benefit Analysis Study*. GHD
21. Therivel, R., & Wood, G. (2017). *Methods of environmental and social impact assessment*. Taylor & Francis
22. Schreiner, L., & Madlener, R. (2021). A pathway to green growth? Macroeconomic impacts of power grid infrastructure investments in Germany. *Energy Policy*, *156*, 112289. https://doi.org/[10.1016/j.enpol.2021.112289](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.enpol.2021.112289)
23. Sacks, J. (2002). *The Money Trail: Measuring your impact on the local economy using LM3*. New Economics Foundation
24. Barney, A., Polatidis, H., Jelić, M., Tomašević, N., Pillai, G., & Haralambopoulos, D. (2021). Transition towards decarbonisation for islands: Development of an integrated energy planning platform and application. *Sustainable Energy Technologies and Assessments*, *47*, 101501
25. Ameen, R. F. M., & Mourshed, M. (2019). Urban sustainability assessment framework development: The ranking and weighting of sustainability indicators using analytic hierarchy process. *Sustainable Cities and Society*, *44*, 356–366. https://doi.org/[10.1016/j.scs.2018.10.020](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2018.10.020)
26. Saaty, T. (1980). The analytic hierarchy process: Planning, priority setting, resource allocation, McGraw-Hill, New York.
27. Awad, J., & Jung, C. (2021). Extracting the Planning Elements for Sustainable Urban Regeneration in Dubai with AHP (Analytic Hierarchy Process). *Sustainable Cities and Society*, *76*, 103496. https://doi.org/[10.1016/j.scs.2021.103496](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2021.103496)
28. Barney, A., Polatidis, H., & Haralambopoulos, D. (2022). Decarbonisation of islands: A multi-criteria decision analysis platform and application. *Sustainable Energy Technologies and Assessments*, *52*, 102115.
29. Duman, A. C., & Güler, Ö. (2018). Techno-economic analysis of off-grid PV/wind/fuel cell hybrid system combinations with a comparison of regularly and seasonally occupied households. *Sustainable Cities and Society*, *42*, 107–126. https://doi.org/[10.1016/j.scs.2018.06.029](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2018.06.029)
30. Breyer, C., & Gerlach, A. (2012). Global overview on grid-parity. *Progress in Photovoltaics: Research and Applications*, *21*(1), 121–136. https://doi.org/[10.1002/pip.1254](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1002%5Cpip.1254)
31. Kost, C., Shammugam, S., Julch, V., Nguyen, H. T., & Schlegl, T. (2018). *Levelized cost of electricity Renewable Technologies*. Fraunhofer Institute for Solar Energy Systems ISE.
32. Notton, G. (2015). Importance of islands in renewable energy production and storage: The situation of the French islands. *Renewable and Sustainable Energy Reviews*, *47*, 260–269. https://doi.org/[10.1016/j.rser.2015.03.053](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.rser.2015.03.053)
33. Sigrist, L., Lobato, E., Rouco, L., Gazzino, M., & Cantu, M. (2017). Economic assessment of smart grid initiatives for island power systems. *Applied Energy*, *189*, 403–415. https://doi.org/[10.1016/j.apenergy.2016.12.076](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.apenergy.2016.12.076)
34. Wang, N., Verzijlbergh, R. A., Heijnen, P. W., & Herder, P. M. (2020). A spatially explicit planning approach for power systems with a high share of renewable energy sources. *Applied Energy*, *260*, 114233. https://doi.org/[10.1016/j.apenergy.2019.114233](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.apenergy.2019.114233)
35. Cullinan, R. (2018). In Collaborative Work Cultures, Women Carry More of the Weight. Harvard Business Review. *Harvard Business Publishing*.

https://doi.org/[10.1016/j.scs.2021.103539](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.scs.2021.103539)

1. Wagner, H. M. (2011). The bottom line: corporate performance and gender diversity in the c-suite (2004-2008). *Available at SSRN 1980371*.
2. Www3.weforum.org. 2021. *Global Gender Gap report*. [online] Available at: <https://www3.weforum.org/docs/WEF\_GGGR\_2021.pdf> [Accessed March 2021].
3. Statistiska Centralbyrån. 2020. *Statistics Sweden*. [online] Available at: <https://www.scb.se/en/> [Accessed 2020].
4. Koirala, B. P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R. A., & Herder, P. M. (2018). Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. *Energy Research & Social Science*, *38*, 33–40. https://doi.org/[10.1016/j.erss.2018.01.009](file:///C%3A%5CUsers%5Cxc2021%5CDownloads%5C10.1016%5Cj.erss.2018.01.009)
1. Source: Instituto Canaior de Istadistica: http://www.gobiernodecanarias.org/istac/temas\_estadisticos/ [↑](#footnote-ref-2)
2. Source: Gotland in Figures 2017, available at: https://www.gotland.se/104323 [↑](#footnote-ref-3)