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Integrated energy and transport planning: Targeting islands' sustainable development

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Integrated energy and transport planning: Targeting islands' sustainable development

Ioannis Kougias

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Abstract

The present Master Thesis focuses on islands' sustainable development and contains the output of a research activity addressing several sustainability issues in an integrated manner. It creates a *nexus* analysis framework, where energy and transport systems are analysed in parallel while interactions with the environment and water infrastructure are also examined. The Thesis builds on three main pillars i.e. the analyses of energy systems, new transport schemes for the islands and a qualitative-quantitative analysis of different strategies.

An energy model was specifically developed for islands to assess challenges and opportunities of transforming electricity systems and the potential role of modern renewable energy sources (RES). The model was applied in selected test-cases and processed up-to-date information. A second part of the nexus analysis investigated the potential role of emerging and revolutionary transport concepts in the island setting. Potential synergies were also identified to enable a harmonic operation of transport and energy systems. As a third pillar, the research analysed the different strategies. It processed the priorities defined by a selected group of 44 specialists (scientists, decision makers, industry and project developers) with experience on islands' sustainable development. Selected experts filled a structured questionnaire, specifically designed for the needs of islands, and the collected responses were processed using a Q-technique. The results translated the qualitative experts' input to quantitative output, a valuable information to be used in decision making.

This Thesis supports thus a sustainable development paradigm change by providing evidence about the importance of redefining islands' energy and transport systems in an integrated manner. It highlights the available synergies, provides modelled projections for the future and evidence to understand available strategies according to specialists. It is an attempt to provide science-based input to influence sustainable development strategies for the island societies, with measurable impacts for the economies and environments.

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Nomenclature

AC	alternating current
BEV	Battery Electric Vehicle
CAGR	compound annual growth rate
CAPEX	Capital Expenditure
CAV	Connected and Autonomous Vehicle
DC	direct current
EC	European Commission
EU	European Union
EV	electric vehicle
GHG	greenhouse gas
G2V	Grid to Vehicle
HSA	Harmony Search Algorithm
ICT	Information and Communications Technology
JRC	EC Joint Research Centre
LCOE	levelised cost of electricity
MaaS	mobility as a service
MS	EU member state
NEV	neighbourhood electric vehicle
NGO	non-governmental organization
NPV	net present value
O&M	Operation and Maintenance
PAS	pedal assist e-bikes
PCA	Principal Components Analysis
PHEV	plug-in hybrid electric vehicle
PPP	private-public partnership
PV	photovoltaic
R&D	Research and Development
RES	renewable energy sources
SIDS	Small Islands Developing States
SMP	system marginal price
SUM	Shared Use Mobility
TBL	triple bottom line
TSO	transmission system operator
UNFCCC	UN Framework Convention on Climate Change
V2G	Vehicle to Grid

Chapter 1

Introduction

1.1 Scope of the Thesis

The present Master Thesis collects and presents the findings of a research activity that aims at addressing several sustainability issues in an integrated manner. The topic of interest is islands of the European Union (EU) and particularly island regions where energy and transport systems are not connected with the mainland. This works attempts to develop sustainable EU islands by addressing *in parallel* the various existing challenges. It, thus, examines the challenges and opportunities of transforming islands' energy systems in such a way that they can host large shares of renewable energy sources (RES). At the same time, the analysis investigates the role of emerging and revolutionary transport concepts in the island setting and how these can be harmonically developed and function with RES-based systems. Linkages with water infrastructures and waste/wastewater treatment are also briefly examined. As a third pillar, the research work analyses the different strategies and policy options by quantifying the preferences and priorities drawn by specialists i.e. scientists, decision-makers, industry and project developers with experience on islands' sustainable development.

Thus, the present research Thesis attempts to link research activities that are seemingly heterogeneous. To do so, the key contents of the analysis are packaged together harmoniously in a unique mix that facilitates understanding in a key area for sustainable planning, management and policy-making. Accordingly, this work touches a nexus of energy, water and transport which is in the heart of state-of-the-art European policy-making and R&D.

The *special case* of islands and island states for sustainable development was recognised already in 1992 at the United Nations Conference on Environment and Development in Rio. Since then three international conferences have been organised to support the Small Islands Developing States (SIDS). In the EU, the "Clean Energy for EU Islands Secretariat" supports islands' transition to clean energies and acts as a hub of information for island communities, supports project development and coordinates efforts through the organisation of regular events, workshops and the Clean Energy for EU Islands Forum.

The JRC participated in the Inaugural Forum in September 2017 in Chania, Greece. This Forum revealed the need for evidence-based knowledge and integrated solutions for the sustainable development of islands. This was the moment that the idea of working on the present topic started to take its final shape. Observing the complexity and particularities of a real-world problem showed the necessity to form novel, integrated approaches. To address existing bottlenecks, these approaches will require cross-discipline analyses that can potentially translate to policy decisions with a direct contribution to development plans.

Indeed, the present research work attempts to deal with several of the urgent issues that appear in the EU islands. This includes issues that are directly analysed such as the development of cost-efficient clean energy systems, sustainable transport and the decision-making processes. However, the analysis concerns also climate change, water availability and quality and islands' ecosystems as the analysed topics are indirectly connected to these aspects.

1.2 Sustainability and sustainable development for islands

According to the definition of the World Commission on Environment and Development, sustainable development involves “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987). It was this report in 1987 that linked explicitly environmental conservation with economic development for the first time. Notably, the definition also considers sustainability as a means of social equity; sustainable development makes sure that the needs of future generations will be secured and resources will not be depleted by the current generation.

Sustainable development involves economic activities and development with the environmental agenda and social challenges. This linkage, known as the *triple bottom line (TBL)* approach was introduced by Elkington who strove to quantify sustainable development by encompassing a new framework to measure performance (Elkington, 1994). According to the new accounting framework that was named triple bottom line, traditional measures of profits went beyond metrics such as return on investment to include environmental and social dimensions.

While the principles of sustainability and sustainable development are universal, some of their aspects are particularly important for the islands. Remote islands are isolated and the identified TBL linkages (growth-environment-social) are even more pronounced. The particular geographic isolation of islands magnifies the impacts of non-sustainable strategies. As soon as a resource is depleted (e.g. groundwater aquifer) it cannot be replaced by another resource located nearby (e.g. surface water) as the number of available resources in islands are limited. In such cases, imports appear to be the only option but at a cost that hinders economic growth. Besides, due to their typically small size and internal market, islands do not have the potential to absorb the additional burden.

Accordingly, in case the central government does not provide incentives, the impact will become more pronounced to the local population. But even if the central government can secure such incentives in the short-term, islands growth is not sustainable as future generations (social aspects) will not benefit from the depleted local resource. This means that one of the three pillars of sustainability is not well-founded.

At its core, sustainable development is about responsible economic growth that can last in time as it is implemented in harmony with available natural needs and resources. Already from the late 20^{th} century, an increasing number of organisations related to environmentally friendly growth have experimented with partnership approaches to address environmental and sustainability problems (Elkington, 1998). The core value to develop a sustainable island is that of responsibility (Lenzen and Murray, 2010), implying islands' willingness to take responsibility for their future sustainable development. Available resources (energy, environmental, cultural etc.) must thus be preserved and responsibly explored and utilised in a balanced manner that supports economic growth and fairness for the local population (current and future).

In the present Thesis, islands' sustainability is the connecting point of the nexus analysis. Energy is the basis of the three-piece work as it affects transport and access to water. Strategies to transform energy systems in the islands will define the available options for the other sectors. Through the developed electricity model and the simulations, the analysis confirms the current non-sustainable status of islands' energy systems. It shows that apart from their advantageous environmental characteristics, RES can potentially deliver energy at much lower costs than conventional polluting technologies. An additional contribution of the present work is that it shows that optimal strategies are different between islands. Solutions need to be tailor-made for each island because in some cases smaller systems (e.g. solar photovoltaic (PV)) need to take a major role, while in other cases wind power systems of larger scale dominate. The role of storage also varies between islands.

Electromobility and novel transport schemes can also support the islands' sustainable growth. The present work shows that the available clean transport technologies can cover the unique transportation needs of every island, both private and public. It also shows that emerging vehicle sharing systems can revolutionise the way rental schemes have operated up to date and offer new means of mobility.

Equally important is the third part of this three-piece work i.e. understanding the perceptions of involved specialists. This unique analysis for island settings reveals specialists' opinions and preferences to design the transition. Environmental concerns, financial and economic aspects, interactions with drinking and wastewater treatment systems are analysed in an integrated manner revealing the possible paths to design sustainable islands.

1.3 Context of the study

Remote islands located far from the mainland still use conventional outdated practices to cover their energy and transportation needs. Such small-scale systems are often isolated and not connected to central electricity grids. Despite certain technological advances and breakthroughs in electrical grid designs, islands still need in many cases to produce electricity locally using diesel and (heavy) oil. Accordingly, islands import fossil fuels to operate thermal power plants. High fuel prices and their volatility result in a very high cost of electricity production, challenging islands' sustainable development. Besides, fuels need to be transported to islands by sea and small economies of scale further increase electricity and transport costs.

Equally important is the seasonal variability in power demand. In touristic destinations such as the islands, summer peaks of demand further increase cost and impose additional challenges due to the required over-capacities needed for the power system operation. Moreover, islands do not benefit from economies of scale due to their –generally– low population and small energy/transport markets. Relying on fuel imports for electricity production and mobility also raises energy security issues. So far, the additional costs were subsidised and covered by government budgets. However, there is an increasing need for the islands to take advantage of the decreasing costs of sustainable systems and technologies. Such a strategy would also support efforts to minimise greenhouse gas (GHG) emissions and mitigate local air/noise pollution.

The European Union (EU) has prioritised the decarbonisation of the electricity sector including measures to support the deployment of RES and increase their share in power portfolios. On May 2017, a political declaration supported by the EC and 14 EU member states (MSs) identified islands as potential forerunners in this transition to clean energy, as they have the strongest needs. The "Valletta political declaration" (European Commission, 2017) underlined the urgent need for clean energy and transport for EU islands and, thus, resulted in the "Clean Energy for Islands Initiative" (European Commission, 2018). The initiative aims at supporting the more than 2000 EU islands and their 15 million inhabitants to have access to affordable, clean and efficient systems also promoting energy self-reliance. Priorities include scaling up RES, energy efficiency and clean transport.

The EC has kick-started the process to support islands to become more self-sufficient, prosperous and sustainable. On the 18^{th} of February 2019, 26 European islands were selected as pioneering locations to advance their production from RES, implement energy efficiency measures and adopt clean transport solutions. Six of the selected islands need to develop and publish their clean energy-transport transition agendas already by summer 2019 (European Commission, 2019).

1.4 Aim, objectives and research questions

The Thesis attempts to assess and quantify the value of integrated nexus approaches to develop sustainable islands. Its aim is thus to understand how renewable energy production, energy-water relation and electromobility management could holistically support the sustainable development of islands that are not interconnected to the main grid.

The objectives of the research are: (i) to identify the importance of renewable energy portfolios for islands that are not interconnected to the main grid and their role in drinking water, sanitation and waste management; (ii) specify electromobility solutions and the way with which this would benefit sustainable growth in islands; (iii) examine how sustainable development experts from academia, policy and practice evaluate RES and electromobility interventions for the unique context of island resource management.

In accordance with the defined objectives of the present study, the identified research questions are:

1. What is the importance of renewable energy portfolios for islands that are not interconnected to the main grid and the role of water?

2. What is the current status of clean transport solutions and how these could be implemented to support sustainable growth in islands?

3. How sustainable development experts from academia, policy and practice evaluate RES and electromobility interventions for the unique context of island resource management?

1.4.1 Clean energy for islands

Challenges in electricity production are common among the islands of different countries. In Italy, the island of Pantelleria that is located approximately 100 km south of Sicily is a typical example of islands not connected to the national grid and managed by small electricity producers. In such cases, the required electricity is produced with small-scale diesel generators with low efficiencies. According to the Italian transmission system operator (TSO), such diesel gen-sets lose about three-quarters of the energy in the form of waste heat and involve great noise impacts, GHG emissions and harmful fume (Terna Group, 2016). Apart from the significant environmental impacts, Terna Group (2016) reports that the produced electricity has a cost that it is –on average– six times higher than the price for the central power grid. The additional costs translate to an annual burden of many €million that need to be shared on a national basis just for the single island of Pantelleria.

Sustainable alternatives to the current situation need to utilise local energy sources and minimise islands' dependence on imports. Strategies also need to involve minimal environmental impact catering GHG emissions, air pollution but also ensuring low visual and noise impacts.

RESs utilise indigenous energy sources and generally have a low environmental impact. Recent technological breakthroughs have further increased efficiency of production, while cost reductions in battery storage have reached levels of maturity that allow large-scale installations. Indeed, Lithium-Ion battery prices have fallen by 85%, globally since 2010 (Stubbe, 2018) and the expected further price reductions favour the deployment of a high share of variable RES. Increased share of RES in such power portfolios could be realised gradually, allowing to break down the required investments over a period of time. Taking advantage of RES' modularity would make the transition easier and avoid the immediate phase-out of existing conventional systems. Such a transformation is not competing with future plans to interconnect islands to central power systems: contrary to thermal power plants that seize operation if an interconnection is realised, investments in RES will continue to produce value feeding electricity into local or mainland grids.

Water and energy interrelation

Water availability in islands is an additional issue as several islands face water scarcity challenges. This issue exacerbates in smaller islands since smaller watersheds do not store sufficient water resources. Islands of the Mediterranean are generally characterised by dry and warm climate, and low precipitation. Thus, local water resources are not sufficient to cover the needs and water is often imported from the mainland with water carrier ships or produced locally in desalination plants. This is due to the fact that alternatives (i.e. groundwater extraction, desalination) require much energy that increase costs. Besides, drinking and irrigation water supply systems consume energy in different phases such as extraction, purification and pumping.

For these reasons, islands' sustainable water resources management is directly linked to the energy sector. Desalination is an energy-intensive process with electricity constituting $\simeq$20% of its total cost as it requires between 4 kWh/m^3 and 9 kWh/m^3 (Arampatzis et al., 2017). The option of desalination is, thus, hindered if the cost of electricity is particularly high. In that sense, sustainable and low-cost electricity could support access to clean water in the islands.

A common challenge in water treatment processes is the cost of energy. The particularly high cost of electricity in the islands exacerbates this issue. The production cost of electricity is in certain cases 5-7 times higher than the mainland one (Kougias et al., 2019). This challenge could be partially addressed through the deployment of RES, taking advantage of their advantageous cost feature. Advanced control systems could also allow managing RES power production in accordance with the consumption requirements of a certain wastewater treatment plant. Such cutting-edge water and energy management framework could optimise the diverse stages of water treatment, reduce energy consumption and the cost per m^3 of treated water.

1.4.2 Sustainable transport for islands

Transport practices in islands are also outdated. Services such as mobility-on-demand are not provided. Accordingly, Shared Use Mobility (SUM), car-sharing and bike-sharing, has not been sufficiently developed in islands. The share of electromobility for private and public services is also very low, partly due to power system limitations. At the same time, users are burdened with particularly high prices for gasoline and diesel, since the additional cost of fuel transport results in considerably higher at-the-pump prices compared to the mainland even exceeding levels as high as €2/litre (European Commission, Directorate-General for Energy, 2019).

Action and commitment to transforming islands' energy and transport systems are, thus, of critical importance due to increasing economic pressure. Recent technological breakthroughs also allow islands to become show-case practices for future integration of RES, storage and electromobility. An integrated strategy could also mitigate local air/noise pollution, improve drinking water and sanitation services and –overall– support tourism, a key sector for islands' economies.

1.4.3 How experts evaluate interventions

The scope of this three-piece research is to understand the experts' views on challenges related to the sustainable development of island EU regions, with a special focus on the opportunities provided by clean energy sources and electromobility. The wide range of potential strategies to support sustainable growth result in controversies that hinder decision-making. Policy makers may have different standpoints in complex issues such as environmental conservation, climate change mitigation and energy security. Accordingly, the different perceptions among specialists result in different priorities to achieve growth. Tourism, an important economic activity for many of the islands, further increases the complexity of decision-making as it imposes increased levels of seasonality in the economic activities and needs for resources.

It is therefore imperative to understand the perspectives of decision-makers, specialists with experience in the field of islands' sustainable development. Equally important is to define a measure to quantify the weight of their opinions in order to translate them to measurable input parameters. For this reason, the present research designed a Q-technique specifically for the case of islands. It processes input information using factor analyses, to highlight the various "streams" of opinions and allow grouping together those specialists that share opinions. In that way, it highlights a limited number of alternative solutions and makes decision-making straightforward.

The contribution of the third part of this Thesis supports a sustainable development paradigm change by providing solid statistical evidence about the importance of redefining energy and transport use through the lens of RES and electromobility initiatives. It provides evidence of available strategies as defined by specialists and leads to measurable impacts for the island societies, economies and environments.

1.5 Structure of the Thesis

The structure of the remaining chapters of the Thesis is as follows: Section 2 presents an energy model specifically designed for islands. The model runs an optimisation algorithm in its core and shows cost-optimal strategies to design future energy portfolios for the islands. The developed model was applied in selected islands, using up-to-date information about the test case locations.

Section 3 refers to sustainable transport systems for the islands. This section includes an exhausting literature review of available technologies and their state of maturity. It, thus, provides a unique overview of options that are available and feasible for the island setting. Equally important, it presents emerging mobility concepts that can potentially transform mobility services in islands.

Section 4 presents research that combines qualitative and quantitative methods to investigate the subjective views on the topic. The application of Q-methodology on islands' sustainable design included building a structured questionnaire that was addressed to specialists actively involved in the topic. This one of a kind analysis reveals challenges and opportunities for the particular case of the islands and provide valuable input when shaping implementation strategies.

This Thesis is closely aligned with research articles that were published in scientific periodicals in terms of the author's Masters studies. These publications reflect the knowledge acquired and completed work in terms of the studies at the University of Huddersfield. However, the present Thesis is not a simple collection of published work as in the cases of research degrees by publication nor a classic, conventional Thesis submission. The Thesis aspires to become a pioneering work underpinned by the student's and supervisor's published work and the need to generate a reader-friendly research output that will exemplify new and holistic thinking reflecting and affecting the emerging but still severely understudied topic of islands' sustainable development.

Chapter 2

Energy modelling for islands

2.1 Introduction

The energy crisis of the 1970s triggered the development of a wide variety of energy system models to support energy system planning purposes. These models do not "predict" the future transformations of power systems but enable a better understanding of demand and supply interactions, deployment costs and environmental implications. Energy models can apply different methodologies and, according to Bhattacharyya (2011), are distinguished in four categories:

i. optimisation-based models (bottom-up)
ii. accounting models (bottom-up)
iii. Econometric models (top-down)
iv. hybrid models

The present chapter presents an energy modelling exercise specifically designed for islands. Its aim is to analyse independent electricity portfolios over a specific time-frame (20-year) and provide future projections of cost-efficient power portfolios.

Specific software was developed in MATLAB using a Harmony Search Algorithm (HSA) in its core. HSA is a metaheuristic optimisation technique initially developed by Geem et al. (2001) to optimise the design of water infrastructure. The developed software is an optimisation energy (electricity) model that converges to cost-optimal options for future deployment of power capacities. It is, thus, used to identify low-cost strategies for future investments in energy infrastructure. The developed algorithm optimises different options for covering the future electricity demand in non-interconnected electricity systems. It creates a general purpose model to analyse the degree in which sustainable energy sources may represent an advantageous energy source and take a dominant role in islands' electricity systems. Through a series of dedicated runs for each island system, it investigates whether the deployment of RES would be economically advantageous and decrease the current burden from government budgets to provide subsidies. To do so the model processes future projections of demand and combinations of power production by RES (wind, solar PV) and battery storage.

The electricity system model developed in terms of the present MSc research belongs to the family of bottom-up optimisation-based models and processes both technical and economic parameter values of existing and future stations such as power capacity, efficiency, lifetime, potential, fuel consumption along with estimations on Capital Expenditure (CAPEX) and variable Operation and Maintenance (O&M) costs. Optimisation-based models converge to best technology mix for power portfolios by covering the various needs and minimising the total discounted system cost (Giannakidis et al., 2015) over a studied time-frame and under specific constraints.

2.2 Literature review

The application of the developed methodology included in this Thesis builds and extends the outcome of significant scientific works that studied the potential transformation of energy systems in European islands. More specifically, and due to the islands selected as test cases, the Thesis extends the work of a series of influential studies that focused on the non-interconnected islands of the Aegean Sea in Greece.

The early series of such scientific publications were related to early efforts to design and install an actual RES system in selected islands, typically in terms of a pilot and experimental applications. Efforts included designing RES systems in the best possible way so that the autonomous power systems of the islands can absorb the produced electricity of the –then at early stages of development– clean energy technology. Applications included the design of autonomous mini-scale wind-power systems that are supported with battery storage (Kaldellis, 2002) for the relatively small island of Kithnos. It also included the optimal sizing of off-grid solar PV systems for the island of Rhodes (Kaldellis, 2004) that was also studied in this Thesis. Previous efforts have also assessed the potential gains of developing hybrid independent systems that utilise renewable energy sources with diesel gensets and battery storage (Kaldellis and Kavadias, 2007), a combination analysed in the developed model.

Efforts for system-wide optimisation of islands' power systems have also been the focus of the present research study. An early study developed a multi-objective optimisation algorithm that provided a Pareto-set of possible energy portfolios for the island of Lesvos (Koroneos et al., 2004). The model assessed different deployment options for conventional fossil fuel- and RES-based technologies. It estimated the associated costs and emissions and provided a set of solutions (Pareto front) to illustrate possible gains and compromises. Optimisation of the RES-based electricity cost for the Lesvos island was analysed jointly with a nearby very small island, Donousa, exploring the potential synergies with the interconnections between islands (Kaldellis and Zafirakis, 2007). Prodromidis and Coutelieris (2011) compare the costs of developing off-grid clean energy systems in the islands with the option of interconnecting them with the main grid, using an optimisation technique.

Due to its unique characteristics, the power system of Lesvos island was also the subject of a recent analysis (Psarros et al., 2018) that analysed the integration of (very) high share of RES in the island's power mix. Wind power curtailment under different developments scenarios has been the topic of analyses and discussions for different settings and islands (Kaldellis, 2008, Papathanassiou and Boulaxis, 2006).

Supporting the sustainable character of islands' RES-based systems was studied in selected islands of Greece, including both locations that are independent –Rhodes– as well as islands interconnected to the main grid –Thassos and Zakinthos– (Kaldellis et al., 2009a). Through life-cycle analyses, Kaldellis et al. (2009a) estimated the energy content and degree of sustainability of selected solutions.

The role of energy storage in designing the future energy systems of islands has been in the core of the discussions on clean energy transition (see the case of El Hierro island (Toledo, 2015)). Several studies analysed the case of the Aegean islands covering both well-established storage options (pumped storage) and emerging storage technologies such as flywheels (Kaldellis et al., 2009b, 2010). In a similar manner, the potential role of hydrogen for energy storage on the island of Karpathos was studied in the article of Giatrakos et al. (2009).

2.3 Methodology: energy modelling for islands

Decision variables

The domain of possible solutions that an optimisation algorithm scans is known as *search space*. For every problem, the search space includes all possible combinations of the values the decision variables can take. The latter are the problem's controllable parameters, those that decision makers can adjust. In the analysed application, the decision variables are the annual power capacity installations of each energy technology. Such installations define islands' energy portfolios through the addition/removal of electricity production units in the analysed 20-year time frame. As shown in the following list, the control variables in the energy model are additions of solar photovoltaic, wind and thermal power capacities (X_1–X_3) as well as the deployment of battery storage (X_4).

X_1**:** additional installation of solar PV capacities (MW)
X_2**:** additional installation of wind energy capacities (MW)
X_3**:** additional installation of conventional fossil fuel capacities (MW)
X_4**:** battery capacity additions (MWh)
X_5**:** peak operation of conventional plants (hours/year)
X_6**:** off-peak operation of conventional plants (hours/year)

According to the model design, battery storage, X_4, is used to cover the night demand. Excess electricity output during the day is used to charge batteries mainly by utilising solar PV and wind production. Batteries may provide power and balancing services also during the day in order to cover the needs. However, they need to be at fully-charged state as soon as solar PV systems cease their daily production which approximately coincides with the start of the night system operation. In that way, batteries compensate for the non-producing (i.e. solar) capacities can even compensate for low-productivity of wind.

As far as conventional thermal power plants are concerned, there is an additional parameter that decision makers can control: the time of their operation. Thermal stations have a controllable operation that also has a certain degree of flexibility that is subject to specific technical limitations. The output of thermal stations can, thus, be managed –increased or decreased– according to the demand and market conditions. Decision variables X_5 and X_6 represent the cumulative number of hours such units operate on an annual basis. As initial values for the decision variables X_5 and X_6 were assigned the actual values of the baseline year 2016.

Objective function

The *objective function* expresses in mathematical terms the target of the model. It acts as a metric of the quality of candidate solutions and allows comparisons between alternative options. The developed model for this study is a cost-optimisation algorithm. Thus, the objective function expresses the total costs for installing and operating each candidate energy portfolio over the analysed period (see Eq. 2.1).

$$Total\ cost = Capital\ cost + O\&M\ cost + CO_2\ tax\ cost \tag{2.1}$$

Incoming and outgoing cash flows of year t in Equation 2.1 are transformed into net present values (NPVs) over the 20-year analysed time-frame using the formula in Eq. 2.2. A relatively low discount rate n =3% was adopted, following the conclusions of recent scientific findings (Insley, 2017) and recent policy recommendations (Hermelink and de Jager, 2015) that suggest using relatively lower values of discount rates in EU modelling exercises.

$$NPV = \sum_{t=1}^{20} \frac{CashFlows_t}{(1+n)^t} \tag{2.2}$$

Accordingly, technology-specific capital costs relevant to capacity additions are calculated with Eq. 2.3.

$$(min) \quad Capital\ cost = \sum_{tech} \sum_{t=1}^{20} \{ \frac{1}{(1+n)^t} \times C_{tech} \times P_{add}^{tech} \} \tag{2.3}$$

Where:

$tech$:	technology (solar PV, wind, conventional, battery)
$t = 1 - 20$:	the analysed time-frame (years)
C_{tech}:	technology cost per unit of power (EUR/MW)
P_{add}^{tech}:	capacity additions for each technology in year t (MW)
n:	discount rate

Operation costs include fuel cost (when relevant), maintenance cost (Eq. 2.4) and carbon taxes (Eq. 2.5). Fuel costs are directly related to the hours of operation of conventional stations and variable fuel prices. Annual maintenance costs are technology-specific. They were estimated following the typical practice (IRENA, 2018) that assumes a –generally low– percentage of the capital cost as the annual O&M expenses.

$$\text{O\&M } cost = Fuel\ Cost + Maintenance\ cost + CO_2\ tax$$

$$\begin{aligned} Fuel\ cost &= \sum_{tech} \sum_{t=1}^{20} \{ \frac{1}{(1+n)^t} \times Cap^{thermal} \times H_t^{oper} \times f_t \} \\ Maintenance\ cost &= \sum_{tech} \sum_{t=1}^{20} \{ \frac{1}{(1+n)^t} \times P_{cum}^{tech} \times C_{tech} \times \gamma \} \end{aligned} \tag{2.4}$$

Where:

$Cap_t^{thermal}$: cumulative capacity of thermal plants in year t (MW)

H_t^{oper}: hours of operation of thermal plants in year t

f_t: fuel price in period t (EUR/MW/h)

P_{cum}^{tech}: cumulative capacity of each technology in year t (MW)

γ: annual maintenance cost per technology (% of CAPEX)

CO_2 tax cost is calculated assuming a fixed cost for each tonne of CO_2 that is emitted:

$$CO_2\ tax = \sum_{t=1}^{20} \{ \frac{1}{(1+n)^t} \times Cap_t^{thermal} \times H_{oper}^t \times E_r \times tax \} \tag{2.5}$$

Where:

E_r: emission rate of thermal plants (tCO_2/MWh)

tax: emissions allowance price

Model constraints

Potential solutions need to satisfy various model's constraints. The main model's constraint requires that candidate energy portfolios cover the electricity demand (including system losses) throughout the studied period:

$$Production_t = P_t^{tech} \times CF^{tech} + Cap_t^{thermal} \times H_t^{oper} + Losses_t \geq Demand_t$$

Where:

P_t^{tech}: cumulative capacity of PV and wind in year t (MW)

CF^{tech}: capacity factor of PV and wind in each island

$Cap_t^{thermal}$: cumulative capacity of thermal plants in year t (MW)

H_t^{oper}: hours of operation of thermal plants in year t

$Losses_t$ island's power system losses in year t (MWh)

2.3.1 Model parameters

Capital cost of newly built energy systems was defined based on recent literature evidence. The model assumes that the cost of solar PV systems is €1.1/Wp (Jäger-Waldau, 2018) and that of wind equal to 1.3/W. Conventional systems' installation costs €0.9 million/MW while battery storage cost is €0.12/MWh.

As it is impossible to predict future fluctuations of oil price and estimate the operation cost of heavy oil- or diesel-fuelled power stations, the model assumes a fuel-price scenario that linearly oscillates between recent low oil prices (€40/barrel) and increased prices (€100/barrel) of the past. The age of conventional stations and decommissioning of aged infrastructure was also taken into account. Efficiency and capacity factors per technology were based on values provided in the literature (Szabo and Jäger-Waldau, 2008, IRENA, 2012, 2018).

CO_2 emissions allowance price was defined according to the EU Emissions Trading Scheme (ETS). The additional cost was applied to thermal units that release GHG emissions. Average carbon prices for the 2009–2018 period were used as reference (≃€10/tonne), a value also provided by recent simulations (Gerlagh and Liski, 2018). However, the 2017 reform of ETS resulted in carbon prices rising from €$4.5/tCO_2$ (May 2017) to €$15/tCO_2$ (May 2018) and €$21/tCO_2$ (March 2019). The present analysis assumed a conservative value of €$11/tCO_2$.

2.3.2 Core optimisation process

The developed model operates a metaheuristic algorithm that converges and identifies the best options. HSA was selected due to its suitability to non-linear, continuous problems and its successful application in similar applications (Kougias et al., 2016, Geem and Kim, 2016). HSA is suitable for energy portfolios' optimisation as they can cope with non-linearity and the stochastic nature of the application (Eriksson and Gray, 2017). Moreover, it was recently successfully applied on mini-grids' optimal design, defining best strategies for PV/wind and battery storage deployment (Geem and Yoon, 2017).

HSA is a nature-inspired, iterative optimisation technique meaning that it progressively converges to best solutions through a series of runs. In each run, the algorithm examines a new potential solution and compares its performance to previously analysed solutions. HSA elements borrow their names from the music field and are:

Harmony: A candidate solution, a set of decision variables' values;

Harmony Memory: The repository where potential solutions are stored;

HM Size: Number of solutions stored in Memory throughout the optimisation.

In order to create a new candidate solution, HSA combines the values of the variables of previous candidate solutions by applying *diversification* and *intensification* operations (Yang, 2014). Structured creation of new solutions makes sure that the full range of possible solutions (*search space*) will be scanned. Diversification consists of exploring a much wider space, with the aim of finding promising solutions that are yet to be refined. Contrary to that, the intensification mechanism refines the solutions through *adjustments* in order to search optimal solutions that are neighbouring (in terms of search space) to the ones tested. In every repetition (*run*), a new candidate solution is created and if it out-performs a solution stored in the *Harmony Memory*, it replaces it. The repetitive process continues until the simulation converges to the best solution which coincides to the minimum value(s) of the objective function "cost".

For each of the selected islands, independent runs analyse plausible scenarios of future energy portfolios. The algorithm optimises the overall cost of future power capacity installation and operation for each island from the baseline year (2016) and for a 20-year period (2036). Numerous runs are held ensure convergence to the best possible solution.

2.4 Case study

Despite the fact that each island is unique, challenges are common. Accordingly, good practices can be exchanged along with common challenges in transforming energy systems. For the present study, five islands in Greece were selected as study cases of the energy model developed and presented in the previous paragraphs. The selection of the case studies aimed for isolated, remote islands that are not interconnected to central power grids. Moreover, for the selected cases there is no plan to connect them to the mainland by sea-cable in the near future. These are also the characteristics of the islands that launched their clean energy transition with the support of the EU Islands Secretariat (European Commission, 2019).

For the needs of the present research, six islands of the Aegean Sea in Greece were selected as test cases. The selected islands are Rhodes, Lesvos, Chios, Karpathos and Patmos. These locations vary considerably both in size, energy and transport needs. Their electricity consumption ranges between ≃19 GWh/year and ≃866 GWh/year (see Table 2.1). Due to their very different size, transport needs and travel distances also vary significantly.

A wide range of test-case applications allows observing the results of the developed energy model at a relatively wide spectrum of island settings. Equally important, findings enable drawing conclusions and, if possible, generalise the output for EU islands with similar characteristics.

Table 2.1 includes information about the analysed islands' size and the number of inhabitants (reference year 2016). It also provides the latest available data (December 2018) of installed conventional-thermal power capacities and annual peak power demand. The annual electricity consumption and the share of RES are also provided for each island.

Table 2.1: Information on electricity production/consumption for the analysed islands (2018). Source: Hellenic Electricity Distribution Network Operator (2019).

Island	Area (km^2)	Population	Thermal capac. (MW)	Annual peak demand (MW)	2018 electr. cons. (MWh)	Share of RES (%)
Rhodes	1401	115,490	232.93	206.70	866,452	16.4
Lesvos	1633	85,330	94.88	67.05	299,448	16.7
Chios	842	51,320	77.78	45.70	207,383	10.8
Karpathos	302	7310	16.50	11.18	38,495	10.0
Patmos	34	3047	8.93	5.90	18,941	18.5

2.4.1 Status of non-interconnected islands

So far, electricity to non-interconnected islands has relied on economic incentives that make certain that citizens in both mainland and islands pay the same electricity tariffs. The average full production cost in 2018 for the analysed islands ranged between €143 and €355/MWh[1] while the average variable production cost was €95-152/MWh. Considering that the average 2016–2018 system marginal price (SMP) of the mainland system was €52/MWh (LAGIE, 2019), it is clear that thermal electricity production in the islands is expensive.

In order to cover the gap between the high production cost and the uniform retail price, a levy on electricity bills has been shared by all consumers. This regular financial intensive covers the higher costs of electricity generation in the islands. For a long time, this option was realistic because alternative solutions were either at very early stages of technological development or too expensive. However, this option is not sustainable for some time also due to significant increases of the oil price since the early 2000s. Interconnection projects are complex, costly and involve long implementation periods. Accordingly, connecting all islands to the central grid is not feasible, at least in the short-term.

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[1] Average full production cost (2018): Rhodes €188/MWh, Lesvos €165/MWh, Chios €143/MWh, Karpathos €209/MWh, Patmos €355/MWh.

2.4.2 Energy model results

In this section, the outcome of the energy model is provided for the selected five islands. The optimisation algorithm converged to cost-optimal development strategies of the energy portfolios including both capital and operational costs for a 20-year period. Figures 2.1–2.5 show the results for all five islands. The coloured lines show the cumulative power capacity of RES (solar PV, wind) in MW (right vertical axis) while coloured bars show the annual electricity production of the different technologies in GWh (left vertical axis). Future projections of electricity demand were calculated using average growth values of the past years.

As expected, for all five cases conventional electricity production decreases steadily and is replaced by cost-competitive RES and battery storage. The developed model does not consider land limitations, e.g. available land for solar PV system installation, local acceptability, e.g. the extent on which local communities accept the installation of wind farms and grid limitations, as issues that exceed the purpose of such energy modelling.

Rhodes

Since 1996, the electricity demand in Rhodes has more than doubled: from 393.2 GWh in 1996 to 866.5 GWh in 2018. Figure 2.1 shows the results of the electricity system model for a cost-optimal energy portfolio. The low-cost strategy suggests rapidly reducing the share of fossil-based to 1/3 of the current values by 2026. Subsequently, oil-fuelled production maintains a low share to cover night demand and periods of low productivity. Wind production gets the lion's share of the output since the model converged to six times the current capacity.

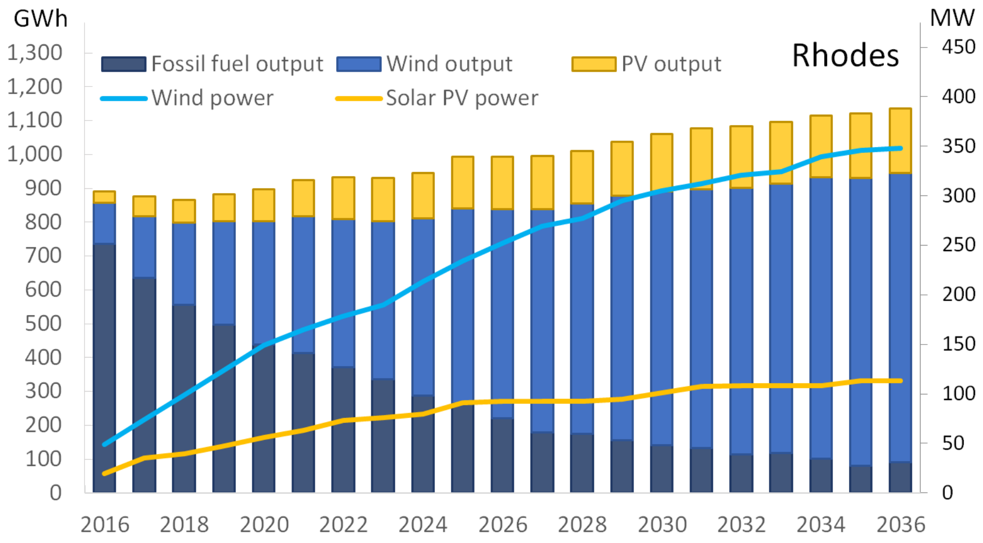

Figure 2.1: Model projections of optimised electricity production for Rhodes

Lesvos

Figure 2.2 shows the model output for Lesvos, where the energy portfolio evolves in a way similar to the one of Rhodes with wind capacities taking over the thermal ones. Solar PV installations increase linearly in the first decade and then develop at a moderate.

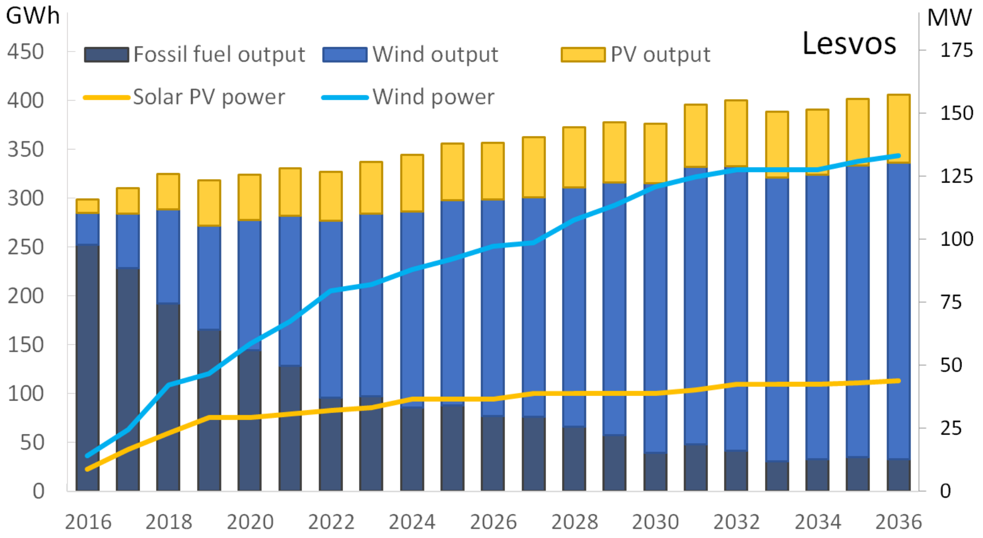

Figure 2.2: Model projections of optimised electricity production for Lesvos

Lesvos island also hosts proven potential of high-enthalpy geothermal energy fields ongoing activities include developing an 8 MW geothermal power plant. Deployment of geothermal energy has faced different need public acceptance in the past with the citizens of some islands being absolutely negative while in other cases public perception was –overall– positive. Accordingly, design and implementation need to address the concerns of local communities also resulting from less successful pilot applications of the past (Kousis, 1993).

Chios

The electricity model results for Chios converged to shifting towards an increased share of RES as shown in Figure 2.3. Compared to the previous cases, solar PV technology receives a more important role eventually covering ≃1/4 of the demand. RES' deployment for Chios is not continuous as shown by the flat parts of the wind and solar curves in Figure 2.3. In smaller islands and smaller power systems, electricity model anticipates periods of no installation until the demand increases or aged-expensive power plants (e.g. old diesel gen-sets) seize operation.

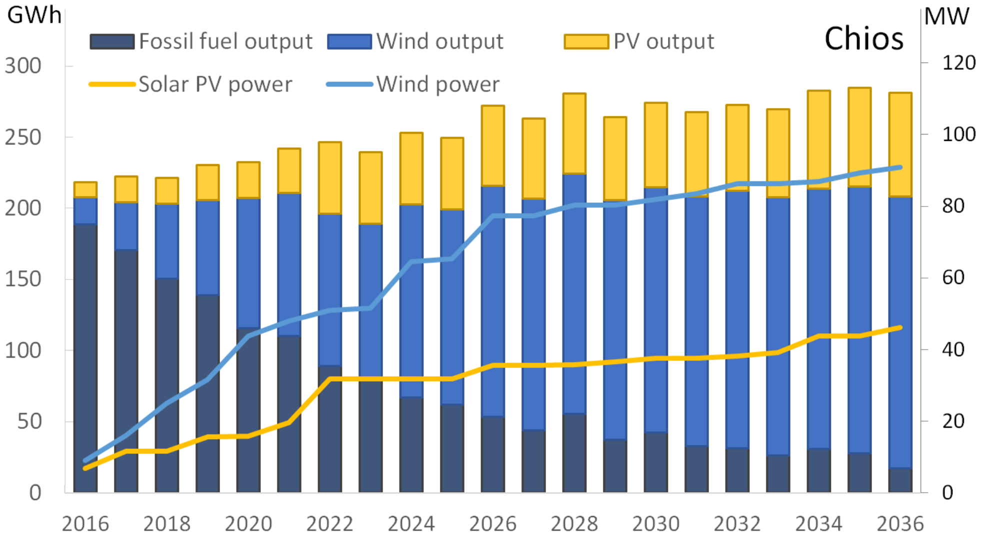

Figure 2.3: Model projections of optimised electricity production for Chios

This observation indicates that the transformation of energy systems in smaller islands may require more time than in larger ones if cost-minimisation is the main priority. In relatively smaller systems, capacity additions of a certain year may result in a production that exceeds the demand. This is shown by spikes in the production curve (see Fig. 2.3 for years 2026, 2028) and is also due to the large nominal capacity of wind turbines. Installations at a small-independent grid may result in a rapid increase of the output exceeding current and future demand and increasing the required curtailment (Psarros et al., 2018).

Two desalination plants operate in Chios with a cumulative potential output of 5000 m^3/day (YPEKA, 2015). It is, thus, imperative to produce electricity at a low-cost for the energy-intensive process of desalination. Current cost figures of €143/MWh result in high cost per m^3 of produced water.

Karpathos

The electricity model results for Karpathos island are shown in Figure 2.4 with a notable high share of solar PV in the final consumption.

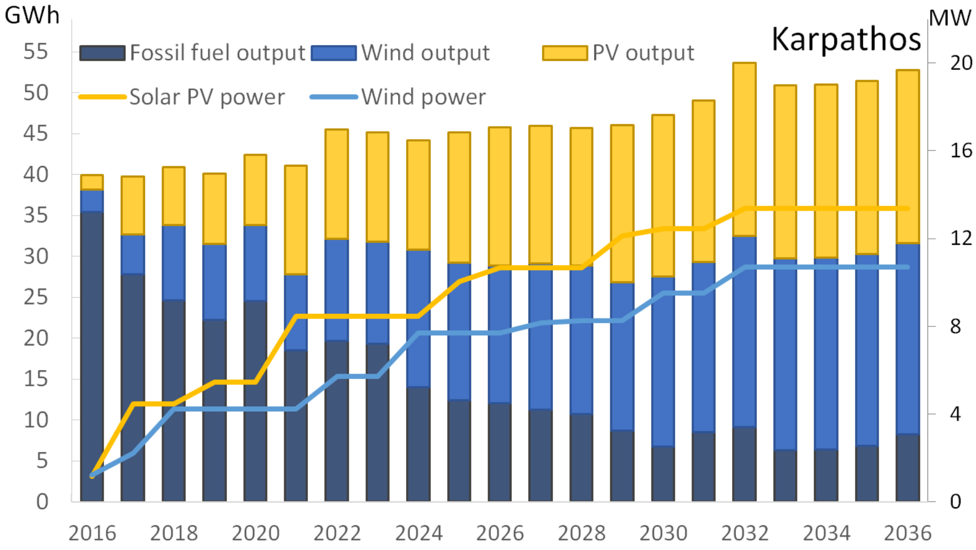

Figure 2.4: Model projections of optimised electricity production for Karpathos

While in larger islands the model converged to power capacities of wind approximately three times higher than those for solar (Figures 2.1–2.3), model results for Karpathos are different. In this island, solar installations are higher than wind at the cost-optimal strategy, throughout the simulation period. The share of thermal power remains at relatively high levels ≃1/6 of final consumption.

Patmos

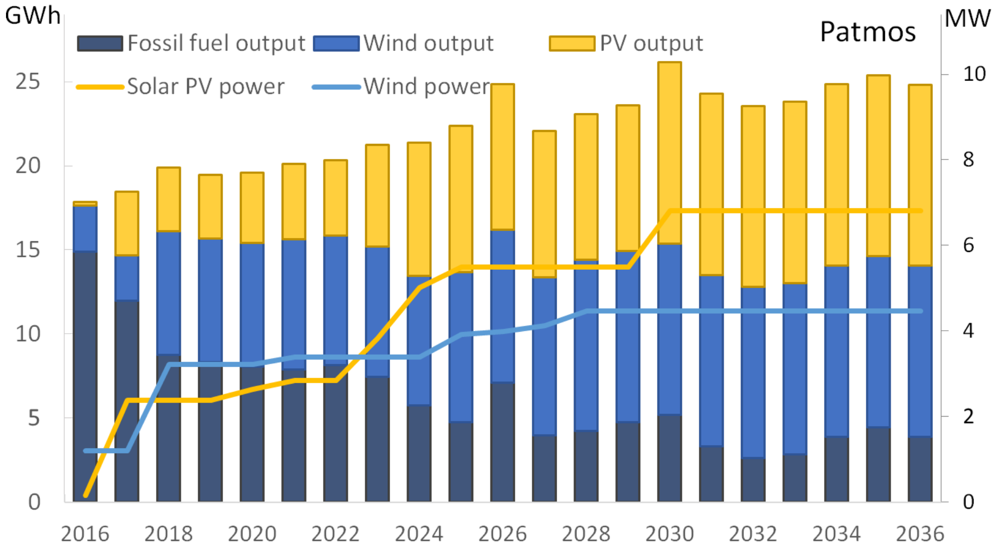

Figure 2.5: Model projections of optimised electricity production for Patmos

Results for Patmos (Figure 2.5) also show notably higher installations for solar PV showing that in grids with lower consumption solar technology is advantageous. In smaller islands, wind units with large unit capacity cannot benefit from economies of scale. On the contrary, modular PV systems installed capacities can be gradually increased according to needs. Similarly to Karpathos, thermal stations maintain an important role in final production (≃1/6) showing that in small-scale power systems conventional production to cover periods of low RES output is advantageous in terms of cost compared to further increases of storage.

2.4.3 Electricity cost, required investments and autonomy

Electricity production cost

Table 2.2 shows the currently installed power capacities (thermal and RES) as well as the modelled ones for the reference year 2036. It also provides relevant annual demand figures (columns #4 and #5). The modelled levelised cost of electricity (LCOE) for each island is also provided in Table 2.2 (column #6). Moreover, average cost values (2014–2018) of electricity production by thermal units is also included in column #7 (Hellenic Electricity Distribution Network Operator, 2019). Comparing these values to the average modelled cost (column #6), it appears that the RES' deployment results in significantly lower costs per unit of electricity.

Table 2.2: Energy portfolios' outlook for the analysed islands and average cost of electricity of the modelled transformation. Sources: author's analysis of data provided by the Hellenic Electricity Distribution Network Operator (2019).

Island	Power cap. 2016 (MW)	Mod. power cap. 2036 (MW)	Cons. 2016 (MWh)	Mod. cons. 2036 (MWh)	Mod. avg cost 2036 (€/MWh)	Avg full cost 2014–2018 (€/MWh)
Rhodes	301.4	510.1	889,741	1,135,754	46.3	183.7
Lesvos	110.5	195.7	298,936	405,876	45.8	145.7
Chios	85.8	153.2	218,272	281,324	49.6	146.3
Karpathos	20.3	27.7	39,970	52,793	55.1	228.7
Patmos	7.95	12.6	17,861	24,828	52.7	311.9

Figure 2.6 illustrates the average full production cost of the islands' thermal units for the period 2014–2018, on a monthly basis. These values range between ≃€45/MWh and ≃€477/MWh and show a large potential for cost-efficient solutions. The near-zero variable cost of RES can result in a significant drop in electricity production costs. Despite the investments required over the analysed period to replace part of the existing capacities with RES, the modelled LCOE are

significantly lower than the historical values showing that fuel savings compensate for the investment costs. LCOE values do not consider required investments in control systems and upgrades of the distribution network since it is difficult to define which part of such investments would be anyhow required.

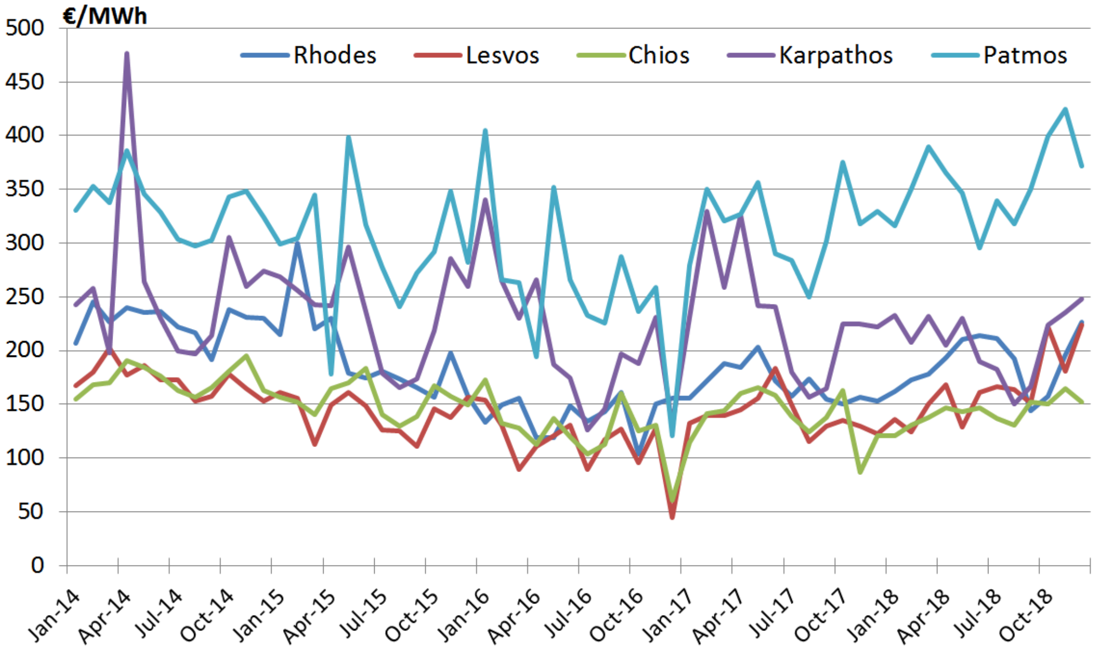

Figure 2.6: Full electricity production cost of thermal power stations in the analysed islands for the period 2014–2018. Source: author's analysis of data provided by the Hellenic Electricity Distribution Network Operator (2019).

The difference between the modelled LCOE values and observed electricity production costs is significant and shows the gravity of the existing challenge and the urgent need to implement sustainable solutions. The advantages of RES (relatively low LCOE, negligible O&M costs) may compensate for the required investments to upgrade the islands' power distribution systems to absorb high shares of RES and integrate an electromobility fleet. Information in Table 2.2 also shows that the potential cost savings for smaller islands are even larger.

Required investments

This section presents the required investments (cumulative) for the analysed islands. It provides investment values to achieve the cost-optimal solution identified by the energy model that are required over the studied period (2016-2036). Results are also broken down per technology type i.e. the required investments for solar PV, wind, battery storage and conventional thermal power stations.

Detailed information on yearly investments is available in Figures A.1–A.5 in the Appendix. It is important to note that in all five analysed cases, the energy model converged to solutions that include the majority of the investments taking place in the early years of the transition period. This means higher upfront investments followed by slower deployment rates. This result is due to the negligible O&M costs of modern RES that places their deployment at an "*as soon as possible*" basis. This shows that the decarbonisation of the islands' energy systems needs to be implemented in the short term in order to achieve advantageous cost terms.

Overall, the lion's share of the investments goes to wind, according to the model. More than 70% of the required capital is related to the deployment of wind power, while solar PV represents an additional ≃25%. Battery storage requires 3% of the investments, in the best-identified solution, while conventional generators receive only 0.5%.

Modelled energy autonomy

An important issue for non-interconnected islands is energy security also shown by the degree of their autonomy. RES utilise an abundant local source but due to their variable production, transformed power portfolios may face challenges in terms of secure electricity supply. Table 2.3 shows the installed battery storage in the analysed islands at the end of the simulation period. Surprisingly, the size of required battery systems in optimal solutions is not proportional to the size of the system or consumption.

Table 2.3 also shows the autonomy for each system under non-favourable conditions for RES productivity. It, thus, analyses the duration of continuous supply in the worst-case scenario (zero RES output, column #3). Moreover, it provides estimations of the islands' autonomy in cases of limited RES production due to unfavourable conditions (e.g. cloud cover and no wind) equal to the 10%, 25% and 50% of the yearly average values.

Table 2.3: Energy autonomy (hours) at the end of the modelled period (2036). Power systems' autonomy for four negative scenarios of RES productivity are presented: 0% (worst case) to 50% of the average daily RES output).

Island	Battery capac. 2036 (MWh)	Autonomy 0% RES (h)	Autonomy 10% RES (h)	Autonomy 25% RES (h)	Autonomy 50% RES (h)
Rhodes	114	4.1	5.8	8.3	12.5
Lesvos	31	4.1	5.9	8.2	12.3
Chios	52	5.6	7.3	9.8	14.0
Karpathos	21	8.2	9.8	12.1	16.0
Patmos	10	7.1	8.7	11.0	15.0

The autonomy of all islands decreases for the case of no/negligible RES production. Lower values (4.1 hours) appear for the larger islands (Rhodes, Lesvos) at periods of zero RES contribution. In short, the transformed power systems in Rhodes-Lesvos can operate for approximately 4 hours without any contribution from solar and wind. Smaller islands' power system are inevitably oversized and such an overcapacity results in relatively higher autonomy. The achieved autonomy of the modelled systems shows that in some cases thermal power stations may be needed as a backup to minimise the risk of power disruptions.

2.5 Discussion

Interest in developing sustainable energy and transport infrastructure in islands has a long history. Although technological limitations and the high cost of solutions with low market maturity were obstacles, islands' need to secure energy supply urged the deployment of modern RES from an early stage. This is showed by the fact that the first European commercial wind park was developed in 1983 on an island in Greece (Kythnos) with a cumulative power capacity of 75 kW – five 15-kW turbines (IRENA, 2012). Since then, technological breakthroughs and cost reduction have placed the transformation of island energy systems a feasible option. Notably, the PV module price of approximately €10/W_p in the mid-1980s has dropped to less than €0.3/W_p in early 2019 (Jäger-Waldau, 2018).

The role of islands in global climate change mitigation strategies is also shown in the UN Framework Convention on Climate Change (UNFCCC). During the recent conference in Katowice (COP24), islands supported an "ambition package". Being locations that are expected to be most affected by the impacts of climate change, several islands and island states have developed clean energy systems in support of sustainable growth. Examples include the islands of Cabo Verde where the government's plan is to cover 50% of energy needs from RES by 2020 and eventually reach 100% by 2025. Plans focus on the development of different RES taking into account future energy needs for water production through desalination (Segurado et al., 2011). The government of Mauritius has also announced plans to increase the role of RES for electricity from the current 21% to 35% by 2025 also extending the technologies used[1]. The Government of Martinique has set an ambitious target to increase the share of RES from 7% in 2015 to 50% in 2020 with a particular focus on PV systems (IRENA, 2016). New

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[1] In Mauritius, 89% of the RES production currently comes from biomass, using bagasse, a residue of sugarcane production, as fuel (Brizmohun et al., 2015).

solar PV systems on the island of Tokelau were designed to cover more than 90% of the electricity demand, saving approximately €680,000 of fuel costs, annually (IRENA, 2016).

In the EU, notable is the example of the Danish island of Samsø where the currently installed 34 MW of wind and district heating systems cover the local needs and export electricity to the mainland (Kuang et al., 2016). Réunion, a densely-populated French overseas territory, has also set a target to become a net zero energy island by 2025 (IRENA, 2016).

As there is no universal solution suitable for every island, each strategy needs to adapt to island's unique characteristics, size, population, and the available energy resources. Findings presented in this section show that islands' transformation should generally be implemented with the majority of the investment being realised in the early phase, in order to benefit from the very low O&M costs. Relatively larger islands favour a faster reduction of the share of fossil-based electricity as they allow larger economies of scale. Accordingly, wind energy is more suitable in such systems, while the lower consumption in smaller islands favours solar PV systems: modularity of solar PV technology and its low per-unit power capacity is more suitable for power systems of the smaller scale.

Findings included in this chapter were published in the following journal article:

Kougias, I., Szabó, S., Nikitas, A., Theodossiou, N. (2019). Sustainable energy modelling of non-interconnected Mediterranean islands. *Renewable Energy*, 133, 930-940.

Chapter 3

Sustainable transport for islands

Islands need to follow a different pathway not only regarding efficient energy production but also by developing sustainable transport systems. Such an approach encourages wide use of electromobility which, in principle, is suitable for the typically short distances in inner-island transport. The present chapter provides a state-of-the-art analysis of mobility initiatives that are applicable in island settings and could potentially shape the future islands' transportation to *smart islands* (Ahern et al., 2015). The analysis includes technologies and mechanisms with encouraging uptake so far and much greater potential to contribute in a shift to a better transport paradigm in islands.

Designing smart transport systems for islands:

While the concept of *smart cities* has attracted the interest of scientists and policy-makers, the characteristics of *smart islands* are still to be defined. According to Kourtit and Nijkamp (2012), smart cities' designs involve knowledge-intensive and creative strategies, aimed at enhancing the socio-economic, environmental, and economic performance of cities. From a transport viewpoint, a smart city provides citizens with socially inclusive, environmentally friendly, safe, cost-effective, integrated and technologically advanced travel options (Debnath et al., 2014). The role of transportation is crucial as it is a proxy of economic growth, quality of life and ecology conservation, therefore a fundamental aspect of societies (Lawry et al., 2017).

In 2016, the *Smart Islands Initiative* was introduced by the EC, inspired by ongoing *Smart Cities and Communities initiative.* The initiative seeks to convey the islands' potential role as exemplars of technological, social, environmental, economic and political innovations. Compared to inland smart cities initiatives, the concept of smart islands goes one step further and extends energy and transport synergies also to water and waste in a circular economy approach (Smart Islands Initiative, 2017). As far as road transport is concerned, the declaration makes the following commitment:

> *We will change our modal split towards sustainable transport modes including new ways of using the car (car-sharing, car-pooling), promoting walking and cycling (trails restoration, bike-sharing) and optimising the design of multi-modal hubs and terminals.*

The present chapter discusses a specific vision of islands' transportation based on a literature review that examined emerging and established but not yet universally embraced, transport initiatives. The choice of the mobility interventions discussed aligns with the targets set by the European islands themselves through the bottom-up declaration (Smart Islands Initiative, 2017). Naturally, each of the analysed mobility mechanisms is at a different level of technological and market maturity. Their tailor-made application in harmony with the specific characteristics of each island can reshape transport systems. Since, a significant degree of consumer stratification is present in the emerging market for electric vehicles (EVs) it is expected that policy interventions may prove more effective to reach higher market penetration levels (Morton et al., 2017). The following sections present the chosen interventions namely: electromobility, shared use mobility, bus rapid transit, and autonomous and connected vehicles.

3.1 Electromobility

The electrification of the transportation sector is considered a feasible solution to mitigate greenhouse gas emissions since transport contributed 27% of the total GHG released in EU during 2016 (European Environment Agency, 2018). Transport's electrification is particularly important for Europe, to address energy security and geopolitical concerns, considering the low availability of fossil fuels and reserves in the continent (Mwasilu et al., 2014).

As far as the sensitive ecosystems of islands are concerned, EVs can play a critical role in improving the air quality and reducing noise pollution. Electric propulsion does not cause local emissions, reduces noise and is more efficient than internal combustion engines (Altenburg et al., 2012). Electrifying the transport is particularly suitable for islands, due to the typically small distances; a single charge could allow covering even the longest distance on the island.

Compared to conventional vehicles, EVs utilise electricity rather than fossil fuels (diesel, gasoline). They are typically powered through batteries and they do not cause any direct GHG emissions during operation (Heinicke and Wagenhaus, 2015). Compared to conventional ones, EVs have higher ownership costs but lower O&M costs, mainly due to the lower cost of energy. EVs are still at a relatively early phase of commercial development and represent a niche but very dynamic market that was –so far– driven by policy interventions. However, in 2017, 1.15 million of EVs was sold worldwide (Cazzola et al., 2018), with estimations for 2018 showing an increase of 64% at $\simeq$2 million vehicles – a record volume.

Socioeconomic characteristics and the emotive meanings of car ownership are directly linked to the users' willingness to purchase and/or use EVs as well as perceptions on issues such as cost and environmental impacts. A research study by Morton et al. showed that the more important individuals consider their car to be, the more hesitant are to use EVs. On the contrary, individuals who claim to be knowledgeable about cars in general and EVs in particular show a higher willingness to adopt pro-EV attitudes (Morton et al., 2016).

EVs vary significantly both in terms of size and technology used. The most recent EVs in production are powered by Lithium-ion (Li-ion) batteries and they are either fully electric known as Battery Electric Vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs) also using a conventional internal combustion engine. In terms of size, they are distinguished in electric cars, low-speed electric vehicles or neighbourhood electric vehicles (NEVs), and various types of two-wheelers. EVs can also refer to larger professional vehicles such as vans, trucks and busses.

3.1.1 Electric cars

The main type of electric passenger cars are the Battery Electric Vehicles (BEVs), vehicles fully powered by electricity stored onboard with rechargeable high-capacity batteries. BEVs charge their batteries by an external energy source, they do not have any internal combustion engine and do not cause any GHG emissions.

Hybrid electric vehicles combine the electric motor with an internal combustion engine. The degree of hybridisation depends on technical features that vary among manufacturers and models. PHEVs, in particular, can be directly charged from the power grid. This special feature allows them to rely mainly on electricity and interact with the grid, potentially placing them as elements of the grid infrastructure. Hybrid cars that cannot be charged directly from the grid heavily depend on their conventional internal combustion engine, while the electric motor has a complementary role to decrease fuel consumption and GHG emissions.

Neighbourhood Electric cars

neighbourhood electric vehicle (NEV) is a term used to describe low-speed EVs. Typically, NEVs have a smaller size, relatively short electric driving ranges and a maximum speed of 40 km/h (in some countries regulation allows up to 70 km/h). Accordingly, in terms of size and provided services, NEVs stand between electric cars and two-wheelers. They have lower costs and favourable regulation compared to electric cars (e.g. no requirements for driving license or insurance).

Their small size and agile transportation make them particularly suitable for heavily populated cities and the mega-cities of emerging economies. The only limited number of NEVs that are officially registered makes it difficult to know their exact number. Estimations for China, the biggest NEV market, indicate approximately 4 million units (Cazzola et al., 2018). Increased market interest in NEVs is shown with their sales in 2016 ranging between 1.2 million and 1.5 million (Cazzola et al., 2018). In 2018, 1.4 million low-speed vehicles were sold in China alone (Bullard and McKerracher, 2019). The global was valued at €2.1 billion in 2017 and is projected to reach €6.7 billion by 2025, growing at a compound annual growth rate (CAGR) of 15.4% between 2018 and 2025 (Padalkar, 2018). Notably, China hosts approximately 400 EV start-up companies, the vast majority of which produces NEVs.

3.1.2 Electric buses

Fully electric and plug-in hybrid bus systems are an important contribution in mitigating emissions and contributing to sustainable transport since electric bus fleets can be emission-free, easy to integrate into existing infrastructure, ecological and customer-friendly. In an island setting, commercial bus fleets and public transportation are a prime starting point for the introduction of electromobility (Rogge et al., 2018).

So far, electric bus sales have been relatively low. By the end of 2018, 2100 electric buses were circulating in the streets of Europe, Japan and the United States (Cazzola et al., 2018). Low sales figures are mainly due to the high costs. Due to relatively low market maturity, the required technological solutions were –until recently– expensive and the cost of buses' high-capacity batteries was prohibitive. However, rapid drops in batteries cost and advantageous O&M in comparison to conventional diesel buses (Lajunen, 2018) led several cities to plan creation of an electric bus fleet (Cazzola et al., 2018). Several demonstration projects are implemented in terms of the EU-funded *Zero Emission Urban Bus System* (ZeEUS) project.

Electric buses that can operate throughout a single day of operation on a single *overnight* battery charge benefit from the typically low electricity prices in the night. This design requires high-capacity batteries (>250 kWh) to satisfy the required operational requirements (Lajunen, 2018). Islands' relatively short routes may allow lower storage requirements and reduce the ownership costs. Slow, overnight charging is particularly suitable to islands' sensitive grids. Opportunity charging involving fast chargers require high power capacity (200-400 kW). Sudden increases in the demand may disrupt the sensitive independent power system of islands. Fast charging also requires advanced –and expensive– battery technology and more complex infrastructure that increase both installation and Operation and Maintenance costs.

3.1.3 Electric two-wheelers

Electric two-wheelers are means of transportation equipped with an electric motor for propulsion powered by a battery pack. They are mainly distinguished to electric bikes (e-bikes) and electric motorcycles (mopeds). As far as the e-bikes are concerned, a great variety of them exists worldwide extending from e-bikes with a small motor that only assists the user to more powerful ones that resemble the capabilities of a conventional scooter or even a motorcycle. The main categories of electric two-wheelers (Del Duce et al., 2011) are presented in the following paragraphs:

Pedal Assist e-bikes

In pedal assist e-bikes (PAS) the electric motor is activated through pedalling action and assists the rider. A sensor system estimates the user's needs by measuring the pedal movement, pedal torque and bicycle speed. Accordingly, it provides additional power and allows the user to drive over longer or uphill routes. The motor used in such e-bikes is of relatively low power (< 250 W) and is deactivated when the bicycle reaches an upper-speed limit (e.g. 25 km/h). Due to the low speed of operation and required pedalling action regulations generally treat such e-bikes equally to conventional, non-assist bicycles. Thus, the can be used on streets and bicycle lanes.

Throttle control e-bikes

Such e-bikes incorporate an electric drive system that is activated through a throttle element. The latter allows for on-demand simple speed control through a push-button throttle, a grip-twist or a trigger. As in the PAS case, the motor may also be activated through pedalling action. Those throttle control e-bikes that have a high power may be considered as motor vehicles and their use on bicycle infrastructure is prohibited. If the motor power (e.g. < 250 W) and speed limits (e.g. 25 km/h) are below certain values, throttle control e-bikes can benefit from the same rights and access privileges as non-assist bicycles.

Speed Pedal Assist e-bikes (Speed pedelecs)

More powerful PAS are not classed as bicycles, because of their significant transport potential. These are often called speed (or speedy) pedelecs (S-PAS). Compared to PAS, the electric drive system is still activated through pedalling action. However, the S-PAS reach higher top speeds (e.g. 45 km/h), because their power is higher than that of the PAS, reaching e.g. 500 W.

Electric mopeds

Electric mopeds have an electric motor that operates according to the demand. E-mopeds look like conventional scooters and their electric motor is operated manually using a throttle on the hand-grip in a way similar to conventional motorcycles or scooters. Their top speed is generally higher than that of speedy pedelecs, as their motor power may exceed 750 W. Electric mopeds are considered motor vehicles, require licensing and registration and their use is also limited to specific roads.

Electric two-wheelers in the islands' environment

The main advantage of electric bikes is that they are more energy efficient and emit lower GHG emissions per person compared to conventional transport modes. A life cycle assessment compared the ecological footprint of various modes of transportation (Fagnant and Kockelman, 2015). The analysis showed that e-bikes and e-mopeds have the lowest global warming potential from all means of transportation except from normal bicycles (Del Duce et al., 2011).

Social acceptance is also high and played a catalyst role in e-bikes diffusion. Several analysts compare the booming enthusiasm towards electric two-wheelers to the growth of the solar PV market (Geels et al., 2016): both sectors showed an unexpected growth and –in the case of rooftop solar PV systems– experienced an unforeseen enthusiasm from the users. This explains the growing interest in e-bicycles in urban transport systems. The combination of bicycle-friendly policies, smart Information and Communications Technology (ICT) systems and rapid advances in technology has benefited the purchase and use of e-bicycles, because it has made their use cost-effective and feasible. Besides, electric two-wheelers require less effort and, thus, increase bicycle usage (both in terms of frequency of use and average distance covered) and provide health benefits. For this reason, analysts involved in climate issues are optimistic that e-bikes will eventually displace conventional scooters (Fishman and Cherry, 2016).

Apart from their obvious merits, electric two-wheelers are particularly suitable for the short-distanced island routs. They provide flexibility and cost-effectiveness of transportation and allow travelling further on less electricity. It is also important that their low-capacity battery set can be fully recharged in a relatively short amount of time when compared to bigger EVs.

Electric bikes and moped can, thus, support an electromobility initiative that could contribute to increased bicycling in islands, at least the smaller islands. This could benefit tourism activities and the common parking challenges in islands' cities and villages during the peak tourist periods. E-biking is suitable for altitude differences and makes long-distance biking accessible to more people. Thus, it can potentially transform cycling from a, currently, non-issue to a viable door-to-door mobility solution (Nikitas et al., 2017).

The behaviour and characteristics of electric mopeds were studied by Fang et al. (2015) for the case of Penghu (or Pescadores) islands in Taiwan. It analysed usage rates of existing fleets and the existing obstacles that may hamper a widespread usage of electric scooters. They conclude that charging infrastructure and its design are critical aspects to have a successful operation of electric mopeds schemes. Fang et al. (2015) also recommends that data mining and analysis can play a crucial role to reach a good understanding of the local conditions and design tailor made solutions.

3.2 E-mobility transforming islands' transport and energy systems

Introducing e-mobility in islands' transport systems is expected to create both implications and opportunities for the island grids. In general, EV charging takes place either at the users' residences or at dedicated charging infrastructure provided by local authorities and private companies. Increased use of e-mobility in an island will necessarily result in an increased number of private and commercial charging stations that will need to be strategically managed and regulated to maximise benefits of users, power system operators and the charging infrastructure owners. EV charging equipment is commonly categorised in the following three types:

Level 1: It refers to charging with the use of a standard household outlet. Depending on the EV's battery technology, it provides approximately 8 km range per hour of charging. The most common place for Level 1 charging is residences and workplaces;

Level 2: It includes a charging box and cable that allows for a wide range of charging speed at increased safety starting from 40 km range per hour of charging.

Level 3: It is also known as direct current (DC) fast charging at dedicated stations. Infrastructure is costly (up to €100,000 per station) but charging is considerably faster (70 km of range in 10 minutes of charging).

The revised EU *Energy Performance of Buildings Directive* aims at accelerating the deployment of the recharging infrastructure by stating that all every newly constructed or thoroughly renovated residential building with more than ten parking spaces must be equipped with the appropriate pre-wiring for EV charging (European Parliament and the Council, 2018). The directive also states that Level 2 charging (fast alternating current (AC) charging) must always be provided at any public charger, while Level 3 (DC rapid charging) should also be supported.

G2V and V2G

The widespread use of EVs can create new opportunities for island power systems. So far, EVs' interaction with the grid is to simply be charged via a Grid to Vehicle (G2V) connection. The ultimate target is to design technologies and systems with bi-directional connection capabilities, a concept known as Vehicle to Grid (V2G) (Loisel et al., 2014). V2G interaction can potentially transform the EVs' fleet to power system storage capacity, providing invaluable storage and flexibility service to the power system. Storage capacities are crucial for the penetration of high share of variable RES and the efficient operation of conventional thermal power plants. Accordingly, V2G schemes would increase the efficiency of the energy system and allow further reduction of GHG emissions.

An EV fleet in an island could be ideally charging from the power grid during off-peak periods, in a Grid to Vehicle manner. EVs will, thus, utilise the abundant RES generation and act as a storage system. In order to maximise the overall (vehicles and grid) system efficiency advanced control strategies would be required to connect the EVs with the grid dictating the optimal charging strategies (Ioakimidis and Genikomsakis, 2018). In periods when the fleet is not used (e.g. working hours) and in hours of low demand, EVs' batteries would provide voltage regulation and feed energy into the grid in a V2G manner (Pina et al., 2008, 2014) contributing to meeting electricity demand.

A scenarios exercise based on an electricity system model for the São Miguel island of the Azores, Portugal showed the potential of RES deployment parallel to the creation of an EV fleet are not expected to face serious technical barriers for introducing an EV fleet under the G2V mode (Ioakimidis and Genikomsakis, 2018). Although the technological basis to operate EVs in a way that can also provide V2G services exists, it has not yet reached a degree of maturity that allows its application in a cost-effective manner (Shirazi et al., 2015). More importantly, the operational framework of V2G services has not been defined and the policy regulations are still to be placed. For these reasons, V2G has not yet reached market maturity and its applications have mainly been tested in pilot projects. Accordingly, the application of V2G technology needs to overcome technological and regulatory barriers. Its successful application will open a wide range of application such as the use of EVs to dispatch power and provide *peak shaving* of the load profile.

Introducing an EV fleet as a distributed energy storage system that would increase the penetration of renewable energy sources (RES) could be particularly appealing for the isolated island systems studied in chapter 2. Such an approach was simulated in the island of Tenerife and has shown promising results: the additional battery storage allows increasing the RES share, reduce GHG emissions and the total cost of electric generation (Díaz et al., 2015). E-mobility particularly favours the relatively more populated islands, as they host bigger car fleets, thus having the critical mass for justifying the creation of the necessary infrastructure i.e. charging stations. Prioritising EV schemes for the bigger islands can be a reasonable approach for developing sustainable energy-transport systems for them (Nikitas et al., 2017).

Shifting towards electromobility is an approach that gains increasing support, especially when implemented parallel to decarbonisation of the electricity sector. As the power mix moves towards electricity production from RES, the carbon content of produced electricity that powers EVs will continuously decrease. The future of electromobility is, thus, strongly linked to the degree of penetration of clean energy sources and RES in the power systems of the future. An energy portfolio with low GHG emissions coupled with a transition from conventional to electric vehicles will eventually result in a cleaner transport sector.

Considering the impact of the dual relationship between vehicles and the energy system shows the potential to transform the way vehicles are used in island environments. Alteration in the vehicle ownership schemes (presented in the following section) and novel usage paradigms along with the special features of the EV technology will certainly change the future islands.

3.3 Shared use mobility

Shared Use Mobility (SUM) is, in principle, a new approach to manage mobility resources aiming to maximise the utilisation levels of vehicles. Under a SUM scheme, vehicles can typically be accessed and used by their subscribers on an as-needed basis. Typically, this is done with the use of a mobile app and a fee is directly associated with usage criteria. According to Shaheen et al. (2016), the term SUM describes:

- car-sharing;
- bike/scooter-sharing
- ride-sharing;
- ride-sourcing (or ride-hailing).

SUM can provide important services also for islands as they provide a wider range of mobility choices increasing the efficiency and flexibility of the means of mobility. SUM schemes contribute to reducing the required number of vehicles and, thus, reduce traffic congestion, parking pressure and GHG emissions related to transport. Such schemes are particularly important for those who cannot afford to own a private vehicle and reduce households' transportation costs. Lately, SUM initiatives have also been expanded in the freight and logistics industry in professional vehicles (e.g. trucks, vans).

Car-sharing

Car-sharing is an alternative to private car use in different environments. Currently, it is mainly applied in cities (Kent and Dowling, 2013) and provided sporadic access to a car for users who only make occasional use of an automobile. Car-sharing companies are often managed by car manufacturers and provide services in which subscribed drivers can access for a moderate cost a fleet of shared vehicles for short-term use only. It can be thought off as a systematic short-term car-rental initiative (Shaheen et al., 1998) that runs continuously 24/7 via a self-service and app-based mode.

Bike-sharing

Bike-sharing systems provide customised and affordable short-term access to bicycles on an "as-needed" basis. Bike-sharing is often designed to extend the reach of public transit services to support increased bicycle usage (Nikitas et al., 2016). Although bike-sharing was launched several decades ago, it has lately enjoyed an unprecedented rise as a result of enhancements of ICT technologies that allowed app-based services. It is low-cost means of transportation that decreases traffic congestion, fuel consumption and GHG emissions. In island settings, bike-sharing is linked to touristic activities such as recreational and physical activities.

In order to be efficient, bike-sharing schemes need to cover a wide range of destinations and provide a safe environment for the users. In certain environments (e.g. hilly islands, long distances) where bike-sharing is not appropriate, electric two-wheelers can be an alternative option.

Ride-sharing

Ride-sharing (carpooling) refers to a transportation mode in which individual travellers share a vehicle for a trip and split travel costs (Furuhata et al., 2013). Its advantages for users include reduced costs and travel time, while it is also beneficial for society and the environment. Ride-sharing mitigates traffic congestion, fuel consumption and emissions, also improving the air quality. Technological progress in the ICT sector has allowed real-time monitoring of available ride options.

Ride-sourcing

Ride-sourcing refers to an emerging transport service that allows private car owners to drive their registered vehicles to provide for-hire rides. It is a taxi-like service that builds on app-based platforms to match travel supply and demand in real-time. Its main difference from ride-sharing is that ride-sourcing drivers operate for-profit at competitive to competitive taxi services' prices.

3.4 Connected and autonomous vehicles

Over the last two decades, the automotive industries have developed pilots of entirely autonomous, but still humanely supervised, cars in test-beds meaning that road vehicles capable of operating independently of real-time human control under an increasing set of circumstances will likely become more widely available (Le Vine et al., 2015) and be at the very heart of a smart transport system.

Autonomous vehicles are projected not only to take over the task of driving per se but to have another meaningful power; the capacity to interact and eventually synchronise in real-time with all the elements and actors of the transport network including other vehicles and road transport infrastructure. Connected vehicle technology will provide real-time information about the surrounding road traffic conditions and the traffic management centre's decisions improving efficiency and comfort while enhancing safety and mobility (Talebpour and Mahmassani, 2016). Vehicles with the dual capability of being autonomous and connected are known as Connected and Autonomous Vehicles (CAVs). CAVs are anticipated to introduce numerous different benefits, from substantially reducing traffic accident rates, road congestion, the social exclusion for those currently unable to drive, noise nuisance and carbon emissions. CAVs are also expected to generate new opportunities for integrated services for public transport and shared use mobility mechanisms promoting resource-efficient mobility.

Autonomous cars are already piloted in several settings also including EU-funded projects. There is, however, enough political determination to make a leap forward and design the required policy framework and regulations for self-driving cars to allow their use. Despite the increased interest and investments, a full-scale launch of CAVs needs to overcome many obstacles and is likely to happen later than most expect.

CAVs offer an increased lane capacity (vehicles per lane per hour) that allows a better coordination of traffic and significant reduction in traffic congestion. In the islands' context, where the road infrastructure faces certain limitations (e.g. limited width) CAVs could allow a more efficient travel in islands. Efficient vehicle use will result in relatively lower energy consumption and reduced associated emissions. At the same time, their use could eventually increase safety and reduce the number and gravity of road accidents in islands.

3.5 Discussion: mobility as a service

The future of mobility, may not be about designing and adapting to new modes of transportation or vehicles but in designing a revolutionary way to use existing technologies. Already with Shared Use Mobility (SUM), urban transportation has experienced a radical change in the way vehicles are used. More radical solutions –still at the conceptual phase– are known as mobility as a service (MaaS). Under a MaaS scheme, privately owned vehicles are replaced with personalised mobility services that give access to multiple travel modes, technologies and services on a personalised basis.

MaaS integrates multiple transport modes in a dynamic real-time manner, and, thus, involves complex and very demanding (in terms of computational power) digital platforms. At the same time, MaaS provides access to optimised information and options that exceed from the transport mode and extend to traffic and weather conditions making urban travel controlled, resilient, and convenient. Due to the recent technological advances in the ICT sector, the transport industry is closer than ever before to making this future a reality.

The expected 5g networks (Camacho et al., 2018) will provide the advanced connectivity means to create intelligent transportation systems that are able to re-organise the operation of vehicles at real-time and providing vehicle-to-x connectivity. Advanced connectivity allows not only the effective utilisation of shared transport modes but also supports the utilisation of other services that make urban commuting easier. Such services may include navigation mobile applications to monitor, control and adjust the journey, services to plan and prepare journey by different travel options and their combinations as well as derivative information such as the cost and duration of the journey. So far, the existing such services are uni-modal in their nature and in general only static in terms of time. Unifying various modes and integrating the ad hoc real-time features will be a key step to reach mobility as a service.

Similarly with CAVs, islands being relatively small, controlled, closed and independent transport systems can be excellent living labs and test-beds for the MaaS concept. Islands provide a suitable environment due to their scale and "isolation" for piloting these technologies before these could be launched in a much bigger scale in more metropolitan environments where interventions as such can be more disruptive to the current transport status quo.

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Chapter 4

Application of Q-methodology in energy and transport systems

4.1 Introduction

The present section presents the design, implementation and results of a Q technique (also known as Q-methodology) to analyse islands' energy and transport systems. As shown in the previous chapters, designing sustainable systems for the islands and realising the transition to decarbonised energy and transport involves difficult decisions. Often, the various parts of the decision-making process (e.g. governments and local authorities, private sector and industry, policy-makers, scientists, society) have different views on the topic. Accordingly, the present chapter attempts to reveal the different *points of view* that are held around the topic and identify trends and future directions that will make transition to a different more sustainable development paradigm smoother.

To do so, Q technique was selected as the appropriate method to study the different priorities. Q technique was mentioned for the first time in a 1935 communication article, published in *Nature* journal (Stephenson, 1935). William

Stephenson, the creator of Q technique, describes the possibility to invert factor analysis: instead of testing n individuals in m tests he suggests starting with n different tests which are then scaled by m individuals. The reason to invert the –until then– standard procedure was simply practical for W. Stephenson. This inversion allows "bringing field work into the lab and reaching into spheres of work hitherto untouched or not amenable to factorisation". Q-methodology, thus, allows linking qualitative approaches to quantitative methods in order to investigate the subjective views of those directly involved in a particular topic (Herrington and Coogan, 2011). Building on a small sample approach, it provides a scientific foundation for the systematic study of human subjectivity that typically covers complex issues. It allows processing opinions, priorities, needs and preferences and identifying consensus and disagreements.

4.2 Literature review: Q-method in energy and transport

While the original topic of Q-methodology was psychology and social studies, Q was applied to an expanding range of fields such as political science, human geography and risk communication (Curry et al., 2013). Recently, Q technique has been increasingly applied to environmental analyses, the fields of sustainability and energy to reveal different perspectives on an issue.

Energy

In the energy field, an early analysis of 2008 identified Q technique as suitable for analysing attitudes and behaviours related to demand and consumption supporting, thus, the design of regulation and campaigns to increase energy efficiency. The study also anticipated the use of the Q-methodology on selecting the location of new RES installations, since a better understanding of public opinion could potentially mitigate not-in-my-back-yard (NIMBY) phenomena (Owens and Driffill, 2008). Indeed, the opposition to a wind farm installation was studied with the use of Q in the same period (Ellis et al., 2007) with similar analyses published in the following years for the Isle of Lewis, USA (Fisher and Brown, 2009) and Texas, USA (Jepson et al., 2012). The different opinions of stakeholders in the different countries on wind energy were also compared with the use of Q-method (Wolsink and Breukers, 2010). The application of Q supported building a stakeholder dialogue on biomass energy options from in the Netherlands and its perspectives (Cuppen et al., 2010). The three main perspectives for hydropower development in Switzerland revealed the main tendencies that prioritise either local development, the national "greener" development agenda or the regional government empowerment (Díaz et al., 2017). Aiming at understanding the perspectives of the ongoing debate on energy access in Africa, the study of Matinga et al. used Q-methodology to reveal stakeholder perceptions on energy issues in Africa and identify support groups of centrally-managed power systems that promote grid extensions and supporters of distributed energy production in mini-grids (Matinga et al., 2014).

As far as grid infrastructure is concerned, Q technique was used to analyse an additional controversial issue i.e. the sitting of electricity transmission lines in the UK (Cotton and Devine-Wright, 2011). The responses of both stakeholders and local communities were analysed to reveal the range of opinions. Public opposition on large-scale energy projects, in general, was studied in Cuppen et al. (2016), revealing the various obstacles of the transition towards the future energy portfolios.

Transport

One of the earliest applications of Q technique in transport investigated the relative importance of the various parameters that define use (Steg et al., 2001). Indeed, the majority of Q-method's application on the transport field relates to behavioural analyses of travel-related attitudes. This includes investigating the medium-distance travel decision-making (Van Exel, 2004), shifting to alternative clean transport modes (Cools et al., 2009) and changing the car use patterns (Van Exel et al., 2011). The aim of these analyses was to identify important determinants in transport so that policy-makers design effective policies that will eventually result in more efficient and environmentally friendlier transport modes (e.g. car use reduction). Transport-related social exclusion was analysed in Rajé (2006) and Rajé (2003) also studying the impacts of road user charging on social inclusion/exclusion. Accessibility impacts of Connected and Autonomous Vehicles (CAVs) was studied in a recent study by Milakis et al., where Q-method was applied to assess the impact of CAVs four accessibility components i.e. land use, transport, temporal and individual (Milakis et al., 2018). Q-methodology was also used to understand drivers' attitudes at road junctions in order to design policies and regulations that make junctions safer, and more convenient for users (Flower and Parkin, 2019).

4.3 Methodology: stages of a Q-method research

Identification of research topic

The first stage of a Q study is to identify the typically controversial topic and create the sample of statements known as the *Q-set*. This phase includes identifying the areas to explore. It is a demanding process and needs to follow well-established Q-methodology protocols (Cools et al., 2009). Accordingly, the Q-set needs to be representative of the topic and cover its different angles. Statements need to be the essence of subjectivity meaning that they are designed in a way that enables certain people to agree with certain statements whereas other people to disagree. To do so, the Q-set is compiled from different standpoints and explores as much as possible the topic's implications to cover the different viewpoints. Statements were selected to be short and stand-alone. Special attention was given to clarity making sure that participants with different backgrounds would fully understand their meaning. They allowed different interpretation and they were phrased in a neutral manner, meaning allowing the reader to agree or disagree without prejudice.

For the present study, the identified area of interest is the sustainable energy and transport systems for islands and their implementation. The Q-set comprised of 40 statements provided in Tables 4.1, 4.2. The respondents were asked to sort the statements in a pyramid by using the survey's input interface shown in figure B.1 in the Appendix B. The statements' number was selected after several rounds of statement generation; it covers the discourse's aspects and is manageable both for participants (Q-sorters) and analysts.

The Q-set was strategically sorted in five areas relevant to islands' energy and transport systems (see Tables 4.1-4.2):

i. Mobility and Transport;
ii. Electricity production and electromobility;
iii. Social dimension and public acceptance;
iv. Environment and climate change mitigation;
v. Economic and financial aspects.

Identification of respondents (P-set)

The respondents of the survey are described as the participant set (P-set). Each statement expresses an individual opinion and each member of the P-set will be asked to sort it. Members of the P-set need to be people with different opinions.

Contrary to other survey methods, Q technique does not require a large number of participants and normally 40–60 (or 20–80 according to other scientists). It is more important that the P-set is strategically selected to sufficiently capture the different viewpoints on the issue (Shinebourne, 2009). A larger P-set is not expected to benefit the analysis, as Q-method typically studies topics with a finite number of opinions (discourses). In short, Q-method operates based on the assumption that there are fewer discourses than participants and that certain members of the P-set share opinions (Barry and Proops, 1999). Within a particular discourse domain, there is a limited number of patterns in the way people associate opinions.

Since the aim of Q technique is to access the diversity of viewpoints, participants need to be directly involved with the topic and not selected randomly. Ideally, participants cover a wider range of actors and experts with different background and culture. For the present research, the P-set included specialists covering a wide geographic area and backgrounds:

- academics, researchers;
- policy-makers, international organisations;
- national energy regulatory authorities;
- local authorities;
- representatives of non-governmental organizations (NGOs);
- utility companies;
- private sector, project installers etc.

In total, 44 participants provided their input. They were contacted remotely, mainly via e-mail and their answers were processed anonymously. Accordingly, any personal information that can be identifiable was removed before the analysis.

An additional step in several Q-method analyses, suggests holding interviews with specialists and/or the respondents to support the statements' identification. This phase draws the general direction of the analysed topic and is held before the statements are selected. Derived information from the interviews is supplemented by selected statements coming from a series of secondary sources such as academic and scientific publications, policy documents, reports of international organisations, newspaper and magazine articles, industry reports, political declarations and press releases, positions of NGOs, internet blogs and others.

Using such sources of information, the present research collected a large sample of discussion points that define the concourse. Then, a core group held structured discussions on the identified concourse and narrowed down the –initially large– number of statements to 40 well-targeted statements (see Tables 4.1-4.2). The discussions were held between the 16^{th} and 18^{th} of May 2018 in the premises of European Commission's Joint Research Centre in Ispra, Italy. Apart from the author and supervisor of this MSc Thesis, the participants were scientists, analysts and policy-makers (JRC-based, invited, and remote) with experience in the analysed topic.

Identification of key statements (Q-set)

Tables 4.1-4.2 show the Q-set and the categorisation of the statements. In general, 7 statements cover each area, while the economic/financial one relates to a fairly higher number of statements (11), due to its spillover effects.

Table 4.1: Statements 1–22 and their categorisation

Mobility and transport	
1	Users have no reservations buying e-vehicles over conventional fossil-based ones.
2	Electro-mobility (e-mobility) is meaningful if it is powered primarily by RES.
3	Investing in an electric car fleet is not a meaningful investment.
4	The relatively short travel distances on islands favour e-mobility.
5	E-bikes and e-motorcycles can only play a minor role in islands' e-mobility initiatives.
6	Electrification of public transport should be the basis of an island's e-mobility initiative.
7	Incremental e-mobility development is preferable over a radical full-scale launch for the island context.
Electricity production & electromobility	
8	Islands can be innovation leaders of smart e-mobility and clean energy production.
9	Every island should eventually be interconnected to a bigger electricity grid.
10	Good coverage of charging points is more important than fast charging in an island setting.
11	Photovoltaic-powered charging stations are not suitable for remote areas (e.g. near beaches) for charging e-cars, e-bikes and e-motorcycles.
12	Bidirectional charging, achieving V2G along with conventional G2V, is not required for an efficient island power system.
13	E-car battery storage will soon become the cheapest way to provide storage capacities for clean energy production.
14	Clean energy and e-mobility will increase islands' vulnerability to electricity disruptions.
15	Electricity prices should be uniform in islands of the same Member State, not taking account of their unique characteristics.
Social dimension and public acceptance	
16	E-mobility will not improve much the image of the islands.
17	E-mobility will benefit tourism in the islands.
18	E-vehicle sharing will be particularly attractive for tourists.
19	Local authorities are the most appropriate coordinator for clean energy initiatives.
20	Strong campaign to change users' perception is unnecessary for introducing e-mobility systems on islands.
21	Changing energy-fuel consumption behaviour is a critical element for creating future sustainable islands.
22	Solutions should be tailor-made for the specific characteristics of each island and its local community.

Table 4.2: Statements 23–40 and their categorisation

Environment and climate change mitigation	
23	Clean energy initiatives (including e-mobility) will create additional benefits for the island ecosystem (e.g. protected areas, biodiversity, and groundwater).
24	Visual intrusion produced by the renewable energy infrastructure is a significant barrier in the adoption of a clean energy initiative.
25	E-mobility is not the best strategy for consistent traffic noise reductions.
26	Clean energy initiatives (including e-mobility) should be the primary strategy for improved air quality.
27	Clean energy initiatives (including e-mobility) will radically improve the quality of life in islands.
28	Clean energy planning should be prioritised over waste management and wastewater treatment in the islands.
29	Drinking water availability will be improved by clean energy initiatives.

Environment and climate change mitigation	
30	Transition to clean energy and e-mobility will boost the islands' economy.
31	Clean energy options create less employment than conventional energy solutions.
32	Higher fossil fuel prices in islands are not a strong enough driver for changing the islands' energy and transport systems.
33	Removing the existing subsidies from the islands' energy bills will accelerate clean energy and e-mobility initiatives.
34	High capital cost impedes clean energy and e-mobility development.
35	Clean energy and e-mobility investments will result in higher costs to the end-user.
36	Financial incentives should be provided to users adopting e-mobility.
37	Financial incentives should not be provided to producers of clean energy (e.g. rooftop solar photovoltaic systems, wind turbines).
38	PPPs are more efficient than public procurement strategies.
39	Financial models for the development of clean energy deployment (including e-mobility) are not mature enough.
40	Public funding should now focus on pilot applications of e-mobility and clean energy rather than R&D.

Respondents' completion of Q-sorts

Respondents were required to sort the 40 statements according to their personal views and opinions. A seven-point scale was employed to rank the degree of agreement or disagreement ($+3 \ +2 \ +1 \ 0 \ -1 \ -2 \ -3$) ranging from imperative elements (absolute agreement) to prohibitive (absolute disagreement). In Q-method, judgement is relative, not absolute. Thus, even if respondents (dis)agree with every statement, they still need to sort them in a relative manner that reflects their personal preferences.

As shown in Figure B.1, there is a limit in the number of statements receiving a particular *score*, and such a *forced ranking* is a typical characteristic of Q-method. The analysis followed a pyramidal structure where respondents could sort 2+2 statements at their extreme preferences ("imperative" and "prohibitive"), 4+4 statements as "strongly (dis)agree", 8+8 statements as "somehow (dis)agree" and identify 12 statements as "neutral". The detailed guidelines provided to the respondents for the completion of the Q-sorts are available in Appendix B.

Software used

Each Q-sort is input data and the collected statements are analysed using statistical techniques of correlation and factor analysis. A dedicated Q-method software is typically used to analyse each Q-sort in relation with each other and investigate inter-correlations among Q-sorts. For the purposes of the present research, PQMethod software was used (release 2.35, November 2014), a statistical program tailored to the requirements of Q analyses (Schmolck, 2019). An inter-correlation matrix is created to contain the estimated correlation values and the matrix is then factor-analysed following the centroid procedure. The resulting factors are analytically rotated to a simple structure using *Varimax rotation* and the relevant factors are identified.

4.4 Factor analysis of Q-sorts

Initially, the correlation matrix of all the collected Q-sorts was calculated. This matrix (included in Tables B.1-B.3 in Appendix B) is a direct indicator of the level of (dis)agreement between the individual sorts, a quantitative measure of similarity or difference among the respondents' points of view (Curry et al., 2013).

The calculated correlation is then subject to factor analysis in order to consider the full picture of the statements' sorting. Participants that ranked statements in a similar manner will load significantly on the same factor, revealing a pattern of statements that express their subjective views (Herrington and Coogan, 2011). With the factor analysis, participants who share views and sorted their statements in a similar way will be, thus, associated to the same factor.

As it is important to get a simpler picture of the topic, factor analyses typically target to keep between 2 and 5 factors (Webler et al., 2009), depending on the case. Ideally, it employs a relatively small number of factors that is manageable and represents as much as possible the participants' viewpoints.

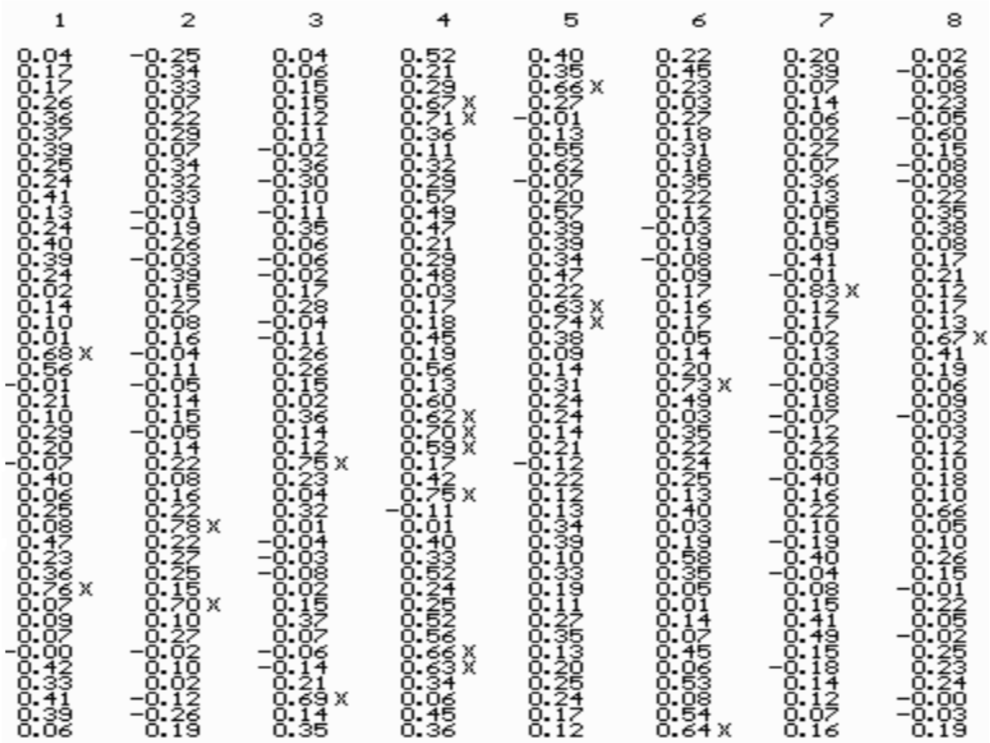
Selecting the number of factors

Although initially Stephenson (1935) used centroid analysis for factor extraction, Principal Components Analysis (PCA) has become the default method and is widely used in statistical packages. PCA is a standard feature of PQMEthod (centroid is also an option) and provides the eigenvalues which provide the degree of variance explained by each factor. In the analysed application, the calculated eigenvalues for every factor are shown in Table 4.3 and their absolute and relative sizes are of some importance when deciding on how many factors to keep for rotation (Schmolck, 2019). In Q analyses, typically the first component explains a large proportion of the variance and the additional share is then reduced with the increasing number of factors. The aim is to select a number of factors that is relatively low but explains the maximum possible amount of variance.

Table 4.3: Eigenvalues of the unrotated factor matrix

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Eigenvalues	18.91	2.62	2.16	1.96	1.64	1.52	1.36	1.32
Expl. Variance (%)	42.97	5.95	4.90	4.46	3.72	3.47	3.10	3.01
Cum. expl. Var. (%)	42.97	48.92	53.83	58.29	62.02	65.48	68.58	71.59

Table 4.3 also shows that factor 1 includes a large percentage of variance (42.97%) while the second component only more than 1/7 of the first (5.95%). The third component adds an additional 4.90% and, after that, factors add smaller parts (3-4%). The share of explained variance already provides an indication of the number of factors that need to be selected.



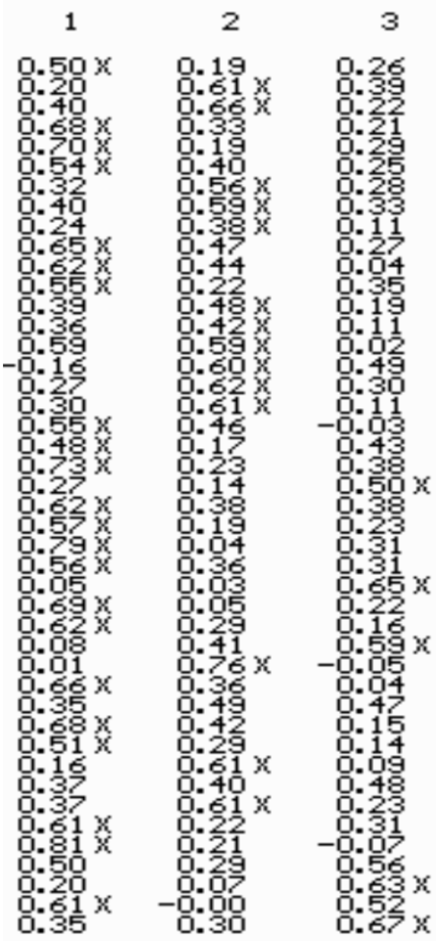
```
      1        2        3        4        5        6        7        8

   0.04    -0.25     0.04     0.52     0.40     0.22     0.20     0.02
   0.17     0.34     0.06     0.21     0.35     0.45     0.39    -0.06
   0.17     0.33     0.15     0.29     0.66 X   0.23     0.07     0.08
   0.26     0.07     0.15     0.67 X   0.27     0.03     0.14     0.23
   0.36     0.22     0.12     0.71 X  -0.01     0.27     0.06    -0.05
   0.37     0.29     0.11     0.36     0.13     0.18     0.02     0.60
   0.39     0.07    -0.02     0.11     0.55     0.31     0.27     0.15
   0.25     0.34     0.36     0.32     0.62     0.18     0.07    -0.08
   0.24     0.32    -0.30     0.29    -0.07     0.35     0.36    -0.08
   0.41     0.33     0.10     0.57     0.20     0.22     0.13     0.22
   0.13    -0.01    -0.11     0.49     0.57     0.12     0.05     0.35
   0.24    -0.19     0.35     0.47     0.39    -0.03     0.15     0.38
   0.40     0.26     0.06     0.21     0.39     0.19     0.09     0.08
   0.39    -0.03    -0.06     0.29     0.34    -0.08     0.41     0.17
   0.24     0.39    -0.02     0.48     0.47     0.09    -0.01     0.21
   0.02     0.15     0.17     0.03     0.22     0.17     0.83 X   0.12
   0.14     0.27     0.28     0.17     0.63 X   0.16     0.12     0.17
   0.10     0.08    -0.04     0.18     0.74 X   0.17     0.17     0.13
   0.01     0.16    -0.11     0.45     0.38     0.05    -0.02     0.67 X
   0.68 X  -0.04     0.26     0.19     0.09     0.14     0.13     0.41
   0.56     0.11     0.26     0.56     0.14     0.20     0.03     0.19
  -0.01    -0.05     0.15     0.13     0.31     0.73 X  -0.08     0.06
   0.21     0.14     0.02     0.60     0.24     0.49     0.18     0.09
   0.10     0.15     0.36     0.62 X   0.24     0.03    -0.07    -0.03
   0.29    -0.05     0.14     0.70 X   0.14     0.35    -0.12     0.03
   0.20     0.14     0.12     0.59 X   0.21     0.22     0.22     0.12
  -0.07     0.22     0.75 X   0.17    -0.12     0.24     0.03     0.10
   0.40     0.08     0.23     0.42     0.22     0.25    -0.40     0.18
   0.06     0.16     0.04     0.75 X   0.12     0.13     0.16     0.10
   0.25     0.22     0.32    -0.11     0.13     0.40     0.22     0.66
   0.08     0.78 X   0.01     0.01     0.34     0.03     0.10     0.05
   0.47     0.22    -0.04     0.40     0.39     0.19    -0.19     0.10
   0.23     0.27    -0.03     0.33     0.10     0.58     0.40     0.26
   0.36     0.25    -0.08     0.52     0.33     0.35    -0.04     0.15
   0.76 X   0.15     0.02     0.24     0.19     0.05     0.08    -0.01
   0.07     0.70 X   0.15     0.25     0.11     0.01     0.15     0.22
   0.09     0.10     0.37     0.52     0.27     0.14     0.41     0.05
   0.07     0.27     0.07     0.56     0.35     0.07     0.49    -0.02
  -0.00    -0.02    -0.06     0.66 X   0.13     0.45     0.15     0.25
   0.42     0.10    -0.14     0.63 X   0.20     0.06    -0.18     0.23
   0.33     0.02     0.21     0.34     0.25     0.53     0.14     0.24
   0.41    -0.12     0.69 X   0.06     0.24     0.08     0.12    -0.00
   0.39    -0.26     0.14     0.45     0.17     0.54     0.07    -0.03
   0.06     0.19     0.35     0.36     0.12     0.64 X   0.16     0.19
```

Figure 4.1: Varimax-rotated eigenvalues of 8 factors with automatic pre-flagging

In the next step, PQMethod software allows performing a factors' rotation either manually or through a Varimax rotation. Varimax option takes the unrotated matrix created by PCA and rotates a number of factors defined by the user. Figure 4.1 shows the output of the rotation for 8 factors. It is obvious that analysing this high number of factors is pointless as in some factors (factor 7, factor 8) only one respondent is flagged with an asterisk. In other words, these factors only express the viewpoint of a single person and do not group opinions of respondents with similar opinions.

The rotation is repeated few times for a different number of factors and the results for the case of five and four factors are provided in Figures B.2 and B.3 in Appendix A. Figure 4.2 shows the output when testing to keep three factors for rotation. Through the comparison of the different tested matrices it appears that the selection of 3 factors for the analysis is the best option, as it is manageable and explains ≃53.83% of the variance, a percentage considered generally sufficient for Q analyses (Curry et al., 2013, Cotton and Devine-Wright, 2011, Ellis et al., 2007). Out of 44 respondents, 34 were associated with one of the three factors and their numbers are shown in Table 4.4 (number of defining variables).



```
    1          2          3

 0.50 X     0.19       0.26
 0.20       0.61 X     0.39
 0.40       0.66 X     0.22
 0.68 X     0.33       0.21
 0.70 X     0.19       0.29
 0.54 X     0.40       0.25
 0.32       0.56 X     0.28
 0.40       0.59 X     0.33
 0.24       0.38 X     0.11
 0.65 X     0.47       0.27
 0.62 X     0.44       0.04
 0.55 X     0.22       0.35
 0.39       0.48 X     0.19
 0.36       0.42 X     0.11
 0.59       0.59 X     0.02
-0.16       0.60 X     0.49
 0.27       0.62 X     0.30
 0.30       0.61 X     0.11
 0.55 X     0.46      -0.03
 0.48 X     0.17       0.43
 0.73 X     0.23       0.38
 0.27       0.14       0.50 X
 0.62 X     0.38       0.38
 0.57 X     0.19       0.23
 0.79 X     0.04       0.31
 0.56 X     0.36       0.31
 0.05       0.03       0.65 X
 0.69 X     0.05       0.22
 0.62 X     0.29       0.16
 0.08       0.41       0.59 X
 0.01       0.76 X    -0.05
 0.66 X     0.36       0.04
 0.35       0.49       0.47
 0.68 X     0.42       0.15
 0.51 X     0.29       0.14
 0.16       0.61 X     0.09
 0.37       0.40       0.48
 0.37       0.61 X     0.23
 0.61 X     0.22       0.31
 0.81 X     0.21      -0.07
 0.50       0.29       0.56
 0.20       0.07       0.63 X
 0.61 X    -0.00       0.52
 0.35       0.30       0.67 X
```

Figure 4.2: Varimax-rotated eigenvalues of 3 factors with automatic pre-flagging

Table 4.4: General statistics of the extracted and rotated factors

Parameter	Factor I	Factor II	Factor III
Number of defining variables	19	11	5
Eigenvalue	18.91	2.62	2.16
Composite reliability	0.987	0.978	0.952
Standard error of factor scores	0.161	0.211	0.309
Percent variance explained (%)	42.97	5.95	4.90

Table 4.4 provides the general statistics of the extracted and rotated factors. A factor's composite reliability r_f is a function of the number p of Q-sorts flagged for the factor (Eq. 4.1).

$$r_f = \frac{0.8 \times p}{1 + (p-1) \times 0.8} \tag{4.1}$$

The standard error for a factor SE_f is a function of the standard deviation s_f of the array (Eq. 4.2) and the standard errors of differences between factors i and j are estimated using Eq. 4.3 (Zabala and Pascual, 2016).

$$SE_f = s_f \times \sqrt{1 - r_f} \tag{4.2}$$

$$SED_{ij} = \sqrt{SE_i^2 + SE_j^2} \tag{4.3}$$

The correlations between factors were also estimated and took values equal to 0.661 (factor 1 with factor 2), 0.565 (1 with 3) and 0.564 (2 with 3). A positive correlation between the three factors indicates the degree of similarity that exists among the views contained in each of the three factors.

A factor loading is determined for each Q-sort, expressing the extent to which the distribution of statements by a single respondent is associated with each factor. The z-score is the weighted average of the factor loading of the Q-sorts related to the factor. Z-scores are key information for the analysis as they provide the ranking of statements within each factor. In other words, the z-scores indicate the relationship between statements and factors; they are the quantitative measure of the degree each factor (dis)agrees with the statements (Zabala and Pascual, 2016). The Z-scores of the present analysis are provided in Table 4.5.

Table 4.5: Factor loadings (Z-scores) of the 40 statements within each factor

	Factor I	Factor II	Factor III		Factor I	Factor II	Factor III
1	-0.129	-1.501	-1.554	21	1.568	1.734	0.941
2	2.232	-0.849	1.167	22	0.941	1.930	1.801
3	-1.541	-1.485	-1.252	23	0.965	0.765	0.527
4	1.518	2.071	2.043	24	-0.775	-0.076	0.940
5	-1.241	-1.109	-1.685	25	-0.687	-0.705	-0.849
6	1.644	1.188	0.408	26	1.137	0.231	1.573
7	0.137	0.479	0.249	27	0.567	0.212	0.000
8	1.189	1.497	0.276	28	-0.694	-0.877	-1.369
9	-1.638	0.172	-0.240	29	-0.029	-0.257	0.427
10	0.412	0.445	0.257	30	0.602	0.721	0.234
11	-1.343	-1.272	-1.173	31	-1.740	-1.029	-0.600
12	-0.943	-0.074	-0.704	32	-0.761	-0.127	1.417
13	0.271	-0.506	-0.295	33	0.719	-0.339	-1.024
14	-1.090	-0.827	0.362	34	0.302	0.567	1.491
15	-0.226	0.400	-2.062	35	-0.657	-0.438	-0.962
16	-1.140	-1.704	-0.120	36	0.337	1.399	-0.078
17	0.729	0.960	0.427	37	-0.600	-1.434	-0.191
18	0.895	0.557	0.127	38	-0.012	-0.363	-0.360
19	0.514	0.123	1.177	39	-0.130	-0.272	-0.922
20	-0.874	-1.130	-0.162	40	-0.429	0.922	-0.242

4.5 Results

The interpretation of the three factors leads to the relevant perspectives that can be considered as three salient views on the topic of sustainable energy and transport for islands. Each perspective does not reflect individual views of the respondents but it can rather be considered as an idealised standpoint that is shared across the respondents associated with each factor (Curry et al., 2013). Statements' z-scores for each factor provide a quantitative indication of each perspective's priorities. In line with the typical Q-methodology practice, perspectives are assigned titles, to aid communication and understanding of the results.

Perspective 1: Tech Enthusiasts – Small is Beautiful

This perspective explained the largest share of the total variance; it is therefore by far the most dominant discourse within the respondents. Its statements in order of agreement (highest z-score) are 2, 6, 21, 4, 8 (Tables 4.1-4.2). The supporters of this perspective prioritise integrated solutions that utilise cutting-edge technologies. As the very first priority, they identify the need to develop e-mobility schemes that are fully powered by RES. The electrification of public transport needs to be the basis of the transition and parallel to that the consumers' behaviour needs to adapt to the new reality. It is an interesting observation that respondents in this concourse underline the need for technological solutions to be coupled with behavioural economics and socio-environmental theories that relate to energy use. Indeed, energy consumption and transport-related pollutant emissions are influenced not only by technology choice, technical efficiency, mode choice and the carbon content of the energy source but also by social, cultural and lifestyle factors (Brand et al., 2019). Accordingly, efforts to implement the transition should be multidimensional.

This perspective not only suggests a change a transition towards clean island systems, but promotes a leading role for the islands in the realisation of smart energy and transport schemes. Islands' systems have relatively small scales and thus favour pilot applications that will act as examples for a wider application.

Statements for disagreement (lowest z-score) are 31, 9, 3, 11, 16, 14 (Tables 4.1-4.2) and further justify the title of this perspective. Respondents is this group believe that small-scale solutions provide equal employment opportunities and large-scale interconnection projects are not an absolutely necessary condition. Investing in e-mobility and PV-powered charging stations are meaningful investments that –among others– will improve the islands' image. Tech enthusiasts of this group also believe that the proposed small solutions will not increase islands' vulnerability to services' disruptions.

Perspective 2: Clean Transport First

This group of respondents prioritises the transition to a clean transport sector and sees RES as only one of the means to achieve that. Although it shares some views with the previous perspective (hence the relatively high correlation coefficient - 0.661), it addresses the topic from a different angle. Main statements in order of agreement are 4, 22, 21, 8, 36, 6 (Tables 4.1-4.2). This discourse builds on the fact that the relatively short travel distances on islands favour e-mobility. Accordingly, solutions need to adopt to this fundamental particularity: tailor-made solutions for the islands are needed parallel to the required behavioural change. Notably, this group prioritises the need to make islands innovation leaders and realise that with financial incentives. Among the three factors, it is the only perspective that highlights the need to incentivise the use of electric vehicles.

As expected, this perspective does not agree with the claim that e-mobility will not improve islands' image (statement 16). Acknowledging users' reservation on buying e-vehicles (1), it supports the need for incentives as an e-vehicle fleet is a meaningful investment (3). Additional important statements for disagreement are 37, 11, 20 (Tables 4.1-4.2). While acknowledging the key role of RES, it underlines the need to implement clean transport systems as an absolute priority. For this group, even in the case that the de-carbonisation of the power system is delayed, islands should take advantage of the merits of electro-mobility.

Perspective 3: Fiscal focus executives

This group of respondents mainly focuses on the financial aspect of the topic. It makes the assumption that existing technological solutions are sufficient and advantageous. Accordingly, for this group, the discussion needs to focus on how the transition can be realised in an optimal manner. The identify the need for clean energy and transport incentives (statement 23) as the high capital costs have impeded, until now, their development (34). According to this perspective, high fossil fuel prices should not be considered as a sufficient driver of this transformation (32) and additional policy measures coordinated by local authorities are needed (19). This is the only group that highlighted the important role local governance can play.

This perspective disagrees with the uniform pricing of energy between islands of the same country (15) and considers it a limiting factor. It also believes that a –partial and/or gradual– removal of existing subsidies would accelerate the implementation of smart energy and transport island systems (33). It considers that electric two-wheelers can play a major role in islands (5) especially if supported by Shared Use Mobility schemes and powered by off-grid PV powered stations (11). Support for electric vehicles is needed to convince users to invest to electric vehicles (1) that this concourse acknowledges as a meaningful investment (3).

Consensus statements

Consensus Statements are those that do Not distinguish between any pair of factors. In the present study, they are the approaches that all three perspectives recognised as valuable to implement sustainable energy and transport systems in islands. Six statements received similar rankings among the factors: 25, 10, 11, 3, 7, 30 with the common viewpoint in those statements presented in Figure 4.3.

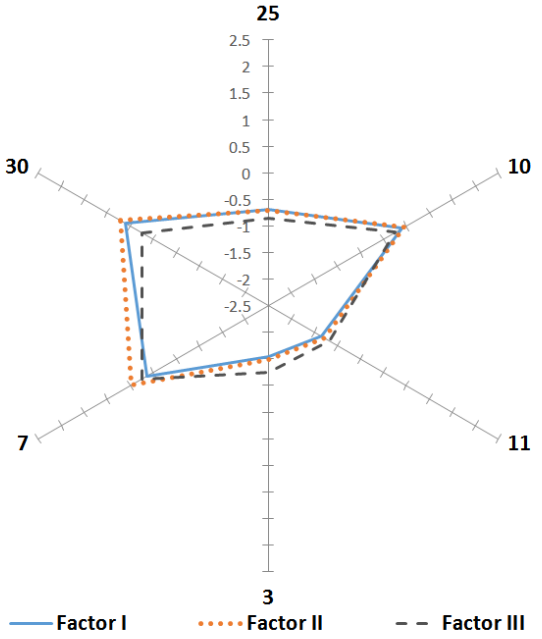
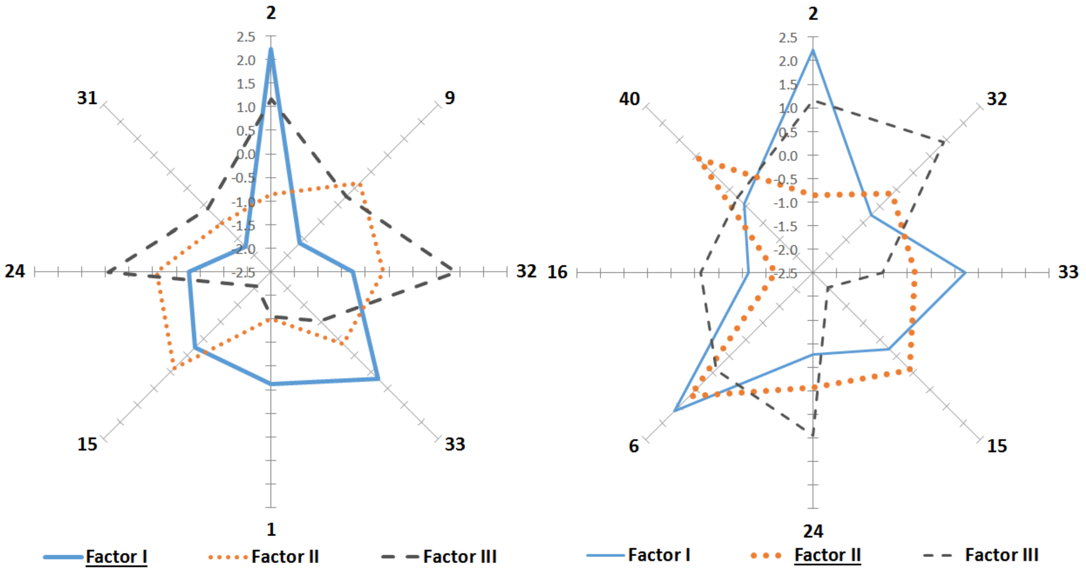


Figure 4.3: Distribution of average factor loadings for consensus statements

Respondents generally agree that e-mobility is an appropriate strategy to reduce noise. They also consider good coverage of charging points as more important than fast charging stations. They also agree that PV-powered charging stations could cover remote areas in the islands for EVs and electric two-wheelers. There is also a general consensus that a fleet of EVs is a meaningful investment. However, they are also generally neutral whether the introduction of EVs should be radical or incremental in the island settings. Equally important, respondents agree that this transition will generally have a positive impact on islands economy.

Distinguishing statements

In order to allow comparisons between the three factors, distinguishing statements are identified. A statement is considered as *distinguishing* for a factor if it receives a z-score significantly different than that in the other factors. In other words, its importance in one factor ranks in a position that is significantly higher or lower than that in other factors. The z-scores in statements where the highest difference is observed is typically shown in radar charts as that of figure 4.4.


(a) Factor I (b) Factor II

(c) Factor III

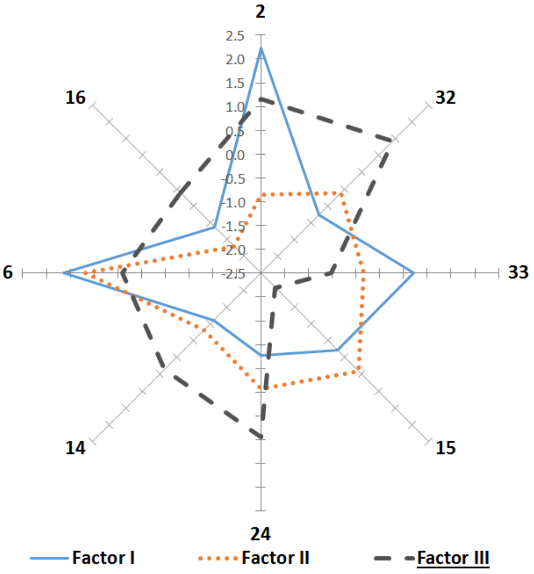


Figure 4.4: Distribution of average loadings for factors' I–III distinguishing statements

4.6 Discussion

The results show that there is substantial support for developing sustainable energy and transport systems in islands including the use of electric vehicles. Respondents agree that these are priority issues that must be addressed in the islands especially in view of the very high cost of the current situation. Specialists acknowledge that the current situation is not sustainable and new schemes need to be urgently adopted. An interesting finding of the analysis is the respondents' opinion on the need to support pilot applications over Research and Development (R&D). Perspectives-I and III do not find pilot applications the best strategy and stand for finalising the designs of required solutions before moving to implementation projects. They believe that by boosting current knowledge will boost technological and market maturities and allow developing final solutions and this is shown by the negative z-score they assigned in the relevant statement 40 (see Table B.4). The z-score shows that they are not absolutely against pilot solutions but they believe that further R&D activities are still required. Most probably, they believe that a major technological breakthrough may bring profound transformations to the electric power generation industry. Such an example are perovskite photovoltaics; addressing current issues of their materials properties and addressing stability (Snaith, 2018) will make commercially available a technology of significantly lower cost. Contrary to that is the viewpoint of respondents supports perspective-II that includes technology supporters of clean transport systems (*clean transport first*). They consider pilot applications an important step to realising the islands' transition even if this is going to be done with incremental and not radical manner. This is not surprising given that a significant part of the respondents work in the Academia and research organisations and are directly involved in R&D activities.

Respondents share views on the role of future interconnection of the islands to mainland power grids. While recent technological breakthroughs have made such projects technically feasible, specialists do not favour such an approach, most likely due to the involved complexity and the required time and cost to develop such projects. Although they generally do not exclude such an option, they do not consider it as realistic for all islands. This particularly the case of perspective-I (*small is beautiful*) that prioritises small-scale solutions that are tailor-made for the islands and use the latest technologies.

The biggest disagreement in the analysis is on whether electric vehicles need to be powered by renewable energy sources or not. Specialists generally prioritise integrated solutions i.e. a clean transport sector that runs on energy produced by clean energy sources. This secures that the avoided GHG emissions are high and islands contribute to local and global mitigation efforts. Perspective-II, though, supports a *clean transport first* solution, recognising the air quality and noise improvements as well as the islands' suitability to EVs' use. According to them, the widespread use of EVs will anyhow result in high amounts of avoided CO_2 emissions and with the decarbonisation of the power sector, these savings will further increase.

It is interesting that respondents underline the need to expand such integrated solutions to cover a wider extent i.e. waste and water infrastructure. They generally do not prioritise clean energy projects over waste management ones and identify the potential synergies to design sustainable islands. Equally important they do not believe that by simply developing clean energy and transport systems will automatically improve access and quality to water. Well-targeted strategies are needed to take advantage of the opportunities a sustainable island system provides to have positive spillover effects on water and waste management.

Findings included in this chapter will be published in a journal article that is currently in preparation phase: Kougias, I., Nikitas, A., Thiel, C., Szabó, S. Application of Q methodology in islands' Energy and Transport systems, (intended to be submitted on a Special Issue of *Transportation Research Part D (or similar)* on the Topic: "Role of Infrastructure to Enable and Support Electric Drive Vehicles", deadline: 30^{th} June 2019)

Chapter 5

Conclusions

The present Thesis explores the potential synergies between energy and transport systems in islands. Following a nexus approach, it provides projections on future, cost-optimal energy systems for the islands. This is a notable contribution of the present research as it involves *basic* (fundamental) research activities to design a model and develop the relevant optimisation software for islands' energy systems.

Taking into account the recent technological advancements and cost reductions, it provides evidence on the potential role that renewable energy sources and battery storage can play in non-interconnected island locations. The application of the developed energy model in selected islands shows that clean energy technologies are the cost-optimal option. Independent from size, population, needs and consumption patterns, the energy model converged to a very high share of RES in all test-case islands.

This is a key contribution as it shows the path for sustainable energy systems that not only minimise GHG emissions and pollution but also provide business opportunities. The analysis reveals that even a major transformation of islands power systems can be realised at lower costs than continuing the polluting business as usual practices. Modern clean energy technologies have reached such a market maturity that the levelised cost of electricity produced is significantly lower than that of conventional diesel gen-sets. Equally important, the analysis shows that the transformation can even include upgrades of the grid infrastructure and *smart island* technologies at competitive cost terms.

The message is valuable also for policy-makers. It becomes evident from the present analysis that any delay of the transformation will involve significant costs. As we already knew, the current situation is not sustainable from the climate and environmental perspective and very expensive for the central government budget. The analysis showed that the life-cycle costs of energy production are in all analysed cases much lower than the current practice indicating the urgent need to plan the transition. Policy-makers need to plan the implementation plans and design optimal strategies for each of the non-interconnected European islands.

Continuous technological progress, ongoing Research and Development activities and further cost reductions will support the transition and create additional opportunities. This is related to energy production technologies (e.g. solar PV, wind power) but also to storage technologies that are at a relatively earlier stage of development. Continuous improvements of efficiencies and production costs will render batteries a standard solution to store the excess output of variable RES.

Battery technology is directly linked to the second pillar of this Thesis i.e. clean transport. Islands are in need to upgrade their mobility services. So far, policy-makers' priorities have focused on developing island infrastructure and road networks that enable mobility inside islands. It is now the time to prioritise the next step of the islands' mobility by incorporating cutting edge technologies that will upgrade islands' economic and social activities. The present Thesis provided an exhaustive analysis of both emerging and advanced technologies that are suitable for the island setting. It also presented vehicle-sharing schemes that could easily be adapted for the island and cover the long-existing mobility gaps.

In that way, this work shows business opportunities in the islands, for companies active in the field.

The Thesis highlighted the important role and the synergies that electromobility can create. Presenting and analysing the G2V and V2G concepts it identifies an additional role that EVs can play in the islands, by providing additional flexibility to the local grid. More importantly, the important link between energy and transport is highlighted, underlining the need to develop nexus approaches in policy-making.

As far as electromobility in the islands is concerned, the analysis also considered the potential role of electric two-wheelers. The particular geographic characteristics of many islands favour a wide use of electric two-wheeler fleet. Being very low-impact transport means, this would have an immediate positive impact on islands environmental footprint (GHG emissions) and life quality (noise, flexibility). It can also provide island populations low-cost means of transport to cover day-to-day needs.

The research work included an additional step: analyse specialists' view. Experts in the energy, transport and developing economics fields provided their input on European islands' transformation. These experts represented every part of the implementation phase ranging from scientists and R&D organisations, the industry, project developers, and policy-makers. Identifying leading figures of the field that were willing to participate in the analysis was a challenging and time-demanding task.

For the first time, a Q-methodology was used to process preferences, opinions and distinguishing strategies to transform islands' energy and transport systems. Using appropriate software, the analysis identified the main viewpoints that correspond to relevant policy decisions.

This was particularly important as it filled a gap that is often overseen; the gap between scientific evidence and policy decisions. Accordingly, the third pillar of this Thesis targeted to cover this underestimated need and identify to what extent the obtained scientific results are reflected in the experts' preferred strategies.

Overall, the present Thesis shows that nexus approaches can transform islands and make them leaders of the ongoing energy and transport transitions. The unique island characteristics allow them, even under the current technological and market conditions, to become leaders and pioneers in embracing the latest technological solutions at a competitive cost. More importantly, they can lead the way to low-carbon communities and sustainable growth while bringing important benefits to local societies.

The present research work has not covered the full spectrum of existing challenges. The great number of islands, geographic and climate variability, differences in size, building and population densities require additional research. The described nexus analyses could ideally be extended in future efforts. The important role of tourism in many islands could be reflected in future work, adding an additional pillar in the analysis. Moreover, the developed energy model could be extended to incorporate additional features of island systems and infrastructure (desalination, drinking and irrigation networks) as well as additional technologies.

Appendix A

Modelled annual investments

The following Figures A.1–A.5 show the required annual investments per technology over the analysed period (2016-2036). Each colour corresponds to one technology (blue: wind, yellow: solar PV, green: battery storage, purple: conventional fossil fuel generation). Values are provided in € million.

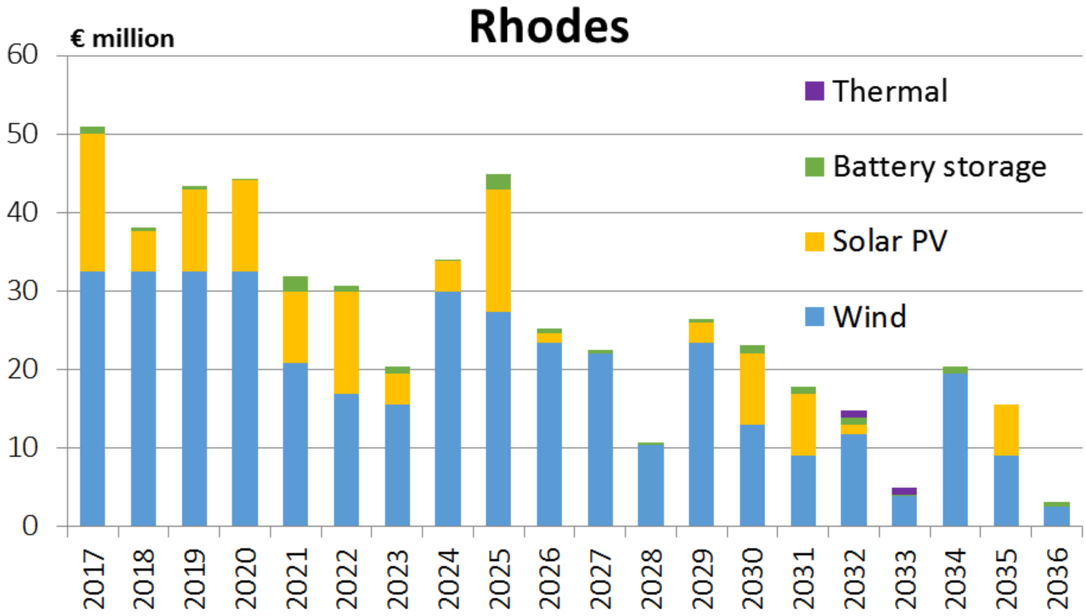


Figure A.1: Annual investments in Rhodes: modelled cost-optimal strategy

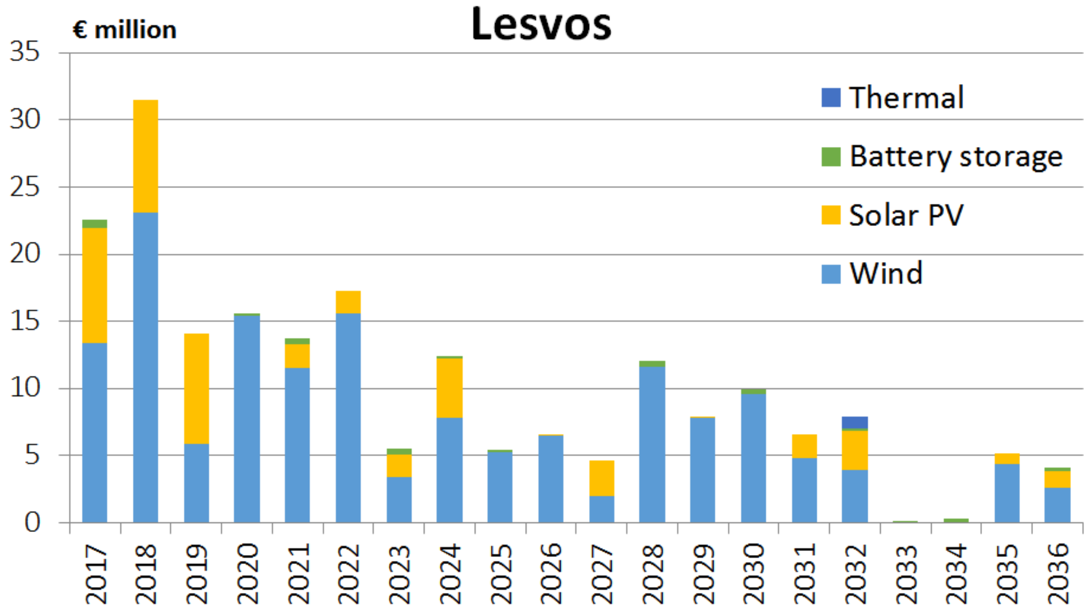


Figure A.2: Annual investments in Lesvos: modelled cost-optimal strategy

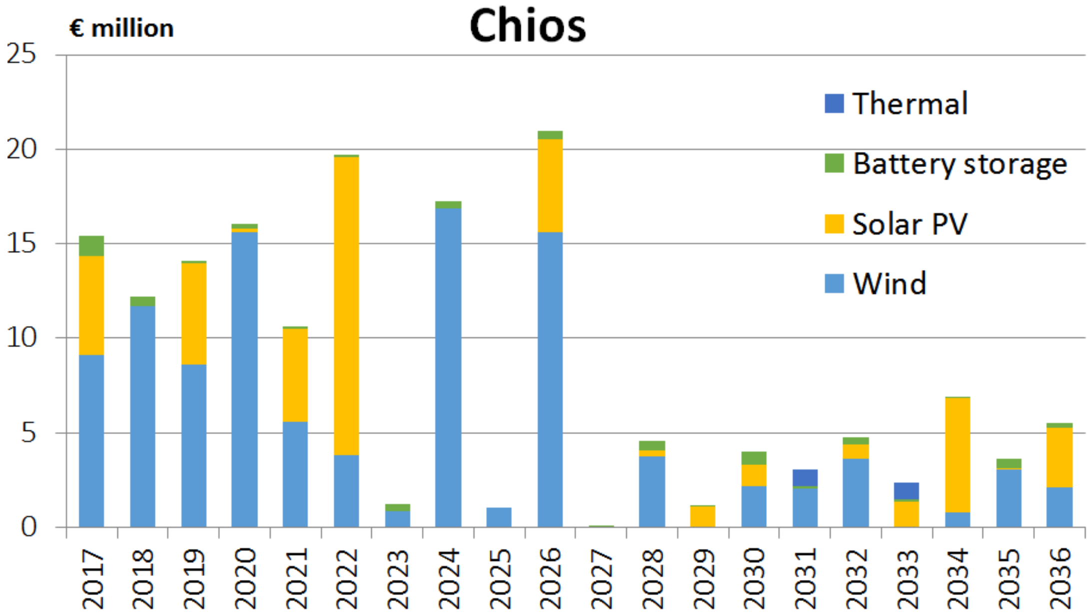


Figure A.3: Annual investments in Chios: modelled cost-optimal strategy

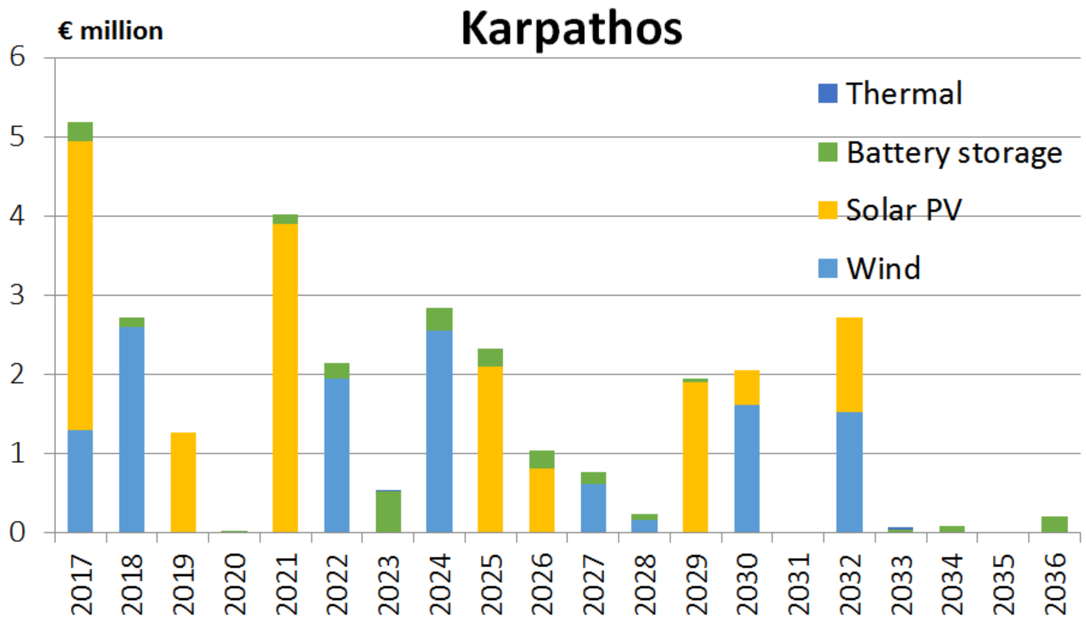


Figure A.4: Annual investments in Karpathos: modelled cost-optimal strategy

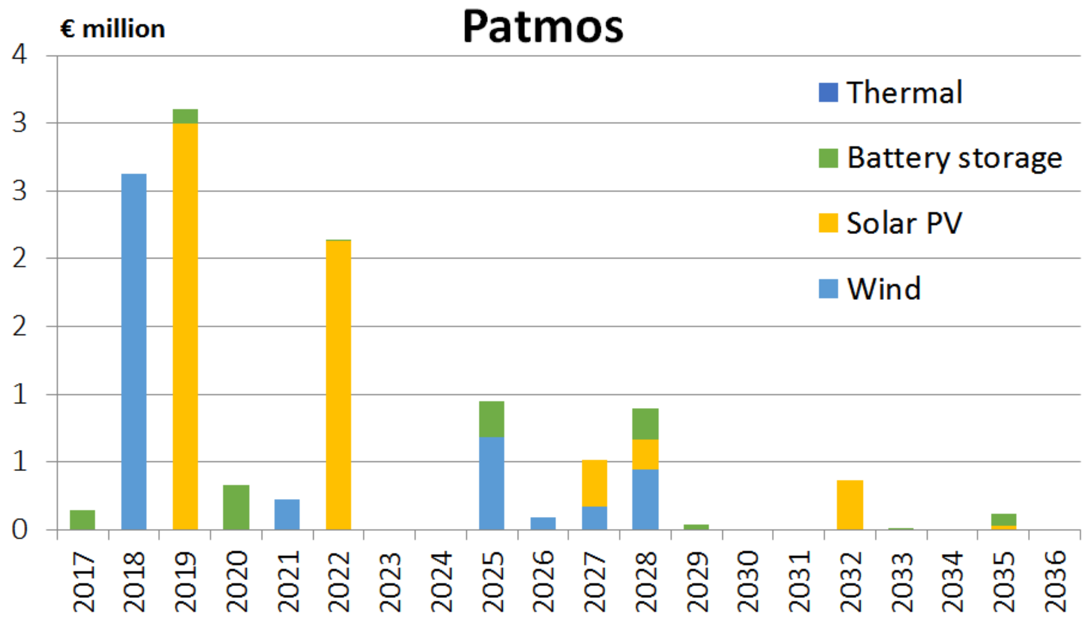


Figure A.5: Annual investments in Rhodes: modelled cost-optimal strategy

Appendix B

Q-method survey and output

The following text provides the Q-method questionnaire as provided and completed by the survey participants. It includes the instruction and the forty (40) statements that the participants were asked to classify.

Instructions

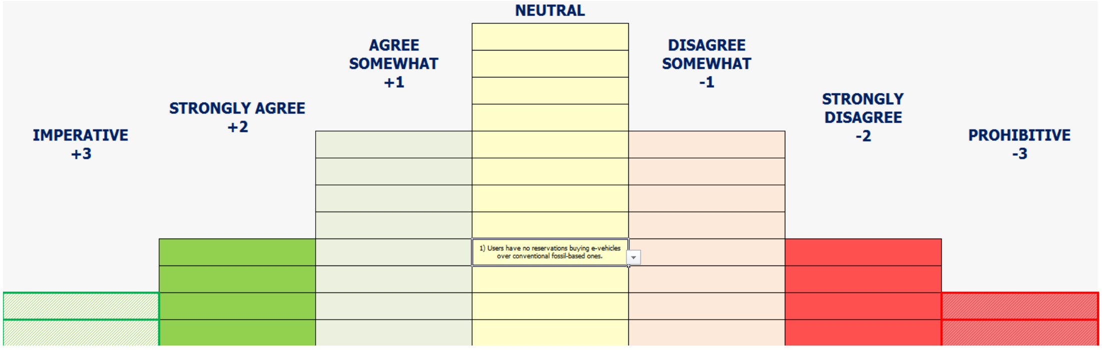
Scope: Many of the 2200 inhabited EU islands depend on conventional fossil fuels both for their electrification and transport. Dependance on expensive fuel imports increases the costs, raises energy security and climate issues and creates air pollution. The present exercise calls for the experts' opinion on what extent alternative solutions could foster sustainable and resilient economic growth.
Step 1: The questionnaire includes 40 statements about energy production, mobility, social and environmental parameters and the economic and financial aspects. Please read and become familiar with them. Note that the order of the statements is random.
Step 2: Please proceed to the pyramid at the top of the statement list to sort them in piles, according to the extent to which you agree or disagree with. There are seven options ranging from imperative to prohibitive in terms of your personal preference (see Figure B.1).

Step 3: Go to a particular cell on the pyramid and select click to reveal the drop-down menu. You can scroll up and down the available statements.

Step 4: Select a statement you feel belongs to this cell by clicking it as appropriate. The statement will appear in the cell. Remember, we are interested in your point of view. Therefore, there are no right or wrong answers. Also, it does not matter which one goes on top or below.

Step 5: Once you have finished sorting all statements in all five columns, make sure all cells are filled and correspond to your views. Please do not leave any statements un-allocated.

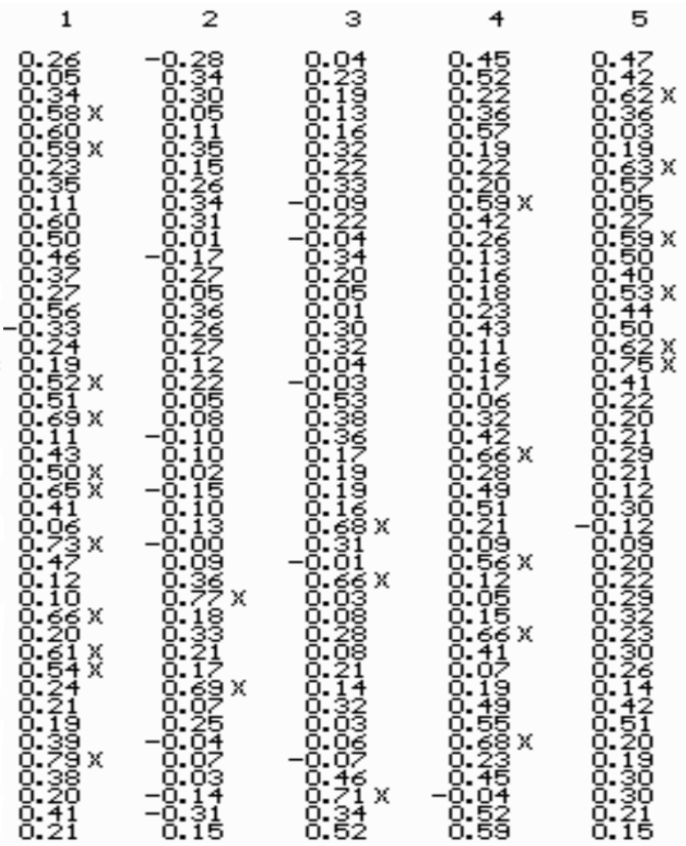
If you need to move some sentences around simply click in the appropriate cell and select sentence accordingly. Multiple inserts are highlighted with purple colour at the right column to be avoided. At the end of the exercise, the far right column should be highlighted in green, indicating that all statements have been inserted only once.



1) Users have no reservations buying e-vehicles over conventional fossil-based ones.

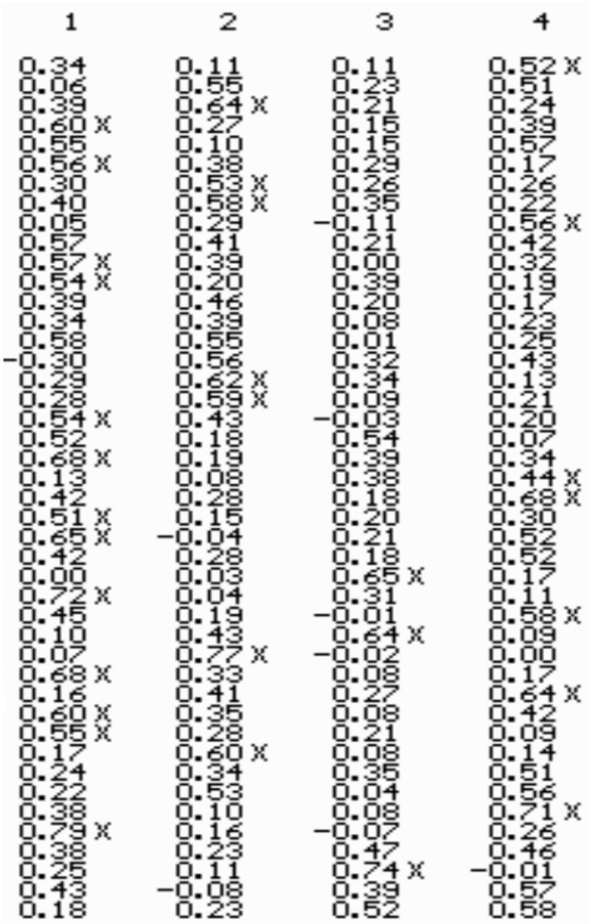
Figure B.1: Statements' pyramid and survey's input interface

Background: Provide information about your background. Please note that answers will be processed anonymously and any personally identifiable information will be removed before the analysis.



1	2	3	4	5
0.26	−0.28	0.04	0.45	0.47
0.05	0.34	0.23	0.52	0.42
0.34	0.30	0.19	0.22	0.62 x
0.58 x	0.05	0.13	0.36	0.36
0.60	0.11	0.16	0.57	0.03
0.59 x	0.35	0.32	0.19	0.19
0.23	0.15	0.22	0.22	0.63 x
0.35	0.26	0.33	0.20	0.57
0.11	0.34	−0.09	0.59 x	0.05
0.60	0.31	0.22	0.42	0.27
0.50	0.01	−0.04	0.26	0.59 x
0.46	−0.17	0.34	0.13	0.50
0.37	0.27	0.20	0.16	0.40
0.27	0.05	0.05	0.18	0.53 x
0.56	0.36	0.01	0.23	0.44
−0.33	0.26	0.30	0.43	0.50
0.24	0.27	0.32	0.11	0.62 x
0.19	0.12	0.04	0.16	0.75 x
0.52 x	0.22	−0.03	0.17	0.41
0.51	0.05	0.53	0.06	0.22
0.69 x	0.08	0.38	0.32	0.20
0.11	−0.10	0.36	0.42	0.21
0.43	0.10	0.17	0.66 x	0.29
0.50 x	0.02	0.19	0.28	0.21
0.65 x	−0.15	0.19	0.49	0.12
0.41	0.10	0.16	0.51	0.30
0.06	0.13	0.68 x	0.21	−0.12
0.73 x	−0.00	0.31	0.09	0.09
0.47	0.09	−0.01	0.56 x	0.20
0.12	0.36	0.66 x	0.12	0.22
0.10	0.77 x	0.03	0.05	0.29
0.66 x	0.18	0.08	0.15	0.32
0.20	0.33	0.28	0.66 x	0.23
0.61 x	0.21	0.08	0.41	0.30
0.54 x	0.17	0.21	0.07	0.26
0.24	0.69 x	0.14	0.19	0.14
0.21	0.07	0.32	0.49	0.42
0.19	0.25	0.03	0.55	0.51
0.39	−0.04	0.06	0.68 x	0.20
0.79 x	0.07	−0.07	0.23	0.19
0.38	0.03	0.46	0.45	0.30
0.20	−0.14	0.71 x	−0.04	0.30
0.41	−0.31	0.34	0.52	0.21
0.21	0.15	0.52	0.59	0.15

Figure B.2: Varimax-rotated eigenvalues of 5 factors with automatic pre-flagging



1	2	3	4
0.34	0.11	0.11	0.52 X
0.06	0.55	0.23	0.51
0.39	0.64 X	0.21	0.24
0.60 X	0.27	0.15	0.39
0.55	0.10	0.15	0.57
0.56 X	0.38	0.29	0.17
0.30	0.53 X	0.26	0.26
0.40	0.58 X	0.35	0.22
0.05	0.29	-0.11	0.56 X
0.57	0.41	0.21	0.42
0.57 X	0.39	0.00	0.32
0.54 X	0.20	0.39	0.19
0.39	0.46	0.20	0.17
0.34	0.39	0.08	0.23
0.58	0.55	0.01	0.25
-0.30	0.56	0.32	0.43
0.29	0.62 X	0.34	0.13
0.28	0.59 X	0.09	0.21
0.54 X	0.43	-0.03	0.20
0.52	0.18	0.54	0.07
0.68 X	0.19	0.39	0.34
0.13	0.08	0.38	0.44 X
0.42	0.28	0.18	0.68 X
0.51 X	0.15	0.20	0.30
0.65 X	-0.04	0.21	0.52
0.42	0.28	0.18	0.52
0.00	0.03	0.65 X	0.17
0.72 X	0.04	0.31	0.11
0.45	0.19	-0.01	0.58 X
0.10	0.43	0.64 X	0.09
0.07	0.77 X	-0.02	0.00
0.68 X	0.33	0.08	0.17
0.16	0.41	0.27	0.64 X
0.60 X	0.35	0.08	0.42
0.55 X	0.28	0.21	0.09
0.17	0.60 X	0.08	0.14
0.24	0.34	0.35	0.51
0.22	0.53	0.04	0.56
0.38	0.10	0.08	0.71 X
0.79 X	0.16	-0.07	0.26
0.38	0.23	0.47	0.46
0.25	0.11	0.74 X	-0.01
0.43	-0.08	0.39	0.57
0.18	0.23	0.52	0.58

Figure B.3: Varimax-rotated eigenvalues of 4 factors with automatic pre-flagging

Table B.1: Correlation Matrix Between Sorts I (1–15)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	100	36	46	52	35	27	33	38	19	40	38	45	24	44	31
2	36	100	61	37	50	40	45	52	33	56	36	23	40	24	44
3	46	61	100	43	43	50	58	67	17	60	54	39	45	39	60
4	52	37	43	100	58	57	40	51	33	51	65	57	55	45	54
5	35	50	43	58	100	52	42	50	33	73	49	32	35	35	52
6	27	40	50	57	52	100	49	37	24	63	51	48	45	39	52
7	33	45	58	40	42	49	100	56	21	48	62	33	49	56	36
8	38	52	67	51	50	37	56	100	26	68	51	56	61	36	65
9	19	33	17	33	33	24	21	26	100	43	24	12	27	15	39
10	40	56	60	51	73	63	48	68	43	100	51	55	44	48	68
11	38	36	54	65	49	51	62	51	24	51	100	52	33	38	58
12	45	23	39	57	32	48	33	56	12	55	52	100	33	40	57
13	24	40	45	55	35	45	49	61	27	44	33	33	100	37	51
14	44	24	39	45	35	39	56	36	15	48	38	40	37	100	42
15	31	44	60	54	52	52	36	65	39	68	58	57	51	42	100
16	27	50	32	29	18	17	38	38	37	32	26	35	31	35	19
17	38	58	65	44	30	46	49	68	14	54	38	55	43	40	58
18	29	45	58	37	23	26	61	58	26	39	68	37	46	32	57
19	40	31	54	54	30	61	32	33	15	56	68	52	30	25	55
20	24	31	30	39	39	58	45	32	13	58	36	54	33	40	35
21	43	42	48	70	70	69	54	55	31	74	55	55	38	48	49
22	33	33	31	25	27	20	42	42	14	29	36	29	26	12	21
23	55	62	55	65	60	54	52	52	50	61	57	44	45	37	57
24	33	30	43	55	50	33	23	57	17	57	48	51	33	18	42
25	46	32	40	63	68	44	43	42	25	56	56	42	35	33	46
26	39	56	49	61	60	54	44	46	21	61	45	49	60	35	45
27	12	17	20	26	27	24	11	35	2	21	-1	24	17	-4	7
28	35	24	52	44	55	50	20	46	4	58	38	44	42	26	60
29	33	31	35	58	62	42	33	46	35	61	46	46	45	29	52
30	13	39	36	35	20	61	43	35	18	40	32	37	44	20	33
31	6	44	50	25	19	38	37	45	23	35	25	4	33	19	43
32	45	29	51	52	45	55	49	51	31	50	49	39	45	37	61
33	33	63	52	36	49	49	48	43	51	69	38	36	36	37	50
34	51	49	67	54	54	62	44	54	51	71	52	48	48	38	63
35	25	38	42	45	46	36	42	46	30	49	33	39	45	35	44
36	5	31	42	36	37	40	29	45	27	50	26	17	33	31	48
37	51	49	56	45	57	38	39	52	29	55	43	55	24	38	58
38	48	58	62	57	52	40	44	49	35	51	49	38	37	51	52
39	55	42	40	54	55	51	38	35	31	55	50	44	39	39	45
40	33	25	44	57	67	48	38	43	26	64	57	48	44	32	57
41	42	50	50	50	56	50	49	56	42	62	50	50	48	37	58
42	20	24	39	36	24	31	30	48	1	29	23	46	30	20	19
43	46	45	39	44	58	35	40	38	29	52	39	48	39	25	32
44	37	44	48	44	57	51	43	48	32	51	38	37	31	32	44

Table B.2: Correlation Matrix Between Sorts I (16–30)

	16	17	18	19	20	21	22	23	24	26	26	27	28	29	30
1	27	38	29	40	24	43	33	55	33	46	39	12	35	33	13
2	50	58	45	31	31	42	33	62	30	32	56	17	24	31	39
3	32	65	58	54	30	48	31	55	43	40	49	20	52	35	36
4	29	44	37	54	39	70	25	65	55	63	61	26	44	58	35
5	18	30	23	30	39	70	27	60	50	68	60	27	55	62	20
6	17	46	26	61	58	69	20	54	33	44	54	24	50	42	61
7	38	49	61	32	45	54	42	52	23	43	44	11	20	33	43
8	38	68	58	33	32	55	42	52	57	42	46	35	46	46	35
9	37	14	26	15	13	31	14	50	17	25	21	2	4	35	18
10	32	54	39	56	58	74	29	61	57	56	61	21	58	61	40
11	26	38	68	68	36	55	36	57	48	56	45	-1	38	46	32
12	35	55	37	52	54	55	29	44	51	42	49	24	44	46	37
13	31	43	46	30	33	38	26	45	33	35	60	17	42	45	44
14	35	40	32	25	40	48	12	37	18	33	35	-4	26	29	20
15	19	58	57	55	35	49	21	57	42	46	45	7	60	52	33
16	100	35	30	19	24	17	23	27	17	1	39	15	-13	21	48
17	35	100	54	40	37	45	32	46	39	32	44	27	31	30	44
18	30	54	100	50	30	29	26	45	29	37	32	6	26	39	31
19	19	40	50	100	39	43	21	43	35	37	44	10	42	49	44
20	24	37	30	39	100	71	30	39	36	48	37	20	42	35	55
21	17	45	29	43	71	100	33	67	63	70	58	27	57	54	40
22	23	32	26	21	30	33	100	39	25	44	37	20	25	30	31
23	27	46	45	43	39	67	39	100	51	68	56	32	44	57	38
24	17	39	29	35	36	63	25	51	100	57	44	26	39	52	18
25	1	32	37	37	48	70	44	68	57	100	58	27	51	50	18
26	39	44	32	44	37	58	37	56	44	58	100	24	37	62	27
27	15	27	6	10	20	27	20	32	26	27	24	100	24	19	39
28	-13	31	26	42	42	57	25	44	39	51	37	24	100	38	32
29	21	30	39	49	35	54	30	57	52	50	62	19	38	100	13
30	48	44	31	44	55	40	31	38	18	18	27	39	32	13	100
31	32	40	24	27	15	32	17	26	26	4	26	10	18	19	29
32	0	50	39	45	51	65	38	51	35	61	44	13	46	36	21
33	49	39	43	48	49	51	40	70	25	44	51	24	40	55	54
34	18	45	38	56	43	64	40	71	57	52	45	8	56	50	33
35	19	30	32	33	55	54	10	45	29	44	37	13	42	24	27
36	36	42	27	36	25	29	15	29	32	37	31	31	13	31	37
37	45	45	46	37	40	51	17	57	48	49	43	42	29	48	32
38	51	40	48	45	31	51	23	56	35	40	61	20	27	65	17
39	27	36	29	44	27	46	39	75	39	68	58	21	36	50	31
40	1	31	35	57	43	57	23	49	32	58	58	8	57	55	17
41	32	46	43	39	48	62	46	65	35	50	51	35	51	40	56
42	29	32	26	4	50	49	23	24	29	32	27	40	39	18	35
43	26	35	33	26	50	55	49	54	45	65	50	14	56	46	30
44	36	39	35	36	36	58	64	56	33	56	46	48	48	48	52

Table B.3: Correlation Matrix Between Sorts I (31–44)

	31	32	33	34	35	36	37	38	39	40	41	42	43	44
1	6	45	33	51	25	5	51	48	55	33	42	20	46	37
2	44	29	63	49	38	31	49	58	42	25	50	24	45	44
3	50	51	52	67	42	42	56	62	40	44	50	39	39	48
4	25	52	36	54	45	36	45	57	54	57	50	36	44	44
5	19	45	49	54	46	37	57	52	55	67	56	24	58	57
6	38	55	49	62	36	40	38	40	51	48	50	31	35	51
7	37	49	48	44	42	29	39	44	38	38	49	30	40	43
8	45	51	43	54	46	45	52	49	35	43	56	48	38	48
9	23	31	51	51	30	27	29	35	31	26	42	1	29	32
10	35	50	69	71	49	50	55	51	55	64	62	29	52	51
11	25	49	38	52	33	26	43	49	50	57	50	23	39	38
12	4	39	36	48	39	17	55	38	44	48	50	46	48	37
13	33	45	36	48	45	33	24	37	39	44	48	30	39	31
14	19	37	37	38	35	31	38	51	39	32	37	20	25	32
15	43	61	50	63	44	48	58	52	45	57	58	19	32	44
16	32	0	49	18	19	36	45	51	27	1	32	29	26	36
17	40	50	39	45	30	42	45	40	36	31	46	32	35	39
18	24	39	43	38	32	27	46	48	29	35	43	26	33	35
19	27	45	48	56	33	36	37	45	44	57	39	4	26	36
20	15	51	49	43	55	25	40	31	27	43	48	50	50	36
21	32	65	51	64	54	29	51	51	46	57	62	49	55	58
22	17	38	40	40	10	15	17	23	39	23	46	23	49	64
23	26	51	70	71	45	29	57	56	75	49	65	24	54	56
24	26	35	25	57	29	32	48	35	39	32	35	29	45	33
25	4	61	44	52	44	37	49	40	68	58	50	32	65	56
26	26	44	51	45	37	31	43	61	58	58	51	27	50	46
27	10	13	24	8	13	31	42	20	21	8	35	40	14	48
28	18	46	40	56	42	13	29	27	36	57	51	39	56	48
29	19	36	55	50	24	31	48	65	50	55	40	18	46	48
30	29	21	54	33	27	37	32	17	31	17	56	35	30	52
31	100	39	32	36	19	51	20	46	8	13	11	6	-10	27
32	39	100	36	61	57	37	39	44	43	57	46	21	42	42
33	32	36	100	54	43	38	51	57	57	37	61	17	54	68
34	36	61	54	100	51	36	45	46	57	58	56	25	55	49
35	19	57	43	51	100	29	38	31	18	52	38	31	44	24
36	51	37	38	36	29	100	33	37	32	32	19	13	2	38
37	20	39	51	45	38	33	100	64	48	29	60	38	40	58
38	46	44	57	46	31	37	64	100	43	37	35	30	36	54
39	8	43	57	57	18	32	48	43	100	52	54	10	56	50
40	13	57	37	58	52	32	29	37	52	100	50	17	40	25
41	11	46	61	56	38	19	60	35	54	50	100	43	51	62
42	6	21	17	25	31	13	38	30	10	17	43	100	38	38
43	-10	42	54	55	44	2	40	36	56	40	51	38	100	54
44	27	42	68	49	24	38	58	54	50	25	62	38	54	100

Table B.4: Factor loadings (Z-scores) of the 40 statements within each factor

	Factor I	**Factor II**	**Factor III**
1	-0.129	-1.501	-1.554
2	2.232	-0.849	1.167
3	-1.541	-1.485	-1.252
4	1.518	2.071	2.043
5	-1.241	-1.109	-1.685
6	1.644	1.188	0.408
7	0.137	0.479	0.249
8	1.189	1.497	0.276
9	-1.638	0.172	-0.240
10	0.412	0.445	0.257
11	-1.343	-1.272	-1.173
12	-0.943	-0.074	-0.704
13	0.271	-0.506	-0.295
14	-1.090	-0.827	0.362
15	-0.226	0.400	-2.062
16	-1.140	-1.704	-0.120
17	0.729	0.960	0.427
18	0.895	0.557	0.127
19	0.514	0.123	1.177
20	-0.874	-1.130	-0.162
21	1.568	1.734	0.941
22	0.941	1.930	1.801
23	0.965	0.765	0.527
24	-0.775	-0.076	0.940
25	-0.687	-0.705	-0.849
26	1.137	0.231	1.573
27	0.567	0.212	0.000
28	-0.694	-0.877	-1.369
29	-0.029	-0.257	0.427
30	0.602	0.721	0.234
31	-1.740	-1.029	-0.600
32	-0.761	-0.127	1.417
33	0.719	-0.339	-1.024
34	0.302	0.567	1.491
35	-0.657	-0.438	-0.962
36	0.337	1.399	-0.078
37	-0.600	-1.434	-0.191
38	-0.012	-0.363	-0.360
39	-0.130	-0.272	-0.922
40	-0.429	0.922	-0.242

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Research outputs delivered in terms of the present MSc studies

1. Ioannis Kougias, Sándor Szabó, Alexandros Nikitas, and Nicolaos Theodossiou. “Sustainable energy modelling of non-interconnected Mediterranean islands.” *Renewable Energy* 133 (2019): 930-940.
2. Alexandros Nikitas, Ioannis Kougias, Elena Alyavina, and Eric Njoya Tchouamou. “How can autonomous and connected vehicles, electromobility, BRT, hyperloop, shared use mobility and mobility-as-a-service shape transport futures for the context of smart cities?.” *Urban Science* 1, no. 4 (2017): 36.
3. Ioannis Kougias, Sándor Szabó, Alexandros Nikitas, and Nicolaos Theodossiou. “Modeling the transition to sustainable energy using harmony search: A water-energy nexus case in Greek islands.” 10th World Congress on Water Resources and Environment “Panta Rhei”, *European Water Resources Association*, (5–9 July 2017), Athens, Greece.
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