

Sustainable Energy for Islands: Opportunities versus Constraints of a 100%Renewable Electricity Systems

El Hierro (Canary Islands) and Flores (Azores) case studies

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Abstract

Islands' characteristics provide several advantages as laboratory for studying 100% renewable energy sources (RES) systems. Their isolation makes them a "unique laboratories, to gain knowledge and understanding of people/ environment relationships"¹; to prove its feasibility and acquire the needed knowledge for such systems to work; to be pioneer project, basis of other islands' projects and even a global 100%RES electricity system. The objective of this research has been to evaluate if 100% renewable electricity systems are feasible based on the experience being done in two European islands' with different RES potentials and 100% RES commitment. For such a system to be sustainable, a proper renewable energy potential to cover the actual and future demand is needed. A holistic approach is required; a case specific combination of RES has to be established. Profitability in the exploitation of renewable energy sources has to be assured. The electricity market has to lead to the convenient energy mix, as to support the subsistence of the electricity system. A proper governmental intervention will be required. The, traditionally not accounted, social and environmental cost of the electricity systems can play a significant role in its feasibility. Factors influencing the sustainability of the system; driving forces, risk and barriers has been identified.

¹ Pierre Lasserre, Director of the Division of Ecological Sciences, UNESCO at the 1^o European Conference on Sustainable Island Development, 1997, in Minorca (Spain). Consell Insular de Menorca, INSULA (1997) "1^o Conference on Sustainable Island Development: Agreements – Minorca Commitments - European Island Agenda" Menorca: Secretariat ECSID, pg.19-20.

Executive Summary

The increasing world's concern for achieving a sustainable society and the recognition of enhanced global warming as a consequence of human action has in sustainable energy practices one of its main bases for solutions. Actual international commitments to the Kyoto Protocol will force the ratifying countries to reduce their greenhouse gas emissions. This reduction is aimed to be achieved in an economic efficient way. Nevertheless, it should not be forgotten, that this commitment should just the first step in retrieving the natural cycle of greenhouse gases. As such the ultimate aim should be an efficient, sustainable 100% renewable energy sources (RES) system. In order to achieve this social and technological development are required.

Islands' characteristics provide several advantages as laboratory for studying such kind of systems. In the path to a global sustainable society, islands represent a "unique laboratories, to gain knowledge and understanding of people/ environment relationships, in an international context and conscious of the current phenomenon of globalisation"². This is a consequence of their "high level of interdependence between economy, society and environment"³

Tourism, water, waste and energy management will clearly determine island future sustainable development. Equilibrium between economic development and the carrying capacity of the islands, its infrastructures and services has to be achieved to prevent permanent environmental damage.⁴ Integrated planning practises should therefore be promoted, stimulating intersectoral synergies and environmental management.⁵

The energy sector, due to its strategic relevance as supporter of all economic activity, is one of the main areas on which policies should act to promote a sustainable society:⁶ Energy self-sufficiency based on RES is required to avoid money leakage from region, assure supply and avoid outside dependency, to create better job opportunities, promote local research and development, to protect the local environment as to comply with international agreements and, at the end, to achieve a sustainable island community.

In order to be energy self-sufficient, a holistic approach is required; a case specific combination of RES has to be established. Politicians and researchers play therefore a crucial role in the design of an efficient system. Once designed, investors and implementation supporting policies play the key role in building up the system. Energy efficiency measures, as rational energy consumption requires the island inhabitants' participation.

As a result of islands are unique laboratory to research and develop feasible low impact energy models. In small independent grids, islands small-scale renewable energy technologies represent rapidly a high percentage of the total energy production. They can serve as laboratories for combining RES, increasing their penetration in the energy market until reaching hundred percent renewable energy systems. As these projects represent a small-scale application of, what hopefully will be the future of all energy systems, they establish a learning process for further spreading of these technologies, at a cost-efficient way.

² Pierre Lasserre, Director of the Division of Ecological Sciences, UNESCO at the 1^o European Conference on Sustainable Island Development, 1997, in Minorca (Spain). Consell Insular de Menorca, INSULA (1997) "1^o Conference on Sustainable Island Development: Agreements – Minorca Commitments - European Island Agenda" Menorca: Secretariat ECSID, pg.19-20.

³ European Island Agenda: Operational field pg 53

⁴ Secretariat ECSID (1997). European Island Agenda: Operational Fields.

⁵ Secretariat ECSID (1997). Minorca Commitments.

⁶ Secretariat ECSID (1997). Minorca Commitments.

The objective of this research has been to evaluate if 100% renewable electricity systems are feasible based on the experience being done in two European islands' with different RES potentials and 100% RES commitment. For such a system to be sustainable, a proper renewable energy potential to cover the actual and future demand is required. Profitability in the exploitation of renewable energy sources is also a must. Market conditions surrounding the electricity needs are therefore to be studied. Substantial benefits of renewable energy uses are ignored in a traditional business environment, as these benefits are allocated on the society and/ or the natural environment. As a consequence, the personal commitment of the different the actors, involved in the energy market, towards the society and environment gain in importance; as leaders or barriers of change.

Three main kinds of information sources were handled to sustain this thesis.

Literature review: Mainly to obtain background information as to sustain the required general knowledge in the field.

Interviews: Face-to-face interviews, telephone interviews and email queries regarding both case studies have been undertaken. As a consequence also further specific documentation was obtained.

Statistical data: Energy consumption and productions statistical series has been used to analyse past-trends, as to foresee future scenarios. Also other statistical data has been handled to support statements or provide a better understanding of the observed situation.

The research questions have been stated as follows:

Can the system be considered sustainable, given the renewable electricity potential as the foreseeable technical and electricity demand evolutions?

To answer these questions a basic understanding of the technical requirements for such a system to work is needed. In this sense an overview of the existing renewable energy sources and exploitation technologies for electricity generation has to be undertaken. As the electricity produced by these media should cover the electricity demand, a general view into the demand formation has also been completed. Factors influencing the demand, electricity uses and consumer groups, as measures to control or manage their evolution have been thereby addressed. Key factors for a proper sustainable electricity supply are a proper combination of RES and energy storage systems. The highly stochastic behaviour of many RES results in an uncertain production, which doesn't match in time with the demand requirements; subsequently energy storage systems gain relevance in such a system. Therefore, a study about their characteristics as solution to reduce risk of blackouts and guarantee energy supply has to be undertaken.

When looking into the long-term feasibility of such a system, the most important factor becomes the possible future development of the actual electricity demand, as the improvement in converting the RES potential into technical potential. These considerations have been taken into account while looking upon the behaviour of the energy demands of El Hierro (Canary Island, Spain) and Flores (Azores, Portugal). The RES potential and future supply possibilities will have to support a sustainable system.

As many of the modern renewable energy technologies are still in development, a long-term strategy should to be developed. 100% RES plans should not define the exact percentage energy that will be covered by a specific RES, but measures and actions to increase RES implementation, as to assure the final system to work. The electricity market plays a key role in this process; governmental intervention tools act through the market to guide producer and consumer to change their behaviour. Islands' particular characteristics have lead to special market rules within the major, national electricity market. As such special attention has to be given to their specific market frame and the disturbances imperfect adaptation represents.

Finally, it is the economic perspective which will assure the sustainability of the project. As mentioned before, electricity supply and demand doesn't match in time. In islands' small systems this reflects in a increased storage necessity or electricity generation overcapacity to assure the capacity of providing the requested electricity in each moment. The associated investment increases the cost of the electricity system, but this doesn't mean that, from an economic point of view, the final system is not worth, even if it shows to be inefficient. The economic results of the final system has to be compared to the actual system, which given its actual high cost, also can be inefficient; especially, when considering the expected continues growth of fossil fuel prices. Nonetheless, the final system implies substantial social and environmental benefits when compared with actual fossil fuel based system. Exactly these circumstances are the one given in both analysed case studies: The production costs of the new systems are still higher than the incomes gained from the electricity distribution market, but lower than with the actual system. Moreover, the international energy market evolution makes foreseeable the production cost of RES to be reduced, while the production cost of the actual system is expected to increase due to fossil fuel price increases. Both analysed electricity systems endure thanks to a compensation system, where their associated continental electricity market compensates for the excess cost.

Concluding, both analysed case studies seem to be sustainable, if none of the following risk of failure disturbs it.

Which are or could be the driving forces of the change?

The main driving force has been the search of a secure, long-lasting, economic efficient electricity supply. These projects carry more then enough added benefits for each of the involved actor, to lead them to post for its implementation, despite the risk innovative projects represent. The additional benefit the different actors involved in the projects expected suit from social and environmental benefits of the project, to the ones result of the pioneer project these project represent, the research and development (R&D) promotion they embody, the image they yield, the funds they obtained, up to the expected incomes, which thanks to sharing the, through these projects, technical and managerial won skills, can be gathered.

Which are the existing risks of failure?

A major risk for the project to endure is an uncontrolled electricity demand growth, very likely to happen if no measures to avoid it are taken. This is mainly due to their still low energy intensity increase, a foreseeable population increase and the change on electricity consumption patterns and electric appliances which social change will produce.

Another further risk is linked to problems could result of an improper final energy mix. If any implemented measure or action undertaken to lead to the planned energy mix, fails or has unexpected negative results, the final energy mix will imply an enhanced cost to the system. Grid control problems, which, for example, could result of the complexity an increased number of suppliers entail, will also affect the sustainability of the 100%RES electricity system. The solution to these problems would require further investment, which affects the economic feasibility of the system.

The actual market rules are not designed for a 100%RES system. Consequently, a risk of market rule changes exists. The efficiency of any new frame will be very constrained, given the regional, national and European existing legislation on energy markets. Adding the commonly existing lack of confidence investors have on innovative projects and the risk any concession procedure entails, high risk exist linked to not gathering the for these projects high investment required. Nevertheless, this risk isn't big enough in the analysed case studies, when compared to the attraction these projects have caused.

Another risk, very difficult to avoid, given its characteristics, is the negative impact hidden power can exert on the project. Obviously, passing from the actual system to the new one will affect negatively parties, as for example, fossil fuel suppliers. With the intention of preserving their actual position they could try to affect the process in many different ways.

A last risk is linked to the opportunity cost which waiting a further technical and market development represents.

How can other islands profit from these experiences?

The actual high participation of different organizations from other islands or research institutes of countries with high number of islands, demonstrate not only the interest on analysing its applicability, but the interest of undertake the path to 100%RES electricity system islands. The learning curve will reduce progressively the cost of implementing such systems on islands. Skills will be gained in establishing the proper RES combination that assures a trustful system.

Are 100% Renewable Electricity Systems on Islands feasible in European context?

Technically a 100% electricity generation systems will mostly be limited by the possibility the feasible RES mixes allow, economically it is clearly a chance to consider. Two have been the main obstacles identified to a more rapid implementation: the high initial investment required for such a system to work and the high risk involved, as innovative system. EU's policies have been meant to reduce these obstacles, while promoting higher RES penetration within Europe.

Islands 100%RES projects are a cost efficient way to obtain results at European level, in its RES promotion strategy. Islands added difficulties leading to highly complex systems provide certainty about the applicability of results to other environments.

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1 Introduction

1.1 Background

The increasing world's concern for achieving a sustainable society and the recognition of enhanced global warming as a consequence of human action has in sustainable energy practices one of its main bases for solutions. Actual international commitments to the Kyoto Protocol will force the ratifying countries to reduce their greenhouse gas emissions. Even if the Protocol just entered in force it has already since 1997 let in many countries to several measures at all governmental levels. These measures focus on energy savings, as supporting research and investments in modern renewable energy technologies. A progressive shift into exploitation of renewable energy sources (RES) is required if the carbon dioxide (CO₂) reduction goals should be achieved.

To achieve an efficient 100% RES system social and technological development are required. All kind of organisations should cooperate: from electricity companies to non related ones, from non governmental organizations (NGO's) to the single human being, from research institutes to universities, from supranational governmental organizations to municipalities; all can collaborate through energy savings, investments or research in this field.

Islands' characteristics provide several advantages as laboratory for studying such kind of systems. In the path to a global sustainable society, islands represent a "unique laboratories, to gain knowledge and understanding of people/ environment relationships, in an international context and conscious of the current phenomenon of globalisation"⁷. This is a consequence of their "high level of interdependence between economy, society and environment"⁸

Islands can be seen as isolated, independent, closed system, but they are not. Contrary, they are highly dependent in many contexts, suffering under their isolation and their scale. Table 1-1 lists advantages and disadvantages of island communities in achieving a sustainable society⁹, as highlighted during the First European Conference on Sustainable Island Development.¹⁰ Islands special circumstances were previously considered by United Nations (U.N.) Agenda 21 in 1992.¹¹ Also the European Union took these factors into account, when revising the Maastricht Treaty, incorporating European Parliament resolution on island regions: "The handicaps from which island regions suffer, which clearly distinguish them from mainland regions, arise – albeit in varying degrees – from the limited availability of usable land and fisheries resources and of potential water and energy supplies, marine and coastal pollution, a particularly difficult waste and sewage management problem, depopulation, coastal erosion, the shortage of skilled labour, the fact that businesses have no possibility of benefiting from economies of scale, additional transport and communications costs, the doubly disadvantaged status of smaller islands forming part of an archipelago ('dual insularity') and the high cost of

⁷ Lasserre, P., (1997) Opening Speeches: Director of the Division of Ecological Sciences, UNESCO, In *1^o European Conference on Sustainable Island Development*, [Online] Available: <http://www.insula.org/publicpdf.htm> [2004, May 25]

⁸ Secretariat ECSID (1997). *European Island Agenda: Operational Field*, In *1^o European Conference on Sustainable Island Development*.

⁹ **Sustainable Society** should be understood as a society which cover all their needs aiming not to deplete available natural resources: Reusing and recycling, conserving matter and energy resources, preventing pollution and preserving biodiversity, not exceeding the carrying capacity of nature and the regenerative cycle of renewable resources. (Miller, 1994) In this sence, **Sustainable Development** looks for a economic and social development of the human society with the aim of achieving actual and future generations' wellbeing.

¹⁰ hold in 1997 in the island of Minorca (Balearic Islands, Spain)

¹¹ See appendix 1: United Nations (U.N.) (1992) Sustainable development of small islands. *A genda 21*, Chapter 17g, [Online]. Available: <http://islands.unep.ch/da21c17g.htm> [2004, May 5]

infrastructures, to which, in some cases in the North, must be added isolation in winter caused by ice¹². As a result, the European Union (EU) considers island as an identity itself when designing development policies.¹³

Table 1-1 *European Islands' sustainable development limitations and strengths*

Limitations	Strengths
<ul style="list-style-type: none"> • Limited range of resources Leading to: <ul style="list-style-type: none"> ○ Excessive specialization of the economy ○ Very high overseas trade dependency Resulting in high vulnerability to changes • Inability to achieve economies of scale <ul style="list-style-type: none"> ○ Prohibitive costs of gaining access to conventional markets ○ Frequent negative impact of market factors and natural and environmental constraints on usual economic activities • Particularly affected by globalisation and the process of European integration Requiring special attention to enable islands to integrate on equal terms to other European regions • Often seasonal dramatic increase of population Resulting in limited resources under enormous pressure, often exceeding the carry capacity. • High proportion of endemic species and high level of biological diversity Resulting in high risk of species becoming extinct • Higher infrastructure costs 	<ul style="list-style-type: none"> • Unique natural and cultural heritage, becoming basic assets of island economies • Exceptional human resources, with enormous creative capacity and used to changes, as to overcome difficulties with imagination • Geographical and human differential added value assuring long-lasting competitive advantage in specialised activities, as tourism.

After Consell Insular de Menorca, *INSULA* (1997)

Due to their geographical isolation islands preserve a biological and/ or geological uniqueness, which ranks island among the location with highest biodiversity level. This is due to two factors:

- Distance to the continent
- Microclimates within an island

¹² European Union (EU) (1998). *Resolution on the problems of island regions of the European Union A4-0118/98*, 28/5/98. Quoted in Hache, J.D. (2000). *The European islands and their governance: from the nation states to the European Union*. International Journal of Island Affairs, Issue 9, 1, 13-20. [Online] Available: <http://www.insula.org/listjournals.htm> [2004, May 28]

¹³ Amsterdam Treaty, article 130a) "...the community shall aim at reducing disparities between the levels of development of the various regions and the backwardness of the least favoured regions or islands" European Union (EU) (1999) Amsterdam Treaty quoted in Hache, J.D. (2000) *The European Islands and their Governance: from The Nation States to The European Union*.

Islands have let to high number of endemic species of flora and fauna, as built up unique ecosystems.¹⁴ Therefore, islands are very vulnerable to changes. These fragile systems leave little margin for mistakes while implementing economic growth.¹⁵

As many of biodiversity's hotspots are found on islands, United Nations Educational, Scientific and Cultural Organization (UNESCO) Man and Biosphere Programme had given special attention to islands, considering them "as laboratories par excellence for conservation and management of natural resources".¹⁶

European island represent a large proportion of European bio-diversity, which has been reflected in their higher percentage of protected area compared to continental Europe.¹⁷ This uniqueness makes them attractive for foreigners.

The environmental uniqueness of islands, but also their frequently favourable climate had brought on them the image of paradise on earth. This has lead in certain islands to an inversion of the depopulation trend, trend that represented a constant loss of human skills. The most prepared population is the one who tends to leave the island searching for a better job opportunity or a better economic situation. The population stagnation or even growth has not been the main consequence of the attractiveness of islands.

Tourism represents the keystone of 70 % of European Islands' economies, accounting for more than 50% of the gross domestic product (GDP) of one third of them.¹⁸ This increases the existing high dependency on imports, as the local environment is unable to provide all the, by the tourist requested, products and services. European Islands' tourism is mostly seasonal, increasing substantially island population during several months. This forces to overcapacity in infrastructures in all fields, which, by the way, "are up till three to four times higher than on the mainland."¹⁹

Tourism is also a high-quality water and energy consuming activity. Islands have their own hydrological system, with characteristics that differ from the continental ones, but also among themselves. Potable, sweet water is mostly a scarce good on islands. This is a consequence of human action through overexploitation and/ or pollution of the water table, but sometimes, just consequence of island's geological conditions. "The carrying capacity has, in many cases, been exceeded especially due to tourism."²⁰ This scarcity is been defied through seawater desalination or water imports: expensive solutions to the problem. Desalinations processes are additionally high energy consuming processes, which increases the energy needs of the island community. "Typical data per cubic meter of fresh water are 8-15 kilowatt per hour (kWh) for commercial distillation (heat consuming processes) and 4-7 kWh for commercial membrane systems (electricity consuming processes)."²¹

¹⁴ Unknown (2001). *Island and biodiversity the insular paradigm*. International Journal of Island Affairs, Issue 10, 2, 7-10. [Online] Available: <http://www.insula.org/listjournals.htm> [2004, May 28]

¹⁵ Tocino, I., (1997) Opening Speeches: Minister of the Environment of Spain, In *1^o European Conference on Sustainable Island Development*.

¹⁶ Unknown (2001). *Island and biodiversity the insular paradigm*.

¹⁷ Tocino, I., (1997). Opening Speeches: Minister of the Environment of Spain.

¹⁸ Secretariat ECSID (1997). *European Island Agenda: Operational fields*.

¹⁹ Forum for Energy and Development (2000) *Renewable Energy on Small Islands - Second Edition*. [Online] Available: http://www.re-islands.org/documents/re_second_edit.pdf [2004, May 3]

²⁰ Secretariat ECSID (1997). *European Island Agenda: Operational fields*.

²¹ Marin, C. (2000). *The 'trinomial' energy water tourism* International Journal of Island Affairs, Issue 9, 1, 53-56. [Online] Available: <http://www.insula.org/listjournals.htm> [2004, May 28]

Tourism also increases the waste, as wastewater streams, introducing a seasonal effect on these important problems for islands. The waste amount produced per capita is from two to three times the one on the mainland. One of the main reasons for it is the high amount of transport packaging required. "Islands typically have a pronounced imbalance between material flows from the mainland and their capacity to treat and return waste."²² The waste treatment problems are due to:

- The limited area and the, in islands environment, enhanced environmental problems of land filling,
- The scale of many recycling processes and the high costs, that must therefore be assumed, if these kind of material are to be recycled,²³ and
- The political reluctance to waste incineration facilities, as mostly not social accepted and proclaimed to have negative impact on tourism.

Energy recovery technologies should be considered as a solution with overall less environmental impacts and cost savings if compared to the fossil fuel based energy generation.²⁴

Briefly, tourism, water, waste and energy management will clearly determine island future sustainable development.

The service sector, omitting the tourism activity, often represents a higher percentage of the economy than at continental level, just because certain services, as for example health care, has to be assured at island level, requiring a higher investment per capita than at continental level. This is not only applicable to public administration, but many infrastructure or equipment maintenance services.

When not based on tourism, island economies are mainly based on agriculture and fishery, actually facing serious structural problems in European context. Being these activities low energy consuming. Agriculture often has a higher impact on the energy demand when linked to islands water scarcity.

The increased relevance of primary and tertiary sector in the economy is due to the high restrictions the secondary sector²⁵ suffers. Industries development is very restricted to islands' limited resources, high infrastructure and transport costs, as to the limited markets in which companies can compete. As a result of these constraints the industry is rarely high energy consuming.

Historically, in order to protect islands economies certain tax releases or exclusive markets were established at national level. These measures have been released or relented in European Islands due to the World Trade Organization and European Union's requirements. Islands strategy for their integration "in European and global markets, should therefore go through

²² Secretariat ECSID (1997). European Island Agenda: Operational fields.

²³ In European Islands' specific case recycling is a must; given EU's waste minimization policy.

²⁴ Miranda, M.L., Hale, B. (Unpublished). *Paradise recovered: energy production and waste management in island environments*. Energy Policy, Article in Press (May 2004).

²⁵ The economic activities are frequently divided into three sectors: Primary sector (agriculture and fishery), Secondary sector (manufacture industry), and Tertiary sector (service industry).

preserving local identities and maintaining a balance between economic efficiency, social equity and environmental conservation”²⁶

Globalisation has not only had negative effects on islands: The information society is reducing islands’ isolation. It provides new business opportunities for intangible goods, which do not suffer under enhanced transport costs. Energy assurance is a must for such a society.

Cooperation among islands has been identified as the solution to many of their problems, especially in the Research and Development (R&D) field. “Diverse and complex island problems need an efficient transfer of information in order to learn about the solution of other islands and to share new, integrated approaches in all the different fields of island interest.”²⁷ Synergies among projects on different islands can be found. Cooperation will lead to optimise result, but also to produce technologies and processes in the proper scale for island’s needs. These developments, possible in all economic sectors, lead also to a diversification of the economy, reducing overall risk.²⁸ This is especially relevant in the energy sector, where the scale problems among several other problems can be addressed through renewable energy technologies.

Equilibrium between economic development and the carrying capacity of the islands, its infrastructures and services has to be achieved to prevent permanent environmental damage.²⁹ Integrated planning practises should therefore be promoted, stimulating intersectoral synergies and environmental management.³⁰

The energy sector, due to its strategic relevance as supporter of all economic activity, is one of the main areas on which policies should act to promote a sustainable society.³¹ When planning an appropriate energy system, pros and cons of the different alternatives have to be evaluated. Table 1-2 relates the advantages and disadvantages island have regarding their energy needs, as set by the European Island RES Agenda.³² As a result of these islands are ones more a unique laboratory, but now to research and develop feasible energy models with low environmental and increased social and local economic impacts. In their small independent grids islands small-scale renewable energy technologies represent rapidly a high percentage of the total energy production. Islands can serve as laboratories for combining RES, increasing their penetration in the energy market until reaching hundred percent renewable energy systems. Such 100% renewable energy islands represent a small-scale application of, what hopefully will be the future of all energy systems; they establish a learning process for further spreading of these technologies, at a cost-efficient way.

²⁶ Secretariat ECSID (1997). European Island Agenda: Introduction - Instruments for Sustainable Island Development, In *1^o European Conference on Sustainable Island Development*, 48-50.

²⁷ Secretariat ECSID (1997). European Island Agenda: Operational Fields.

²⁸ Secretariat ECSID (1997). Minorca Commitments, In *1^o European Conference on Sustainable Island Development*, Consell Insular de Menorca, INSULA, May 1997, 25-27.

²⁹ Secretariat ECSID (1997). European Island Agenda: Operational Fields.

³⁰ Secretariat ECSID (1997). Minorca Commitments.

³¹ Secretariat ECSID (1997). Minorca Commitments.

³² Island 2010 Initiative (1999). *European Island RES Agenda*. [Online] Available: <http://www.islandsonline.org/island2010/PDF/EI%20RES%20Agenda.pdf> [2004, June 04]

Table 1-2 Pros and Cons to consider when designing an islands energy system

“Strategies based on sustainable energies is not merely a technological, cultural or financial alternative, it is very probably the only rational choice we face”³³

Cons	Pros
<ul style="list-style-type: none"> ● Isolation and dependence <ul style="list-style-type: none"> ○ Extreme dependence on imported energy products, mostly accounting for over 15% of all island imports ○ Energy production is an extremely large item in GDP ● Limited range of conventional energy resources <ul style="list-style-type: none"> ○ Generally limited or none existent ○ No great variety in energy sources either <p>Leads to overexploitation or premature exhaustion</p> ● Specialisation of economies <p>Forces to install over-sized energy capacity to cover factors as:</p> <ul style="list-style-type: none"> ○ Prominent seasonal demand ○ Abrupt market changes ○ Greater territorial dispersion than normal <p>Especially in the case of significant tourism industry</p> ● Islands’ scale, a technological and market constraint <ul style="list-style-type: none"> ○ The efficiency of conventional energy systems, conceived and designed for other economies and areas, is seriously limited. The cost of generating electricity on small and medium size islands can be ten times bigger than in the mainland ○ Islands’ energy markets are unattractive and often public sector depending ● High sensitive environment <p>Enhance impacts of energy environmental problems, as islands have to reproduce all energy generation and storage infrastructure in a small area</p> ● Inefficient use of energy resources <ul style="list-style-type: none"> ○ Imported rigid mainland models of production and consumption patterns leads to very poorly final use adapted energy vectors ○ Imported modes of mobility and internal transport are usually extremely inefficient. ○ Strong presence of the service sector leads transport to account for more than 50% of the total energy consumption 	<ul style="list-style-type: none"> ● Abundant renewable energy sources <p>Most islands have excellent RES, often enough to guarantee ample energy self-sufficiency: Solar, wind, hydropower and ocean energies are extremely abundant sources of energy on all islands. Some islands have also excellent geothermic resources or biomass by-products</p> ● Small scale can be an advantage <ul style="list-style-type: none"> ○ Renewable energy technologies adapt much better to island scales and needs ○ Integration of renewable energy sources in most island cases is an economically feasible solution despite their relatively high energy-prices ○ Technological trend: Micro-generation as a guarantee of quality and service security, favouring islands’ position ● Island economic specialities are not very energy intensive <ul style="list-style-type: none"> ○ Hardly ever home of energy intensive economic activities ○ Increasingly moving into tertiary sector: Most demand goes to the service sector, transport and housing ● The great island renewable energy technology market <p>Actually larges niche market for renewables with the greatest relative growth and largest percentage in the energy balance</p> ● Growing acquisition of technology and availability of human resources <ul style="list-style-type: none"> ○ High capacity of islanders to learn the new energy technologies ○ Isolation has always generated an accentuated ability to find new solutions in an emergency ○ Human resources of islands represent one of their greatest future assets, as they have an exceptional creative capacity.

After Island 2010 Initiative (1999)

³³ Island 2010 Initiative (1999). *European Island RES Agenda*.

Constant research linked to the existing high collaboration and information exchange between projects on islands of various countries avoids parallel research as provides synergies among them.³⁴ They represent the perfect starting point to prove that 100% RES systems can work. Other islands will profit from the experience gathered in pioneer projects, as common factors will facilitate worldwide RES implementation. This opportunity also exists for isolated areas, which can be considered as islands in the continent. As a result of the learning process, actual renewable energies excessive cost in continental context will be reduced, allowing the further spreading of these technologies.

Islands have a good renewable energy potential.³⁵ Wind and solar energy are mostly high available resources. Hydro is highly available in some islands, but mostly totally non-existing. Biomass use implies a reduction of waste streams as the avoidance of green house gas emissions produced by natural decomposition processes, if biogas is, for example, produced from discard natural matter or captured in landfills. Biomass is also, due to the possibility of producing bio-fuel, nowadays the only suitable solution for transport. The further development of the hydrogen technology will allow RES diversification for transport activities and a chance to cover through RES the energy needs of the transport sector. Many islands have a volcanic origin, which is basis of their geothermal potential. Finally, ocean energy, as waves or tides, surely exist, but with high exploitation limitation at the actual technological development state.

Islands rarely have exploitable fossil fuel resources. Consequently, conventional energy production is based on highly costly fuel imports, with full dependency on it for transport and highly for heat and electricity production. The normally very limited industrial activity is as well highly dependent on fossil fuel. This dependency on fuel import means a remarkable, constant money stream leaving islands economy as well as it implies high supply insecurity. For European islands energy imports often represent more than 15% of all their imports.³⁶ It represents a constant money leakage, which could be avoided through further RES implementation.

European islands represent the biggest niche in the European renewable market, with the highest growth in its niche and representing Europeans highest quota of renewable in their energy balance.³⁷

Islands environment is one of the most affected by the climate change effects: sea level rising, increased climate variability and the climate change itself affects islands straight: reducing the territory, causing punctual disasters and, in the long-term, undermining the whole economic, social and environmental systems, which supports the islands population.

An island population would typically be very proud and conscience about their environment, as knowledge about its uniqueness. Regrettably, this knowledge isn't the same regarding the negative impacts of the actual energy production as the advantage RES could provide at several levels; economic, social and environmental level.

As searching for sustainability and stopping money leakage, the new system should be based on local knowledge. Building up this capacity provides high educational job, which islands normally lack of. During the last two decades several efforts from supranational organization, from governmental and non-governmental side, have been undertaken in order to build up

³⁴ Examples of such collaboration are organizations, programs and networks as: EU's Altener Programme, Euisles, Islenet, CPMR, Insula, FREI or Inforse.

³⁵ Forum for Energy and Development (2000). *Renewable Energy on Small Islands - Second Edition*.

³⁶ Island 2010 Initiative (1999). *European Island RES Agenda*.

³⁷ Island 2010 Initiative (1999). *European Island RES Agenda*.

this knowledge as the human and technical capacity to achieve the effective RES implementation.³⁸ As a result of it, a high local political concern and determination to further implement RES exists.

Additional problems as local air pollution, risk of environmental disasters directly related to fossil fuels transport and storage, waste management, etc., can be solved through increasing the use of RES.

Islands electricity demand is mostly very variable. Additionally to the ordinary fluctuation during the day, working and not-working days, a considerable seasonal fluctuation due to the variations in the tourism activity mainly exists. As the electricity systems are mostly independent, small grids, the existing scale economies for conventional electricity generation technologies cannot be exploited. Subsequently, the technologies in place entail high infrastructure³⁹ and production costs. The adaptation of the system to growing demands is, therefore, also very expensive. Consequently, actual island energy systems are very rigid and costly. RES aren't cheap either, but as mostly small-scale technologies, they introduce flexibility to the system, not only at technical level, as meant above but, also at economic level. Generally, as benefits could rarely be made on island energy systems, the energy generation companies established on the islands were under public support or even public owned. Even though measures to increase competitiveness in the European energy market have been introduced, due to islands scale a natural monopoly has been created for the established companies. Nowadays, an opportunity to break this monopoly exists, if new generators take the chance to implement small-scale technologies to cover the growing demand. In this context and considering the European support to RES, renewable energy technologies are being the one chosen by the new energy generators. Established companies, aware of this risk, can act against further RES development, by using the power and influences they nowadays have, or can work with the unavoidable trend, promoting themselves RES system with big investments to control a high quota of the renewable energy market and thereby keep their actual position in the electricity market.

In summary, energy self-sufficiency based on RES is required to avoid money leakage from region, assure supply and avoid outside dependency, to create better job opportunities, promote local research and development, to protect the local environment as to comply with international agreements and, at the end, to achieve a sustainable island community.

In order to be energy self-sufficient, a holistic approach is required; a case specific combination of RES has to be established. Politicians and researchers play therefore a crucial role in the design of an efficient system. Once designed, investors and implementation supporting policies play the key role in building up the system. Energy efficiency measures, as rational energy consumption requires the island inhabitants' participation.

Acknowledging all these, several has been the islands world wide that have committed themselves to achieve a 100% renewable energy system: La Dominica, La Maddalena in Italy; Samsøe and Arosøe in Denmark; Pellworm in Germany; Gotland in Sweden, El Hierro in Spain; Flores in Portugal among others. There are also lots more with high RES penetration, which will sooner or later follow the previous ones example.

³⁸ Medina Warmburg, B. (unpublished-2004) "Renewable Energy Sources on Islands: Assistance Partnership and Networking – Capability Building?" Assignment for the ARPEA II course, Master of Science in Environment Management and Policy, IIIIEE, Lund University.

³⁹ "Infrastructure costs such as energy are up till three to four times higher than on the mainland." Forum for Energy and Development (2000). *Renewable Energy on Small Islands - Second Edition*.

1.2 Research objective

The objective of this research is to evaluate if 100% renewable electricity systems are feasible based on the experience being done in two European islands' with different RES potentials and 100% RES commitment. For such a system to be sustainable, a proper renewable energy potential to cover the actual and future demand is required. Profitability⁴⁰ in the exploitation of renewable energy sources is also a must. Market conditions surrounding the electricity needs are therefore to be studied. Substantial benefits of renewable energy uses are ignored in a traditional business environment, as these benefits are allocated on the society and/ or the natural environment. As a consequence, the personal commitment of the different the actors, involved in the energy market, towards the society and environment gain in importance; as leaders or barriers of change.

As such the research questions could be stated as follows:

Can the 100%RES electricity system be considered sustainable, given the renewable electricity potential as the foreseeable technical and electricity demand evolutions/deveolpment?

Which are or could be the driving forces of the change?

Which are the existing risks of failure?

How can other islands profit from these experiences?

Summarising:

Are 100% Renewable Electricity Systems on Islands feasible in European context?

To answer these questions a basic understanding of the technical requirements for such a system to work is needed. In this sense an overview of the existing renewable energy sources and exploitation technologies for electricity generation has to be undertaken. As the electricity produced by these media should cover the electricity demand, a view into the demand formation has also been done. Factors influencing the demand, electricity uses and consumer groups, as measures to control or manage their evolution will thereby be addressed. Key factors for a proper sustainable electricity supply are a proper combination of RES and energy storage systems. The highly stochastic behaviour of many RES results in an uncertain production, which doesn't match in time with the demand requirements; subsequently energy storage systems gain relevance in such a system. Therefore, a study about their characteristics as solution to reduce risk of blackouts and guarantee energy supply has to be undertaken.

The ultimate objective is to look into the market elements: demand, supply and market conditions as a main driver of change into the future system. As such economic and political tools used to promoted renewable energies will be identified and analysed regarding its results.

When looking into the long-term feasibility of such a system, the most important factor becomes the possible future development of the actual electricity demand, as the improvement in converting the RES potential into technical potential. These considerations will be taken into account while looking upon the behaviour of the energy demands of El Hierro (Canary Island, Spain) and Flores (Azores, Portugal). The RES potential and future supply possibilities will have to support a sustainable system.

Without economic benefits, no change into a new system will occur. Therefore the actual electricity market will be studied, as a main mechanism of change. Considering the actual

⁴⁰ Profitability in this context means that the company will not go on losses; that at least a normal return on investment is obtained; that the capital investors of the company will get a risk linked return on their investment.

electricity market rules and actors as the renewable energy potential a future electricity market can be foreseen.

Benefits and cost of the planned or expected systems will be identified and if possible quantified. Additional benefits have to be considered, there for a glance into possible social and environmental benefits of the new system will also be done: Inter alia, the avoided environmental impact of the current energy generation technologies, as the ones generated by the new ones, job opportunities, self-reliance, collaboration schemes, research and development.

In the process also barriers, solved or not during the project progress, as the solutions for its avoidance, as far as they have been relevant in the projects will be identified. Such barriers could be: Capacity building needs consequence of the lack of technical and/ or managerial skills; problems to gather the required initial investment, problems related to the existing political structure, the decision taken process, the positioning of actual energy market actors and the existence of political corruption; lack of maintenance services or customers trust in technology.

1.3 Scope

First, when talking about energy, the focus has been put on the electricity generation, specifically on electricity generation fed into grid. Other energy productions, as heat production, have only been considered as a strategy to reduce electricity requirements from the grid. This is due to the significant constrains islands impose on the already complex electricity systems and markets, with its specific actors and regulations. Energy uses for transport needs would only add additional complexity, with different regulations and actors. It builds an additional subsystem within the energy system, which should only have a positive impact on the other subsystem of the electricity generation, as synergies appear in common supply chain actors.

In the same sense, a more thoroughly discussion about waste as energy source has been avoided, as implies analysing the whole waste problematic, its economic and technical feasibility at island scale as the limitations local, national and supranational regulations establishes on its use. Ultimately, the electricity system is just a part of the whole island system and its interaction with other systems will always lead to synergies, where negative ones should be avoided and positive ones should be excelled. If further synergies have been identified, they just have been accounted.

Second, when talking about renewable energy technologies, only modern renewable energy technologies are meant. For example, technologies fed with solid biomass will only be considered in the term it is used to produce electricity or biofuel/ biogas, which could than be use to generate electricity. Traditional use of biomass for cooking and heating is, therefore, excluded.

Third, islands are defined as land mass smaller than a continent, surrounded by water⁴¹. This definition would include at European Level, big land areas as Great Britain and Ireland. Therefore, and in order to apply special policies to island regions the European Parliament defines them as “segment of a Member State which is entirely surrounded by sea, has no physical links to the mainland and is not the seat of the capital city of any European Union country”⁴²

⁴¹ Forum for Energy and Development (2000) *Renewable Energy on Small Islands - Second Edition*.

⁴² European Union (EU) (1998). *Resolution on the problems of island regions of the European Union, A4-0118/98, 28/5/98*. Quoted in Hache, J.D. (2000). *The European islands and their governance: from the nation states to the European Union*.

There are more than 500 inhabited islands in the European continent⁴³, to which the conclusions of this work could apply. Two are the European islands being studied:

- Flores, Azores Archipelago, belonging to Portugal
- El Hierro, Canary Islands Archipelago, belonging to Spain

Both islands suffer of two aggravating island factors, which could limit the extrapolation of the results:

- Dual insularity, as small islands belonging to an archipelago. These results among others in higher costs than on the main islands, difficult or even lacking access to certain services, and distance and isolation of the regional decision makers.
- European Union outermost or ultra-peripheral region, which means that:⁴⁴
 - “They are located well beyond the geographical confines of Europe, and are either totally isolated in the Atlantic Ocean, or close to the shores of Africa and America
 - They have distinct tropical climate, specific agricultural productions
 - They are prone to natural disasters such as cyclones or volcanic eruptions
 - Their immediate neighbours are less developed countries with whom they cannot compete in term of man-power costs and with whom they have very little trading links”

The latest has been taken into account in the European Union Treaty, where its article 299, 2 says: “The provision of this Treaty shall apply to the French overseas departments, the Azores, Madeira and the Canary Islands. However, taking account of the structural social and economic situation of the French overseas departments, the Azores, Madeira and the Canary Islands, which is compounded by their remoteness, insularity, small size, difficult topography and climate, economic dependence on a few products, the permanence and combination of which severely restrain their development, the Council, acting by a qualified majority on a proposal from the Commission and after consulting the European Parliament, shall adopt specific measures aimed, in particular, at laying down the conditions of application of the present Treaty to those regions, including common policies.”

In this context, EU Clear Energy Policy Targets affect both islands. They contribute to European commitment to the Kyoto protocol, to increase substantially the share of renewable energy, improving energy efficiency and assuring energy supply.⁴⁵ EU’s Action Plan has affected them especially through support measures to RES and the Take-off Campaign.

1.4 Methodology

This thesis is based on a literature review, carried out to sustain the required general knowledge in the field. As the renewable energies, especially its high penetration in the energy sector has been a development of the last decades, mostly papers and conference proceedings underlay this study.

⁴³ Triay Humbert, C., (1997) Opening Speeches: President of the Minorca Island Council, In *1^o European Conference on Sustainable Island Development*.

⁴⁴ Hache, J.D. (2000). *The European Islands and their Governance: From The Nation States to The European Union*.

⁴⁵ Commission Communication Com (97) 599 final *Energy for the Future: Renewable Sources of Energy - White Paper for a Community Strategy and Action Plan*

Chapter 2: Electricity demand and renewable energy sources, represents an introduction to the electricity demand and supply problematic, basis for analysing the case studies circumstances.

The issues addressed in this chapter, as several issues addressed in Chapter 3, concluded in the questions carried out within the interviews and email exchanges of the case studies research.

Chapter 3: Energy storage: Matching demand and supply, represents the need of understanding which technical alternatives exist within matching supply and demand, as basic requirement to allow than market forces to match demand and supply in an economic way. Without assuring the technical stability of the system, market issues will have no relevance.

Regarding both case studies, several interviews had been undertaken: face-to-face interviews, telephone interviews and email queries. As a consequence of these contacts also further documentation was obtained, analysed and included in the study.

Energy consumption and productions statistical series has been processed, in order to analyse their past-trends, as to foresee their future evolutions. Also other statistical data has been handled in order to support statements or provide a better understanding of the observed situation.

In order to analyse the case studies particular market circumstances an understanding of the Portuguese and Spanish electricity market and RES promotion system was required. Information regarding these issues was obtained on one hand from the interviewed persons, but mostly from the institutional pages of the market actors and from the laws ruling the markets.

Also policy issues at local and regional level were addressed in the interviews, especially the RES promotion actions undertaken at these levels. The influence national and supranational policies have had or are expected to have in the implementation of these projects where as well addressed.

Once analysed the case studies regarding its demand, supply, market circumstances and companies structure, two possible, but antagonistic future market scenarios were identified and analysed.

Statistical energy data has been obtained from:

- Regarding El Hierro Island case study:
 - Consejería de Industria del Gobierno de Canarias
[Industry Department of the Canary Islands' Regional Government]
 - Instituto de Estadística de Canarias
[ISTAC – Canary Islands Statistic Institute]
 - Instituto Nacional de Estadística
[INE – Spain's National Statistic Institute]
 - Instituto para la Diversificación y Ahorro de la Energía
[IDEA – Spain's Institute for the Energy Diversification and Saving]
 - Instituto Tecnológico de Canarias
[ITC – Canary Islands Technical Institute]
- Regarding Flores case study
 - Electricidade Dos Açores
[EDA - Energy of the Azores – Azores Regional Energy Company]

- Instituto Nacional de Estatística
[INE - Portugal's National Statistical Institute]
- Serviço Regional de Estatística dos Açores
[SREA – Azores Regional Statistical Service]

Interviews regarding El Hierro case were hold with:

- Cabildo de El Hierro [El Hierro Island Governance]
 - César Espinosa Padrón
Technician of the Planning Area
- Instituto Tecnológico de Canarias [ITC-Canary Islands Technological Institute]
 - Gonzalo Piernavieja Izquierdo
Director of the Energy, Water and Bioengineering Division
 - Julieta C. Schallenberg Rodríguez
Project Manager of the 100%RES: El Hierro Project
- Unión Eléctrica de Canarias⁴⁶
[UNELCO, Canary Islands Electricity Company]
 - Juan Luis Padrón
Director of UNELCO-El Hierro

Regarding Flores Island several interviews were hold with

- Empresa de Electricidade e Gáz -EDA⁴⁷ [EEG-Gas and Electricity Company]
 - David Luis Remalhinho Estrela
Executive Manager of EEG

Several difficulties have been found related to the contacted Portuguese organizations apart from Electricidade Dos Açores [EDA- Azores Electricity]. Even when the e-mails were translated to Portuguese, rare responds were obtained, and if so, they referred to EDA as the actor to be contacted. As result, and given the brief information available on the organizations websites, not much can be said about the effects of regional policies or energy agencies actions regarding renewable energies are having. Such actions surely exist, but can not be evaluated with the available information.

In general, there has been certain difficulty to obtain certain data. On one hand, because these data were considered strategically important for the addressed actor and therefore confidential; on the other hand, because the volume or format these data were available, didn't allow them to be processed by actual existing statistical tools, as stated by the one or the other addressed actors. As result the peak load data of one of the Island is missing and no daily electricity consumption distribution and evolution, as their distribution by consumer type could be analysed. Some of these data could be found in the Statistical Institutes web sides, but only at archipelago level, being not representative for the island's electricity market. In the way it was

⁴⁶ See appendix 6.1

⁴⁷ See appendix 6.2

possible, through information obtained from the personal contacts, in certain cases, an approximation could be obtained and than analysed.

2 Electricity Demand and Renewable Energy Supply

2.1 Introduction

When planning a sustainable and reliable 100% renewable electricity system for a limited, isolated areas, as an islands, certain questions should initially be done:

- Which is the actual and future expected exploitation potential of the different renewable energy sources available on the island?
- Can these potential cover the demand? How is the demand going to develop? Which measures can be taken to manage its development?
- Which should be the priorities when defining the road to a 100% system? CO₂ avoidance, supply reliance, regional development? Social benefit maximization should be the overall goal.
- And finally, how and by whom is the system going to be implemented? Which policy measures could path the way to the future system? Who are the actors to be involved in the process? Which functions should each of them take over? How and by whom will the reliability of the final system be assured?

Obviously, the answers to these questions are site specific and fully dependent on the resulting exploitable combination. As such, a 100% renewable electricity system on an island will always be unique.

This chapter aims to give a general overview of the characteristics of the electricity demand and of the different RES, which limit or enhance their use in the proper combination for the future systems, when considering islands specific characteristics. As many of the modern renewable energy technologies are still in development, a long-term strategy should to be developed. 100% RES plans should not define the exact percentage energy that will be covered by a specific RES, but measures and actions to increase RES implementation, as to assure the final system to work. When electricity production from RES is to be fed into the grid, special control systems must be developed and implemented in order to control the different electricity incomes with their different characteristics and temporalities. This control system aims, among others, to minimize the risk of blackouts and stabilize the voltage in the distribution system.

All these specific requirements of the future electricity system call for R&D. Collaboration among different actors, such as universities, research centres, energy companies and regional authorities, providing additional benefits at the same time it assures an effective future electricity system. Also interregional collaboration can help: “Renewable sources of energy such as solar, wind, biomass and wave power offer some hope in the long-term, especially if islands work together to develop technologies that are tailored to their unique requirements.”⁴⁸

One main actor in the change to RES should be the energy user. Its decision about how to cover certain needs through energy and the choice about the energy conversion technologies and the energy carrier to be used will define the future electricity demand. Paragraph 2.2 will focus on the electricity demand, the user and their needs. Paragraph 2.3 will focus on renewable energy technologies. Initially all kind of renewable technologies are meant, to later

⁴⁸ Monterio Alves, L.M., Lopes Costa, A., Carvalho, M.d.G., (2000) *Análisis of the potential for market penetration of renewable energy technologies in peripheral islands*. Renewable Energy,19, 311-317.

on focus on renewable energy technologies for grid connected electricity production. From the last, technical, economic and environmental aspect which can favour or limit one RES from another will be briefly addressed, to, finally, take a glance into policy measures and economic data related to renewable electricity production.

2.2 Electricity demand

To foresee trustfully the evolution of the actual electricity demand, a better understanding of the uses end-consumers have for electricity is required.

2.2.1 Energy carriers and energy services

An energy carrier is the medium through which energy is transmitted. The energy can be stored chemically in a gaseous, liquid or solid medium.⁴⁹ It allows to “move and deliver energy in a usable form to consumers”⁵⁰, which thanks to technical applications can then cover its needs. The needs satisfied through these applications are known as energy services. The specific appliance by the consumer of this energy to a cover a certain need is known as energy use. Energy sources, naturally occurring form of energy, could be seen as an energy carrier, but generally, only the by human actions processed materials are considered energy carrier.⁵¹

Electricity is a very suitable energy carrier, which provides all kind of energy services, but is not the only one, as Table 2-1 shows. The consumer’s decision regarding which energy carrier or energy source should provide him with the requested energy service depends on the convenience and the cost of the different energy carriers/source and its transformation technologies. The outstanding convenience of electricity, regarding other energy carriers, relies mainly on its flexibility for changing its final use, the reliability when connected to a stable grid and its clean conversion technologies.⁵² The production cost of electricity can vary a lot depending on its generation technology, but mostly because certain cost, as for example, environmental and health problem of certain generation options are not being considered by the market prices. These other impacts of the electricity generation are often not considered by the end-user when taken their decision.

The public recognition of the negative impact certain energy sources and technologies have, as their associated cost can lead to change the consumers appreciation regarding the different available options, causing a change of the consumers behaviour.

Table 2-1 Energy carriers providing directly energy services

Energy carrier (Energy source)	Energy Services
Electricity	Warm water, comfortable living conditions through heating or cooling, cooking, light and numberless services provided by the large variety of existing electric application, services provided by mechanical motion

⁴⁹ General Motors Corporation (2005). [Online]. Available: http://www.gm.com/company/gmability/enviroment/products/fuel_cells/glossary/energy_carrier.html [2005, 29 January]

⁵⁰ United States National Renewable Energy Laboratory (2005). [Online]. Available: http://www.nrel.gov/clean_energy/hydrogen.htm [2005, 29 January]

⁵¹ Consumer Energy Council of America (2005). [Online]. Available: <http://www.cecarf.org/Programs/Fuels/SourcesCarriers.html> [2005, 29 January]

⁵² United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council (2000). Energy and the challenge of sustainability. World Energy Assessment. Washington D.C.: Communications Development Incorporated.

	applications
Steam – high temperature	Space warming, warm water, services provided by mechanical motion applications
Steam - low temperature	Space warming, warm water
Fuel (fossil, hydrogen, biomass)	Warm water, comfortable living conditions through heating or cooling, cooking, light and numberless services provided by the large variety of existing electric application, services provided by mechanical motion applications
(Wind)	Services provided by mechanical motion applications
(Geothermal radiation)	Space warming, warm water
(Water motion – Wave, tidal)	Services provided by mechanical motion applications
(Solar radiation)	Space warming, warm water

Increasing interest has been put on hydrogen as energy carrier linked to fuel cells as its conversion technology. A reduction of the fossil fuel dependency or at least an achievement a significant CO₂ emission reduction has led to research and development of this alternative. As the use of hydrogen as energy carrier, linked to renewable energy electricity generation, is related to energy storage alternatives, it will be discussed thoroughly in the following chapter, under the paragraph on hydrogen-fuel cell energy storage system.

2.2.2 Users and uses⁵³

The users of electricity are often divided into three categories:

- Domestic sector: referring households and their consumption to cover their needs for comfort and living.
- Service sector: referring intangible goods, which during its production or distribution require energy services as lighting, heating, and electric applications or transport.
- Industrial sector: referring to the production of tangible goods, which require a processing of raw materials.

Obviously, there are other consumer groups as the agriculture sector or the public sector, with specific characteristics. The agriculture sector, representing in developed countries a decreased proportion of the GDP, is mostly not very electricity consuming. In this context, the agriculture sector has lately become less and less relevant regarding the electricity demand. This tendency seems to continue in the future given the development of self-supply based on biofuel and biogas within the sector.

The public sector includes activities that could be classified under industry, but mostly services. They are provided with a sense of service to the society, paid directly by the consumer of the service or indirectly through taxes. In this sense, the development of the electricity demand of this sector is totally linked to the presence of public administration on the island and its expected development. Considering islands' isolation, in order to assure a certain living standard, public administration could represent a higher proportion per

⁵³ Ter-Gazarian, A. (1994). *Energy storage for power systems*. London: Peter Peregrinus

inhabitant than on at continental context. The need of certain medical infrastructure, as a hospital, is an example. Consequently, public administration will also represent a higher share of the total electricity demand.

One specific energy service, public lighting, is often accounted separated to the remaining public service consumption. It represents generally a significant percentage of the total public electricity consumption on which lighting energy saving measures can easily be implemented with a significant result.

Going back to the main categories of energy users, Table 2-2, list the main energy uses of each category. For all of them electricity can be used, but for certain uses other alternatives exists. As it can be observed, the services covered by energy for the domestic and services sector are the same. It is mainly the timing, which differentiates them. The service sector has its main consumption on working days and working hours; contrary, the peak consumption of the domestic sector lies during the late afternoon of weekdays, and has its own particular behaviour during weekends.

The pattern of the service sector can vary significantly when tourism represents a high proportion. This sub-sector doesn't show any similarity to the previously mentioned consumptions; as such, if it is a significant part of a specific island economy special attention should be given to its study.

Table 2-2 Energy users and energy uses

Users	Energy use
Domestic sector	Space heating and/ or cooling, water heating, cooking, lighting, electrical appliances
Service sector	Space heating and/ or cooling, water heating, cooking, lighting, electrical appliance and equipments.
Industrial sector	Space heating and/ or cooling, water heating, cooking, lighting, electrical appliance and equipments, process heat (often high temperature), motive power

After Boyle (1996)

As established in chapter 1, the industrial sector rarely represents a major role in island economies due to their strongly limited and/ or sensible natural resources. This could lead to disregard the study of its electricity demand, even more, when considering the high share of the industrial activity energy generation represents itself. Contrary, its study gains in relevance as these industrial activities are highly relevant for the society, representing often a fundamental supply for the remaining sectors. The strategic relevance of the sector calls for a special attention when meeting its energy needs. The expected future development of one or another activity within the sector can have a significant impact on the development needs of the electricity system. Water desalination industry serves as an example: Considering islands often increasing problem of water scarcity, the high energy consuming solution of water desalination could increase significantly the electricity requirements of an island. Technical or economic aspects of the desalination activity will then influence the behaviour of the electricity demand. Briefly, the different activities represented in the industrial sector should be analysed, considering its future development, in order to assure its performance and, consequently, the society well being.

A way to influence the electricity consumption of industry and households has been the development of specific demand management tools. These tools can act through market

forces, through the economic behaviour of the consumers: Tariff setting taking into account the different consumers and their particular electricity needs, as establishing reduced electricity prices to increase the consumption during low demand periods and vice versa, leads the economic rational consumer to adapt its consumption pattern. This kind of tools have less the impact on the service sector, for which energy consumption represents a low percentage of the total service production cost and where the service has to be produced when consumed, when requested by the consumer.

Technical applications have been also designed. Remote switch off of certain electrical applications as heating units can, for example, be used when the demand increases beyond a certain level. Blackout risks are thereby reduced.

Certain needs vary throughout the year. Lighting needs increases in the wintertime. Space heating and cooling needs are also seasonal conditioned. Nothing to say about the impact of tourism activities, holidays periods or enhanced consumption periods, as Christmas can have on the service sector. Electricity demand's strong seasonal conditions will force to oversize the whole electricity generation system.

2.2.3 Energy savings and its impact on the electricity demand

Countless actions can be done to reduce energy needs: On the consumer side and distribution system, but also through reducing the dependency on electricity from the grid, which also leads to energy efficiency gains. The latest will be addressed in the point 2.3.

Energy savings can be won through technical improvements as through behaviour change of end-consumers. Table 2-2 list a number of technical energy saving measures, applicable to the different sectors. The energy savings gains by each one of these measures can be seen as meaningless, but all together, for each measure and all existing consumer, it leads to a more than significant energy consumption reduction. As acknowledged in United Nations' World Energy Assessment's "Energy and the challenge of sustainability" 25 to 35% of primary energy consumption can cost-efficiently be reduced in industrialised countries over the next 20 year. Most of these gains can be achieved thanks to energy saving measures in the consumption side.

Table 2-3 Energy saving measures applicable by the different energy users

Users	Energy saving measures
Domestic sector	Improved isolation/ Passive solar design-modern house design, heat recovery from exhaust gases, low consumption light bulbs, energy efficient household equipment
Service sector	Insulation, draught proofing, control measures (use when needed: turn of lights control of heating cooling systems), bulbs and lamps, energy efficient equipments, daylight use/spot and task lighting
Industrial sector	Energy recovery through out the process, redesign of the process, more efficient machinery, drives and controls, more careful use of energy intensive materials, shortened of process routes, yield improvement, technical changes to raise process efficiencies, greater use of integrated energy technologies, heat recovery schemes

After Boyle (1996)

Technical possibility will not lead to energy savings with out behaviour change of consumers. More long time thinking has to be achieved. Long-time economic benefits of energy saving measures have to prevail to short-time economic savings.

Additional energy saving measures are directly linked to behaviour change. Small custom changes, as switching of lamps or electronic devices when not in use can have a big impact, but are difficult to obtain. Awareness is, in any case, the first step to go.

2.3 Renewable energy

Renewable energy is “energy obtained from resources that are regenerative or for all practical purposes cannot be depleted.”⁵⁴

Three are the main sources for this energy

- Solar radiation, transformed into solar, wind, waves, hydro and biomass energy
- Gravitational forces, transformed into tidal energy, and
- Earth core’s radioactive activity, providing geothermal energy.⁵⁵

All of them can, in a more or less efficient economical and technological way, provide energy to cover human needs.

Based on the specific primary energy sources used the actually existing and in development renewable technologies can be classified as follow:⁵⁶

- Wind energy

Solar energy produces temperature differences on atmosphere and earth/ water surfaces which produces air currents, known as wind. This wind can be used to move blades, transforming its kinetic energy into mechanical energy, which can then be use either directly or transformed into electrical energy through a generator.

- Hydro energy

- Terrestrial hydro energy

Solar energy evaporates water, which can fall through rainfall on the ground forming water flows which can be captured. When captured in a height, the water contains potential kinetic energy which can be transformed into mechanical energy, when released through turbines. This energy can then be used directly or transformed into electricity through a generator.

- Ocean energy

- Tidal energy

Gravitational forces between moon and earth produce movements of the ocean’s water masses. This energy can be used by capturing water in high tides and releasing it through turbines when low tide. The mechanical energy can than be used directly or to generate electricity.

⁵⁴ Windustry (2000) [Online] Available: www.windustry.com/resources/glossary.htm [2004, September 21]

⁵⁵ Based on Boyle, G. (1996). *Renewable Energy: Power for a Sustainable Future*. Oxford: Oxford University Press.

⁵⁶ For this paragraph Boyle, G. (2004). *Renewable Energy: Power for a Sustainable Future*. Oxford: Oxford University Press.

- Waves energy

The energy released through the waves is used directly to move turbines or captured by buoys. Mechanical energy is thereby obtained, which connected to generator can then produce electricity.

- From marine currents

Solar radiation has a thermal effect on the oceans and atmosphere. Marine currents are the equivalent to wind, but in the sea. The energy contained in strong marine currents can be used to move underwater turbines, to capture this kinetic energy to transform it into mechanical energy, which can then be further transformed into electricity.

- Solar

- Photovoltaic (PV)

Solar radiation is converted directly into electrical energy, thanks to a photovoltaic panel. Thanks to the semiconducting behaviour of some materials, the additional, by the sun transferred, energy forces free electrons of a positive semiconductor to move toward a negative semiconductor, as attracted by its negative charge. In this process the electrons are guided out of the solid matter, creating an electrical current.

- Thermal solar

Solar radiation is captured by collector panel through which a liquid is being pumped through. In this process heat is transferred from the absorber plate to the inflowing liquid. For hot water or heating purposes the out coming hot liquid is stored in a tank until it is required. A heat exchanger in the bottom of the tank provides then the requested service. For electrical purposes, as higher temperatures must be achieved, the solar radiation must be first concentrated. Once steam is achieved, steam turbines provide the mechanical energy which can be converted into electricity through generators.

- Geothermal

In a closed system a fluid is pumped into a hole drilled in the ground. The higher subsoil temperature heats the liquid from which, when coming up, the heat is extracted through a heat exchange. High enthalpy⁵⁷ steam allows generating electricity through steam-turbines and generators. Warm water services can be covered by low-enthalpy reservoirs.

- Biomass

The technology used to transform the energy stored in the chemical compounds of the biomass into useful energy is mainly the same used for fossil fuel, coal or natural gas. All the more, many of these technologies have its origin in the biomass application.

⁵⁷ "Heat content of a substance per unit mass; function of pressure, volume and temperature." "high enthalpy: 180-200°C steam temperature, medium enthalpy: 100-180°C, low enthalpy: <100°C" Boyle, G. (2004).

Basically, the energy is released through combustion; the heat released can be used directly or/and transformed into mechanical energy through turbines, which can then be transformed into electricity through a generator. Otherwise, gas can be obtained via different methods and feed into an engine which transforms the energy within the compounds directly into mechanical energy.

- Solid biomass

Solid organic matter is used directly, without change of its chemical form, to obtain the energy within its compounds.

- Biofuel/biogas

Through decomposing processes and/or certain bacteria and/or chemical processing the organic matter is transformed into a fuel or gas.

Waste streams of our society are also often considered as renewable energy source. There is an ongoing discussion about if it should be considered as such or not. Comments in this chapter about waste as energy source are not meant to express any point of view on this discussion, but intent to reflect a full image of the actual technical possibilities as the economic consequences of these available options. Regarding the energy transformation processes the same to the biomass case applies.

The above given explanations are obviously very simplified and only try to illustrate the logic behind the harvest of the different renewable energy sources. As some technologies are still in an experimental phase, as the ocean energy applications, some overlapping between energy conversion processes and energy source could exist. It also is for sure that certain technologies are not reflected in this classification, which only focuses on the main tendencies in each field.

A relevant aspect to take into account is that when transforming primary energy into electric energy, while passing through different energy forms, as the second law of thermodynamics posits, energy is “lost”. Each transformation implies a conversion of part of the energy into not useful energy. For this reason a strait use of previous energy forms to electricity to cover some energy services linked to motion or heating results in higher energy efficiency.

One of the biggest constrains for 100% renewable electricity systems on islands is the ephemeral nature of many renewable energy sources. The energy supply of some of these sources can vary substantially through out the seasons, through out the days, even from one moment to the other. Figure 4-2 represents the rank of reliability of the different renewable energy sources.

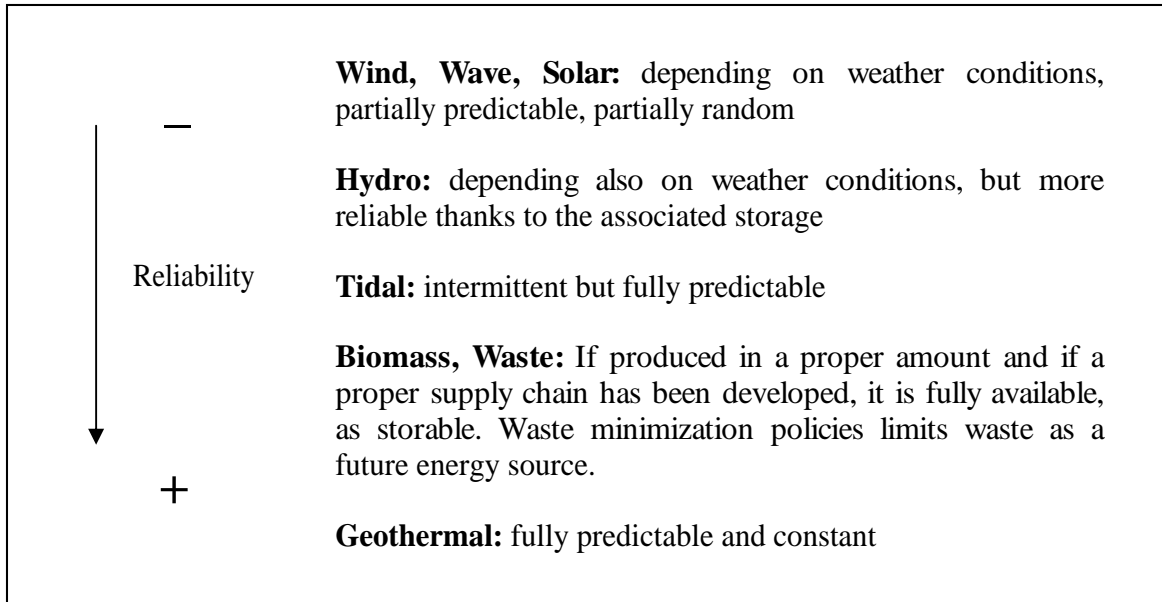


Figure 2-1 Renewable energy sources and its reliability as energy source

After United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council (2000) and Anderson, Leach (2004)

A 100% renewable electricity system will therefore need to be based on a mixture of RES providing a highly reliable electricity generation. This will most of the times require investing in an oversized supply system.

Regarding the selection of the proper RES combination, following aspects should be considered, in order to reduce the volatility in the electricity generation:⁵⁸

- Diversity in generation types and locations: With a broader number of renewable energy sources supplying electricity, the probability of a significant supply reduction diminishes. Thanks to the variety of microclimates generally existing on islands, diversification of locations for energy sources as wind and solar diminish also this probability. A more constant outcome is thereby assured.
- Correlation of output and demand: The availability of the different renewable energy sources and the electricity demand through out the time should be studied. This allows taking advantage of positive correlations between generation and consumption, as avoiding negative ones. For example, if the demand increases during the wintertime and wind availability also increases, but solar radiation reduces drastically during this period, wind energy should be preferred to solar energy.
- Minimize prediction errors: In order to assure the supply and to manage the system properly, accuracy of the prediction methods should be excelled. A special effort has to be done to develop models for predicting the demand, as the output of every one of the renewable energy sources. These efforts should be especially focus in increasing the accuracy of the more unpredictable renewable energy sources, to allow proper backup by manageable renewable energy sources, as hydro and biomass, or, alternatively, by available storage systems.

$$\text{Min } \sqrt{\text{error in predicting demand}^2 + \text{error in predicting variable output}^2} \quad 59$$

⁵⁸ Adapted to islands constrains from Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*. Energy Policy, 32, 1603-1614.

In a medium-term, if the island system is not connected to a major grid, it is highly probable that the backup system will continue to be provided by diesel engines fed with fossil fuel. As know-how, control systems and renewable shares has to be build up, conventional, quick responding small electricity generation equipments must be still in place. Nonetheless, this should be seen as a step in the path to a 100% RES system: “Non-renewable energy sources must be considered as provisional solutions, unsuitable as a long-term solution to the energy problem in islands”⁶⁰ As such, the final solution for this problem relies on a proper energy storage system, which obviously implies additional investments cost. “At high level of market penetration (of RES) the effects are more pronounced (intermittency) and some form of backup or storage becomes a technological and economic necessity.”⁶¹ Energy storage systems applicable to renewable energy storage will be addressed in the following chapter.

Several renewable energy technologies provide the opportunity to exploit renewable energy sources to produce electricity. This electricity can be consumed by the same producer or fed into the grid. Other renewable energy technologies provide with other energy carrier, which can produce directly the required energy services, reducing the consumer’s grid dependency, at the same time higher energy efficiency is achieved. This will be discussed in the following paragraphs.

2.3.1 Impact of renewable energy technologies on the electricity demand

One of the major opportunities renewable energy technologies are providing is the increased availability of small-scale production units, which allows a decentralization of the energy production. Energy losses in the distribution system are in this manner avoided. Many of these technologies reduce substantially the links between energy source and energy service, providing higher energy efficient services. This is the argument for promoting certain applications to be installed where the service is to be consumed. Table 2-4 list some of these applications.

Table 2-4 Renewable energy technologies for electricity dependency reduction.

Transformation Technology	Renewable Energy Source Origin (Energy Carrier)	Energy Service
Heat pump	Subsoil, Groundwater aquifers, Sea (Fluid)	Cooling or heating, warm water
Solar Thermal panel	Solar (Fluid)	Heating, warm water
Solar PV panel	Solar (Electricity)	All electricity based energy services
Wind Turbines	Wind (Electricity)	All electricity based energy services
Solar PV Lighting	Solar (Electricity)	Lighting
Biomass Boilers	Biomass (Fluid)	Heating, warm water

⁵⁹ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen.*

⁶⁰ Secretariat ECSID (1997). European Island Agenda.

⁶¹ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen.*

The industrial sector is the sector where a broader number of technologies can be applied. Self-reliance in this sector is not new, but can now, thanks to smaller scale and/ or cleaner energy production of the renewable energy technologies, can be expanded. The intermittency of the renewable energy production can be covered by grid connection or through energy storage. As companies can foresee much better their energy requirements for each moment, self-supply reduces significantly the adverse effects of certain industrial activities have on the electricity demand. For certain processing companies an additional advantage can emerge: Depending on the technology chosen to cover their energy needs and their processing residues, the lasts can be use to recover energy, while minimising their waste streams.

Regarding the service sector much can be done. The initial investments required are easier to be gathered by a business than by a private household. The benefits obtained by the investment are higher as the energy services could be required around the clock, which doesn't happened for households, where these services are mostly only required during evenings and early morning hours. An additional benefit can be also achieved, not easily quantified, but existing: Image. Image, won thanks to environmental friendly corporal behaviour, can become even a competitive advantage when looking upon activities such as tourism and considering aware customer groups.

Taken into account the increased benefits of RES implementation for industrial and service sector, households will require specific promotions. The impact of promotion campaigns will be probably very limited, if not escorted with financial helps or investment subsidies to cover the high initial investment of certain measures.

2.3.2 Renewable electricity production technologies: technical, environmental and economic aspects⁶²

As mentioned before, the major problem of establishing a 100% RES electricity generation system for an isolated area, as an island is the supply assurance to cover the demand in each moment. This leads to prime technical aspects to economic reasons of acquiring the cheap electricity. In this context, one major technical aspect is related to the grid properties: power quality, grid capacity and minimization of grid losses.⁶³ Grid control becomes a crucial aspect. Bigger suppliers are therefore more desirable than small supplies, as an highly increasing number of suppliers adds complexity to the control system and thereby increases the risk of failure and blackouts. Grid aspect could also limit certain applications as individual PV-roof installations or individual wind turbines. If the existing grid doesn't hold up overproduction feeding and electricity pulling when the production doesn't cover the producers own needs, such applications suffer under an enormous barrier. Feasible location for bigger installations could also be limited because of grid connection aspects. The question is which actors cover the required grid adaptation costs. If it is the producer, the economic feasibility of the project is under question marks. If it is partially covered by the producer or totally covered by the distribution system, the cost will partially or fully convey to the end-consumer. In any case, the total independence of the decision taking process regarding grid connection and electricity transport has to be assured to not add additional barriers to RES applications introduction, as it will affect differently to different renewable energy technological alternatives. In any case, the integration of the different productions will be most important.

Renewable energy applications are much more environmental friendly then applications based on fossil resources or nuclear power, but they are not impact free. Each RES application has

⁶² For this paragraph Boyle, Godfrey (2004). *Renewable Energy: Power for a Sustainable Future* has been consulted.

⁶³ Centre for Analysis and Dissemination of Demonstrated Energy Technology (Caddet) (2003). *Wind farm on remote island reduces grid losses*. Technical brochure N.177. [Online] Available: <http://www.caddet.org/public/uploads/pdfs/Brochure/RE177.pdf> [2005, March 28]

its own frame of possible environmental and social impacts. They should also be taken into account when selecting locations and RES to be harvest, especially in islands circumstances, where environmental damage could easily mean the extinction of some species or affect directly fundamental parts of the islands economy or culture.

Incomes from the different energy sources are a result of energy price establishment mechanism with in each European country and their fiscal frame for promoting RES. The incomes related to renewable energy generation will depend on the mix of, in the following paragraph alluded, case specific, applicable policies on the electricity market rules and its resulting structure of each country.

Table 2-5 shows the general expected cost of renewable energy generation, as acknowledge in the world energy assessment outlook 2004. A higher cost on island level should be expected given the higher infrastructure costs on islands, as acknowledge by Forum for Energy and Development in *Renewable Energy on Small Islands - Second Edition*: “Infrastructure costs such as energy are up till three to four times higher than on the mainland.”

A diminishment of this cost are expected due a learning curve processes in the production and user phase, but also due to increase production levels and the consequent appearing economies of scale.

Another aspect which will make RES exploitation more economically feasible is the expected growing fossil fuel prices. Shrinking resources and increasing supply assurance problems are expected to force the fossil fuel prices up. Primary energy source diversification will reduce its effect on final electricity prices. In this environment, RES exploitations become more and more competitive.

Table 2-5 Cost of renewable energy production for electricity

RES (€/ kWh)	Turnkey investment		Current energy cost		Potential future energy cost	
	Min	Max	Min	Max	Min	Max
Wind	960	1,919	5	9	3	11
Hydro						
• Small Hydro	790	9,031	2	14	2	11
• Tidal	1,919	2,822	9	17	9	17
• Waves	2,258	5,645	11	34	6	11
Solar						
• PV	5,645	20,320	28	181	6	28
• Thermal Electric	2,822	6,773	14	38	5	23
Geothermal	903	3,387	2	11	1	9
Biomass	564	6,773	3	14	5	11

Euro-exchange rate 31/12/00: 1.1289€/ \$

A adapted from United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council (2004). Overview: advanced copy.

Briefly follows some technical, environmental and economic comments regarding each RES will be addressed:

- Wind energy

The generation capacity of each wind turbine has been growing, their lifetime also; at the same time wind turbine production costs have decrease steadily. All this has lead to significant cost reduction per Megawatt per hour (MWh), what makes it nowadays economically competitive, even more than in island context, given enhanced fuel prices.

Given islands additional fuel costs, this competitiveness is assured. As acknowledge in Forum for Energy and Development's (FED) study on renewable energy on islands, already in the year 2000 wind energy was "the by far most utilised renewable energy resource utilised for electricity production." This is due to the by average island better wind potential compared with the continental average, profiting from the see winds and the option of off-shore wind farms.⁶⁴

But the proximity to the see can also enhance on of the first environmental impact related to this energy exploitation: Costal areas are very relevant when it comes to seabirds' conservation. Island's isolation could lead to a number of autochthonous species. The environmental damage this kind of exploitations can have on local and migratory birds population an enhance impact.

Also landscape damage is often argued as a negative impact of this resource, but this appreciation can vary depending on human perception. Nevertheless, it is better than smoking chimneys from fossil fuel electricity generation plants. In highly touristy areas the impact could be enhanced by tourist perceptions. Off-shore wind farms could damage the free see skyline.

Another aspect to be considered is the area needed to cover a certain production, which could be a quite limiting aspect in limited areas as islands.

- Hydro energy

- Terrestrial hydro energy

Abundant waterfalls will be the initial requirement for this kind of exploitations, but also certain height difference will be needed. Many islands lack from one or the other circumstances. Even with abundant waterfalls, and water storage use, it will have to compete with alternative water uses. This could be a problem at scarce water periods. In certain circumstances alternative water uses could be even beneficial for such investments. The high initial investment required for the dam construction could, for example, be shared among the different water users.

Environmental problems are mostly linked to the dam construction. Islands high biodiversity could play a role when endemic species are established in the dam's location.

Regarding its production cost, the long life time of the investment, low maintenance costs and mature technology, assures its profitability.

- Ocean energy

⁶⁴ Forum for Energy and Development (2000). *Renewable Energy on Small Islands - Second Edition*.

As located in island surrounded by sea this alternative surely exist. Between the islands of an archipelago sea currents can be quite strong, as water is forced through channels. Open sea conditions provide abundant waves energy. Tidal effects will depend on the islands latitude. The problem is that the technological solutions are mostly under research; as such its production costs aren't by far competitive. High uncertainty regarding the economic results of such exploitations exists. At the same time it is an excellent opportunity to invest in R&D, looking upon future markets and job creation.

Environmental problems of experimental projects are often difficult to quantify. An example could be the effect of marine current exploitations on whales' or fish schools' are not fully known. The impacts could be worse in sensible island ecosystems; as such a higher risk exists. Apart of marine ecosystems problems, also certain tourism activities could be affected, especially when competing for costal areas or when it affects its landscape.

- Solar

The sun potential varies very much depending on the latitude, varying more or less throughout the seasons. In general, in European islands context, this resource can be only exploited in southern European islands and their outmost islands.

Actual high electricity generation cost are expected to drop, while the demand for this kind of applications increases, markets barriers disappear and mature technology is achieved. Actual high cost requires high subsidy levels.

Its impact in the user phase could be quite ignored if roof are use for its installation. If not landscape problems and alternative land uses are their worse impacts. The flora of the region could be also affected as competing for light.

Electricity generation based on PV on roofs will compete for space with thermal solar applications for heating and hot water purposes. This battle is lost by PV applications, as solar thermal applications are more energy efficient and less costly.

Thermal solar applications are not suited for roof installations as the requested solar concentration for electricity generation requires a certain plant dimension. This kind of application are also still under development.

- Geothermal

As islands often have a volcanic origin, higher probability of finding geothermal activity, but as for electricity generation high enthalpy resources are needed. When it is exploitable, it is the best RES to be the support of a 100% RES system given its constant supply. Certain exploitation problems could appear if the resources are linked to tourism activities or are located in protected areas, more frequent on islands. Its cost will depend on how deep has to be drilled to achieve a sufficient high enthalpy level. Maintenance costs are afterwards significantly low.

- Biomass

Biomass electricity generation achieve competitive cost when abundant local supply can be assured. As such islands circumstances is not a limitation. The problem appears when additional supply is needed, as then the shipping cost increases substantially the biomass price.

The use of forestry residues could be an incentive for reforestation of set aside land, but could only be considered in a long-term perspective. At European level, where each time more agriculture land is set aside, islands are more affected, as the competitiveness of the agriculture products is affected by additional transportation cost of the final product to the consumer markets, as high water prices, when water scarcity problems exist. An alternative solution could be energy crops. Local crops should be studied to avoid negative impacts on local species by foreigner species. Local species will also be more adapted to the climate and the soil conditions. This calls for R&D.

- Waste⁶⁵

The problem of landfills as limited areas and high sensible nature will enhance the use of waste for energy recovery.

EU policies tend to promote waste minimization, in this sense to establish a strategy of waste energy recovery doesn't seem very convenient, as this should be the last solution. But islands circumstances carry specific issues to be considered: Recycling costs are enhanced. The use of recycling material in industrial processes requires often production scales which can not be achieved on islands. As such, the additional transport cost burden has to be taken on. In this context a more global perspective should be taken: Is the environmental benefits of recycling worth the negative environmental impact of transporting the matter to be recycled? Is it worth, when considering the negative impact of importing fossil fuels for electricity generation? Isn't it more worth to consider energy recovery options instead? Economic arguments favour this alternative; environmental impacts will be always case specific.

In any case, energy recovery will be more a solution to waste problems than to electricity generation needs.

2.3.3 Policy aspects of renewable electricity production in Europe⁶⁶

Intelligent Energy for Europe is a working programme established for the period 2003-2006 as part of EU energy strategy. It establishes so called "non-technological actions" linked to energy efficiency and renewable energy sources. Market barriers for their application should through these actions be removed. Obviously, financial and administrative support is given to these actions; in the dimension they provide results in a cost efficient way. In this sense they don't finance investment in technologies, but will influence the cost of projects, by, for example, promoting a market for a certain application and thereby reducing its market price. "Its aim is to support sustainable development in the energy context, making a balanced contribution to achieving the general objectives of security of energy supply, competitiveness, and environmental protection (Art.1 of the programme Decision)."⁶⁷

This program has been established as part of the "long-term stable framework for the development of renewable sources of energy covering political, legislative, administrative, economic and marketing aspects"⁶⁸, which aims to be the European Energy Strategy.

The actions with in this plan are intended to affect all actors of the energy market; as such the actions have been structures at two directions: ⁶⁹

⁶⁵ For further insights: Miranda, Miranda Lynn, Hale, Brack. (Unpublished). *Paradise recovered: energy production and waste management in island environments.*

⁶⁶ Basic source for this paragraph: Commission Communication Com (97) 599 final

⁶⁷ Intelligent Energy – Europe (EIE), European Commission. (2004) [Online]. Available: http://europa.eu.int/comm/energy/intelligent/index_en.html [2004, May 15]

⁶⁸ Commission Communication Com (97) 599

Vertical Key Actions:

These are actions promoted within a specific application field to be applied at all the Community. The SAVE program is one of the four programs developed. It focuses on energy efficiency and rational use of energy. As such, its main actions are focussed on the building and industrial sector.

ALTENER is a second vertical key action programme. Its actions are lead to promote “new renewable energy sources for centralised and decentralised production of electricity and heat and their integration into the local environment and the energy systems”.⁷⁰

Cooperation with developing countries through the COOPENER key action program, will not affect islands project, when not meaning competing for obtaining capital investments, which rarely will be the case.

Horizontal Key Actions:

These actions are directed to a local and regional level, promoting sustainable energy communities, as continuing with the promotions of regional and local energy agencies. They are meant to involve all actors. These actions should establish a pathway for further implementation; as such networks among energy agencies as among the local communities are promoted. Several actions are link to support local decision-making regarding financing mechanism and incentives, policy measures and its impacts, or to acknowledge future trends. Speeding of the acquired knowledge is a key factor.

The aim of energy agencies is to promote energy management, which means energy efficiency, energy savings and local or renewable energy sources. Energy agencies support thereby the horizontal key action of the Community, administrating, financing or executing vertical key actions. Energy agencies are aimed to be independent bodies, which represent the different actors involved in the energy market: local representatives, consumer representatives and local companies.⁷¹ They should lead to social awareness, provide or transmit technical and economic support for improvements, spread best practices and provide confidence to investors.

Several other actions are taken at regional level. A sub-programme of the Community Support Program gives special attention to “the development of new technologies and processes adapted to local and regional needs in the area of RES.”⁷² Islands communities’ special requirements fit the request needed for this support.

The EU promotes also the establishment of regional policies to promote RES. European region development funds can in less developed areas of Europe, also be applied to renewable energy applications. “In less favoured regions, peripheral and remote areas, islands, rural areas in particular those lacking traditional energies, RES have a high potential for new job creation, for the development of indigenous resources and industrial and service activities, particularly in objective 1 areas. New incentives should also be undertaken in tourism sector as the great

⁶⁹Appendix 3 lists the horizontal and vertical key actions established by the European Commission (2003) *Intelligent Energy for Europe program 2003-2006* [Online] Available: http://europa.eu.int/comm/energy/intelligent/call_for_proposal_2003/doc/eie_detailed_description_of_key_actions_vs_1_dec03.doc[2004, September 18]

⁷⁰ Intelligent Energy – Europe (EIE), European Commission. (2004)

⁷¹ European Commission (n.d.). *Charter of the regional and local energy management agencies in Europe*. [Online] Available: http://europa.eu.int/comm/energy/library/savch_en.pdf [2004, June 1]

⁷² Commission Communication Com (97) 599 final

potential of renewable energies in this area is largely unexplored.”⁷³ Many islands, due to the in the introduction mentioned limitations to its development, fall under this category. The common agriculture policy also has its effects on RES development when, for example, taken measures to promote energy crops. The Joule-Thermie program promotes of innovative and efficient renewable energy technologies and dissemination of related information, by creating a network for information exchange, promoting market acceptability, as providing consumer protection.

A special partnership program for islands has been created among the ones established under the frame of the Take-off Campaign for Renewable Energy for Europe program. It established a network for information exchange, but also to achieve synergies among the different projects and often diversify investment risk through participation in the different projects; it “promotes the implementation of large-scale project in different renewable energy sectors.” These projects should represent pioneer projects using cost efficient technologies.

EU’s actions promoting renewable energy technologies are directed to following aims:

- Promoting R&D in the field
- Promote pioneer project of not proven technologies
- Increasing the share of renewable energy generation, promoting applications
- Increase technology and management knowledge transfer in the field.

Funding for RES projects can be obtained at EU level from:

- Altener programme
- Demo projects
- R&D projects
- Renewable Energy Partnerships- Take-off campaign.

EU’s policy in the energy sector is very opened to each country’s singularities. An overall target of 12% RES penetration for 2010 has been established, but the target each member state has to achieve, as the strategy to achieve it, is defined by each member state itself. Despite the liberalization processes of several national energy markets, as the harmonization of the related country legislation to EU requirements, the energy market rules are still varying a lot, from country to country. As a consequence the specific market conditions for renewable energies change a lot from one country to another, but also from one renewable energy source to the other. As such, EU’s measures described in the previous paragraph just “provide added value in terms of the sharing and transfer of successful technological and market experience”.

⁷⁴

To assure the increase of renewable energy generation the EU allows through its energy directive the countries to create market based instruments as to give preference dispatcher to renewable energy production. The resulting schemes are being analysed and its effects evaluated to serve as a basis for a new directive, which will try to harmonize these schemes into the most efficient one. The, through the variety of schemes created, trade distortions will thereby be avoided. ⁷⁵

⁷³ Commission Communication Com (97) 599 final

⁷⁴ Commission Communication Com (97) 599 final

⁷⁵ Commission Communication Com (97) 599 final

Three are the main fields of economic measures: Taxes and subsidies, financial market measures, and energy market measures⁷⁶

- Carbon tax: Based on their carbon emissions certain industries are taxed. Which industries must pay, from which level of emissions on, if at a constant or progressive way depends on the specific tax design. Several variations exist.
- Tax exemption/reduction on certain RES applications
- Subsidies supporting prices linked to RES exploitation, as for example energy crops prices.
- Subsidies interest rates on initial investments
- Subsidies on capital investments in renewable energy installations
- Flexible depreciation of renewable energies investments
- Favourable tax treatment for third party financing of renewable energies
- Tax releases for benefits resulting from RES production
- Financial incentives for consumers to purchase renewable energy equipments and services.
- Golden or green funds: bank accounts with reduces interest rates for the customer, who is shifting the difference interest rate to renewable energy investor bank operation.
- Public renewable energy funds: equivalent to general public funds but with renewable energy application of the obtained capital.
- Soft loans and special facilities, as credit guarantees, from institutional banks
- Creating special facilities for renewable energies
- Development schemes facilities loans for small renewable energy projects, as guidelines and risk evaluation schemes for commercial banks.
- Energy price establishment rules for the different renewable energy sources. Basically they can be formed based on objectives established for each renewable energy source, or based on the real cost of each renewable energy production
- Green certificates: Certificates given to green energy producers to be purchased by non-green energy producers or by end-consumers, in which case energy distributors will act as middleman. Who will have to purchase will depend on the enforcing legislation.
- Green tariff: The costumer has the choice to apply a special higher price to its electricity consumption. If so this higher price is directly applied to certain RES production level.
- Preference dispatching: All renewable energy produced has to be purchased by the energy market.

Finally, any kind of long term research and development promoted through policy measures will later or sooner has its effect on RES cost reduction, as shorting the learning process, and thereby, allowing a more rapid RES penetration.

⁷⁶ The measures are mentioned in the Commission Communication Com (97) 599 final

3 Energy Storage: Matching Demand and Supply

3.1 Introduction⁷⁷

Energy Storage is nothing new; it is an implicit part of any energy system. The initial development of most of the existing storage systems was not linked to renewable energy applications, but to technical and economic reasons related to the electricity distribution system, demand requirements and supply availability. These requirements are, mainly, the need of backup, assuring energy supply; the wish of achieving higher efficiency thanks to more constant production, or to take advantage of the price fluctuations in the energy market pool. Other minor energy storage needs rely, for example, in avoiding investment in grid reinforcement or controlling the voltage within the electricity distribution system.⁷⁸

The increased importance renewable energy is achieving, as the expected bigger share they will represent in the future electricity market, has only enhanced the relevance of energy storage systems. In this context the role of energy storage systems is to “mitigate the effect of intermittency and improve the economic return of the system”⁷⁹

Anderson and Leach (2004) mention three reasons for no further development of energy storage systems in the actual electricity market:

- “Continuous improvement in generation equipment, declining costs for peak-load electricity capacity.
- Difficulties of finding low cost and abundant storage beyond the limited opportunities for pumped storage
- Reducing peak- load fluctuations through demand management.”⁸⁰

Island’s environment changes substantially these assumptions:

- Independent island electricity generation systems are much more rigid than continental ones. If not connected to a major grid, the local generation system has to cover the relatively small demand. In order to assure covering peak demands, as a certain demand growth, the generation capacity has to be oversized. Economic exploitation efficiency will be a secondary objective, prevailing supply assurance. Nevertheless, energy storage units can help to achieve better economic features. In any case, it implies a higher investment redemption cost. Consequently, the electricity generation technology in place will be exploited as long as possible, which will also retard the introduction of technological improvements.

Taking also into account islands’ electricity systems’ fossil fuel dependency, as additional transport costs, the increasing international fuel prices, electricity generation costs are generally significantly higher to mainland ones and less controllable by the electricity generators.

⁷⁷ For general background information Ter-Gozarins, A. (1994). *Energy Storage for Power Systems*. has been consulted.

⁷⁸ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*.

⁷⁹ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*

⁸⁰ Anderson, D., Leach, M. (2004) *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*.

All this implies that the continuous improvement in generation equipment, declining costs for peak-load electricity capacity, will have less impact in islands circumstances.

- Given the, in many islands, existing water scarcity, pumped storage options will often compete with alternative water uses. As such the difficulties of finding low cost and abundant storage are even more acute. On the other hand, the above argued higher electricity generation cost makes other more costly energy storage systems economically feasible.
- Demand management should reduce peak load fluctuation, but demand management tools have a reduced impact on islands with limited industrial sector, with high relevance of domestic, public or service sector, in which the electricity cost represents a relatively small share of the total product cost. The electricity demand will therefore probably be much more inelastic, price insensible.

Consequently, islands electricity sector have a major interest in the further development of energy storage systems.

Accordingly to the commonly enhanced islands' electricity generation cost, the prices in the generation markets are often fixed within a specific regime, are subsidised or the additional cost is internalised within a bigger company, working in a bigger market, from which it gets its benefits. Therefore, market forces are mostly not leading the prices. In such regimes, benefits of storing low price electricity to be sold in high price conditions can be dismissed. This is one of the benefits of storing energy D. Anderson and M. Leach (2004) identify. Providing ancillary services is another source of benefits. Technical aspects gain on islands, as with higher RES penetration, more relevance, as changes in the electricity input can destabilize easily the whole system. As such the economic value of ancillary services is higher:

- Avoided investment in overcapacity: Without a proper energy storage capacity, in order to cover the electricity demand through renewable electricity production would lead to an excessive overinvestment in electricity generation plants to assure covering peak demands even with wind scarcity or during dark days.
- Renewable energy applications allow a variety of micro-generation, which, on one hand, reduces the risk of full blackouts, but, on the other hand, makes the distribution system more unstable, increasing the number of suppliers feeding the grid. As such, the need of energy storage systems as a grid control tool is enhanced, reinforcing the reliability of the system.
- Given the high cost of electricity produced by back-up electricity generation systems, started when the existing supply can't cover peak demands, electricity stored when the demand doesn't cover the supply, can be comparatively cheaper, even being the cost of the stored electricity higher than the electricity price.

Clark, W. and Isherwood, W. ⁸¹ studied the economic feasibility of an isolated electricity system, combining RES and energy storage, assuming a Wind and Solar energy of 50%. Based on their conclusions the economic feasibility of a 100% RES electricity system is not so clear. The intermittency, which this system assumed, can cost efficient be covered by an appropriate storage devise.⁸² In a 100% RES system the intermittency should be reduced:

⁸¹ Clark, W., Isherwood, W.. (2004). *Distributed generation: remote power systems with advanced storage technologies*. Energy Policy, 32, 1573-1587.

⁸² Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*.

- By a high utilization of a more stable and predictable RES source, as geothermal, biomass or even hydro, or/and
- By a big storage capacity, or/and
- By excessive installation of more volatile RES sources in multiple locations.

Any of both latest solutions will reduce significantly the economic efficiency of the system, as it implies certain overcapacity. This doesn't mean that, from an economic point of view, the final system is not worth, even if being inefficient. The economic results of the final system has to be compared to the actual system, which given its actual high cost, also can be inefficient; especially, when considering the expected continues growth of fossil fuel prices. Nonetheless, the final system implies substantial social and environmental benefits when compared with actual fossil fuel based system.

One main question, which has to be answered in order to stir the market to the new system, is: Which will the price versus cost of stored electricity be? How will the cost of the energy storage system be distributed among the different actors of the electricity market? Which changes must the actual electricity market overcome to address these issues?

As for the renewable energy sources and technologies to be used in the final system, an appropriate combination of storage systems has to be found. The capacity and speed of storing and recovering the stored energy of the different available systems has to be combined to the electricity generation characteristics of the selected RES combination, as to the demand characteristics.

Table 3-1 represents actual energy storage alternatives for electricity systems, summarising their main characteristics. The efficiency data are only referred to the specific technology mentioned, not to the whole electricity conversion and recovery process.

Nowadays electricity system is based mostly on the fuel storage as energy storage. Fossil fuel, natural gas has identical storage properties as biofuel and biogas. The future switch into these secondary biomass products will not require big research and development, even investment in new storage systems. For this reason this kind of storage will not be further addressed. This chapter focus on energy storage systems that store electricity directly or convert it into another energy carrier, to be stored and restored into electricity whenever needed. In this sense, other energy storage systems, as underground thermal energy storage, which takes advantage of surface and underground temperature differences for heating or cooling purposes, cannot be used to store electricity, and are, therefore, not addressed at all. Their possible impact on the electricity demand as reducing electricity needs for heating and cooling purposes should anyhow not be dismissed.

Given the expectations on hydrogen as the main future energy carrier, a special attention has been given to the hydrogen storage system, addressed in paragraph 3.2, to follow up with the remaining storage alternatives in paragraph 3.3.

Table 3-1 Large-Scale Energy Storage Systems

Storage technology	Energy Carrier	Technical data	Environmental Impacts	Costs
Fuel cell	Electrochemical products (A variety of possible fuels, being hydrogen the one with the highest conversion efficiency)- chemical energy	Efficiency: 45-80 % Capacity: 0.3-2,000 kWh Weight: 30 kg/MWh Lifetime: 10 years	No pollutants	Investment cost: 15,916 €/ MWh Maintenance cost: 11€/ MWh Use of platinum, rare substance, as catalyst Corrosive environment requires special materials
Flywheel	Spinning wheel – kinetic energy	Efficiency: 90-93 % Capacity: 50-750 kWh Weight: 3,000-7,500 kg/MWh Lifetime: 20 years System efficiency: Up to 75%	Noise	Investment cost: 318,318–26,526,500 €/ MWh Maintenance cost: 3-4 €/ MWh Commercial available, cost efficient
Pumped Hydroelectric Energy Storage	Water – potential kinetic energy thanks to gravitational forces	Efficiency: 80 % Capacity: 22,000 kWh Weight: 3,000 kg/MWh Lifetime: 40 years System efficiency: High	Only depending on the type and the location chosen for the reservoirs	Investment cost: 7,427 €/ MWh Maintenance cost: 4 €/ MWh High infrastructure cost, but significantly low operating costs
Compressed Air Energy Storage	Air – kinetic energy between air molecules	Efficiency: 85 % Capacity: 2,400 kWh Weight: 2.5 kg/MWh Lifetime: 30 years System efficiency: 1/3	Green House Gas emissions, from running the gas turbines Risk regarding the geological structure reliance.	Investment cost: 2,122 €/ MWh Maintenance cost: 3 €/ MWh Depending on the geological formation used, from low to very high cost. neconomic if using pressure tanks
Superconducting Magnetic Energy Storage	Magnetic field – electric energy	Efficiency: 97 % Capacity: 0.8 kWh Weight: 10 kg/MWh Lifetime: 40 years	No chemical reactions, no emissions	Investment cost: 10,611 €/ MWh Maintenance cost: 1 €/ MWh
Supercapacitors	Electric field – electric energy	Efficiency: 95 % Capacity: 0.5 kWh Weight: 10,000 kg/MWh Lifetime: 40 years	Very positive impact as substitutes of conventional batteries	Investment cost: 29,709,680 €/ MWh Maintenance cost: 5 €/ MWh
Biomass storage	Biofuel – chemical energy	Depends on the fuel characteristics	Possible spills, evaporation	Available fuel storages can be adapted - low cost

Adapted from Chueng, Chueng, Navin de Silva, Juvonen, Singh, Woo (2003)

3.2 Hydrogen - Fuel Cell Energy Storage System

This energy storage system implies three steps: Energy is used to produce hydrogen, which then can be stored to later on convert the chemical energy of hydrogen into electricity. Given different technical alternatives in each step, a deeper look into each of them will follow.

Several arguments reinforce the convenience of this system. These arguments are not so much linked to the economical or technical solutions for electricity storage, but with a broader view of the whole future energy system. High hopes have been put on the development of hydrogen and fuel cells a solution for energy storage, but mainly for eliminating the fossil fuel dependency of the transport sector in an overall CO₂ emissions reduction strategy. In this sense, its clean exhaust gas, water vapour, is one of the strongest arguments to its implementation, but, as specified in K. Hassmann's and H.M. Kühne's article "Primary energy source for hydrogen production", not the only one. They list the following reasons to expect its real application:

- The opportunity of using "fuel cell as an economically promising decentralised source of combined heat and power, for which hydrogen would be the ideal fuel."
- The possibility of using hydrogen also as "fuel for combined-cycle power stations, gas turbines and micro-turbines". This allows a smoother path to a hydrogen economy as these technologies are actually being used.
- The need of "carbon abatement measures".
- For countries which lack in fossil natural resources it is an option to achieve "Energy security". In a long term perspective, given the resources limits all countries could be in the same situation.
- Actual lower natural gas prices, fossil resource with similar technically applicable to hydrogen, is a strong limitation to its introduction. "Innovation in hydrogen production such as photo-electrolysis may change the relative costs of hydrogen and natural gas."
- In the path way to a hydrogen economy, a "low-cost hydrogen production via steam reforming of fossil fuels and biomass exist."

Nowadays energy system is predominantly fossil fuel dependent; given its limited resources and the cleaner energy generation needs, a growth of the natural gas share is expected. This could facilitate a later on introduction of hydrogen as a fuel. Many of the investment needs for establishing a natural gas distribution and use system can often be adjusted to hydrogen requirements. Hydrogen becomes this way an alternative to transmit electricity over large distances, when using natural gas pipelines or tanks. This allows the "harvesting of renewable energy from diverse and widely distributed sources, storage in the form of hydrogen and redistribution of hydrogen for use by large and small scale generators, for electricity production, industry and transport."⁸³

The main driver for a real hydrogen implementation will be society's assumption regarding the external cost of the energy system. If the society assumes the high external cost of actual energy system, the additional production costs of hydrogen⁸⁴ will be covert. Several policy instruments, economic, but also awareness tools, can be used achieve this aim. "Public/ Private partnership will be a key aspect of the demonstration. Policies to implement hydrogen will be

⁸³ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen.*

⁸⁴ See appendix 4 for delivered cost of hydrogen figures.

enacted in island countries, and in urban areas with high air pollution emissions.” “A vigorous program of R&D on hydrogen can be considered a prudent insurance policy against the need to begin radical decarbonisation of the fuel sector within a few decades, while simultaneously addressing energy security and pollution problems.” Without the society’s compliance a hydrogen economy will doubtfully be achieved.⁸⁵

3.2.1 Hydrogen

Hydrogen “can be considered as

- A non-energetic raw material (Mostly used by refineries and ammonia producers)
- A potential propellant for commercial or private transportation
- A secondary energy carrier for electricity and heat production
- As energy storage medium.”⁸⁶

Use in for combustion or in fuel cells, the exhaust gases is clean water vapour, but fuel cells has certain advantages regarding a, for example, a Combined Heat and Power Plant (CHP), which is actually the most energy efficient combustion technology. These advantages are linked to its distributed power option, avoiding electricity losses in the distribution system as capital investment in electricity distribution systems; on the other hand, hydrogen distribution also implies this kind of costs. A major advantage is the higher energy efficiency of fuel cells. Actual high fuel cell costs are expected to decrease as material and system design is improved and mass production is achieved.⁸⁷ Hydrogen production cost will also sink considerably thanks to hydrogen transport use. As soon hydrogen market is initially established, growing markets, economies of scale and learning curve processes will decrease substantially hydrogen prices.⁸⁸

Given the role of hydrogen in the carbon abatement strategy, only hydrogen production with out emissions has a technical and economical sense. Hydrogen can therefore be produced from:⁸⁹

- Nuclear power
- Fossil resources, if the resulting CO₂ emissions can be captured and stored safely
- Renewable energy sources.

⁸⁵ Ogden, J.M. (2004). Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050. *The 10-50 Solution: Technologies and Policies for Low-Carbon Future*. March 2004. Washington, DC. The Pew Center on Global Climate Change and the National Commission on Energy Policy. [Online] Available: <http://www.pewclimate.org/docUploads/10%2D50%5FOgden%2Epdf>

⁸⁶ Hassmann, K., Kühne, H.M. (1993). *Primary energy sources for hydrogen production*. International Journal of Hydrogen Energy, Vol.18, 8, 635-640.

⁸⁷ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*.

⁸⁸ Anderson, D., Leach, M. (2004). *Harvesting and redistributing renewable energy: on the role of gas and electricity grids to overcome intermittency through the generation and storage of hydrogen*.

⁸⁹ based on Ogden, J.M. (2004). Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050 and Pascala, S., Socolow, R. (2004). *Stabilized wedges: Solving the climate problem for the next 50 years with current technologies*. Science, Vol.305, 5686, 968-972.

Increasing energy prices due to increase fossil fuel prices and the added nuclear waste problem of nuclear power plants, favours hydrogen produced from RES as the sustainable alternative.

Basically, the hydrogen production relies on two different processes:⁹⁰

- Chemical cycles:

In a high-temperature environment⁹¹, starting with any kind of carbon compounds (fossil resources, biomass or waste) a synthetic gas is obtained from which hydrogen is extracted through a, so called, reformer; through reacting steam with methane or, the latest development, still not technically mature, through splitting water a series of chemical reactions.

The first alternative, actually being used in the hydrogen production, is linked to high-efficient big-scale production.

The resulting hydrogen can contain impurities, which could, for specific uses, require special cleaning processes, adding additional cost to the production.

- Electrolysis:

Electrodes introduced in water split it into hydrogen and oxygen. As such electricity, disregard from which source, is the starting point of the process.

Electrolyzer can be build for all productions needs, as such its can be used for small and big scale production. Obviously, its production costs are linked to the production level, being bigger plants more cost efficient, but the marginal cost reduction is significantly smaller then for the previous alternative.

The final hydrogen production cost will in this case depend mainly of the cost of the electricity being used.

There other alternatives under research, as the strait conversion of sunlight to hydrogen in electrochemical cells and hydrogen production by biological systems such as algae or bacteria,. Given its small expected production scale and the time frame to its implementation they will, surely, not play a major role in the change to a hydrogen economy.

Considering the above mentioned technologies, renewable energy sources, as solar (focused sunlight), geothermal and biomass, could be used to produce hydrogen through a chemical cycle. The remaining renewable energy options are to electrolyzer use.

Islands circumstances make the electrolyzer option also the most appropriate: First, the scale of the production unit can easily be adjusted to islands need. Second, as using electricity, a homogeneous good, it allows the use of all kind of RES. Off-peak power can thereby be used for hydrogen production, maximizing also the exploitation of the existing renewable energy generation, optimizing the investment. Thanks to this a whole 100% RES energy system can be designed; for electricity, heat and transport.⁹² From an economic point of view, especial gains would be: full energy self-reliance and the cutting of a constant money outflow from the region, as actual fuel imports could be avoided. These has to be taken into account when

⁹⁰ based on Ogden, J.M. (2004). Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050 and Pascala, S., Socolow, R. (2004). *Stabilized wedges: Solving the climate problem for the next 50 years with current technologies*.

⁹¹ Depending on the specific process used the temperature needed could lay between 400° to 900°C. (Ogden, 2004).

⁹² 52,5 kWh produces 1kg of hydrogen, equivalent to 1,816.95 litres of gasoline (1 US gallon of gasoline). A car would need 100 kg per year. (Pascala, Socolow, 2004)

choosing among other alternatives as producing hydrogen from fossil fuel with carbon sequestration or the strait import of cheap produced hydrogen.

Safety is also another aspect to take into account. This is often appointed as a problem, but “hydrogen has been used safely in industrial settings for many decades, and there are efforts underway worldwide to extend this knowledge to general use of hydrogen as a fuel.”⁹³

3.2.2 Hydrogen Storage Systems⁹⁴

Hydrogen storage systems are actually the weak part of the hydrogen energy storage systems. Hydrogen can be stored in liquid, in gaseous form if compressed in cylinders, or in solid metals.

Liquid Hydrogen

To liquefy the hydrogen a temperature of -253.15°C is at least required and must be kept. The energy conversion efficiency of this method is around 25%. As such liquid hydrogen storage will surely be used for other purposes but not for electricity storage. Considering the 65% efficiency in the hydrogen production and the up to 80% efficiency of the fuel cell, the final efficiency of the system would be down to 13%.

Adding high investment costs, linked to the cooling system and storage units, as high current costs related to its energy consumption, makes it a prohibitive storage method.

Compressed Hydrogen

The energy needed to compress the gas also reduces efficiency of this method, but substantially less than in the previous one. Consequently, current energy cost is also lower.

Solid Metal

This is the storage technology with highest potential. The hydrogen atoms are squeezed in the remaining space between the atoms of the metal molecules. This process requires energy. Some energy is also lost, due to the collision among different atoms; meaning kinetic energy loses during the whole storage period. Finally, a certain energy input is needed in order to invert the process. Nevertheless, the energy efficiency of this technology is the most promising. Regarding the economic efficiency of this storage method, its high cost directly related to the high cost of the metals being used.

3.2.3 Fuel Cells

Fuel cells are based on transforming “chemical energy directly into electrical energy”⁹⁵. More thoroughly, a molecule is split through passing through a positive charged electric field (anode catalyst), divided into positive charged ions and free electrons; they are conducted through a membrane to a negative charged oxygenised environment; the positive charged ion reacts with oxygen; the remaining free electrons create than the electric current, which is the purpose of

⁹³ Ogden, J.M. (2004). Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050

⁹⁴ Technical data are taken from Chueng, K.Y.C., Chueng, S.T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J.J. (2003). *Large-scale energy storage system* [online] Available: http://www.doc.ic.ac.uk/~mpj01/ise2grp/energystorage_report/storage.html

⁹⁵ Chueng, K.Y.C., Chueng, S.T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J.J. (2003) *Large-scale energy storage system*.

the fuel cell. Hydrogen molecules are an option, but also carbon monoxide, propane or natural gas molecules can be used. Also biogas, as a direct renewable alternative, can be use.⁹⁶

Actual real limitation for a more rapid development of fuel cells as storage systems is the catalyst, mostly platinum. Its singular characteristics make it the most suitable catalyst.⁹⁷ Platinum is a rare and, therefore, expensive metal. It already represents a high percentage of the fuel cell cost, but the mass production of fuel cells would cause a price increase of the platinum, as its demand increases. Thus, cost reductions consequence of economies of scale and learning curve effects will probably be compensated by material cost growth. Platinum is not the only high costly material required for fuel cells: The corrosive environment in which a fuel cell works requires also other high quality materials as stainless steel to assure its lifetime. A high material cost, in general, reduces the probability of cost reduction due to mass production. “Higher temperature increases the efficiency and allows the use of cheaper catalysts, but this shortens the lifetime of the cell as it promotes corrosion”⁹⁸ This is a main problem R&D efforts face: The development of cheaper, but effective catalysts, as reducing the remaining material requirements of the fuel cell is therefore of main relevance. The high temperature requirement for efficient working forces the use of a secondary energy source to achieve the right conditions, adding an additional cost to the energy recovery.

Table 3-2 summaries the characteristic, advantages and disadvantages of the actual fuel cells’ technologies suitable for hydrogen. The economic efficiency of the system can be improved thank to the fuel cells being almost noiseless. This allows them to be located where ever the significant waste heat of the fuel cells can be recovered and reused.

The Alkaline Fuel Cell has an additional advantage which synergies should be taken into consideration in a scarce potable water island environment. The water produced as exhaust of the fuel cell is potable. The use of this fuel cell is also enhanced through its higher energy conversion efficiency, which is the major interest of this application in the island environment. The resulting benefits of these advantages could overcome the additional cost of the fuel cell.

⁹⁶ Chueng, K.Y.C., Chueng, S.T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J.J. (2003) *Large-scale energy storage system*.

⁹⁷ Chueng, K.Y.C., Chueng, S.T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J.J. (2003) *Large-scale energy storage system*.

⁹⁸ Chueng, K.Y.C., Chueng, S.T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J.6J. (2003) *Large-scale energy storage system*.

Table 3-2 Characteristics, advantages and disadvantages of the fuel cell technologies

Fuel Cell Technology	Characteristics	Advantage	Disadvantage
Alkaline fuel cell	Efficiency: $\approx 70\%$ Operating temperature: 150 - 200°C Output: 300 W – 12 kW	The water produced is drinkable.	As using platinum, they were too expensive to be used in commercial applications until recently.
Polymer electrolyte membrane	Operating temperature: $\approx 80^\circ\text{C}$ Output: 50 – 250 kW	Suitable for household heating Suitable for portable applications Can vary quickly the load High power density	Sensitive to impurities, which limits the feasible fuels
Phosphoric acid fuel cell	Efficiency: $\approx 40\%$ (with cogeneration: 85%) Operating temperature: 150 – 200°C Output: ≤ 200 kW	Used as stationary power supply Can use impure hydrogen as fuel Commercially available	Low power and current compared to the others Comparable large size and weight
Molten carbonate fuel cell	Efficiency: 60 % (with cogeneration: 85%) Operating temperature: $\approx 650^\circ\text{C}$ Output: 10 kW – 2 MW	Can use a variety of fuels Cheaper catalysts	Shorter lifetime
Solid oxide fuel cell	Efficiency: 60 % (with cogeneration: 85%) Operating temperature: 1000°C Output: 100kW	For big, high power applications	

Adapted from Chueng, Chueng, Navin de Silva, Juvonen, Singh, Woo (2003)

3.3 Further storage alternatives

3.3.1 Regenerative fuel cell

This special kind of fuel cell uses an electrolytic solution to store energy instead of the commonly oxygen and hydrogen or alternative fuel combination. This solution is able to convert electrical energy into chemical energy and vice versa, storing and recovering whenever needed. In this sense it is a very flexible system, as the process can be reversed in any moment. High efficiency is therefore obtained. Utility-scale units are under development “estimated to be able to discharge up to 500 Megawatt (MW) of energy for up to 12 hours.”⁹⁹

3.3.2 Flywheel

Electricity is converted into kinetic energy and kept in a spinning disk taken advantage of the inertia of a moving body.

Thanks to its velocity of response it can provide rapid electricity supply, allowing a backup, while other energy storage systems with lower velocity of response can follow up. It can also be designed to provide a long lasting support, providing than a small, constant amount of energy. Flywheels are especially suitable for short-term storage. Although they are commercially available, its development, which started 20 years ago, is still an ongoing process. To reduce energy losses caused by friction and ohmic losses¹⁰⁰, as in controlling the centre of the spinning disk has been the main focus of this development. Friction causes another disadvantage of flywheels: Noise!

Steel flywheel

This first application has considerable energy losses due to friction. To reduce these losses, a so-called rectifier has been developed, increasing its efficiency up to 75%, but also increasing its costs. Even though its lower cost, beside its high safety, is an advantage regarding other flywheels technologies. Steel flywheels are able to release up to 1650 kilowatt (kW) power in a few seconds.

Composite flywheel

This later developed technology is more proper to store large amounts of energy. Its improvement is based in the introduction of magnetic bearings, which reduces the friction losses, as a better control of the rotation vertex is achieved. This increases the need of control systems, as safety issues get relevant. It requires partial vacuum, which also reduces the noise formation, but traps heat generated by ohmic losses. “About 750 kW can be released for about 20 seconds or even 100kW for up to an hour”¹⁰¹

Passive magnetic bearing

Through a further development to passive magnetic bearing control needs are avoided, but the material costs are increased, as special low resistance materials that repel magnetic fields are required.

⁹⁹ Chueng, K.Y.C., Chueng, S. T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J. J. (2003) *Large-scale energy storage system*.

¹⁰⁰ Ohmic losses: losses caused by the resistance of matter to electric currents.

¹⁰¹ Chueng, K.Y.C., Chueng, S. T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J. J. (2003) *Large-scale energy storage system*.

3.3.3 Pumped Hydroelectric Energy Storage

Two water reservoirs at different level are used to store potential kinetic energy in the upper reservoir and released through water falling to the lower one whenever required. Pumping units convert electricity into potential kinetic energy; turbines re-establish, through kinetic energy won by gravitational forces, the electricity. This is the basic idea behind this energy storage system that had proven its efficiency for large and long-time energy storage. Modern plants use a generator that can be also used as electric motor to feed the pumps, achieving 80% energy conversion efficiency. This represents a significant infrastructure cost reduction. The velocity of respond also has been improved significantly through out the years: Full power can be achieved in 10 seconds when working and up to one minute from standstill.¹⁰²

Due to islands frequently water scarcity this energy storage system can provide synergies between energy storage needs and water storage requirements. This storage system is normally link to big infrastructure cost due to the building of the upper and lower reservoirs, as such, alternative uses, reduces investment risks as it allows to share infrastructure cost among the different users. This system also provides energy savings as the water distribution system can be handled with less energy requirements, on a more energy efficient way. Normally, small pumping units keep the needed pressure for the water distribution system. This can be now replaced through appropriate use of the potential kinetic energy in the stored water. An increased and steady use of bigger pumping units allows achieving higher efficiency of the equipments.

Further synergies can be achieved if further water needs lead to water desalination. Its energy requirement and common infrastructure needs not only to initial investment reduction for each single project, but during the exploitation phase, when electricity generation and electricity needs for water desalination are properly coordinated to the remaining electricity demand.¹⁰³

3.3.4 Compressed Air Energy Storage

Electricity is stored in kinetic energy among air molecules. The compressed air is than stored in rock, salt caverns or aquifers. When released the air is passed through turbines directly, or used mixed with natural gas in gas turbines. The latest is the more efficient process, nevertheless two third of the energy produced is consumed by the compressor.

Their typical capacity for such plants is between 50 to 300 MW and it has a good respond velocity: around 9 minutes in quick starts, around 12 normally.

The probability to locate an appropriate underground cavern on an island and that the implicit investment and the island storage needs make it economically feasible is very low. As a consequence the only alternative is to store compressed air in pressure tanks. Their actual cost makes this option nowadays uneconomic.

3.3.5 Superconducting Magnetic Energy Storage

These storage units are based on a specific property of superconducting materials property: They offer almost no resistance to discontinuous electric currents in a low-temperatures environment. As such, the storage system needs:

¹⁰² “Conventional combustion turbine peaking plants typically require 20 to 30 minutes for a normal start-up” Chueng, K.Y.C., Chueng, S. T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J. J. (2003) *Large-scale energy storage system*.

¹⁰³ Marin, Cipriano. (2000). *The ‘trinomial’ energy water tourism*

- a power conditioning system, transforming alternating current (AC) into discontinuous current (DC) and back;¹⁰⁴
- a cryogenically cooled refrigerator and a cryostat/vacuum vessel to keep the environment between the mostly required -196.15 to -223.15°C ; and
- a superconducting coil thanks to which electric energy is stored in the magnetic field created by the DC flow.¹⁰⁵

This system achieves efficiencies above 97% with energy losses of around 0.1% per hour of the stored energy. “Theoretically, a coil of around 150 to 500 m radius would be able to support a load of 5000MWh at 1000MW.”¹⁰⁶ Sadly only small-scale systems, up to 10MW, are effectively working. Higher capacity units under research could keep the load for seconds. Further research is centred on reducing the cooling needs, while managing the critical magnetic field and critical current density. All three represent the actual limitations of superconductors. Their rapid development gives hope of future big storage capacities. Superconductors can, additionally, be classified as environmental friendly if compared to other storage units based on chemical reactions.

Superconductors are able to store and discharge power within minutes, very many of times, without disruption. Actually, superconductors are used to provide grid stability and power quality, as are suited to control voltage fluctuations, as to enhance grid distribution.

3.3.6 Supercapacitor

A capacitor, formed by two conductive plates detached by a dielectric insulator, is the basic idea underlying a supercapacitor: By using film polymers as dielectric insulator and carbon nanotubes as conducting plates, the storing capacity is quadrupled.¹⁰⁷

Energy is stored in the electric field generated by the opposite charged conductive plates.

Due to its low energy density, supercapacitor is considered, but limited, to replace batteries, as avoiding most and main batteries main problems:

- Its performance is not affected by use
- Virtually illimitable charge and dischargeable
- Allows huge currents in milliseconds
- Low maintenance cost due to its long lifetime
- Extremely safe
- No thermal losses
- No hazardous substance can be released
- Easily dismantled

Supercapacitors are suitable for voltage fluctuations as to store energy for long periods.

¹⁰⁴ In the case of the also AC application, this system is not requested. The higher resistance losses are minimized through proper wire and device design. (Chuang, Chueng, Navin de Silva, Juvonen, Singh, Woo, 2003)

¹⁰⁵ Ohmic energy losses are dissipated thanks to cooling. (Chuang, Chueng, Navin de Silva, Juvonen, Singh, Woo, 2003)

¹⁰⁶ Chuang, K.Y.C., Chueng, S. T.H., Navin de Silva, R.G., Juvonen, M.P.T., Singh, R., Woo, J. J. (2003) *Large-scale energy storage system*.

¹⁰⁷ Capacitors are not suitable as storage system given their very low energy density of around 0,5 Wh/ kg. (Chuang, Chueng, Navin de Silva, Juvonen, Singh, Woo, 2003)

4 Case studies

Table 4-1 list several data of El Hierro and Flores islands, reflecting characteristics influencing renewable energy technologies implementation.

Table 4-1 Case studies general data

		El Hierro	Flores
Geografy	Area (km ²)	268.7 ¹	141.7 ²
	Costal length (km)	105.50 ¹	not available
	Height (m)	1,501 ³	915 ⁴
	Depth	4,924 ⁵	1,500 ⁶
	geological origen	volcanic	volcanic
	Population	gross	10,162 ^{1c}
per km ²		37.82 ^{9b}	27,7 ^{12a}
annual growth		1.6 % ^{9c}	
Climate	average temperature (C°)	20.4 ⁷	17 ⁴
	pluviosity (mm)	170 ⁷	not available
	humidity (%)	75 ⁷	77 ⁴
	solar radiation (hours/year)	2,339 ⁷	not available
	wind conditions	steady, predominant north-east ¹⁴	not available
Economy	Primary sector	4.6 % ^{9a}	8.6 % ^{10a}
	Secondary sector	20.0 % ^{9a}	16.9 % ^{10a}
	Tertiary sector	75.4 % ^{9a}	74.5 % ^{10a}
	Electricity sector/Secondary sector	4.3 % ^{9a}	15,2 % ^{10a}
	Unemployment	4,9 % ^{9a}	3.6 % ^{2d}
European Union	Status	ultraperipheral island	ultraperipheral island
	Regional development cathegory	Objective 1 ¹³	Objective 1 ¹³
UNESCO		Biosphere reservoir	
Energy		Independent Grid ¹¹	Independent Grid ⁸
	Consumers	5641 ^{1a}	2,194 ^{8a}
	Production (GWh)	25.8 ^{1a}	8.7 ^{8a}
	Peak load (MWh)	not available	1,632 ^{8a}

1. ISTAC www.gobiernodecanarias.org/istac/

2. INE Portugal www.ine.pt

3. <http://www.canario.net/islas/elhierro/>

4. <http://www.destinazores.com/>

5. <http://home.pi.be/~p4u00071/canarias/canorig-esp.html>

6. <http://www.minerva.uevora.pt/eschola/acoresh/olhar.htm>

7. Instituto Metereológico Nacional (1973-2000) <http://www.inm.es/web/index.html>

8. Monteiro Da Silva, Jose Manuel, EDA (n.d.) The prospect of renewable energy sources in the Azores islands. Presentation [handed out]

9. Elaborated based on information of the ISTAC

10. Elaborated based on information of the INE

11. ENDESA http://www.endesa.org/porta/corporate_integrity_rules/portada.asp?url=/portal/es/default1.asp&idioma=es&

12. SREA <http://srea.ine.pt/>

13. EU: <http://europa.eu.int/scadplus/leg/en/lvb/g24203.htm>

14. <http://www.mgar.net/mar/alisisos.htm>

* Regional data

a. 2001

b. 2002

c. 2003

d. 2004

As mentioned before El Hierro and Flores are, both, considered small islands belonging to an archipelago. Both islands achieve a considerable height in a small area. This reduces the number of available locations for big solar or wind farms, but increases the opportunity of kinetic energy storage through water dams. Hydropower, in the conventional sense, is limited to the rainfall. As such no economic potential exists at El Hierro, but considerable one on

Flores.¹⁰⁸ Biomass potential, regarding wood residues, forestry residues or even energy crops will be very limited due to economic reasons, as the islands' orography will lead to high extraction costs. The best arable land obviously will be kept for the actual uses, much more profitable and very relevant for the island society. Water scarcity on El Hierro leads to high water prices and competition among alternative uses. This has also a considerable impact on the economic feasibility of energy crops for biomass.

The depth among the islands of both archipelagos is considerable; as a consequence no grid connection is feasible among them. An increased grid size would allow an easier compensation of intermittency effects in the renewable energy electricity generation. With increased number of locations and available renewable resources exploited; lacking production on a specific side could be compensated by the increased production on another. The depth also limits the possibility of off-shore wind-farms and certain ocean energy applications.

As located in the Atlantic Ocean, ocean energy exists, but again due to its depth, actually its exploitation possibilities are technically very limited. As exploitation possibilities are fully site-specific, studies, that haven't been undertaken on none of the islands, should show the real potential use of this energy source. The conventional tourism activity could be in conflict with such kind of exploitation, as the coastal area is often the more tourism intensive and free skyline represents a significant part of islands attraction.

Both islands have a volcanic origin, for which geothermal activity exists. No study has been undertaken on El Hierro regarding the real potential of this energy source, but on Flores its lower enthalpy than in the nearby island of Terceira, as it smaller electricity demand, doesn't allow its exploitation for electricity generation.¹⁰⁹ The option of using it for heating and cooling purposes has not been considered, but could be an appropriate measure to reduce or at least stop electricity demand increases to cover these energy services.

The islands are not dense populated, especially if compared to the main islands in the archipelago. In both cases the emigration trend to the main islands or to the mainland has stopped. Actually their population on El Hierro has been growing. This reflects in an increasing electricity demand.

Concerning their climate, several differences exist between these two islands. Flores has a considerable rainfall, which supply an enormous hydropower potential. El Hierro needs from water desalination to cover its water need, increasing additionally its electricity demand.¹¹⁰ Flores is often clouded, reducing the solar radiation and the possibility to exploit this energy source. El Hierro contrary has high number of sun hours.¹¹¹

Heating and cooling needs are significantly low; first because of their latitude, second because of oceans' buffering effect on climate, which moderates summer and winter temperature compared to mainland situations at the same latitude.

Both islands have a good wind potential, but El Hierro has a more constant availability of this resource thanks to the "Alíseos", north-eastern winds, which blow all the year round from the

¹⁰⁸ Monteiro Da Silva, J. M., EDA (n.d.). The prospects of renewable energy sources in the Azores islands. Presentation.. Handed out by EEG.

¹⁰⁹ Estrela, D.L.R. (June) E-mail to Beatriz Medina Warmburg

¹¹⁰ Espinosa Padrón, C. (June) Telephone Interview.

¹¹¹ Schallenberg Rodriguez, J. C. (23/09/04) E-mail to Beatriz Medina Warmburg

Tropic of Cancer to the Equator. Flores suffers under very variable, often strong winds, sometimes even too strong, affecting negatively wind farms maintenance.¹¹²

The islands society, following the trend of developed countries, has evolved into a service society through out the years. As a result around three thirds of their GDP has its origin in the service sector. Tourism plays an important role, but not alone: services provided by the public administration represent also a significant part, especially if considered in relation to the existing population. The electricity sector is one of the major components of the industrial activity, representing, in Flores case, more then 15% of the GDP produced within the sector. In the Canary Islands the electricity company is the major industrial activity and the second company regarding its turn over.¹¹³ The agriculture sector means a relatively small percentage of the GDP, but, in both cases, it is a crucial activity for the island society, as providing noteworthy employment and exports. It is a consolidated sector.

Regarding their status in the EU both are ultra-peripheral islands. Due to their comparatively low GDP they are classified as objective 1 of Europe's regional development policies. This means that their GDP is below 75% of the EU average GDP. As a result special funds for regional development projects, as renewable energy technology projects represent, are available for both islands.

4.1 El Hierro (Canary Island, Spain)

The UNESCO declared El Hierro Biosphere Reservoir in January of 2000. The local island government, Cabildo de El Hierro, as including a 100% renewable energy source project in its sustainable development plan¹¹⁴, has been the main promoter of this project. Other relevant actors supporting and enhancing it are Canary Islands' electricity company, Unión Eléctrica de Canarias (UNELCO), Canary Islands' technological institute, Instituto Tecnológico de Canarias (ITC), and the regional government, Gobierno de Canarias.

The actual and expected future electricity system on El Hierro will now be described and analysed.

4.1.1 Actual state

4.1.1.1 Demand

The island economy has passed from a mainly primary sector depending economy to depend mainly on the service sector.

The agriculture sector was concentrated on a few crops, being their markets strongly affected through EU's and World Trade Organization (WTO) requirements to reduce barriers for free trade. As such some exclusive markets were lost. This affected negatively El Hierro's economy. Nevertheless, the island government decided to support this sector promoting a diversification of the export agriculture, the local cattle and fishing industry. Nowadays, El Hierro has a stable and strong agriculture sector, but which has been mostly degraded to a secondary family activity.¹¹⁵

¹¹² Estrela, David L.R. (September) Telephone Interview.

¹¹³ Energía de España, S.A. (ENDESA) (2002) Actividad de UNELCO Endesa en Canarias. Press release: 22 march 2002. Available: [Online] <http://www.endesa.es/Portal/portada?url=/Portal/es/prensa/noticias/default.htm&idioma=es&> [2004, 7 July]

¹¹⁴ The sustainability plan was made official in 1997. OPET island, Renewable Energy For Europe-Campaign for Take-off. (2001) Renewable energy partnership declaration: El Hierro Island Biosphere Reserve 100% RES Supply. [Online] Available: <http://www.islandonline.org/opet/pdf/EIHierroform.pdf> [2004, 7 October]

¹¹⁵ Espinosa Padrón, César (June) Telephone Interview.

At the same time, increase services were offered at island level. The health care system and public administration, for example, were reinforced and many services were created. Regional government investments to reduce the inequity among the minor and central islands enhanced also other commercial, building and services activities.¹¹⁶ This is also the main reason why the island has past in the last decades from a depopulation trend to steadily increase its population. During the period 1985-1995 1,684 persons immigrated to the island.¹¹⁷ Nowadays, around 25% of the employees are working for the administration.¹¹⁸

The tourism industry has also grown. In its growth, contrary to most of the other Canary Islands, a sustainable tourism industry has been developed. This is mostly due to its much later development, but also on the kind of tourism activities that can be offered, with high emphasis on rural or “alternative”¹¹⁹ tourism.

All these have meant a shift from low electricity using activities to more electricity consuming activities: But it has been the population growth, as the growing electricity services demanded by this population, which has finally lead to an impressive electricity demand growth. Reflected in figure 4-1, the electricity demand in El Hierro grew with an annual average of 7.1% from 1996 to 2003¹²⁰. Comparatively, the average growth in the Spanish mainland has been around 4%.¹²¹

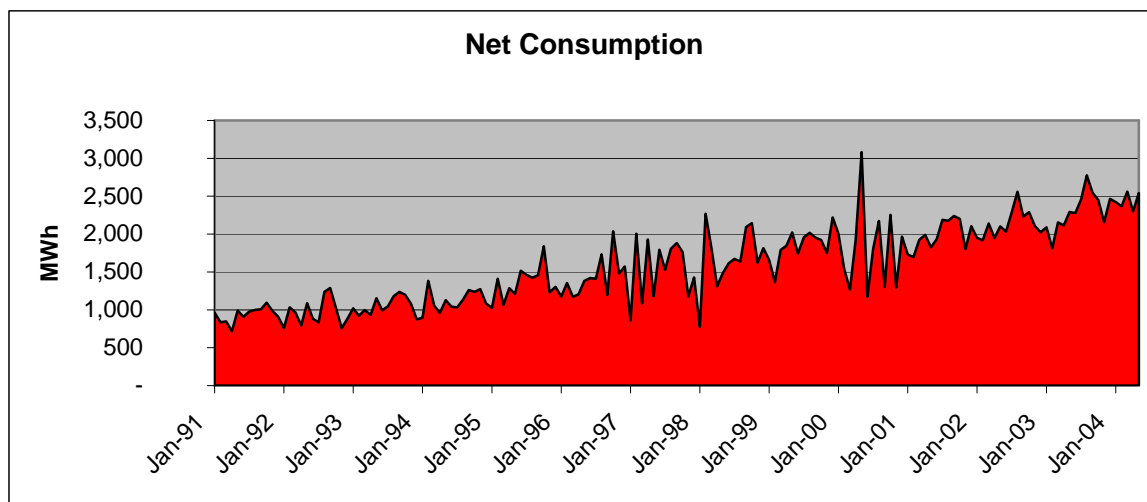


Figure 4-1 Monthly electricity consumption evolution on El Hierro Island
Data Source: ISTAC [2004]

Figure 4-2 shows the electricity demand regarding the end-consumers at Canary Island level: As the highest electricity consuming industrial activities are located on the major islands of the archipelago, Tenerife and Gran Canaria, the proportion, which the industrial sector represents

¹¹⁶ Espinosa Padrón, César (June) Telephone Interview.

¹¹⁷ Instituto Nacional de Estadística (INE-Spain) [Spain’s National Statistical Institute] (2004). [Online]. Available: <http://www.ine.es> [2004, 19 July]

¹¹⁸ Espinosa Padrón, César (June) Telephone Interview.

¹¹⁹ Contrary to the mass tourism offered in the other islands, El Hierro tourism activities try to attract tourism through enhancing the island heritage, local cultural, nature, preserving traditional activities that out of the tourism activities has lost their meaning.

¹²⁰ Based on data of the Instituto Canario de Estadística (ISTAC) [Canary Islands’ Statistical Institute] (2004). [Online]. Available: <http://www.gobiernodecanarias.org/istac/> [2004, July 10].

¹²¹ Padrón, J.L. (July) Telephone Interview.

in El Hierro's energy consumption, must be understood as significantly smaller. As an example, the petrol refinery and cement factory electricity consumption represents 3%¹²² of the whole electricity consumption. These activities are not present on El Hierro. As such the electricity consumptions of the industrial sector will be less than 6%.

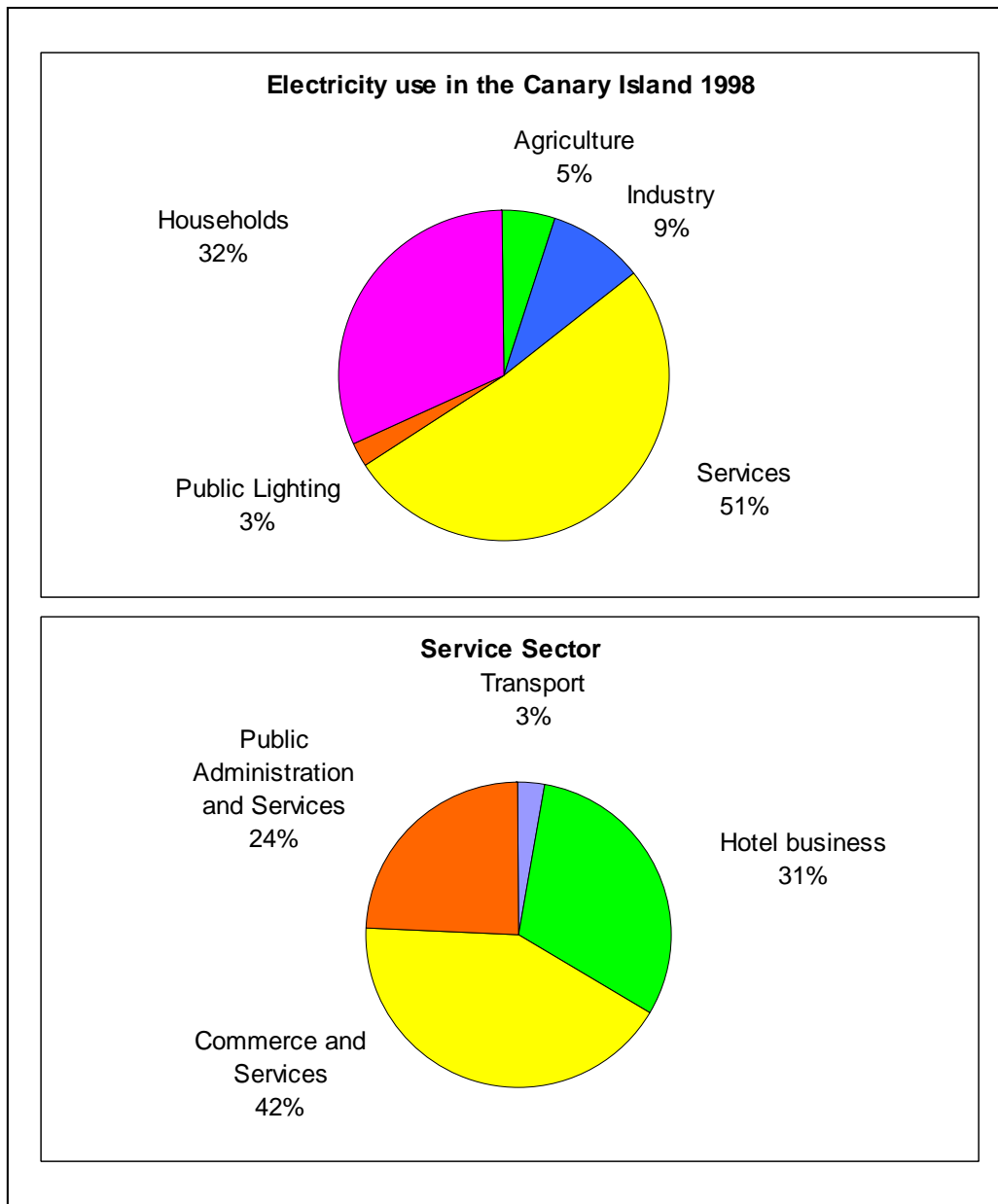


Figure 4-2 Electricity consumptions per end user in the Canary Islands
Original data source: ISTAC [2004]

Regarding the distribution of the service sector electricity consumptions among the different activities within this sector, taken into account the above-mentioned smaller impact of the tourism activity on El Hierro, this activity causes fairly smaller electricity consumption than for the average Canary Islands. Based on official data about the numbers of beds assigned to this activity, 864 beds were declared in 2003 on El Hierro, which represents 0.08 beds per capita. Canary Islands average is around 0.21, achieving in islands as Lanzarote a ratio of 0.6.¹²³

¹²² Based on data of the ISTAC (2004)

¹²³ Based on data of the ISTAC (2004)

As a result of the significantly smaller electricity consumption of the tourism sector, the weight of the service sector regarding the overall electricity consumption will be also diminished.

The transport sector assigned small proportion of the service sector electricity consumptions is only the electricity consumption consequence of its administrative work. All the transportation is based on trucks, buses or cars, and therefore 100% on fossil fuels. No railway, metro or tramway exists actually on any island. The introduction of these transport alternatives is not foreseeable on El Hierro given its small dimension, small population and complex orography.

Mr Juan Luis Padrón, Director of UNELCO on El Hierro, quantifies households’ electricity consumption around 50 percent of the total electricity demand on El Hierro.¹²⁴ Therefore, an increased importance has to be given to the electricity use in households.

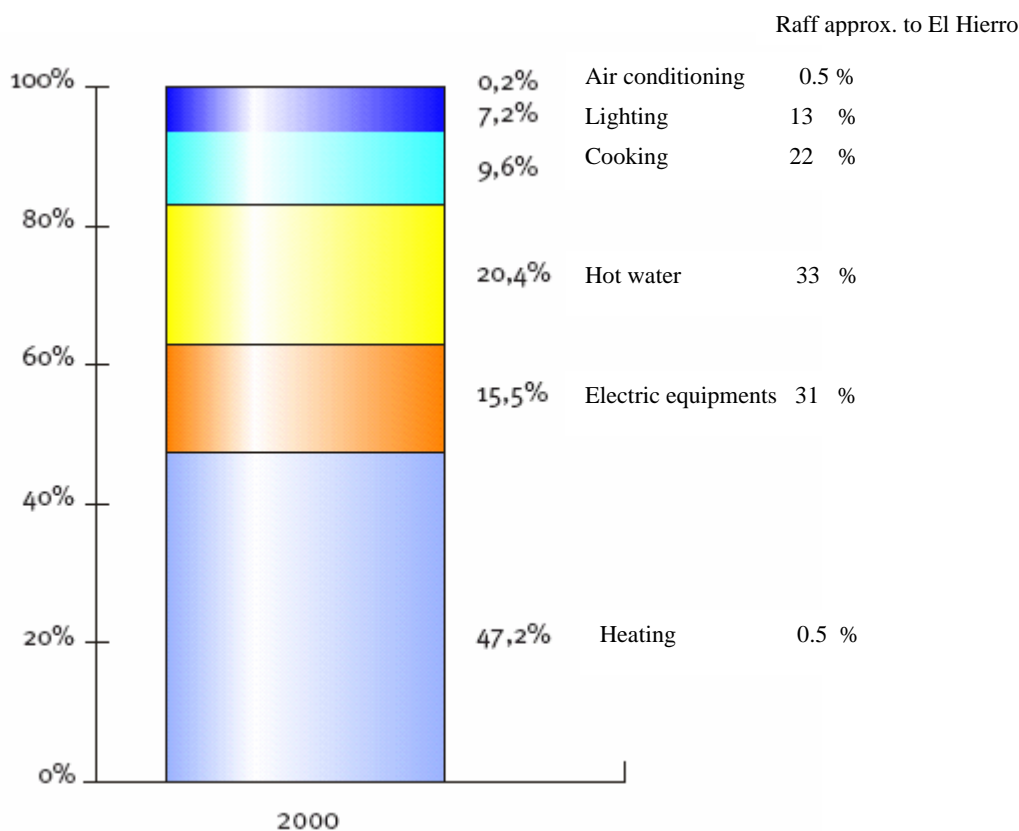


Figure 4-3 Distribution of the energy consumption in Spanish households

Source: IDEA (2004)

Figure 4-3 represents the energy services demanded by Spanish households. Obviously, there is a difference between households’ energy and electricity demand, as electricity is just one energy carrier and other energy carriers can also provide the same requested energy services. At Canary Island level, due to the electricity demand characteristics, existing distribution networks of alternative energy carriers, which enhanced the comfort of using electricity, energy and electricity demand for households are quite matching. Based on Figure 4-3, one of the main energy services provided by other energy carriers is heating. This factor can be ignored for El Hierro circumstances. Due to the climate conditions heating requirements will

¹²⁴ Padrón, J.L. (July) Telephone Interview.

be around the same then cooling needs and these will not be higher than the ones in the continental Spain, with cold winters and hot summers. Considering additionally, the lower water heating needs¹²⁵ and higher number of solar hours, resulting in lower lighting needs, the estimated shares mentioned together to Figure 4-3 reflect probably better El Hierro's reality.¹²⁶

Regarding the ordinary electricity services required by households, the growth in the electricity demand is mostly consequence of an increased number of electronic equipments use per households. The introduction of washing machines and televisions had initially the biggest impact among this kind of equipments. Nowadays it is the increase switch from gas to electricity to cover hot water and cooking needs, especially due to the use of vitro ceramic hobs.¹²⁷ Computers are not very introduced at household level in a population where in 1996 more than 56% of the population was classified as low to low-medium income, and where in 2001 over 72% of the population didn't exceed the basic school education, with up to 3.2% illiteracy¹²⁸

Another main reason for electricity demand to grow lately above 9 percent is consequence of growing water scarcity. In order to cover the increasing water needs from households, two seawater desalination plants have been installed and groundwater is pumped to surface. The water distribution system requires additional electricity for pumping due to the islands height. Traditionally, households on El Hierro are very linked to the rural activities with orchards for self supply. These orchards need irrigated during dryer periods, consuming additional electricity, for pumping and groundwater extraction. As a result 3 percent of the electricity demand growth is directly linked to households water needs. Two percent can be linked to energy loses in the upgraded power capacity of households, given their increased number of electric appliances.¹²⁹

All the above-mentioned considerations are reflected in the tendency the electricity intensity of El Hierro follows, as observable in Table 4-2. Nevertheless the average electricity intensity El Hierro is more than 1/3 smaller than the average Canary Island data. One reason for this is, in a certain manner, the lower industrial and tourism sector.

Table 4-2 Average electricity consumption per consumer

kWh/Costumer-Year	1997	1998	1999	2000	2001
Canary Island	5,897	6,130	6,308	6,532	6,864
El Hierro	3,750	4,008	4,213	3,976	4,221

Base data: ISTAC [2004]

Another characteristic to be analysed regarding the electricity demand is its daily and seasonal behaviour. As its daily behaviour doesn't vary much regarding the general description given in Chapter 2, only the seasonality will be commented.

¹²⁵ Hot water represents 1/3 of the electricity bill, regarding the PROCASOL brochure promoting Solar heating for hot water consumption. (Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Instituto Tecnológico de Canarias (ITC) (n.d.))

¹²⁶ The hot water requirements could represent a significantly lower proportion.

¹²⁷ Padrón, J.L. (July) Telephone Interview.

¹²⁸ Based on data of the ISTAC (2004)

¹²⁹ Padrón, J.L. (July) Telephone Interview.

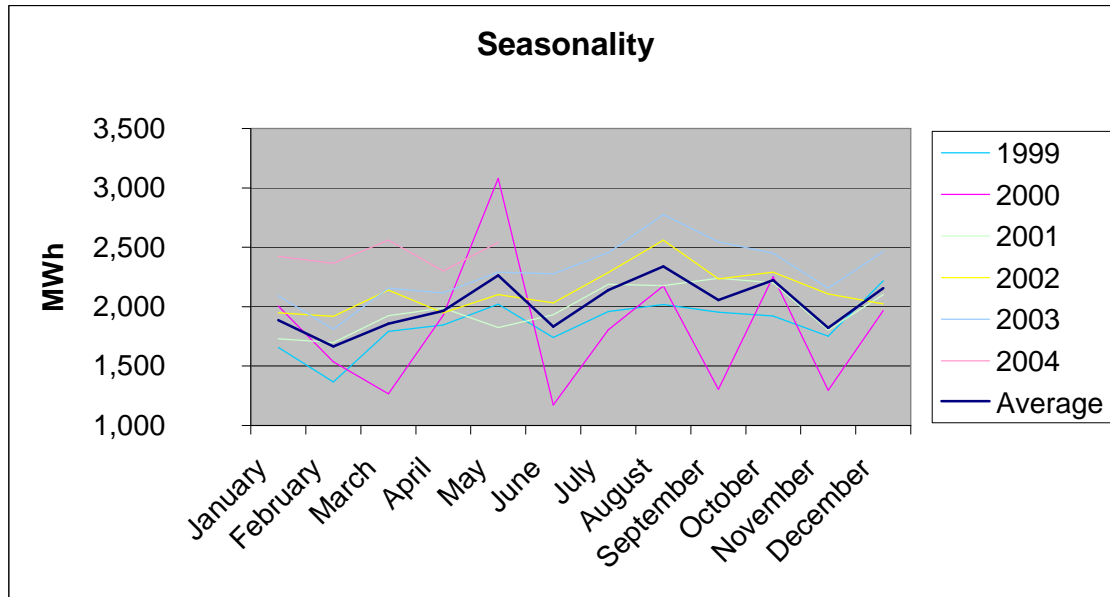


Figure 4-4 Monthly electricity consumption behaviour 1999-2004
Data source: ISTAC [2004]

As located near the Tropic of Cancer, its climate attracts tourism the whole year round, but the possibility of alternative destinations concentrates the demand against winter and spring seasons. Nevertheless, the electricity demand is not so affected by seasonal effects as other more highly touristic islands. Even though, the periods of highest electricity consumption are linked to holiday periods as August and Christmas, but because of a particular kind of tourism: population from the bigger islands commutes to their ancestor houses, as regional tourism is generally also increased.¹³⁰

The other peaks that can be observed in Figure 4-4, ranking from March to May and October, are linked to irrigation needs of the agriculture sector. Depending on the rainfalls of the year, the pineapple and banana plantations need to be irrigated from March on until May in order to assure their productivity. In October other crops are planted to grow throughout the more humid winter months. Water is required to assure its growth until the rains starts. Once more, water scarcity leads to pumped groundwater and irrigation systems, which especially increases the electricity demand during these periods.¹³¹ In general, the water needs of the island increments drastically the overall electricity demand.

4.1.1.2 Supply

Three are the actually energy sources used for electricity production on El Hierro: fossil (diesel fuel), wind and solar. A pig farm produces biogas of its residues, which only assures its self supply.¹³² As such this production can be ignored.

The photovoltaic installation, with 6.5kW capacity,¹³³ was originally planned to be connected to grid, but hasn't been due to technical difficulties. As the scope of this work is limit to grid

¹³⁰ Padrón, J.L. (July) Telephone Interview.

¹³¹ Padrón, J.L. (September) Telephone Interview.

¹³² Espinosa Padrón, C. (September) Telephone Interview.

¹³³ European Commission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro (2003) *Basic design of the system (wind hydro power station)* Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

connected RES exploitation, a deeper look onto this option will be undertaken when looking on El Hierro’s renewable energy future.

Figure 4-5 reflects the evolution of the electricity production connected to grid and the contribution of the existing wind farm and diesel plant to its achievement.

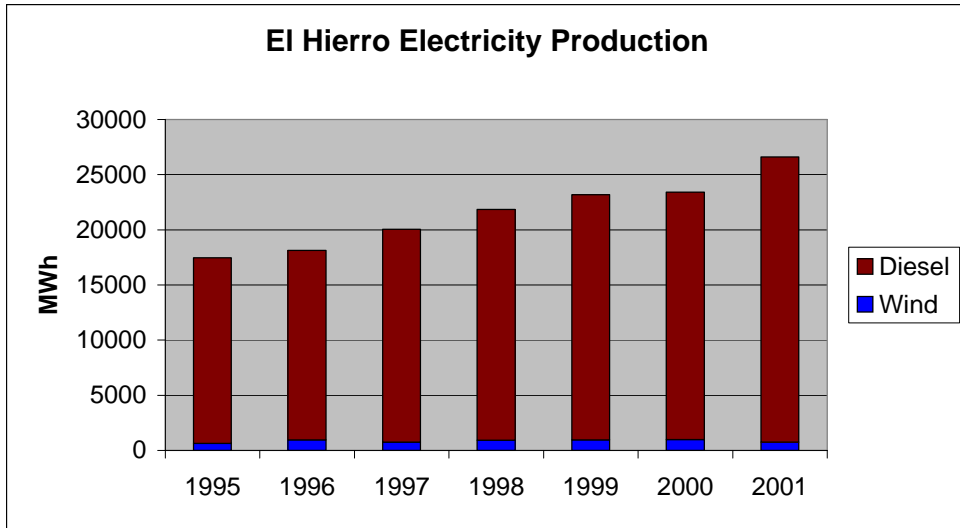


Figure 4-5 Electricity production evolution regarding the used energy carrier
Data Source: ISTAC [2004]

The wind farm of 280 kW of capacity, thanks to an average wind speed of 8.8 m/ s, achieves an annual production from 760 to 1000 MWh, depending on the specific efficiency achieved by the different wind mills.¹³⁴ That means that despite wind availability technical problems did sometime not allow its harvest. This can be observed, when comparing Figure 4-6 and 4-7: wind availability and electricity production. In September and January, for example, the production was must less than the existing exploitable energy.

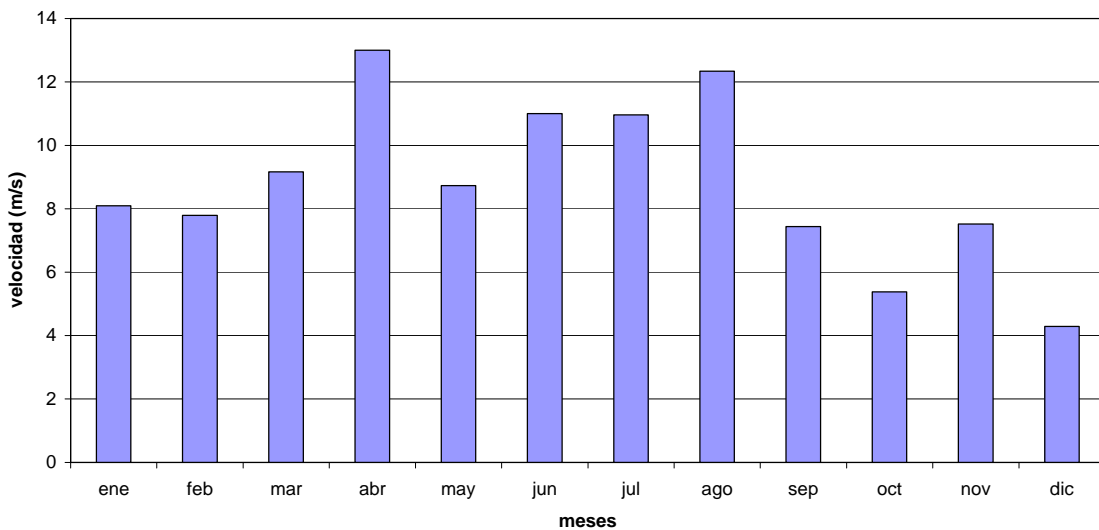


Figure 4-6 Wind speed on the island of el El Hierro for 2001
Source: European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro (2003)

¹³⁴ European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro (2003) *Basic design of the system (wind hydro power station)*

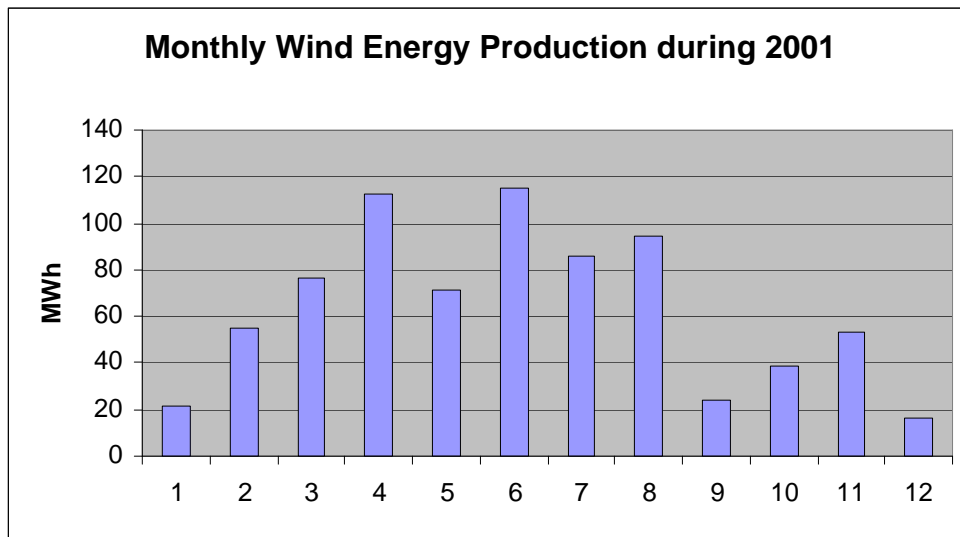


Figure 4-7 Monthly wind production distribution

Data Source: *Consejería de Industria del Gobierno de Canarias [2004]*

No real growth of the wind production can be observed. To establish a new wind farm a license from the regional government must be obtained. The *Consejería de Industria del Gobierno de Canarias* [Industry Department of Canary Islands Government] hasn't handed out such licenses for over 10 years. The argument has been that an initial study of the wind potentials within the island had to be undertaken. Given the widely demand exceeding wind potential existing on the Islands, rationality in its harvest through optimal locations will lead to minimize investments, the negative impacts of wind farm, as the soil surface needed (a specially relevant aspect within island context, where land is a scarce resource).¹³⁵

The thermal-diesel plant of 10,015 kW capacity¹³⁶ consists in 9 diesel engine¹³⁷, fed with imported crude, treated in the refinery on the nearby island of Tenerife into the required diesel-oil. *Distribuidora Industrial, S.A. (DISA)*¹³⁸, the petrol company, and UNELCO are both together responsible to keep a fuel storage on the island to cover, the by law required, 25 days of electricity consumption.¹³⁹ Diesel-oil is combusted, producing vapour, moving turbines which generate electricity.¹⁴⁰ The annual fuel consumption has been in 2002, 6,184 tones¹⁴¹ and during 2003 7,178 tones¹⁴², which reflects the significant impact actual electricity demand increase has on the fuel consumption.

¹³⁵ Schallenberg, J. (June) Personal Interviews

¹³⁶ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) *Nuevos Vientos para la Isla de El Hierro* [New Winds for El Hierro Island] Brochure Handed out by ITC.

¹³⁷ European Commission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro "Basic design of the system (wind hydro power station)" (2003) Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

¹³⁸ *Distribuidora Insular Sociedad Anónima (DISA)* (2004) [Online]. Available: <http://www.disa-corp.es/>

¹³⁹ Padrón, J. L. (July) Telephone Interview.

¹⁴⁰ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) *Nuevos Vientos para la Isla de El Hierro* [New Winds for El Hierro Island]

¹⁴¹ ISTAC (2004)

¹⁴² Espinosa Padrón, César (cespinosa@el-hierro.org) (July) E-mails to Beatriz Medina Warmburg (Beatriz.Medina@iiiee.lu.se)

The adjustment of the production to the electricity demand fully relies on the control of the diesel engines' electricity generation. The electricity is then distributed to the end-customer throughout a 15 kV grid.¹⁴³ The final supply system provides actually a higher supply security than in continental Spain, representing a worldwide excellence regarding isolated systems.¹⁴⁴

4.1.1.3 Electricity market

Regarding the ownership of the production system, the diesel plant is owned and managed through UNELCO II¹⁴⁵, who also controls the grid. UNELCO was a local public company originally established to handle the electricity market in the Canary Islands. In the liberalization process, consequence of Spain's integration to the EU and the thereby requested adaptation to its policies, an increased competitiveness within the electricity market through disconnecting electricity generation and distribution was required; UNELCO has become a private company, owned 100% by the Spanish multinational Energía de España, S.A. (ENDESA), as it has formed two subsidiaries: UNELCO II, for its electricity generating activities and UNELCO I for its electricity distributing activities.

The wind farm is managed by ENDESA Cogeneración y Renovables¹⁴⁶, another filial company of ENDESA multinational¹⁴⁷. As a consequence, the wrong impression of a competitive market situation hides a highly centralized decisions making process within the same company: ENDESA. An example of how the holding influences individual company decisions is the one taken, when deciding about the wind turbines actually being used in the existing wind farm. The turbines acquired were produced by a company, at that moment, part of the holding; disregard other technically more convenient alternatives. Actual exploitation problems seem to be related to this issue.¹⁴⁸

When looking upon the Spanish electricity market, two different regimes exist:

- The regime which controls the open generation market, and
- The so-called especial regime, which is a specific framework introduced to promote renewable energies.

Their implication on the island energy market is different within regimes. In general the electricity prices in the generation market are established at national level by the Compañía Operadora del Mercado Español de Electricidad (OMEL), the Spanish electricity market operator. OMEL matches the expected demand for a defined period with the supply the different generators offer to provide considering their individual production costs.¹⁴⁹ The price the distributor acquires the electricity, as the price the end-consumer pays, are annually established through a Royal Decree. The tariff works, regarding the distributor and end-

¹⁴³ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro [New Winds for El Hierro Island]

¹⁴⁴ Energía de España, S.A. (ENDESA) [Energy of Spain] (2002) *A ctividad de UNELCO Endesa en Canarias*. Press release: 22 march 2002. [Online] Available: <http://www.endesa.es/Portal/portada?url=/Portal/es/prensa/noticias/default.htm&idioma=es&> [2004, 7 July]

¹⁴⁵ See Appendix 2.2: UNELCO-ENDESA

¹⁴⁶ ENDESA (2002) *Actividad de UNELCO Endesa en Canarias*.

¹⁴⁷ Energía de España Sociedad Anónima. (ENDESA) (2004) [Online] Available: http://www.endesa.org/portal/corporate_integrity_rules/portada.asp?url=/portal/es/default1.asp&idioma=es& [2004, July 15]

¹⁴⁸ Schallenberg Rodriguez, Julieta C. (June) Personal Interviews

¹⁴⁹ Operadora del Mercado Electrico Español (OMEL) (2004). [Online] Available: <http://www.omel.es/> [2004, 18 October]

consumer relationship, as maximum electricity prices. It takes into account the previous year generation market electricity prices, which should reflect the average production cost of electricity. The tariff varies depending on the end user, the power required, the consumption level reached, etc., but being unique for whole Spain with in these categories. This is granted thanks to the constitutional right of non-discrimination, which leads to create same access conditions to electricity.¹⁵⁰ As a consequence, a certain additional cost added on the tariff exists.¹⁵¹ Therefore, all Spanish consumer pays an additional amount, known as “Compensación Extrapeninsular” (Out-Spanish mainland compensation). These amounts build a fund to be distributed, based on their annual production cost declaration, among all non-Spanish-mainland electricity systems: Canary Islands, Balearic Islands, Ceuta and Melilla.¹⁵² As this compensation is always paid with an annual delay a financial cost has also to be added to these remote electricity systems.

Figure 4-8 simplifies El Hierro electricity market. If UNELCO would act as an individual player in the generation market, due to its increased cost the final electricity price of the market as decided at national level, would never cover its cost. UNELCO is forced to cover the demand of the end-consumers, which leads in actual El Hierro’s conditions to production cost above 9 c€ per kWh¹⁵³, being 2002’s the average electricity price obtained in the Spanish generation market of 4.57 c€. ¹⁵⁴ As such, UNELCO would always run on losses. Under these considerations the compensation system assures the system to work.

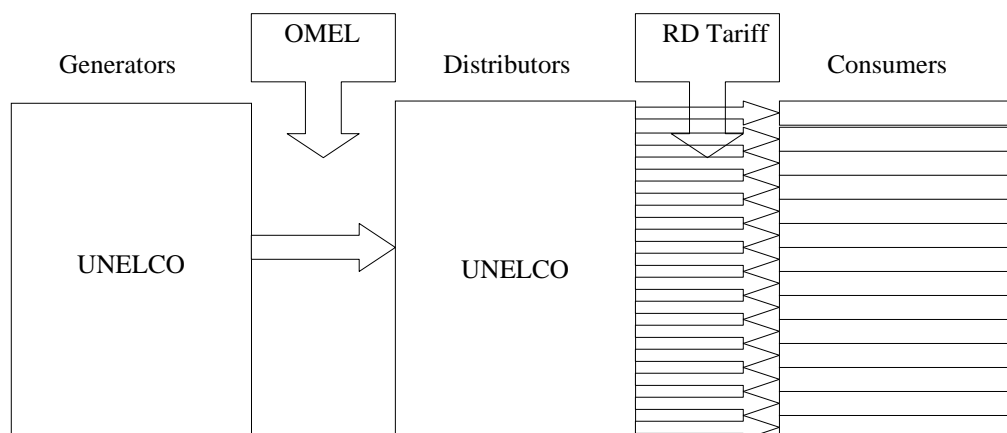


Figure 4-8 El Hierro’s electricity market

UNELCO’s internal policy is limited to minimize production costs, considering each island’s individual production function, depending on their electricity demand and the generation technologies present on each island. It is ENDESA Generación, at national level, who will follow a benefit maximizing policy, acting strategically in the generation market. UNELCO’s

¹⁵⁰ ENDESA (2002) *Actividad de UNELCO Endesa en Canarias*.

¹⁵¹ Ministerio de Economía [Ministry of Economy] “Real Decreto 1802/ 2003, de 27 de diciembre, por el que se establece la tarifa eléctrica para 2004” [Royal Decree 1802/ 2003, of 27 of December, through which the electric tariff for 2004 is established”] Boletín Oficial del Estado [BOE – State Oficial Bulletin] n°310, pg 46,239-46,253.

¹⁵² Small Spanish territories in the African Continent

¹⁵³ Padrón, Juan Luis (September) Telephone Interview.

¹⁵⁴ Instituto para la Diversificación y Ahorro de la Energía (IDEA) [Institute for Energy Diversification and Saving] (2004) *Boletín IDAE n°6* [Online] Available: <http://www.idae.es>

decisions at local level are, therefore, very limited, being ENDESA's headquarters the ones taken the strategic decisions.

As declared by ENDESA in a press release regarding UNELCO's activities on the Canary Islands, the additional market risks of these island systems are link to:

- the lack of specific regulations
- the timeframe between the additional cost that companies have to have and the payment of the compensation systems which allows to maintain the unique electricity tariff system, and
- the infrastructure cost of the archipelago.

This increased risk has a negative impact on the development of the electricity sector.¹⁵⁵

Regarding the distribution market, as mentioned before, is regulated by a tariff system. As these small and isolated electricity systems don't profit from nuclear power production in the mainland, distributors and consumers of these systems don't have to contribute to an additional payment linked to the phase out of nuclear power. Distributors of these systems are also exempt of paying their proportion of the "Compensación Extrapeninsular".¹⁵⁶ Considering, additionally, the reduced added value tax applicable in the Canary Islands, the end-consumer electricity bill is somewhat smaller on the islands than on continental level. This small benefit has been declared as not against the non-discrimination principal, mentioned above, as taken into account the other existing costs of insularity.

When looking on the price evolution of the generation market during recent years, no specific trend can be found. Passing from a regulated to open market situation should have increased competition forcing the prices down, but several other influences, as increasing fuel prices has probably compensated such effects. Although with one-year delay, the tariff prices should react on the electricity generation prices, but tariff setting includes also other cost components, which had increased the end-consumer electricity bill through out the years. Such costs are related to market and system operating cost, as the above mentioned, "Compensación Extrapeninsular" and nuclear power phase out costs. A significantly increasing share of the system costs is linked to the increasing share of renewable energy and the market regime established to promote them.¹⁵⁷

Regarding how the electricity markets treats electricity produced from RES, three systems has been design at governmental level,¹⁵⁸ within which the renewable energy generator has to choose. All of them have the same common rule of privileged access to the distribution system. The generator has thereby assured sales of the whole production. Only one regime is actually really being applied, result of generators decisions. This regime will be the one addressed from now on as the especial regime, regulated by the Royal Decree (R.D.)

¹⁵⁵ ENDESA (2002) *Actividad de UNELCO Endesa en Canarias*.

¹⁵⁶ Ministerio de Economía, R. D. 1802/2003

¹⁵⁷ Ministerio de Economía (n.d.). La tarifa eléctrica para el 2004 [The electricity tariff for 2004] Presentation [Online] Available:

<http://mderecho.itam.mx/cursos/materiales/cursos/CURSO%20DE%20ESPECIALIZACION/matcurso/modulo%205/Dr.%20Jorge%20Fabra%20Utray/LA%20TARIFA%20ELECTRICA%20PARA%20EL%20A%DIO%202004.ppt>

¹⁵⁸ For more information: Reich, Daniel (2002) *Handbook of Renewable Energies in the European Union*, Frankfurt am Main: Peter Lang, Europäischer Verlag der Wissenschaften, chapter about Spain, pg. 211 –226.

436/ 2004, actualizing the earliest R.D. 2818/ 1998. The generator within the especial regime has to choose in advance among to price setting models:

- Tariff price: established annually through R.D. based on a percentage of the previous year electricity prices.
- Free market price: where a bonus is added on the electricity market price.

With growing electricity prices the second option is more profitable than the first one, with decreasing electricity prices the first one is more profitable than the second one. The decision on which system to choose should therefore be taken based on the expected electricity prices trend. Nowadays the expectations are that the prices will continue growing, consequently the second scheme should be chosen.

This system allows the costs of introducing these new technologies to be within the electricity market. As mentioned above, the price tariffs for the distributor and end-consumer are established taken into account the additional cost of the renewable energy promotion. As such renewable energy promotion is paid finally by the electricity consumers.

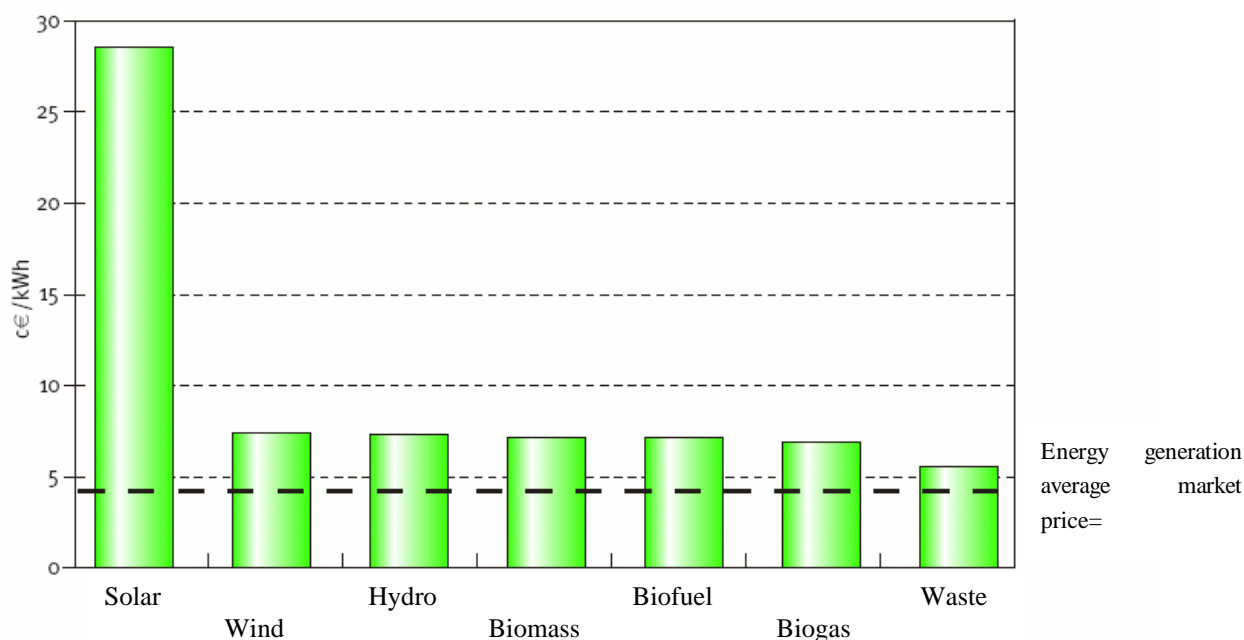


Figure 4-9 Spain's renewable energy prices in 2002
Source: IDAE (2004)

The figure above shows the average prices for energy produced from RES. The different renewable energy sources get different bonus considering the national objective established for one specific niche market, but also considering the different cost related to the different exploitation technologies available. As an example, special attention is been given to the production of electricity from solar energy. Even though the higher technology costs, Spain's high solar potential has lead to establish an even higher electricity price with the intention of enhancing investment in the sector, enhancing a more rapid market growth, reducing future cost thanks to technological development and learning curves effects, but also achieving a pioneer position in the international solar energy market. As the amount of the bonus is reviewed annually, prices will adjust considering the cost reduction of the new technologies, thanks to learning curve and growing markets effects, but also the achievement of the established policy objectives of promoting one or the other kind of RES. In this sense, a decrease in the amount of the bonus has to be foreseen in a long-term perspective.

These prices are the same for mainland and non-mainland producers.

As mentioned before, the conventional electricity generation cost on El Hierro are above 9c€/ kWh. In this environment, the renewable energy use is mostly cheaper for the electricity market system than the conventional energy production. Only the solar energy production is in actual circumstances more costly.

4.1.2 100% RES plan

4.1.2.1 Demand

In order to assure a future sustainable electricity system based 100 percent on renewable energy sources the main factor to predict and control has to be the electricity demand. This becomes especially crucial if the growth follows the below-observable trends. The demand has been growing far more than the average growth at national level, not to say regarding EU level, where the average growth of the final energy demand has been 1 percent.¹⁵⁹

Two statistically feasible growth scenarios have been considered as analysing the actual growth trend: A linear and a logarithmic growth.¹⁶⁰ Based on them, the demand could lay between 37.000 and 48.500 MWh annual electricity consumption in 2010. If compared to 2003 annual consumption of 27.500 MWh, it represents an overall increase of 35 to 76% in a 6 year period, ranking the annual average growth from 8 to 11 percent. Obviously, such a growth trend is fully unsustainable.

¹⁵⁹ Reich, Daniel (2002) *Handbook of Renewable Energies in the European Union*

¹⁶⁰ See Appendix 3

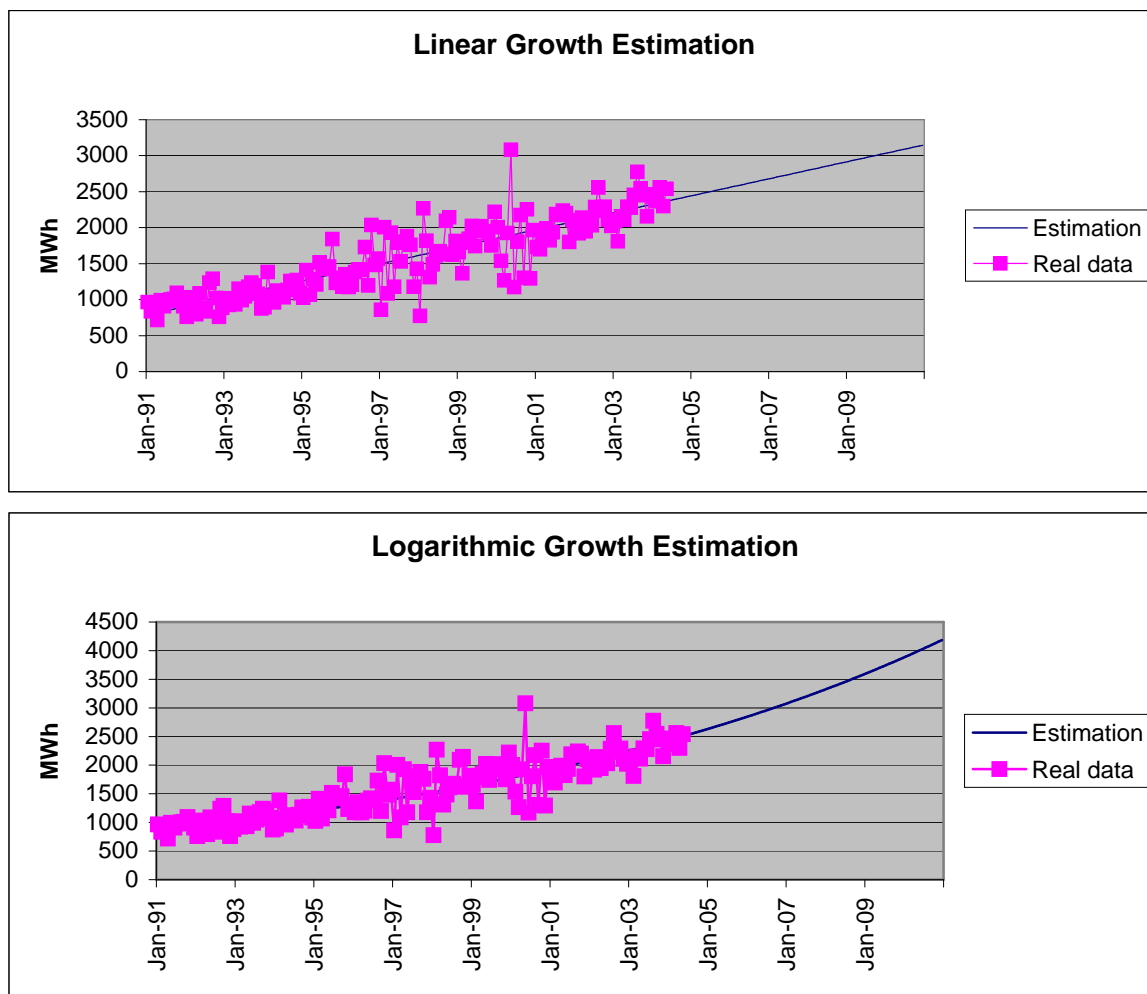


Figure 4-10 Electricity demand growth trends scenarios on El Hierro Island
Data source: ISTAC [2004]

In this sense, several future demand scenarios has been analysed, based of a smoothening of the growth slope. The results can be observed in Table 4-3. Assuming that the demand will later or sooner break the actual growth trend as awareness campaign, energy saving measures and alternative energy generation for providing certain services have their effect different slopes has been considered. Obviously, as sooner a considerable break of the trend is achieved, as more relevant will the effect on the final demand be.

Table 4-3 Future demand scenarios for El Hierro

MWh	Demand Growth Slope					
2004	9.86					
Demand	28,583.47	28,583.47	28,583.47	28,583.47	28,583.47	28,583.47
	Demand Growth Slope					
2014	9.86	4	4	2	2	1
Demand	42,775.48	34,729.93	34,729.93	31,981.93	31,981.93	30,607.93
	Demand Growth Slope					
2054	9.86	4	1	2	1	1
Demand	99,543.55	57,769.93	42,055.93	43,501.93	39,175.93	36,367.93

Identifying reasons behind the actual growth, as potential causes of future growth, is a priority, and of extreme relevance. Once these causes have been identified actions to control its growth or reduce its impact on the electricity demand have to be found and applied.

Reasons to expect a further increase of El Hierro's electricity demand rely on:

- The expected further growth of the island population;
- The lower energy intensity than in Spain's, EU's, and even Canary Islands' average, although it should always be above them, given its smaller industrial sector and less energy intensive tourism sector;
- The still considerably lower use of electric appliances in households than in average Spain and EU;
- The effects of the, recently approved Island Sustainable Tourism Plan¹⁶¹, which hopes to double the number of beds offered, passing from 2000¹⁶² to 4000 beds;
- The expected further growth of water needs, given the expected population and tourism growth.

Four of them are related to the already highly relevant households' electricity consumption. Acknowledging it, El Cabildo de El Hierro, has established several actions under the 100% RES plan of El Cabildo de El Hierro, to achieve a strong public awareness about energy saving measures. The awareness campaign aimed at administrative, political and end user level, but also focus on training courses for electricians providing them with the required know-how on installation and maintenance of new technologies.¹⁶³

In order to reduce the electricity requirements from the grid the focus has been put in promoting solar thermal installation for hot water. The use of an electric water heater in a four member's family represents 2,500 kWh annually, around 1/3 of their whole electricity requirements if living on El Hierro. 4 square metres (m²) solar panel can substitute it.¹⁶⁴ In 1997 the Canary Island Government initiated the PROCASOL program. Financial helps are given through a fix subsidy per m², a subsidy on the interest rate for the required investment or a combination of both. Another advantage of this program is the risk reduction of implementing an unfamiliar technology, as all installations are done under technical supervision of the ITC.¹⁶⁵ Actually 425 m² solar thermal collectors have been installed. The campaign hasn't achieved the objective of 500 m² established for its first four year period. The main barrier identified among others is the lack of qualified installers and maintenance services on the island. In a renewed campaign, within the frame of a European Commission DG Tren Program this program has been now reinforced with the above mentioned awareness campaign, hoping to achieve the establishment of 500m² within the period 2004-2007.

¹⁶¹ Espinosa Padrón, César (September) Telephone Interview.

¹⁶² Data provided by Cesar Espinosa, based on the Islands Government estimation of legal and illegal accommodation.

¹⁶³ European Commission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro "Description of the improved grid connected PV funding/ financing programme on El Hierro" Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

¹⁶⁴ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro

¹⁶⁵ Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Instituto Tecnológico de Canarias (ITC) (n.d.) PROCASOL - La energía solar térmica: Una opción económica y ecológica para producir agua caliente.

Nevertheless, the achievement of the goal imposed in this second phase of the PROCASOL program means a demand reduction of something more than 1%. The potential market for hot water installations has been estimated in 2559 m² of solar panels.¹⁶⁶ This represents potential electricity savings of 1,599 MWh/ year.¹⁶⁷ Considering for 2014, a constant growth of the population at the actual trend and the achievement of the Sustainable Tourism Plan, the savings would reach 2,699 MWh yearly. With actual population growth considered until 2054, the savings would reach around 3,334 MWh/year.

Juan Luis Padrón identified another major risk of electricity demand increase. The average temperature on El Hierro has been growing, the purchasing power of the population has also increased, and the cost of the cooling systems has been sinking. Future peak demands could be link to high temperature periods. 100 air conditioners require 500 kW power, according to Juan Luis Padrón. This would lead to a 10% increase of the actual islands capacity requirements. On characteristic of the hot temperature periods in the Canary Islands is that they are relatively short but quite extreme, as they are linked to effects of South-East Sahara winds. This would foreseeable lead to peak demands for very short, somehow foreseeable periods. The need for air conditioners could be reduce, as it can actually be observed regarding heating requirements, through improved construction quality, improving isolation and building properties. Another alternative would be the introduction of heat pumps, which would allow cooling in hot temperature moments and heating in winter. The introduction of such technology regarding population awareness is quite easy, as the use of caves as housings is part of the traditional construction culture on the Canary Island and the beneficial effects of subsoil as temperature regulator is generally know and accepted.

Other electronic equipments like dryers and computers could also increase the demand, as their actual average per household is far below the Spanish mainland and European standards. Thanks to the climate conditions and households customs the introduction of dryers seems be less an issue then in other environments.

4.1.2.2 Supply

The long-term feasibility of a 100% renewable electricity system will also rely on the existing potential of each of the renewable energy sources available. Its technical potential will increase based on the technical development within renewable electricity generation technologies. The economic exploitation potential will increase based on several factors, as RES promotion policy measures, through reduction of existing market barriers, production cost reduction through mass production, etc. The particularities of each RES imply a whole frame of individual circumstances which influences the economic potential of each particular RES. As such every action influencing these variables positively will increase the economic potential of the RES it's associated to. Tables 4-4 to 4-6, show estimations of biomass, wind and solar technical potentials for El Hierro Island.

Table 4-4 Estimated Technical Biomass Potential on El Hierro

¹⁶⁶ Households 1.024; Tourist sector 115; Swimming pool heating 1420; European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro “Description of the solar thermal energy awareness campaign on El Hierro”

¹⁶⁷ 500 m² could suppose a demand reduction of 312.5 MWh a year. Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro

	TEP/year	kW
Biomass Potential	4.256	1.391
Cattle residues	82	27
Agriculture residues	600	196
Forestry	2.517	823
Cultivation ¹	1.038	339
Organic matter in MSW	19	6

1. Weighted proportion of the estimation done for the whole Canary Islands regarding El Hierro's surface

Source: ITC, Subiela (2004)

When looking upon the economic potential of different biomass estimations, high extraction and transport costs, given El Hierro's orography, could reduce significantly the figures. When it comes to cultivation, the high water cost, result of its scarcity, could lead to a final production cost which makes doubtful the economic exploitation of energy crops. Generally acknowledge barriers for biomass use, as non-existence supply markets, are foreseeable on El Hierro. Another aspect to consider is that different biomass resources could require different electricity generation technologies. If the potential feasible for a certain technology is not enough to assure the economic exploitation of this technology, certain sources of biomass could not be exploitable or require specific biomass imports. If so, the advantage of energy self-reliance is discarded, as ones again money flows out of the region. In one or the other way, in actual market circumstances the economic potential of biomass is very limited.

No explicit shares has been assigned to biomass production in El Hierro's 100% RES electricity generation scheme. Only a study of the biomass supply potential has been undertaken. Furthermore, the need to cope with energy requirements for transport need, does foresee its application for biofuel production, with no electricity generation purposes.

Actions have been planned related to waste problems, as animal residues or sewage water sludge, which treatment is meant not only to produce biogas, but to avoid environmental damage. It is still an unanswered question if this would be use for electricity generation, just self-supply by the farmers producing it or to supply energy to isolated houses out of the grid connection, which actually are basically relying on small fossil fuel motors to cover their electricity needs.¹⁶⁸

The waste management plan of the island is very linked to the Canary Islands on, strongly centralized on the island of Tenerife. Following EU's directive, waste separation for recycling is a must. Actually only glass is being recycled at Canary Island level. Remaining recycling material is first shipped to Tenerife and than to the mainland. A high cost is implicit to these activities.

The only landfill of the island of El Hierro has been closed. A study regarding the possibility of extracting biogas out of it has been undertaken. As not build for biogas extraction, given the existing dry climate, slow decomposition and bacterial activity little hope has been given on its future exploitation.¹⁶⁹

Table 4-5 Estimated Technical Photovoltaic Solar Potential on El Hierro

¹⁶⁸ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro

¹⁶⁹ Espinosa Padrón, César (September) Telephone Interview.

	kW	GWh/year	Solar radiation (kWh/m ²)
PV Solar Potential			
Energy conversion efficiency factor 6	124.751	1.751	1.852
Energy conversion efficiency factor 20	124.751	5.836	1.852

1. Weighted average of measurements taken by the ITC in both municipalities regarding the population living in each of them
2. Considering 50% of the flat roof area: 30 m² per capita (Dirección General de Ordenación Territorial, Consejería de Obras Públicas y Medio Ambiente: Plan insular de ordenación territorial de la isla del Hierro)
3. Considering 1,200 kWh/kWp (source: IDAE- "instalaciones de energía solar fotovoltaica, menos de 5kW, conectada a red")
4. Considering 2,339 hours/year (source: Instituto Meteorológico Nacional (1973-2000) <http://www.inm.es/web/index.html>)

For the calculation of the above listed solar energy potential, only PV-roof exploitation has been considered. If accounting the use of PV fields, the potential is much higher, but more difficult to estimate, as alternative uses of soil compete for space. It is also true, that the above mentioned PV potential shares its surface and consequently its potential with thermal applications for heating and hot water uses.

The actual high PV cost seems at the moment to be economically covered thanks to the measures undertaken by the national, regional and local government. Especially the two latest actions at national level have improved considerably the economic figures for such kind of installations: First, the price paid for electricity produced by small installations has past from 36.06 c€/ kWh to 41.44c€/ kWh, but what is more relevant, the concept of small installations includes now installations up to 100 kilowatt peak (kW_p), previously limited up to 5 kW_p.¹⁷⁰ This has lead to promote the establishment of a cooperative for a 100 kW_p PV field in the region with the highest solar radiation of the Canary Islands: 5.2 peak hours. The previously established objective of achieving 50kW_p production connected to grid¹⁷¹ will just be covered by this installation, representing 0.5% of the actual electricity demand.¹⁷²

Even though the PV roof application for self supply is technically feasible, reducing electricity demand from the grid, the PV market price leads to grid connection. When self-supply the consumer has a cost saving of, average consumer tariff price, but if connected to the grid he will gain 41.44c€/kWh produced, paying 8.2 c€/ kWh for his consumption.

Also at national level, a soft loan up to 70 percent of initial investment can be obtained for such kind of installation.¹⁷³ At regional level the PROCASOL has been considered to be adapted to PV requirements.¹⁷⁴ In any case, at local level, PV promotion takes advantage from the, for solar thermal designed, awareness campaign and, somehow, from the capacity building programme for such installations.¹⁷⁵

¹⁷⁰ New electricity price established by the Royal Decree 436/ 2004. European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro "Description of the improved grid connected PV fundind/ financing programme on El Hierro" Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

¹⁷¹ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro.

¹⁷² Based on data of Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro.

¹⁷³ Specific requirement for such instalations are listed under: Confederación de Consumidores y Usuarios (CECU) (2004) Incentivos y medidas fiscales http://www.cecuc.es/index_marcos.htm (Temas de interés/ Medioambiente/ Proyecto información RES & RUE energías limpias/ Dossier técnico/Incentivos financiero y medidas fiscales)

¹⁷⁴ Schallenberg Rodriguez, Julieta C. (June) Personal Interviews

¹⁷⁵ European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro "Description of the improved grid connected PV fundind/ financing programme on El Hierro" Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

In general, the high initial cost of solar electricity installations will more rapidly recovered at Canary Islands level, than in mainland level due to the generally higher solar radiation. In this sense the Canary Islands should be a preferred destination for PV investors.

Table 4-6 *Estimated Technical Wind Potential on El Hierro*

	kW	GWh/year
Wind Potential	143.000	715

Original data source: Schallenberg E-mail (2004)

Wind energy exploitation on El Hierro has proven its economical feasibility in actual market circumstances. Its high potential itself assures the actual and future feasibility of the 100% RES established for El Hierro. The problem is to create an electricity system able to deal with its intermittency.

Given El Hierro's huge wind potential its 100% RES plan has to rely on it. Canary Islands particular constant wind conditions allows, based on a study undertaken by the University of Las Palmas de Gran Canaria, a stable wind penetration up to 30%.¹⁷⁶ If higher wind penetration is to be achieved an energy storage alternative is required: A hydropower plant has been identified as the solution. This is the starting point of the wind-hydropower plant project which should cover 70 percent of the actual electricity demand. Basically the project combines a wind farm and a hydropower plant. The innovative part of the project is linked to the water supply for the hydropower plant. As actually the caption of rainwater doesn't even cover the islands actual demand, the hydropower plant must rely on two water reservoirs of 225,000m³ capacity, one at sea level and another at 700 meters. The water is pumped up to the upper reservoir with the energy provided by the wind farm and recovered when released to the bottom reservoir. The wind farm will probably not be connected to the grid; it will be the hydropower station the one to provide the electricity to the grid. This system considers energy losses due to energy conversions, but wins in stability, avoiding the conventional problem of high wind penetration.

In order to reduce the investment requirements, the system will be pumping or releasing water, avoiding the need of a penstock.¹⁷⁷ Also the investment in the upper tank will be considerably lower as taken advantage of an existing crater which only has to be waterproofed. The water storage capacity achieved assures covering the actual full electricity demand during 7 windless days. As the actual legislation foresees energy storage on the island for full electricity consumption of 25 days in order to assure the island's electricity supply, or well the legislation must be adjusted to the new system or further storage capacity will have to be installed.

A desalination plant is also considered in the project, as evaporation of the stored water has to be replaced. It is still under study if one of the actual desalination plans will cover this demand or a new one has to be added. In any case the need of desalinated water has implicit a further energy efficiency reduction of the whole system.

¹⁷⁶ Piernavieja, G., Pardilla, J., Schallenberg, J., Bueno, C. (2003) El Hierro: 100% RES – An innovative Project for islands' energy self-sufficiency *International Conference RES for Island – Tourism and Water*. 26-28 May 2003, Azores. Handed out by Instituto Tecnológico de Canarias [Canary Islands Technological Institute].

¹⁷⁷ Piernavieja, G., Pardilla, J., Schallenberg, J., Bueno, C. (2003) El Hierro: 100% RES – An innovative Project for islands' energy self-sufficiency

The wind-hydropower station is expected to provide 17,300 MWh, while an additional grid connected wind farm is expected to provide 9,800 MWh:¹⁷⁸ A higher direct wind-electricity feed into the grid will increase the energy efficiency of the whole system. The real sensibility of the system to increased wind penetration will have to be studied to achieve the highest penetration in an optimal stability level. This is one of the main technical studies to be undertaken ones the system starts to produce.

The initial objective established in the plan was to achieve 75% of RES penetration during 2005. Administrative barriers, as that until this year no further licences for wind farm installations were handed out, as the slow negotiation among the project partners about the structure and property of the company which will manage the wind-hydropower station, has been the main reasons for the delay.

Basically the final aim is to cover 70% of the electricity production through the wind-hydro power station, to achieve an increase of the biomass and solar use up to 5% and to cover the remaining part directly through wind energy. All these actions should lead to a 100% electricity system based on renewable energies. The final proportion covered by each renewable energy source will depend very much on individual actions of investors, consumers as from the governmental support to these activities.

Meanwhile the actual electricity generation plant is considered to provide the necessary backup if the wind doesn't provide enough energy to the system.¹⁷⁹ The ultimate phase-out of the plant hasn't yet being considered, as the reliability of the system must first be proven. The light diesel import is supposed to be reduced to 6 tones, ones the wind-hydro power station is working. A possible substitute fuel for this support system could be hydrogen, especially when taken into account fuel needs of the transport sector. Synergies among hydrogen, produced from local RES, to cover islanders' transport needs as to supply an additional electricity storage system should be studied.

A final reason, mentioned worth, for the existing positive environment for RES in the Canary Island, beside the fiscal releases related to RES investments, applicable at whole Spain, is the need of apply the Reserva de Inversiones en Canarias [RIC - Reserve for investment in the Canary Islands]. This reserve allows Spanish companies to get a total tax release on the applied quantity. Up to 90% of its net benefit can be applied while compromising its future investment at Canary Island level in a 5 year period. A further argument for local companies to invest in RES project could be allows them risk diversification, while assuring a solid electricity system needed for their businesses.

4.1.2.3 Electricity market

A new company to be established will manage the wind-hydropower station. This company, "Gorona del Viento", will be owned 60% by the island government, El Cabildo de El Hierro, 30% by UNELCO and 10% by ITC. The negotiation among the two main participants regarding the share each of them should control has been one relevant factor delaying the project. The high initial investment required as the need to assure the electricity distribution forces El Cabildo de El Hierro to negotiate with UNELCO, who has until now controlled the electricity system. The reasons given by El Cabildo de El Hierro to keep the control on the project has been the need of assuring a proper management of the electricity produced, as assuring a proper service to the island community.¹⁸⁰ El Cabildo de El Hierro's limited funds

¹⁷⁸ Piernavieja, G., Pardilla, J., Schallenberg, J., Bueno, C. (2003) El Hierro: 100% RES – An innovative Project for islands' energy self-sufficiency

¹⁷⁹ Padrón, Juan Luis (July) Telephone Interview.

¹⁸⁰ Espinosa Padrón, César (June) Telephone Interview.

call for capital investors. UNELCO provides not only this capital but technical knowledge of the existing system. If not participating in this project UNELCO would lose later or sooner its whole position in El Hierro's electricity market. ITC provides additional R&D know-how. El Cabildo had to agree upon a future cession of 10% of the capital to private investors. These private investors are meant to be local companies, which could profit from the tax releases linked to RES investment, apply the RIC funds, as diversifying their activity.

Considering the additional RES supplies addressed in the previous paragraph, the island's electricity market will change drastically breaking down the actual monopoly, changing the major electricity generation to a kind of public good and increasing the self-reliance of energy. Figure 4-11 shows a possible future market scenario.

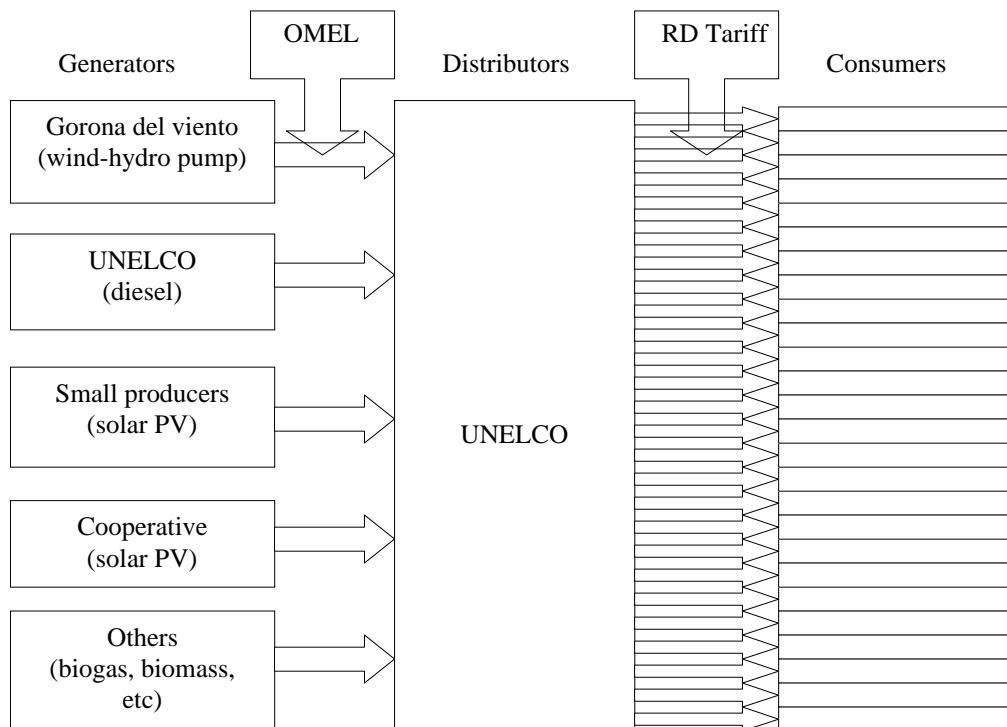


Figure 4-11 Possible future energy market scenario on El Hierro Island

One of the major questions regarding the new system is who is going to control it. Technical aspects of the distribution system will gain relevance and the stability of the system will suffer under an increasing number of suppliers feeding the grid.

RED ELÉCTRICA, part of ENDESA's group, is who handles electricity transport in the Spanish mainland. Summer 2004 it also took over this kind of activities at Canary Island level. On El Hierro no electricity transport activities exist, as understanding such as medium, high and very high tension distribution grids. Nevertheless, given RED ELÉCTRICA's established by law independence from producers' and distributors' decisions, considering only technical issues of the distribution net, RED ELÉCTRICA could be an interesting actor to be involved in the future system, providing technical adaptable knowledge. Another alternative would be the distributor UNELCO I to take this kind of decision, but this would limit the freedom in the distribution market, creating a barrier to new incomers, nowadays lacking. If UNELCO I would take over these decisions a conflict between supply security and economic excellence is very likely to happen; economic aspects would affect considerably more in the decision taking process.

A further option would be the generators taking these decisions as a trust. This option means a complex and therefore probably slow decision problem, which surely would show up in a worse final service. It also has an increased risk of individual actions, as for example, feeding additional electricity to the grid, which would disestablish the system. RED ELECTRICA mission is defined to be to manage the operation market: identifying and solving problems resulting of the agreed transaction of the production market, as it handling the distribution and control of the grid. Tension control, back up and automatic start ups are additional services provided¹⁸¹. Taking over these functions on El Hierro will reduce the risk of a system failure, as the decision taker is an independent actor, not profiting from the end decision, but from a working system: supplying a proper electricity distributing service.

One of action the chosen actor will surely have to address is the grid adaptation to the upcoming system. He probably will have to adapt the system control programs. In this sense, RED ELÉCTRICA has already adapted its system used at national level to islands characteristic for their operations at Canary Island level.¹⁸² RED ELÉCTRICA uses an adapted MORE CARE (2001) control system, program elaborated at EU level for isolated areas and island systems, based initially designed CARE control system, but considering now higher RES penetration.¹⁸³ This system will also have to be adapted to a full RES penetration. In this sense, RED ELÉCTRICA has a good initial tool to define how much of the energy produced by wind energy can be feed directly as electricity to the grid or provided from the hydropower station, with higher stability but lower conversion efficiency.

A fundamental change to be addressed is the adaptation of the actual legal framework ruling the electricity market. This system creates several questions regarding an electricity system based 100% on RES. One main action required is the annulment of the privilege grid access rule existing for RES. This rule only has sense when other energy sources are being use. If the network is forced to take over all the electricity produced from renewables, as a certain overcapacity has to be considered, an overproduction fed into the grid system would create considerable problems. The system could buy this excess electricity production to be stored and used in scarcity moments, but this would require from considerable storage capacity adapted to overproduction. As a consequence, the system costs will rise: First due to the investment in storage units, second, due to the high RES price paid to the producer, which provides unnecessary electricity. This, on the islands, excess electricity production would not help to achieve Spain's commitment with Kyoto and EU's 12%RES objective. Even more, as a result of the often better economic figures achieved on the island an RES investment shift from certain mainland projects could occur. If not adapting to special regions condition, the Special Regime will require more time and higher costs to achieve its objectives. The path to a higher RES penetration will be achieved under an unnecessary cost, profiting a few producers, paying all electricity consumers.

It is true that other policy tools, as licenses, can rule the access to new producers, but how these tools are going to be used has to be clear from the beginning if policy instruments, small PV installations promotion campaigns, are to succeed.

¹⁸¹ Red Eléctrica de España (2004). El sistema eléctrico español - síntesis [Spain's electricity systems – Sinopsis][Online] Available: http://www.ree.es/apps/index_dinamico.asp?menu=/cap07/menu_sis.htm&principal=/cap07/sintesis-2.htm [2004, 15 September]

¹⁸² Red Eléctrica de España (2004). El nuevo modelo eléctrico en Canarias. Operador del sistema y gestor de transporte. [The new electric model on the Canary Islands. System operator and trasport manager.] In El nuevo modelo eléctrico en Canarias, November, 2004, Las Palmas de Gran Canaria.

¹⁸³ Developed for Crete and Madeira Islands within the framework of an EU project. Pecas Lopes, J. A. (jpl@fe.up.pt) (2004, July 14) *Information requirement for master thesis* Email to Beatriz Medina Warmburg (Beatriz.Medina@iiiee.lu.se)

As decision on grid input will have to be taken first on technical stability constrains based on forecasted availability of the different sources, but at the same time minimizing the economic cost of the systems, given the actual market frame, several conflicts appear:

Just disregarding the privileged grid access rule the, at national level fixed, RES electricity prices would lead to exclude automatically PV electricity production from the market. If this technology wants to be promoted, this problem has to be addressed as soon as possible. Investors in an, at least 50 years life-time project will not like such uncertainties regarding future incomes and, consequently, on its final pay-back. Such problems will affect to all more costly renewable electricity productions. A fully new pricing model should therefore design for this specific case.

The need of a local adapted electricity regulation, already acknowledge by the Canary Islands electricity market actors, has now significantly increased. Even the regional energy strategy, action plan established until 2010, which should be the starting point to create specific energy regulation considering Canary Islands characteristics and peculiarities within the Spanish energy regulation, is actually another barrier. When stated in 2002, this document establishes a 12% limit to wind penetration. Considering that the licences for wind farms are based on this data, the study undertaken by the University of Las Palmas de G.C., which concludes system stability with up to 30% wind penetration, as the further wind farm requirements considered in El Hierro's system, call to change this limit.

As identified in chapter 3, one of the economic potentials of energy storage relies on taken advantage of the price fluctuations in the electricity market pool. In the actual circumstances, if the energy stored is produced from RES and sold like this, no price fluctuation exists. Actually, wind and hydro electricity production have the same market price and it is fixed. To store the electricity instead of feeding it into the grid provides no benefits, but losses: the amount of electricity that can be gain back after storing is smaller than the initially stored, and will therefore provided less revenue. In this sense, certain compensation to the wind-hydropower plant will have to be design. Given the volatility of electricity produced from the other RES to be harvest, the wind-hydropower plant will have to assume to produce in each moment only the electricity required to cover the remaining demand; it will probably be the tool used to control the electricity supply. As such its electricity production level in each moment will never depend on economic reasons. The wind-hydropower plant should be compensated for the ancillary service it will be providing. If not, and even though, other storage alternative would probably be required.

Based on this, a whole new compensation system has to be designed in order to cover the cost of handling, controlling and managing the electricity system. The problem gains in complexity when taken into account, that if the final electricity cost is higher than the actual production cost, the final islander electricity consumer will only pay a small part of the increased electricity production cost, as this increase will be assumed by all Spanish electricity consumers. At the moment too many uncertainties regarding market aspects exist. This implies a high risk when approaching investments.

4.1.3 The three dimensions of sustainability

4.1.3.1 Social dimension¹⁸⁴

The first impact such a pioneer project has socially is the increase of the island reputation. The effect of this increased reputation has several aspects. In a scientific level the island becomes an example for further implementation of such kind of projects. The acquired know-how

¹⁸⁴ Padrón, Juan Luis (July) Telephone Interview.

becomes an asset, which properly managed, can be source of new business opportunities, qualified employment and income, representing a chance of social and economic development with any remarkable environmental impact: a sustainable development.

Related to tourism, especially the kind of tourism which the island government tourism strategy addresses, alternative tourism, this project could become a competitive advantage when comparing to other alternative tourism destinations.

This project also represents an investment opportunity for small and medium enterprises of the island. Investment diversifying leads to reduce business risk, creating more stable business, assuring their actual and future development, which reflects in social wellbeing.

Regarding the island community itself, this project has meant a general acknowledgement of energy problems. As such the first step to implement energy saving measures at individual and collective level is achieved: Awareness. This social impact will hopefully lead to break the actual electricity demand trend.

When it comes to the health aspects, as no studies regarding the effects the actual electricity production has been undertaken, no quantitative results about the positive effect this project can be given. The location of the pollutants' emitting plant and the strong predominate winds make foresee no considerable direct impact on human health. Nevertheless, as the project represents a significant reduction of the islands pollutant emission, a benefit should be accounted.

Juan Luis Padrón foresees an initial duplication of the employees directly linked to the electricity production. The new plant will require new specialised employees, while the employees of the actual plant have to continue their activities. In a long-term the number will decrease around the actual number. The real opportunity to increase the number of employees of the electricity sector relies on the RES diversification, mainly solar thermal and PV applications, but also small wind farms. While the equipments will come from overseas the maintenance services should be assured locally. As addressed previously, one of the barriers to the increase PV and solar thermal applications has been the lack of local qualified suppliers/ installers and maintenance services.¹⁸⁵ Growing demand for such installation will assure suppliers to provide them, generating employment in this field. The actual biogas project, undertaken by the municipality has had no effect on the number of employees, as all the required function could be cover by the municipality staff. Employment could race if the biogas project is to be developed further. Nevertheless, actually it represents a more efficient use of the existing resources.

4.1.3.2 Environmental dimension

The environmental benefit of a 100% RES electricity production on such an island is fully related to the avoided impact of the fossil fuel use. These benefits aren't limited to the avoided pollutant emissions when burning the fuel, but also all negative impact related to its transport, refinery and extraction process. Even locally the benefits are more then only the emission avoidance, as spilling during its unloading, storing and distribution is also avoided, as the risk of accidental damage.

¹⁸⁵ European Comission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro. (2003). Description of the improved grid connected PV fundind/financing programme on El Hierro.

Only the wind-hydropower plant, supposed to cover 70% of the electricity demand reduces the fuel consumption in about 8,791 tons/ year, which means avoiding 30,548 tons/ year CO₂, 174 tons/year SO₂ and 633 tons/year NO_x a year.¹⁸⁶

As any project, negative impacts are also generated. The negative impacts related to the life cycle of the new equipments can be seen as equitable to the ones which the actually used technology generates. As such no considerable difference exists.

It is the location of the upper reservoir and the pipes to the hydropower plant, which accounts for the worst negative impact of this project, as located in a protected area. The impact of the pipelines can be quite avoided through putting them underground and restoring the natural cover of the area. When it comes to the upper reservoir, the benefit of choosing the crater for it represents an impact minimizing option, when compared to building a whole upper reservoir. The visual impact of the upper reservoir is fully avoided.

When studying the PV solar potential only roofs has been accounted as exploitable areas, as such no negative impact can be associated to its location. In the PV cooperative case, the impacts are related to visual impacts, as to possible ecosystems disturbance as reducing the solar radiation to the ground, affecting the flora and through it to the local fauna.

4.1.3.3 Economic dimension

Table 4-7 shows a cost analysis for the new wind-hydropower plants. It shows the cost if the electricity generated by the wind farm and pumped to the upper reservoir covers 70% of the actual demand, or if this plant grants by itself the full supply. This latest scenario is only a theoretical scenario, being highly energy inefficient and therefore implying an unnecessary overcapacity. Energy efficiency is won just by feeding the electricity generated from wind energy directly into the grid. Thanks to these two scenarios, the effect of an increase in the wind energy penetration on the required wind farms investment is shown: If the share of wind energy penetration can in a supply assuring sense be increased the investment needs for wind turbines decreases drastically. The economic figures of the 100% scenario can also be reduced significantly by increasing the water storage capacity, reducing the investment requirements for the wind farm.¹⁸⁷

Table 4-7 Investment cost related to the wind-hydropower plant

¹⁸⁶ Piernavieja, G., Pardilla, J., Schallenberg, J., Bueno, C. (2003) El Hierro: 100% RES – An innovative Project for islands' energy self-sufficiency. *International Conference RES for Island – Tourism and Water*. 26-28 May 2003, Azores.

¹⁸⁷ European Commission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro. (2003) Basic design of the system (wind hidro power station).

Investment cost	Covering 70% of the demand	Covering 100% of the demand
Wind farm	10,670,000 €	83,457,000 €
Hydraulic Turbines	3,948,000 €	3,948,000 €
Pumping Station	1,884,000 €	4,675,000 €
Upper reservoir	1,271,000 €	1,271,000 €
Lower reservoir	3,853,000 €	3,853,000 €
Desalination plant	311,000 €	311,000 €
Total	21,939,000 €	97,516,000 €

Source: European Commission, DG Tren, Contract N°:NNE5-2001-00950:100%RES-El Hierro (2003)

Table 4-8 shows the results of an economic feasibility study made by the ITC, considering no demand increase as any electricity price variation, considering 2003 data. This study proves the project to be profitable, but with no big margin. This figure doesn't reflect the real benefit of the project.

Table 4-8 Economic feasibility study of the wind-hydropower plant

Economic feasibility study	
Overall investment cost	23 - 25 M€
Directly used wind energy electricity produced yearly	9,800 MWh
Hydropower electricity produced yearly	17,300 MWh
Estimated yearly income due to wind energy 0.062806€/ kWh	615,500 €
Estimated yearly income due to hydropower 0.063827€/ kWh	1,104,200 €
Estimated yearly income	1,720,000 €
Exploitation costs related to the production level	475,000 €
Insurance costs	2% of the income
Payback period	18 – 19 years
Net present value (5% discount rate)	511,000 €
Internal rate of return	6%

Source: Piernavieja, G., Pardilla, J., Schallenberg, J., Bueno, C. (2003)

In order to analyse the real meaning of these data, a comparison with the actual system is required. The full investment cost in the new project has been established around 25 Million Euros (M€). Employment cost will be around the same for both systems, considering Juan Luis Padrón estimations. Maintenance cost will probably not vary much. The significant difference appears when looking about the cost of the primary energy required for the system to run. The new systems, as 100%RES, has no cost associated to it, but for the old one, the

diesel purchase costs for a 20 years period¹⁸⁸, with a 3% annual cost increase, has been estimated by the ITC to be 42 M€. Only this figure shows how unprofitable the actual system is, and how significant the economic benefits of the new system are. These figures show how profitable the new system is for the actual electricity producers, but also for whole Spain's electricity consumer, which is finally the one who is paying it.

Even, if ones in place, the new full system shows to require further investment in wind farm, other RES technologies, storage units, etc., the margin between the cost of the actual system and the new one, gives enough playground to undertake these investments.

Actually, as being a innovative project, the economic figures become even better, as rewarded by grants as the one obtained from the EU energy and environmental programme of 2M€. ¹⁸⁹ The overall expected subsidies, which are expected to be obtained from one or another governmental level is around 40% of the total investment. ¹⁹⁰

4.2 Flores Island (Azores, Portugal)

EDA's attitude regarding the sustainable development of the Azores islands has been the main driver of this plan. This, by the local government controlled, energy company establishes its mission as to provide their customers with electricity in a quality and efficient way, assuming a main role in developing the Azores, protecting its environmental and cultural heritage. Its strategy states their growing stake in RES. ¹⁹¹

4.2.1 Actual state

4.2.1.1 Demand

Flores is Portugal's mainland most remote island in the Azores archipelago, as, next to Corvo Island, isolated of its main island group. Azores, as a region, suffers under the highest average price level within Portugal, while its GDP represents around 50% of EU's average. ¹⁹² Flores' indomitable nature has been one of the causes of its steady depopulation ¹⁹³, but actually it is the lack of job opportunities as of chances for personal development, which is the main driver of this tendency. As a result, Flores population decreased above 7% in the period 1991-2001, passing from 4,329 to 3,995. ¹⁹⁴ Despite the population decrease the electricity demand grew with an annual average increase of 6.4% the demand from 1996-2003 ¹⁹⁵, while the annual

¹⁸⁸ Initial life time given to the wind-hydropower plant, based on the life time of turbines.

¹⁸⁹ Energía de España, S.A. (ENDESA) (2004) Endesa desarrolla un proyecto que convertirá a la isla de El Hierro en el primer lugar del mundo abastecido al 100% con energía renovable. Investors communication: june 2004. [Online] Available: <http://www.endesa.com/NR/rdonlyres/erc35m5tuplgzokynpyuc3vidrefsbyulbhkxwov5r3bgxz5rswyxyhxcospvdsq5cdngwvt74much/CENTRALHIDROELECTRICAELHIERROesp.pdf> [2004, 7 October]

¹⁹⁰ Schallenberg Rodriguez, Julieta C. (June) Personal Interviews

¹⁹¹ Electricidade dos Açores (EDA) [Electricity of the Azores] (2004) [Online] Available: <http://www.eda.pt/nos> [2004, july 18]

¹⁹² Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores* [Online] Available: http://shop.ceps.be/BookDetail.php?item_id=49 [2004, october 20]

¹⁹³ Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores*

¹⁹⁴ Instituto Nacional de Estatística (INE-Portugal) [Portugal's National Statistical Institute] (2004). [Online] Available: <http://www.ine.pt> [2004] [2004, July 19]

¹⁹⁵ Calculated based on EEG data of energy consumption. Empresa de Electricidade e Gás (EEG), Estrela, David L.R. (2004, a) Flores Excel sheet. Handed out by EEG.

average increase during 1990-2000 at national level reached 4.5 percent and around 1 percent at EU level.¹⁹⁶

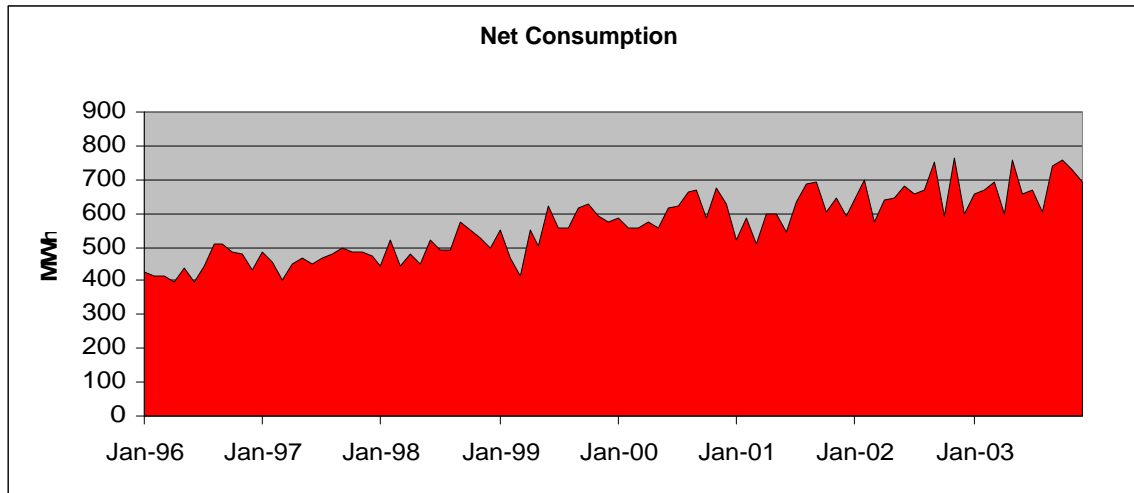


Figure 4-12 Monthly electricity consumption evolution on Flores Island
Data Source: EEG, Estrela (2004, a)

As it can be observed in figure 4-13, the electricity use is heavily concentrated on households and the service sector. The service sector mainly consists in two activities, public sector and tourism activities. Given Azores Islands geographical diffusion, an increased public service infrastructure per capita is required on each island, this lead the public sector to represent a share of 18% of the whole electricity consumption. Tourism, based on eco- and agro-tourism, represent the hope of regional development,¹⁹⁷ meaning already 64% of Flores employment.¹⁹⁸ It is a growing sector, with an 80% capacity increase in a 10 years period, passing from 755 to 1358 bed within the 1992 to 2002 period.¹⁹⁹ As a result, a high percentage with in the 33 % of the private service sector electricity consumption is directly or indirectly linked to tourism activities.²⁰⁰

While the industrial sector's electricity consumption of 3% could lead to ignore it, social and economic issues call for a proper service of the electricity company. The yield of the primary sector, agriculture and fishery, are input of the industrial sector, consisting mainly of dairy, fish and meat industry.²⁰¹ The agriculture sector represents 13% of Flores' employment and

¹⁹⁶ Reich, Daniel (2002) *Handbook of Renewable Energies in the European Union*

¹⁹⁷ Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores*

¹⁹⁸ Instituto Nacional de Estatística (INE-Portugal) [Portugal's National Statistical Institute] (2004). [Online] Available: <http://www.ine.pt/prodserv/Indicadores/indic2.asp> [2004, November 15]

¹⁹⁹ Serviço Regional de Estatística dos Açores (SREA) (2004) Contas Regionais [Regional Accounting] [Online] Available: <http://srea.ine.pt/> [2004, July 13]

²⁰⁰ Estrela, David L.R. (destrela@eda.pt) (2004, September 03) E-mail to Beatriz Medina Warmburg (Beatriz.Medina@iiee.lu.se)

²⁰¹ Estrela, David L.R. (destrela@eda.pt) (2004, September 03) E-mail

industry 28%.²⁰² These activities are also the ones representing exports within the negative island trade balance.²⁰³

Households' electricity consumption' high share hides electricity consumption of the agriculture and industrial sector. This is due to agriculture and cottage activities implicit in Flores' traditional households' activities.

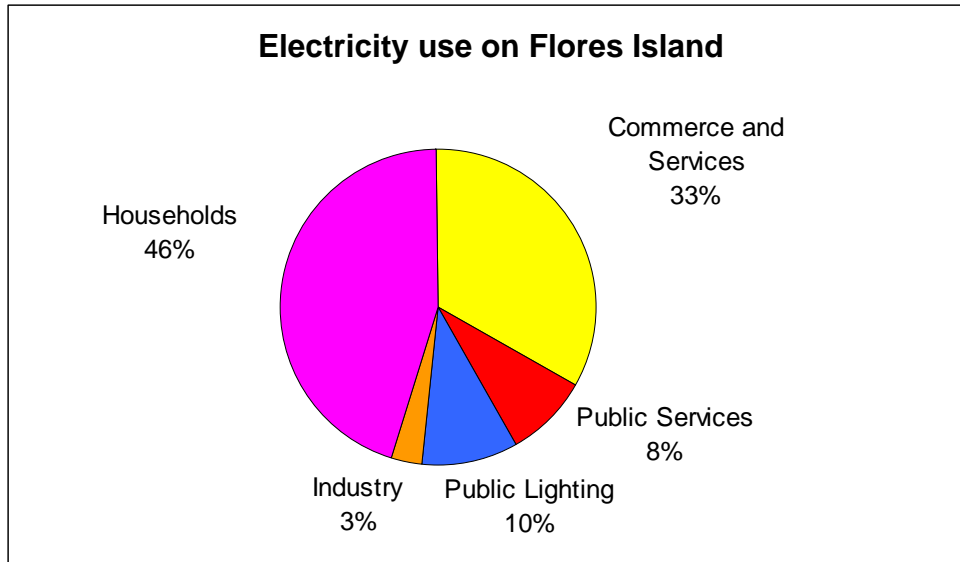


Figure 4-13 Flores electricity uses
Original data Source: INE-Portugal [2004]

Table 4-7 shows how the energy intensity has been increasing within most of the different energy users, being households and service sector the ones with an enhance increase. One reason for it is the increased number of electric appliances in households. The main appliances acquired have been washing machines, dryers, heating and cooling units, as TVs and video-recorders.²⁰⁴ Adding the high share these two consumer groups, households and service sector, the electricity demand increase is just a logic consequence, but not the only one. Also the number of consumers has grown.

Table 4-9 Energy intensity regarding consumer type and average

kWh/Consumer	Households	Commerce and Services	Public services	Industry	Total
1998	1,718	5,594	5,096	25,827	2,846
1999	1,835	6,230	5,420	27,049	3,114
2000	1,904	7,429	5,705	27,603	3,394
2001	1,890	7,089	5,683	26,836	3,336
2002	2,069	8,092	6,210	11,131	3,607

Source: EDA (2003)

²⁰² Instituto Nacional de Estatística (INE-Portugal) [Portugal's National Statistical Institute] (2004). [Online] Available: <http://www.ine.pt/prodserv/Indicadores/indic2.asp> [2004, November 15]

²⁰³ Exports don't even represent half of the imports. Ludlow, Martins, Núñez Ferrer (2000)

²⁰⁴ Estrela, David L.R. (destrela@eda.pt) (2004, September 03)E-mail

The high influence of households' electricity consumption shows also up in the daily electricity consumption distribution. As figure 4-13 shows, the peak demand isn't allocated during the working hours, as generally the case due to industrial and service activities, but during the late afternoon, when households' consumption is uppermost.

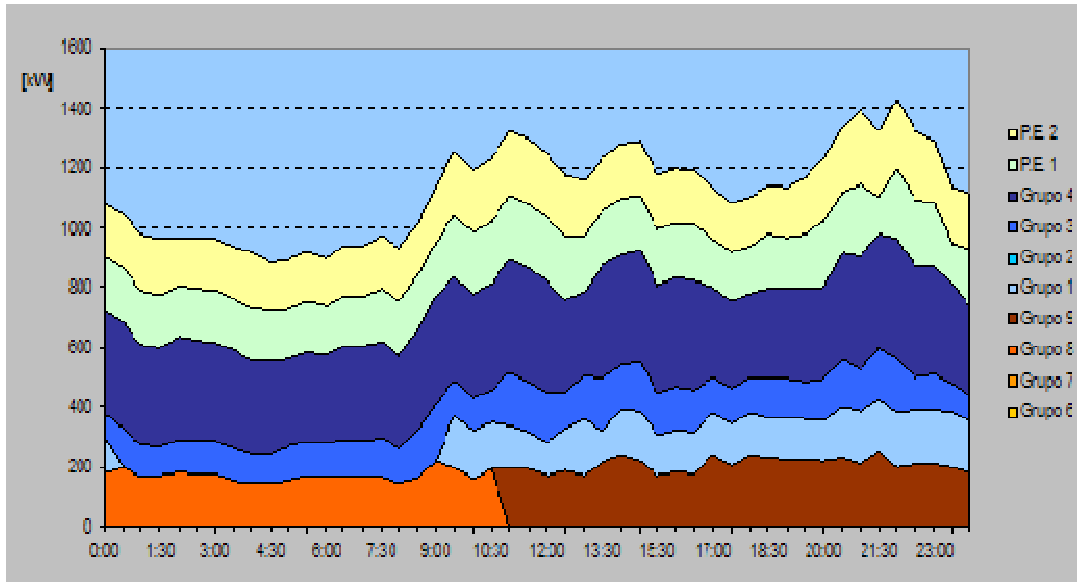


Figure 4-14 Flores daily electricity consumption pattern (6/04/04)
Source: EEG, Estrela (2004,b)

Not much can be said regarding the seasonal behaviour of the electricity demand, apart of a general low decrease in March and increase in September. It seems as the consumption pattern, through out the year, has been changing lately.

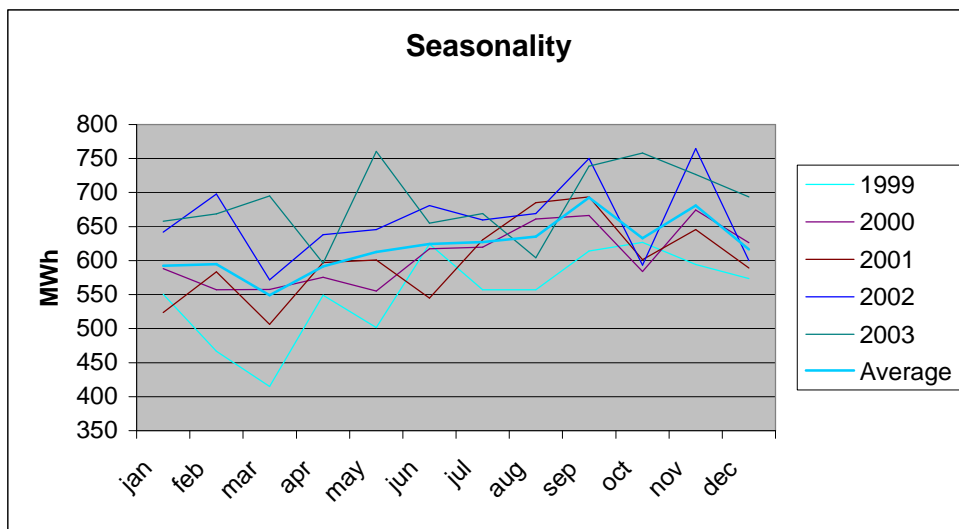


Figure 4-15 Monthly electricity consumption behaviour 1999-2003
Source: EEG, Estrela (2004, a)

4.2.1.2 Supply

Flores's actual electricity production system is based on three energy sources: water, wind and fossil fuel, archiving already 59% renewable energy penetration during 2003. During the winter month, with stronger winds and heavy rainfalls, even 75% of the demand has been

covered successfully with RES.²⁰⁵ This high RES share can be achieved thanks to abundant, manageable hydro resources. The for El Hierro case study commented MORE CARE system is being used also on Flores²⁰⁶, but already studying its 100%RES appliance by testing it in some periods.

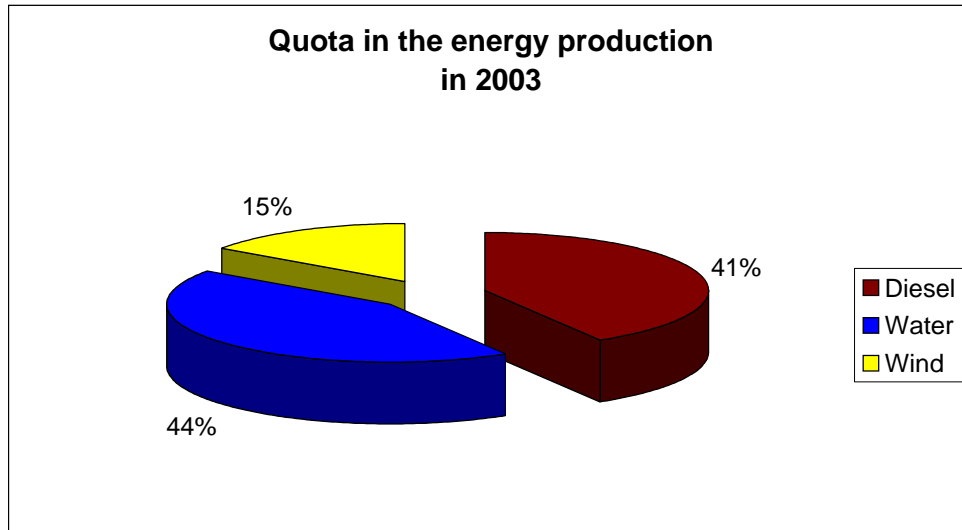


Figure 4-16 Energy production regarding the used energy carrier/source
Data source: Monteiro da Silva (n.d.)

The hydro power plant is formed by four hydroelectric sets connected to the same penstock²⁰⁷: 4 Francis turbines, 3 of 370 kW and 1 of 640 kW. The smaller units were acquired in 1966 and the other in 1984, which means that the capital investment can be seen as redeemed. The wind farm installed in 2002 consists of two 300 kW windmills. The actual diesel thermal plant is constituted by an old 733kW and three, newer, 625kW diesel engines.²⁰⁸ The number of hours in service²⁰⁹ of the different engines seems to show a phase out of the first one. The higher energy efficiency and quicker response of the newer engines makes them more economic efficient. Technical constrains of the actual system are basically linked to the weakness of the existing low and medium tension grid, as to certain system instability due to the age of the hydroelectric turbines, the regulators, as to the network connection to the wind farm.²¹⁰ Another problem is linked to the limited storage capacity within the distribution system.

²⁰⁵ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands.

²⁰⁶ Pecas Lopes, Joao A. (jpl@fe.up.pt) (2004, July 14) *Information requirement for master thesis*

²⁰⁷ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands.

²⁰⁸ Data extracted from the internal report:: Electricidade dos Açores (EDA) [Electricity of the Azores] (2003) Dados estadísticos 1998-2002 [Statistical Data 1998-2002] Handed out by EEG

²⁰⁹ 1987-14h, 1991-4410h, 1995-5294h, 2001-2651h. EDA (2003)

²¹⁰ Monteiro Da Silva, J. M. (2003). *The prospects of renewable energy sources in the Azores islands*. Handed out by EEG.

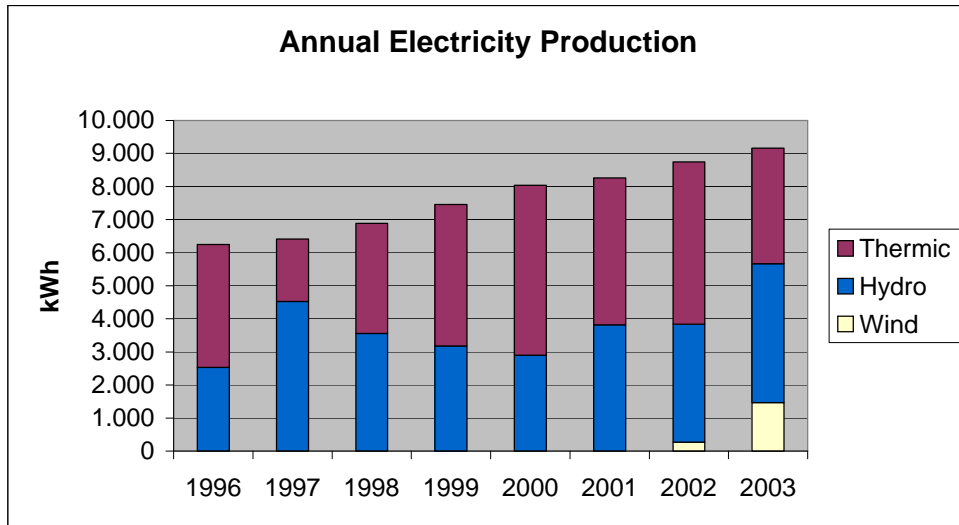


Figure 4-17 Energy sources use development in Flores electricity production
Data source: EEG, Estrela (2004, a)

Figure 4-17 shows how the contribution of the different electricity generation systems has evolved. As the wind farm started to produce late 2002, the wind energy production increase during 2003 is not due to a capacity increase, but to the accounting of a whole annual production. The fluctuation of the hydroelectric production that can be observed is fully dependent on the annual rainfalls. Meanwhile the thermal production has covered the gap between the RES production and the electricity demand at each moment.

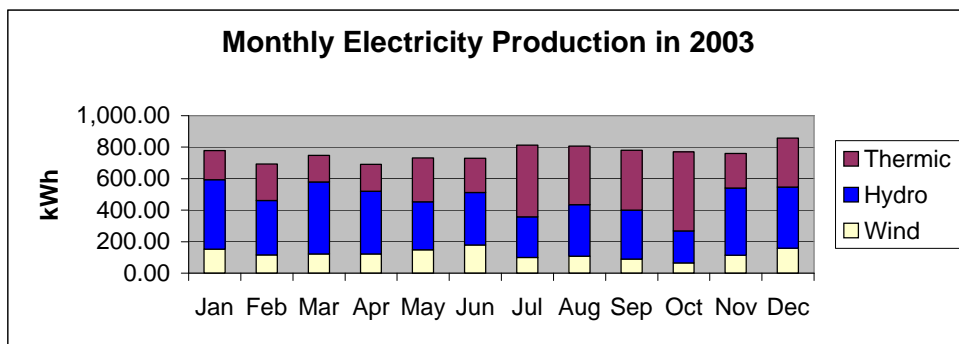


Figure 4-18 Contribution of the different energy sources throughout the year
Data Source: EEG, Estrela (2004, a)

When looking upon the distribution of the different productions throughout the year, Figure 4-18 reflects a quite stable wind electricity production. It is meaningful that in October, the month with lowest wind production, also shows the lowest hydroelectric production. This negative correlation means quite a dilemma for a 100% RES system. Additional RES or for a suitable long-term energy storage alternative will be needed to cove the demand in these periods.

4.2.1.3 Electricity Market

Two generators provide the electricity on Flores. EEG controls the wind and hydropower generation. EDA controls the actual thermal power plant. As EEG is 100 percent controlled by EDA, their actions are interlinked. All electricity produced is bought by EDA, who controls the distribution system. As such all production and distribution of electricity is

managed within EDA group.²¹¹ EEG, as the other companies belonging to EDA's group, was born consequence of Portugal's integration to the EU and the new rules established in the Portuguese electricity market adapting to EU requirements. One of the requirement was the privatization of electricity companies, by than public owned. EDA, private-public Company, owned 90 percent by the regional government of the Azores and 10 percent by EDP²¹², is still in a privatisation process. During the following year, local businesses are supposed to take over shares of this company.

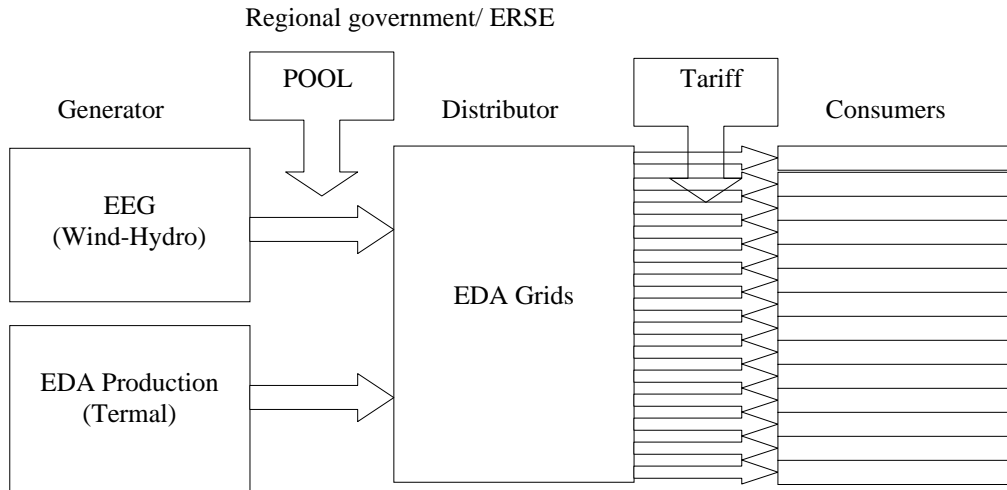


Figure 4-19 Actual energy market in Flores Island

In contrast to Spain's case, "Portugal does not guarantee a unitary price for energy throughout its territories", as a consequence the additional production cost has been traditionally assumed by the islands producers and consumers, within each isolated system.²¹³ As this system means a generally recognized additional burden for the already bad island's economy, Portugal's pricing system has been gradually adjusted to compensate the additional energy cost of the island systems. Actually EDA gets compensated each month for the difference between the annual production cost of each island and the converting tariff established by Entidade Reguladora dos Serviços Energéticos [ERSE-Energy Services Regulating Entity of Portugal] with Azores' regional government approval. The compensation is review every three month and covered through the tariff of global use of the system.

Table 4-10 shows the production cost meaning average electricity prices considered for the compensation for Flores case, as Azores' average cost. The different prices for low and medium power, as the difference between Flores and EDA's average shows how the specific characteristics of each island system affects to EDA's total costs. For medium power Flores production costs are higher than Azores average, for high power they are lower.

Table 4-10 Average electricity generation sales prices in 2002

Cent€/ kWh	Flores	EDA's average
Average Price	12.47	11.85

²¹¹ Estrela, David L.R. (destrela@eda.pt) (2004, June 02) E-mail

²¹² EDP was the previously public, national energy company, actually in the stock market.

²¹³ Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores*

Medium Power	11.74	10.32
Low Power	12.56	12.75

Source: EDA (2003)

When it comes to renewable energy generation, at mainland level, the production is tipped regarding it RES renewable. “The end-consumer pays that policy on the final kWh price, mainly because the payment on renewable energy is higher than traditional fuel or coal production, especially when the oil price is down.”²¹⁴ The tip is calculated considering:

- Fix term based on avoided cost of new production investments and plant availability
- Variable term based on avoided fuel²¹⁵ and network investments
- Environmental term based on CO₂ emission avoidance
- Technology factor based on production cost and/ or operation hours of the different RES
- Network losses factor based on avoided cost of transmission and distribution systems.²¹⁶

Based on this the average selling prices for renewable energy has been, at national level:

Table 4-11 Indicative average selling price for renewable plants

Technology	Selling price (c€/ kWh)
Wind	7.2-8.3
Small Hydro	6.8
Wave	22.9
Solar Photovoltaic	40.5
Others	6.2

Source: Freitas Oliveira (2004)

At Azores level ERSE has established the renewable energy cost at 7.46c€/ kWh, independent of the RES.²¹⁷ Considering that mainland RES prices are based on the above mentioned considerations and therefore for sure covering production costs of this technologies, Azores RES price excludes the exploitation of RES as solar PV or wave energy, which need a considerably higher price to be attractive for investors, disregard the existence or not of a technical exploitation potential for these resources.

When it comes to the end-consumers prices, the tariff setting for Azores and Madeira is ruled by Despacho n.º 19734-A/ 2002, taken into account the particularities of each region.²¹⁸ Ones

²¹⁴ Estrela, David L.R. (August) Telephone Interview.

²¹⁵ “Indexed to the interational crude oil price, independently of the fuel actually used.”

²¹⁶ Freitas Oliveira, Manuel (2004). Portugal turns to decentralized energy with a new legal framework. *Cogeneration and On-Site Power Production*, Volume 5, Issue 1. [Online] Available: <http://www.earthscan.co.uk/news/article.asp?UAN=46&v=1&sp=332156698829342838236> [2004, October 20]

²¹⁷ Estrela, David L.R. (August) Telephone Interview.

²¹⁸ Entidade Reguladora dos Serviços Energéticos (ERSE) (2004) Simulador de facturação da electricidade para fornecimentos no SEPA em BTE e MT [Online] Available: <http://www.erse.pt/frontoffice/index.html> [2004, 25 October]

more the differentiated tariff at insular level is set by ERSE, with the regional government approval. A certain harmonization of the tariff setting criteria has been established, but even though, as visible in Table 4-10, there are still differences regarding Portugal's mainland.²¹⁹

Table 4-12 Simple tariff for low normal voltage 2004

Hired power (kVA)	Azores Tariff (c€/ month)	Mainland Tariff (c€/ month)
1.15	1.85	1.75
3.45	5.53	5.38
6.90	9.85	11.91
10.35	14.79	18.02
13.80	19.72	24.23
17.25	24.65	30.27

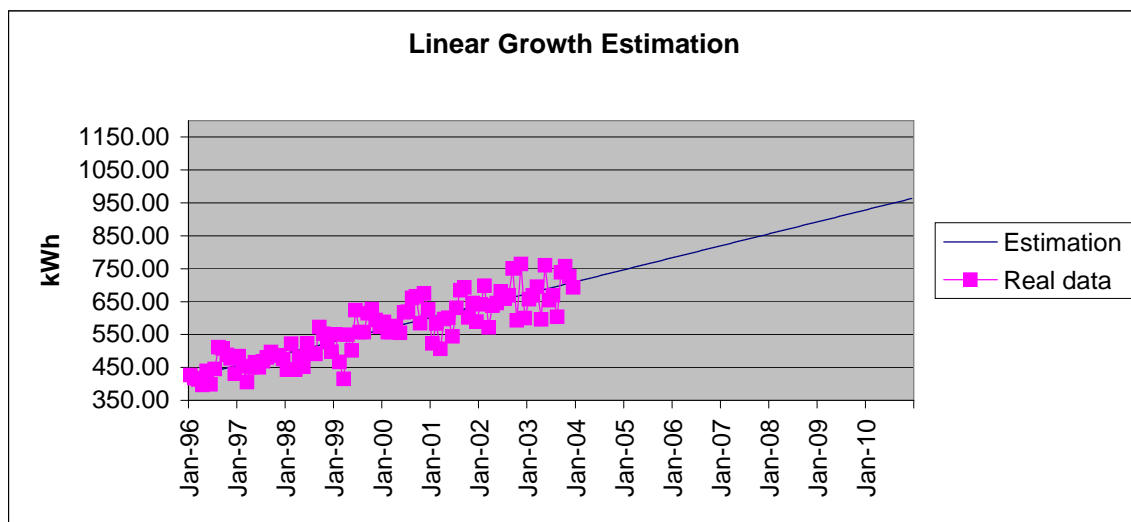
Source: EDP, EDA (2004)

4.2.2 100% RES plan

4.2.2.1 Demand

As for El Hierro case, breaking the actual demand growth becomes a must if the sustainability and long-term efficiency of the 100% RES system has to be achieved. A steadiness in the growth trend has to be foreseen as Portugal, even having the highest energy intensity growth, has still the lowest values within the EU.²²⁰

When locking upon the linear and logarithmic growth scenarios, following the actual growth trend, the electricity demand by 2010 would lay between 11,300 and 13,300 MWh a year, what means a 38 to 61% overall increase on 2003 annual consumption of 8.224 MWh.



²¹⁹ Entidade Reguladora dos Serviços Energéticos (ERSE) (2004) Simulador de facturação da electricidade para fornecimentos no SEPA em BTE e MT

²²⁰ Reich, D. (2002) *Handbook of Renewable Energies in the European Union*

Figure 4-20 Electricity demand growth trend scenarios on Flores Island
Data source: EEG, Estrela (2004, a)

Based on the estimated linear progression on monthly data and considering different slopes, based on different effect of awareness campaigns, energy saving measures and demand control tools, different demand scenarios has been calculated. In order assure the 100% RES continuity, the RES potential should cover the different alternatives or harder demand control measures will have to be taken.

Table 4-13 Flores future demand scenarios

MWh	Demand Growth Slope			
2004	3.03			
Demand	8,740.49	8,740.49	8,740.49	8,740.49
	Demand Growth Slope			
2014	3.03	2	2	1
Demand	13,106.83	11,688.62	11,688.62	10,314.62
	Demand Growth Slope			
2054	3.03	2	1	1
Demand	30,572.20	23,208.62	17,514.62	16,074.62

Locking upon Flores actual circumstances, the expected development of the tourism sector, as planned to be the key stone of the island development, will lead to a demand increase. It probably will also imply seasonality, with an additional increase in the summer months. Even when eco- and agro-tourism is not as sensible as other kind of tourism to weather conditions, the tourism activity is already highly concentrated during the summer months.²²¹ The cottage industry, very relevant as additional income source, has, thanks to the tourism sectors, now a growing market.²²² Depending on the specific activities the cottage industry concept includes and their specific energy needs, its growth could enhance the seasonal effect of tourism or compensate its negative impact by concentrating its electricity demand on the winter months. A strong seasonality concentrated in the summer months will require an oversized electricity system, specially considering that the highest renewable energy figures are concentrated in the winter months.

As Flores' households haven't so far reached in Europe generally existing level of comfort and appliance ownership, a continuous growth in the electricity demand for this reason has to be assumed. The final effect of these growing appliance uses can be reduced through promoting the acquirement of most energy-efficient appliances. Based on how such a promotion is undertaken it also could have effect on the actual consumption, if substitutions of less energy efficient appliances are achieved.

²²¹ Estrela, David L.R. (destrela@eda.pt) (2004, September 03) E-mail

²²² Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores*

When it comes to the specific appliances which could be required by the electricity consumers, the high humidity and clouded weather common in Flores, is the reason for an increase use of dryers. As similar to El Hierro case, the use of computers and related appliances is also expected to increase, given its low presents in actual households. The lower average temperature on Flores than on El Hierro calls for higher heating needs during the winter months. Also higher amount of energy to cover hot water services is required. As the wellbeing of Flores' families grows, the acquisition and use of these and other appliances will rise too.

Considering SEGMA's know-how as a company working as consultancy on energy projects as doing industrial installations maintenance, EDA has an excellent starting point to become an energy service company. Actually SEGMA's activities are focused on the industrial sector only, but they could increase significantly there potential market if they would work on all other kind of consumers. SEGMA's knowledge also represents a possibility of taken over the installation and maintenance needed for solar thermal applications or heat pumps which could reduce significantly electricity requirements for heating/cooling or hot water needs.

4.2.2.2 Supply

One of EDA's biggest assets for the future is their know-how within the use of different RES and their technologies. Within the Azores archipelago they have been part of geothermal, waves, biogas, wind and hydropower projects, some as research projects, but mostly as applied electricity generation projects. Flores is not the only island within the Azores archipelago with 100% RES aspirations: Corvo, next to Flores and significantly smaller²²³, is expected to reach already in 2007 95% renewable electricity generation, with up to 80% wind energy use. Flores objective by then is established at 82% renewable electricity generation. Nevertheless, Flores is expected to be the first island in the Azores to base its electricity generation 100% on RES.

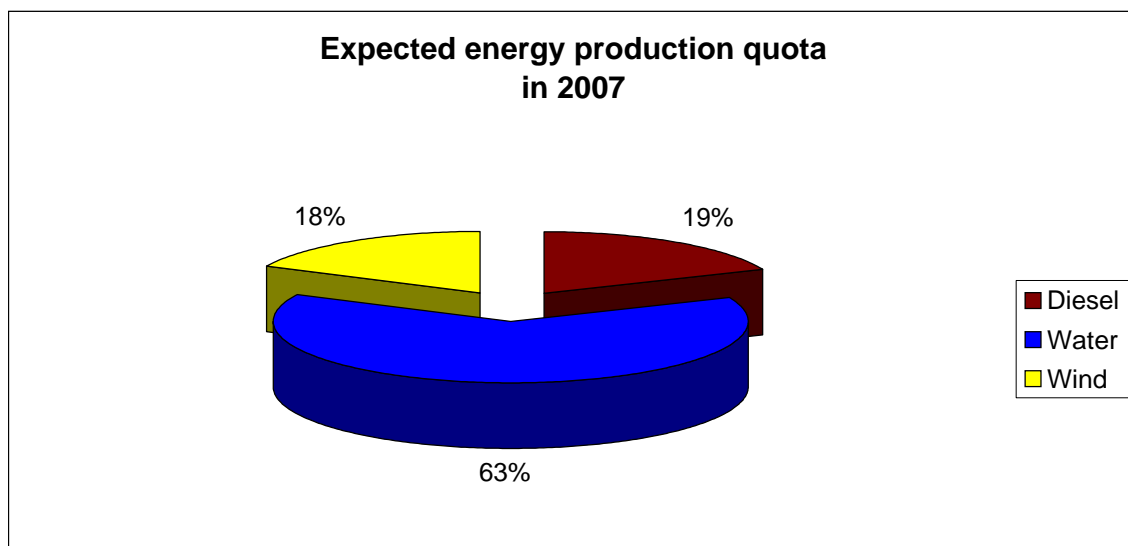


Figure 4-21 2007 planned energy production regarding the used energy carrier

Data source: Monteiro da Silva (n.d.)

Flores 100% renewable electricity generation plan is based primary on its high hydroelectric potential. In order to optimize its hydroelectric resources and given the limited capacity of the existing hydroelectric basin²²⁴ an enlargement of the water storage capacity has to be

²²³ Surface: Flores-142km², Corvo-17km²

²²⁴ Monteiro Da Silva, J. M. (2003)The prospects of renewable energy sources in the Azores islands.

undertaken. Thanks to the orography of the area only an enlargement of the actual basin, through building up its dam up to 70 metres, has to be addressed.²²⁵ The actual stability problems due to the age of the turbines will be solved, while adjusting the hydropower plant to its new conditions. Only through the required turbines' substitution to higher capacity ones, with up to date technology, the energy conversion efficiency will be also improved.

The second headstone of the 100%RES plan is the wind energy. Flores' high annual average speed, higher than Portuguese mainland's one,²²⁶ and its even annual distribution²²⁷, which assures a high economic efficiency of wind farm investments with less technical problems to high wind energy shares, establishes further wind farms to be the best option to increase the RES penetration. The problems Azores' strong winds could cause, as introducing tension and frequency instabilities, are already being tested, achieving more than 50% wind penetration, during low variation periods, meaning nights, "without occurring any fatal instability".²²⁸

As previously addressed in paragraph 4.2.1.2, the negative correlation of wind energy and hydropower availability will require a solution, when approaching a 100%RES electricity system. Either alternative long-term storage units have to supply previously RES generated electricity or other more manageable or other, positively correlated, RES have to be exploited. In any case, this fact increases investment needs to achieve the final goal. As such, EDA expects to achieve a fully 100% RES electricity system only on highly raining years, keeping its actual thermal electricity generation capacity as support system for less raining years.

The biomass use as a way to provide the residual energy supply doesn't seem very feasible. The non existing wood industry as the small amount of waste biomass limits the economical feasibility of electricity generation from these resources.²²⁹ The only environmental friendly solution for these residues seems to be to ship them to a major island for its use.²³⁰ This uses are already in project by all municipalities of San Miguel Island, on which island also a biogas production is in place. The results of a study under development of the Azores University regarding Azores Archipelago biomass potential are expected to give a final outline on real exploitation potential.²³¹ Pellet imports are being considered for the bigger islands' thermal plants. This could lead to build up a residual pellet market base on small technologies for heating and hot water needs. Such a market is very limited at Flores, as the distance to the major islands represents an additional transport costs to be accounted on the surely high future imported biomass cost. The economic results will also be fully depends of the price fluctuations of the international biomass market.

When it comes to geothermal potential, no specific technical studies has been undertaken on Flores.²³² Theoretically, all Azores' islands, disregard Santa Maria, have a geothermal potential, but geothermal electricity generation is not reasonable on small islands due to the high investment cost of drilling. In order to assure return on investment a minimum of a 10-12

²²⁵ Electricidade dos Açores (EDA) [Electricity of the Azores] (2004) [Online] Available: http://www.eeg.eda.pt/fazemos_hidrica.php [2004, October 18]

²²⁶ Monteiro Da Silva, J. M., EDA (n.d.). The prospects of renewable energy sources in the Azores islands.

²²⁷ Monteiro Da Silva, J. M. (2003)The prospects of renewable energy sources in the Azores islands.

²²⁸ Monteiro Da Silva, J. M., EDA (n.d.). The prospects of renewable energy sources in the Azores islands.

²²⁹ Estrela, David L.R. (destrela@eda.pt) (2004, September 20) E-mail

²³⁰ Estrela, David L.R. (destrela@eda.pt) (2004, September 03) E-mail

²³¹ Estrela, David L.R. (destrela@eda.pt) (2004, June 18) E-mail

²³² Estrela, David L.R. (destrela@eda.pt) (2004, June 18) E-mail

MW plant is required.²³³ The increase of fossil fuel prices will allow the implementation of smaller plants.²³⁴ Also the further development of alternative energy carrier generation, distribution and application technologies, as for the hydrogen case, produced from geothermal energy, can lead to allow the economic feasibility of bigger plants in small electricity demand islands, as other energy uses can be covered thanks to the added production of an suitable energy carrier. In an extreme increase of actual fuel price and decrease of hydrogen production and distribution costs, even the hydrogen could become even an export product for the island economy. A local hydrogen market among the Azores islands with or without such installation would be the first to be covered.²³⁵

Solar electricity generation installations don't seem very feasible at Azores Islands. While the regional energy agency is studying the real Azores solar energy potential, the commonly clouded Azorean climate doesn't foresee high solar radiation. As such, that this energy source will not be used for electricity generation can be also foreseen. Solar applications for heating and hot water purposes could be applicable. EDA has no experience in small scale projects as solar application are,²³⁶ but within its company structure SEGMA's actual experience in energy consulting and industrial installation maintenance could be a good starting point for the development of such projects.

The use of wave energy for electricity production on Flores can be ignored in a near future. The research project on wave energy on Pico Island under the Instituto Superior Técnico of Lisbon Technical University (IST) and EDA's developed has lead to no industrial production, calling for turbine improvements for such purpose.²³⁷ The future application of this technology on other locations within the Azores is limited to the positive final results of this research project, as the following study of the applicability of this technology to different location.

When it comes to the electricity system as a whole, the technical constrains of the actual system is causing system instabilities to be solved by adequate investment in grid reinforcement. The need of providing flexibility/ adaptability to the system to manage short as long-time demand fluctuations calls for storage units, as for R&D in control system. Actually the diesel plant is supposed to provide the backup system for the 100% RES electricity system. The use of flywheels is already being considered, as grid stability problems are already appearing in low consumption periods as nights, when the wind energy penetrations increases. This would allow storing excess wind energy during the nights, using a higher share of stable hydropower. During the day less hydropower will be required as consuming the energy stored in the flywheels.²³⁸ Optimizing the wind energy use could lead to an overall higher wind penetration; relegating the unexploited, collected water to long-term energy storage.²³⁹ As this higher wind penetration is achieved with the same wind farm investment, also better reward to this investment is achieved. Nevertheless, the use of a pumping unit to allow medium-term energy storage, linked to a higher wind energy penetration, as designed for El Hierro case, could lead to avoid fully the need of the diesel plant as backup system. In that case, this option

²³³ Bicudo da Ponte, C. A., Martins Cabeças, R. P.. SOGEO (2003) *A aproveitamento de recursos geotérmicas para a produção de electricidade de nos Açores*. Handed out by EEG.

²³⁴ Bicudo da Ponte, C. A., Martins Cabeças, R. P.. SOGEO (2003) *A aproveitamento de recursos geotérmicas para a produção de electricidade de nos Açores*. Handed out by EEG.

²³⁵ Estrela, David L.R. (destrela@eda.pt) (2004, June 18) E-mail

²³⁶ Estrela, David L.R. (July) Telephone Interview.

²³⁷ Estrela, David L.R. (destrela@eda.pt) (2004, June 18) E-mail

²³⁸ Estrela, David L.R. (July) Telephone Interview.

²³⁹ Pecas Lopes, Joao A. (jpl@fe.up.pt) (2004, July 14)

should be considered before reforming the actual hydropower system, as making now the required adjustment would reduce the overall investment cost, when taking the proper decisions regarding penstock design or turbines/ pumping units' acquisition. Basically, the only further investment required would be than the building of a lower water reservoir. Another option could be to continue using the diesel plant as backup system for its lifetime hopping to develop by then a nearby, when not on the island hydrogen production. The economical feasibility of this option will rely on the decrease of actual production, transport and storage costs, the price increase of alternative fuels, as of growing synergies with other hydrogen uses.

Regarding the control system development, the Instituto de Engenharia de Sistemas e Computadores do Porto (INESC Porto) is studying the connection between wind, hydro and thermal production on Flores, using as a bases the MoreCare system,²⁴⁰ previously mentioned in El Hierro case study. This system tries to minimize the use of diesel electricity production, not only considering technical requirements, but also economic dispatch aspects. Based on load forecast scenarios and renewable energy generation forecasts, suggestions for managing the diesel electricity production are done. These proposals consider the system security, trying to stabilize the frequency as to assure proper voltage values through the diesel electricity production.²⁴¹

4.2.2.3 Electricity market

Although different actors could enter the market, as exposed in the possible future market scenario represented in figure 4-22, no real break down of the actual market monopoly is foreseeable. Most actors, all the ones with significant production levels, are somehow underlying EDA's control. It will be EDA itself who will suffer a major change: as still mainly public company, given EU's legislation, EDA is forced to increase significantly its share of private capital. Part of the participation of the regional government is expected to pass to local investors. As mentioned before, this option allows local investors a business risk diversification, while assuring the proper electricity supply needed for their businesses to work. This need of changing the ownership structure opens the door to a capital enlargement manoeuvre to cover partially the investment needs of the 100% RES plan.

Despite EU's requirements, no real division of the distribution and production system seems to exist. As such changes are required if higher competitiveness is to be achieved in the electricity market, at the production side as in the distribution side. Based on the information obtained no change is actually plant. As such the control of the transport and distribution system will still be under EDA's control. EDA will be the main actor adapting the actual control system to cover the new needs, relying on their network activities, at national and international level, at universities' and research centers' level.

²⁴⁰ Estrela, David L.R. (destrela@eda.pt) (2004, June 15) E-mail

²⁴¹ Pecas Lopes, Joao A. (jpl@fe.up.pt) (2004, July 14)

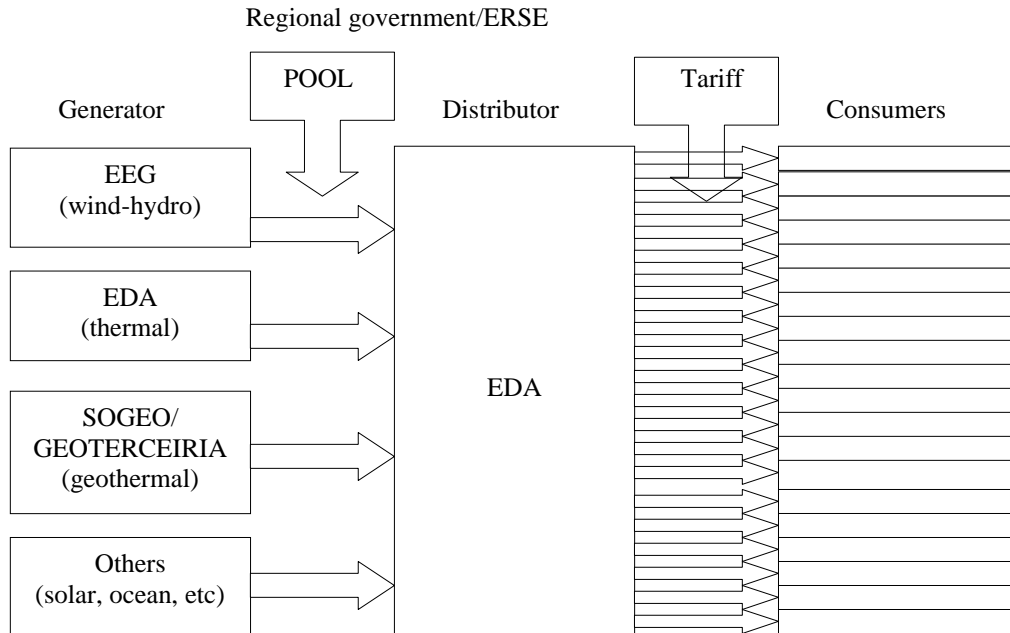


Figure 4-22 Possible future energy market scenario on Flores Island

The actual tendency to equate the electricity prices to Portugal's mainland ones seems foreseeable to continue. As Flores electricity consumer will benefit of this sink in the electricity prices, he can be tempted to increase its individual electricity consumption, which leads to an overall enhanced increase of the electricity demand. Meanwhile Portugal's electricity production continues relying on fossil fuel imports, their rising prices will lead to increase Portugal's mainland electricity. As such the electricity price on Flores, as regulated, will probably suffer more stagnation than decrease, while Portugal's mainland electricity price will approach Flores ones. At least this should be regulator's action to avoid further growth of Flores' electricity demand due to price decrement. The cost of adapting the island system to growing demand is surely higher for the consumer, in the long-run, than continuing paying the actual price.

When it comes to the production side, the actual unique RES price on Flores doesn't work as an incentive for the introduction of more costly RES, as, for example, solar PV. In the study being undertaken by the regional energy agency about the solar potential of Azores islands shows an exploitation potential, a diversification of the RES prices will be required, if this niche of the renewable energy market has to be promoted. Pioneer investors in RES will require an assured return on investment in order to undertake this kind of projects.

4.2.3 The three dimensions of sustainability

4.2.3.1 Social dimension

Flores' recognition world wide, as a result of this project, doesn't defer much from El Hierro case, as both islands activities are quite similar and even interlinked due to networking. Given EDA's much broader range of know-how regarding RES, its considerable asset lead to several business opportunities, within and beyond Azores islands, by diversifying its activities or by applying the same to other isolated areas.

As such the social benefit of this project is linked to social welfare of avoiding money leakage out of the region and, what is more, producing money income when sharing knowledge. This leads to qualified employment, which also has its consequences on the social welfare. The project itself doesn't foresee a considerable employment growth, as these needs can mostly be covered by EDA's actual human resources.

As the only organizations working with this project are within EDA's business structure, little social awareness to the energy problem seems to be achieved due to this project itself. As the vital promoter of the system, the energy company, acting as an independent actor, did not need until now any social involvement to achieve its project goals. As the final goal is a long-term sustainable system, measures to control the demand growth will, later or sooner, have to be taken. Involving the community is the first step to a more conscious energy use. In order to achieve this, the energy companies, the regional government and the regional energy agency should collaborate. Actually the regional energy agency is promoting energy saving measures through a campaign, on which little information has been obtained. Based on the contact undertaken through out the thesis work, the communication among the three above mentioned actors is not very fluent. As a consequence of working independently on energy issues, synergies among the different activities undertaken by the different actors are being lost. As such, achieving certain results will probably require more individual actions, at a global higher cost.

4.2.3.2 Environmental dimension

The fuel oil consumption during 2002 went up to 1,346,660 litre²⁴². Assuming that the demand increase during the last years has been covered by the increase in the electricity production from RES, the 100%RES system will avoid all the environmental impact associated to the use of this amount of fossil fuel.

As no specific study regarding polluting emissions of Flores electricity generation system has been undertaken, an approximation based on Azores global emissions based on Flores fuel consumption has been undertaken.²⁴³ As this approximation doesn't take into account the more inefficient production technologies used on Flores small electricity system than Azores average, the real data for Flores will be somehow larger.

Table 4-14 Production share based Flores pollutant emissions

Tons	Azores Archipelago	Flores
CO ₂	355,496	3821,8
SO ₂	4,323	44,8
NO _x	8,131	84,3
CO	618	6,4
Particles	154	1,6

Azores' data source: Monteiro Da Silva (n.d.)

The negative impact this new system implies is mainly concentrated in the dam enlargement required to increase the hydropower electricity production share. As the larger area will be flowed, changes in the local ecosystems of the affected area will occur. As being on an island with singular natural resources the impact on certain species could be significant. No remarks

²⁴² Electricidade dos Açores (EDA) [Electricity of the Azores] (2003) *Dados estadísticos 1998-2002* [Statistical Data 1998-2002]

²⁴³ Estrela, David L.R. (June) Telephone Interview.

regarding such problems have been done. Moreover, when comparing the increase in the flowed area, regarding to the water storage capacity increase the impact is relatively small. Some negative impact can be also identified regarding installing further wind mills. This impact isn't also very significant; as just installing one windmill represents a significant increase of the wind energy share.

4.2.3.3 Economic dimension

As paragraph 4.2.1.3 proves, Flores considerably higher average electricity generation costs, which includes already a wind energy and hydro energy share, the RES is considerably more attractive for the island electricity generation system than fuel based electricity generation. As such the 100% RES electricity commitment of EDA group regarding Flores electricity system is fully supported by economic figures. The margin between the RES price per kWh and the fuel electricity generation price is significant enough to allow investment in overcapacity of RES generation technologies or storage systems, as probably needed in order to reach a stable 100% RES electricity system.

Table 4-15 Flores' RES production costs for 2003

Flores RES costs in c€	Spares	Supplies	Mortgages	Personnel	Structure costs	Total
Hydro	0.12	0.64	1.12	0	1.91	3.79
Wind	0.06	2.63	3.91	0	1.91	8.51

When looking upon the electricity price paid for RES, as established at 7.46 c€/ kWh, the wind energy production by itself, base on the production cost accounted in table 4-15, is uneconomic. As such its use is only understandable given the even higher cost of fossil fuel based electricity production.²⁴⁴ EDA benefits of substituting fossil fuel electricity generation by wind energy generation. No incentive exists for a new supplier to enter the electricity generation market, neither through wind energy electricity generation, due to its production cost, not through hydropower, due to its large production scale. The cost for exogenous wind energy supplier would be even higher then the one appointed in the table above. EEG has benefit, for example, when the wind turbines for the wind farm were acquired, as acquired as part of a bigger order, for other islands. As a consequence a lower average investment price for the turbines was obtained, as the average transport and mounting costs were also reduced. The same happens with the personnel cost. Human resources needs of EEG are actually covered by EDA's personnel (accounted under supplies), achieving economies of scale, not achievable for small independent producers. The labour cost of Azores electricity system has been established around 40% of the electricity cost compared to the 15% of the mainland²⁴⁵. This is a consequence of the much higher economies of scale achievable at continental level and shows how big this barrier for new incomers is. Actual low mortgage cost share in the total hydropower generation cost is mainly due to the age of the actual installations. This cost will increase ones the new investments in the hydropower plant enlargement has been undertaken. "Hydroelectric specific investments E/kW are in general higher than wind."²⁴⁶ When looking upon EEG business, the decision of undertaking now the enlargement of the hydropower plant has been taken in an optimal moment. As three of the four turbines actually being used in the hydropower plant were acquired in 1966, their capital investment has been

²⁴⁴ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands

²⁴⁵ Ludlow, P., Martins, V., Núñez Ferrer, J. (2000) *Establishing suitable strategies to improve sustainable development in the portuguese ultraperipheral regions of Madeira and Azores.*

²⁴⁶ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands

already paid out, being quite foreseeable the need of undertaking their substitution in any moment. As such, undertaken the hydropower plant enlargement at this point minimizes the cost of changing the system. The increase of the financial cost consequence of financing the new investments will be partially be compensated by a reduction of the actual high maintenance cost resulting of the age of the actual engines.²⁴⁷ Also the choice of enlarging the actual dam instead of establishing new water storage in an alternative location represents a significant cost advantage, unattainable for any potential competitor. As a result of all this; EDA has a very solid monopoly position even for the future, as far the actual market circumstances don't change and the promotion of other RES alternatives are not achieved.

When it comes to the income side, the up to date technology which will be used in the new hydropower plant will lead to increase the actual energy conversion efficiency. Increasing the production regarding amount of stored water will increase the return on investment. Flores higher annual average wind speed compared to Portuguese mainland²⁴⁸, implies a higher average production and therefore a considerable higher return on investment, if it wouldn't be somehow compensated due to Azores bad weather conditions. The deep depression area in which they are located reflects in higher maintenance cost of wind farms.²⁴⁹

50% of the capital investment necessary for enlarging the hydropower plant will be obtained thanks to EU's regional development funds. While other financing helps are available at national level, as they are linked to pay-back requirement, with low interest rates, being Azores an objective 1 region and therefore having privileged access to, not to be paid back, regional development funds, this has been the help being chosen. This could seem an unfair competition regarding other hydropower plant projects, but this help doesn't compensate the investment in overcapacity necessary to assure the 100% RES system to cover pick hour demands.²⁵⁰

Initially this project represents a duplication of investment costs, as traditional thermal source production has to continue guarantee the normal consumption.²⁵¹ A further RES production increase, through other energy sources, will hopefully lead to its total phase out while achieving the actual plant life time, without requiring substitution, cutting investment cost. In order to achieve to control the demand increase is a must.

²⁴⁷ Monteiro Da Silva, J. M. (2003)The prospects of renewable energy sources in the Azores islands.

²⁴⁸ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands

²⁴⁹ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands

²⁵⁰ Estrela, David L.R. (June) Telephone Interview.

²⁵¹ Monteiro Da Silva, José Manuel, EDA (n.d.). The prospects of renewable energy sources in the Azores islands

5 Final analysis

5.1 Demand

Both islands, given its isolation, limited resources, and import dependency, have been historically less developed regions. As a consequence its energy intensity is still expected to increase, to reflect in a further electricity demand growth. Considering renewable energy resources, as any other kind of resource, limited, as the high cost of adapting island's electricity systems to increasing demands, to exert control on its growth becomes a crucial point for the sustainability of the planned 100% RES electricity systems. The control exerted should not avoid its growth, especially considering the delay development these regions suffer within their countries, but manage it growth by reducing the effect island's development has on the electricity demand: by using other energy forms, archiving higher energy efficiency, by better building techniques, etc; cutting our unnecessary electricity consumption.

To pursue control the specific sectors where a potential demand growth exists must be identified. The design of concrete, sector specific actions to avoid its fulfilment should follow. Both islands show a very small and constrained industrial sector where no significant growth is being expected. Since Flores and El Hierro are small and outer islands within an archipelago, the economies of scale, as even further enhanced transport costs, leave on the islands only marginal industrial activities, generally low energy intensive. These industrial activities are heavily linked to island's own perishable goods demand or to agriculture products to be handled for export. Consequently, the industrial sector represents a low share of the full electricity consumption, not accordingly to its relevance at social and economic level. This enhanced relevance calls for assuring a proper service to the islands' industrial sector; to account its specific electricity demand characteristics when presuming islands' future electricity supply needs.

It is the service sector where the major options of economical development have been identified. The path into an "Information Society" reduces substantially the traditional constrains for islands' companies' development. Intangible goods must not be shipped and are mostly not linked to the import of, to the final-good-price proportionally, expensive inputs. The competitive disadvantage that these and other costs represent to islands' economies is thereby avoided. While the development to an information society has not explicitly been mentioned by none of the contacted actors, as part of the, so classified, developed world, this development is a fact. This sort of society enhanced further the need of electricity supply security.

Within the service sector, tourism is expected to be the keystone of the future economic development of both islands. Tourism's specific activities aggravate, even further, many of islands' specific problems: Its increase can be accounted as a population increase, when it comes to infrastructure and service requirements. As such, households' related comments to follow are also applicable to this sector. The increase of its activity can furthermore provoke a seasonal effect on the electricity demand, as already acknowledged on Flores. This can represent a substantial problem to a 100% RES electricity system, as it implies a considerable investment in overcapacity to assure supply in peak demand periods. Fortunately, the tourism wished to be developed on both islands is alternative or rural tourism; the less energy intensive and less seasonal conditioned sort of tourism.

On both island households embody the highest electricity consuming group, representing, in both cases, near to 50% of the total electricity consumption. The islands' social development will continue increasing the population wellbeing as increasing its low educational level. Economic welfare and cultural level are factors generally acknowledged to affect considerably any consumption patterns. In this specific case, the possibility to access increased comfort

through, for example, electric appliances which previously were economically out of reach leads to foresee a significant further increase of households' electricity consumption. The same happens with life style changes with new needs covered by modern electronic devices. This forecast is supported by the fact that, for both islands, the number of electric appliances is still considerably below European average. If a reduced impact of electronic equipments is to be achieved, a major attention on energy efficiency of these elements has to be accomplished. A kind of "green subsidy" on energy efficient equipments could be a good tool to achieve the purchase of the most efficient equipments, generally punished by the market due to their higher cost. This subsidy would lead to increase the competitiveness of energy efficient products in the market, guiding the consumer to its purchase, while avoiding islands enhanced investments cost of adapting its electricity system to increasing demands. To boost the effect of the subsidy, actions, implemented by government or entities as energy agencies, leading to conscious electric appliances consumers will nevertheless be essential.

The fact is that in both cases, little has been done in this field. At least little information regarding consumer pattern forecast and associated actions addressed to steer the market to the acquisition of more efficient devices has been obtained. Much can be gained in the long-term sustainability of these projects if this is accomplished.

The energy saving campaigns that has been undertaken on both islands have put major attention on behaviour change when using electricity, as, for example, switching off of electric devices when not in use. In El Hierro's case, the advantages of using solar panels to cover hot water needs have been also relevant aspects of its awareness campaigns. While this specific option seems doubtfully applicable on Flores, given its low expected solar radiation, the true is that the use of this and other technologies to cover comfort linked electricity needs (hot water, heating/cooling, and lightning) will lengthen substantially the sustainability of the projects. The same occurs while promoting up to date building know-how to reduce energy needs of buildings. In Flores case risks in this field are major linked with heating needs; on El Hierro with cooling and water needs. As the actual tendency is to use electricity to cover these needs, apart of a significant electricity demand increase, seasonal effects on the electricity demand will appear due to the seasonality of these needs.

In summary, the long-term sustainability of the projects cannot be assured if the actual electricity growth tendency continues and seasonal electricity demand effects are to be bold. Much can be gain if actions, as the above mentioned ones, are accomplished.

Concluding, the existing risks for further electricity demand increase can be summaries as follows:

- The expected growth of the island population;
- The still lower energy intensity and number of electric appliances in use when compared to mainland and EU circumstances.
- The effects of tourism and shift into a information society as motor of the future islands' economies.
- The further growth of water, heating or cooling needs linked to population and tourism growth, as to social change.

The need of a secure electricity supply is, and is expected to become even further, relevant for islands society's wellbeing.

5.2 Supply

In both case studies, security supply has been identified as the main objective to be covered by the future electricity supply system, being the economic goal the second objective in the

planners' priority list. It is significant that just the wish of assuring a cost efficient electricity supply on the islands has been already enough to take the path to a 100% RES electricity system.

European Commission's TERES II study proved through its future European energy scenario analysis the sensitivity of the energy mix to policy changes.²⁵² As such policy instruments represent an appropriate tool to guide the suppliers to provide the proper final energy mix. The limitations of applying efficiently these tools at island level will be discussed while analysing the electricity market; briefly, as the slide adaptation of the country's electricity market and policy rules to islands circumstances are established at archipelago level, considerable disturbances on the islands particular electricity market exist, resulting in a more than imperfect working electricity market. If the local government's limitations to create specific policy tools for the local electricity market are additionally considered, little margin exist to guide suppliers through market tools to provide the for the electricity system convenient energy mix.

In order to assure the electricity supply to obtain a proper energy mix is the keystone. As such the first step is to study the theoretical potential of the different RES; in the way they are by now considered, are being studied or have already been discarded. Secondly, the technical and economical potential of these sources has to be analysed, as the ways these potentials may vary in the future.

The energy sources mix considered in both cases studies consists, firstly, of a large stable energy source as hydropower, with the small difference that, for El Hierro, the hydropower system represents verily an energy storage unit. The second energy source chosen has been wind energy. These case studies show the possibility of achieving a much higher wind energy penetration without compromising the stability of the electricity system than generally has been assumed. In El Hierro a 30% of direct wind energy penetration has been planned, representing wind energy a much higher share when adding its, in the hydropower installation, stored amount; on Flores up to 50% wind energy penetration has been already proven to work during night periods without any relevant negative impact on the electricity system.

While in Flores case no further RES is significantly promoted through any institution or organization, in El Hierro grid connected solar PV is governmentally promoted. The diversification of RES used in the energy mix increases the supply security, as it reduces the risk of supply shortage due to the temporal lack of certain RES. At the same time, an increased number of small electricity suppliers leads to increase the complexity of the stability control system; increasing the risk of supply breakdown due, for example, to overfeeding the grid system. Once more it is the government who through their on hand policy tools has to rule the uncontrolled increase of electricity suppliers. The amount of, difficultly controlled, small producers feeding into the grid can be managed through license award for grid connection. This tool represents a potential barrier for new incomers, as it has been proven in Canary Islands case: No license for wind farm establishments has been concede during a 10 years period, what has fully broken the RES penetration increase during this period. The administrative delay in the licence concession has been argued through the need of studying firstly the wind potential in any location in order to reduce the impact of wind energy production. A doubt about UNELCO's influence on this delay, given its power due to its actual monopoly situation, exists. What ever argument is given for this delay the fact is that it has represented an impassable barrier. If real or not, that doubts about the clearness of the licence concession process itself represent a further barrier for RES. Potential investors can get scared of investing money and time in a betting, where the sporting chance is not clear. In

²⁵² Commission Communication Com (97) 599 final

any case, technical aspects should be the guiding point for allowing the grid connection, independent which policy tool is finally being used to rule the connection allowance.

By the other hand, the previously mentioned delay has had a positive economic effect, as investment requirements of wind farms has been going down and the production level per turbine has gone up. Higher production levels per wind turbine also shortage the return on investment. The environmental impact of wind farms emplacements has been thereby also reduced, as lower number of wind turbines are required to achieve equal production levels. The opportunity cost of emission cuttings during the whole 10 years period should not be forgotten.

One, for both case studies, common barrier for the quicker achievement of the 100% RES system has been the development and adaptation needs of the actual grid system to the new requirements. Given the actually problems of the grid system, its adaptation to the future reality will have to be the first step to allow a higher RES penetration and diversification through small electricity generators. The economic side of this issue represents an additional barrier. The investment need for grid reinforcement added to the high initial investment RES electricity generation system required, breaks a more rapid adaptation to the new system.

Azores has much broader RES perspective regarding its theoretical potential, given its know-how about the remaining RES. This puts them in a privileged starting point to diversify the RES used on Flores. The limitation for further RES diversification is basically due to the technical and economical applicability of this know-how to Flores circumstances. The economical exploitation potential is, for example, the barrier for geothermal energy electricity exploitation. On El Hierro this alternative is also additionally broken by the lack of local know-how of this kind of applications. In Flores it seems to be the technical potential what has limited solar energy exploitation for electricity production purposes, as not enough energy conversion of the low existing solar radiation can be actually gained. This option is not feasible. Wave energy is still in a research phase and its applicability on Flores will still be unknown for quite a time. The use of biomass as RES is in both case studies still under study. When it comes to waste residues, its use for energy recovery has been dismissed in both cases due to its negative social recognition. Also economic figures don't sustain its applicability at island level, given the scale a proper waste treatment plant would need. Additional cost of waste residues treatment, transportation to other islands or even mainland, the cost of waste segregation activities, as the case specific actual impact of these activities as the waste problem itself on the island society and environment should be accounted to obtain the real image of the waste-energy problem. Singular solutions should be looked for.

Basically, the economical potential of certain RES uses can increase significantly in a medium term if the source of its actual application is linked to economy of scale problems. The use of H₂ as alternative energy carrier to fossil fuels will increase local energy demand for local H₂ production, as this H₂ could be used to cover other energy uses beside electricity needs, or as part of an energy storage system. Actual economical exploitation limitations of the geothermal potential, for example, could through this become economical feasible. Such a possibility will depend of the cost reduction and technical development of H₂ production, as of the fossil fuel price evolution.

To reduce the impact of RES intermittency, to increase the reliance on RES, the proper correlation among intermittent energy sources has to been sought for. The correlation among demand seasonality and RES seasonality is also desirable. In both cases, the latest hasn't been achieved. Flores demand increases in summer, just at the time where the RES production is reduced due to rainfall and wind diminishment. In El Hierro it is the winter reduced wind availability which represents a risk if the tourism activity, centred in the winter months is expected to grow. Fortunately, rainfalls and less evaporation, increases the hydropower production, as reduces, electricity requirements for desalination when compared to other

periods. In order to balance short time electricity demand and supply discordances the installation of flywheels are being considered in both cases.

As mentioned before, the RES diversification as the increased number of suppliers stresses the importance of an adequate control system. The use of the same initial, isolated electricity systems' control program, adapted to their singular characteristics, reflects the existing synergies in R&D among isolated islands. The MORE CARE system, in use on both islands, is result of EU's collaboration network.

To assure the sustainability of the project following actions are convenient to be pursued:

- Related to the theoretical potential:
 - Deepen into know-how of the theoretical potentials of the existing RES
- Related to the technical potential:
 - Solve or reduce the impact of intermittency of the applied RES mix, through higher correlation among the RES being used, as with the demand seasonality.
 - Investment in R&D to increase the technical potential, but also economical potential of RES exploitation.
 - Investments in grid control and grid adaptation to the new scenario, to avoid energy inefficiencies and through it reduce investment need in electricity generation capacity.
- Related to the economical potential:
 - Improvement of the governmental intervention in the electricity market, as it will be brightened in the following paragraph.

5.3 Electricity market

The still pendent establishment of the Iberian Electricity Market (MIBEL), which will represent the fourth biggest European electricity market, is leading to unify the nowadays existing differences between Portuguese and Spanish electricity market. Actually a great doubt about the final establishment of this electricity market exists. Market forces are guiding to huge concentration processes among energy companies. Portugal's and Spain's energy market has been recently under pressure of these forces: In Portugal's case it has been Energias de Portugal (EDP – Energy of Portugal) and Ente Nazionale Idrocarburi (ENI- Italian National Hydrocarbons' Entity) who have tried to get the control, first of Gas de Portugal and, secondly, of GALP (Portuguese petrol company), who actually controls GDP. In all this cases it has been EU's veto to these market operations that have stop them of becoming true.²⁵³ In Spain's case it is has been the recent, still unsolved, takeover bid of Gas Natural (Spain's major natural gas company) on ENDESA.²⁵⁴ This operation is pendent of Spain's national government's decision regarding its convenience. These concentration operations, if somehow finally accomplished, imply a significant reduction of competitiveness within the energy market. They can lead to an oligopoly or even monopoly situation within certain regions, on which any try to increase the market size will have reduced effect, given the international nature of the involved companies. As such, the MIBEL would not achieve its principal objective: increase the market competitiveness.

²⁵³ Rodríguez, Alfonso (2005) Portugal afrontará el MIBEL con un nuevo modelo energético [Portugal faces MIBEL with a new energy model] [Online] Available: <http://www.terra.com/noticias/articulo/html/act231491.htm#> [05/10/2005]

²⁵⁴ Rodríguez, Alfonso (2005). Los analistas creen que la OPA de Gas Natural dificulta el funcionamiento del MIBEL [The analysts believe that the takeover bid of Gas Natural hinders MIBEL's operating] [Online] Available: http://www.estrelladigital.es/articulo.asp?sec=eco&fech=16/09/2005&name=cover_galp# [05/10/2005]

As, Luis Mira Amaral, Portuguese ex minister of industry, has stated regarding Gas Natural's takeover bid: It will have no sense to continue talking about the MIBEL, because it implies a convergence of competitiveness policies and price fixing regulations among both countries, issue which will manifestly not happen.²⁵⁵

The possibility of achieving a free market in which the energy price to consumer is fixed through market competitiveness becomes in such circumstances improbable. Even more, the cost of the takeover bid will have to be paid out through the market, versus by the end-consumer through energy price increases, or by reducing the investment capacity within the sector.²⁵⁶ As such, the investment needs in, for example, grid reinforcement of Spain's islands' systems, under ENDESA's control, will be lengthened in time.

Given the actual uncertainty regarding the future, the following argumentation will assume that MIBEL will be accomplished and that no oligopolistic/ monopolistic environment will exist in its future scenario. Under these premises, considering the more than foreseeable further price increase of fossil fuel prices, the competitiveness of electricity generation from RES will increase in the future. When it comes to the effect technical development will have on the market, it is also rational to suppose a higher cost reduction per kWh for renewable energy technologies than for fossil fuel based ones, given the technological age of one and the other sorts of technologies. The competitiveness of RES will, though it, be further improved.

When it comes to the overall electricity market competitiveness, MIBEL's establishment should lead to price reductions as higher competitiveness among increased number of electricity suppliers is achieved. Higher number of competitors with an enlarged variety of electricity generation technologies/business models leads certain suppliers to drain their production processes or even to reduce their business margins to assure their sales. As such, higher market efficiency is achieved. It is also through that the scenario for the end-consumer doesn't display a significant final price reduction, moreover its increase, given the abovementioned fossil fuel price raise, as the improved competitiveness of, in the actual RES promoting market frame, for the system more expensive, RES electricity. The electricity price in the generation market can decrease, depending on the resulting balance among cost increases due to fossil price increases and business margin reduction due to improved competitiveness. The increased amount of RES electricity produced and the investment in grid adaptation will raise the cost share the end-consumer pays added on the electricity generation price as RES promotion and distribution system costs. As a result, the end-consumer electricity price is very unlikely to decrease. On the other hand, this end-consumer price stagnation or even increase will have the positive effect of not spurring the electricity demand.

But, which will be the effect on the addressed island systems? Firstly, Portuguese island system will profit from the agreed solidarity principal to be applied at MIBEL.²⁵⁷ The solidarity principal, in force in Spain's energy market, will lead to a unique tariff setting for all MIBEL's end-consumer, also Portuguese islands end-consumer. This tariff only represents an upper price barrier for the expected competitive electricity distribution market. The Portuguese

²⁵⁵ EFE (2005) Ex ministro de Industria afirma que MIBEL carece sentido tras OPA [Ex-ministre declares MIBEL has no sense after the takeover bid] [Online] Available: <http://www.invertia.com/noticias/noticia.asp?idnoticia=1371083> [05/10/2005]

²⁵⁶ Rodriguez, Alfonso (2005). Los analistas creen que la OPA de Gas Natural dificulta el funcionamiento del MIBEL [The analysts believe that the takeover bid of Gas Natural hinders MIBEL's operating] [Online] Available: http://www.estrelladigital.es/articulo.asp?sec=eco&fech=16/09/2005&name=cover_galp# [05/10/2005]

²⁵⁷ Ministerio de Industria, Turismo y Comercio (2004) El MIBEL creará condiciones favorables a la competencia y tendrá beneficios claros para los consumidores [The MIBEL creates positive conditions for competitiveness and will have clear benefits for consumers.] [Online] Available: http://www.min.es/ministerio_informa/notas_prensa/np07-10-04_2.htm [16/10/04]

islander electricity consumer will see its actual electricity cost reduced; mainland electricity consumer will see its tariff increase, but given the much higher number of mainland consumers, the tariff increase effect due to this issue can quite be dismissed. Secondly, a common solution regarding isolated energy systems will have be found. The problem relies in the real need of adapting the system to each isolated area, if an efficient electricity market on each isolated system wants to be achieved.

Given the above mentioned basic frame, the existing dilemma in island's electricity market will be centred in the electricity generation market, as the distribution market will work independently. The only link among both markets is the electricity quantity de distribution market requires at island level to satisfy the consumers demand at the generally established price. This quantity is assured as the electricity generation market is forces by law to provide the, at each moment, demanded amount. As such the islander electricity market dilemma can be summaries in achieving a competitive electricity generation market, assuring an overall efficient electricity supply, taken into account island characteristics in synchrony with the, by the Iberian electricity market established, working rules.

In both cases, the actual regulation is adapted at archipelago level, not at island level. When it comes to the RES electricity promotion system, the regulation is, in Spanish case, unique at national level. These regulations create significant distortions in each island's electricity market and reduce the efficiency of the applied or applicable policy instruments. In both case studies, a monopoly situation, de facto, exists. No significant RES diversification has been achieved due to which low change in the original monopoly circumstances has occurred.

The, on both studied islands, existing compensation systems, where Portuguese ones has a smaller negative financial impact as it is paid out monthly and adapted to real cost quarterly instead of yearly, will not be applicable in the final 100%RES system. This instrument is only applied on not RES electricity generation. RES have specific prices established through other procedure, based on national RES promotion objectives. These pricing systems, deferring at certain level in Portugal's and Spanish's cases, has not been designed for a 100%RES electricity system. Even if a certain readjustment of these systems to be unified will occur, they doubtfully will include consideration to 100%RES electricity systems. Shouldn't, in order to achieve an efficient electricity generation market and considering the singularities of a 100%RES system, the market rules be established independently to the Iberian energy market?

The main problem of these markets is the, historically given and to its size linked, monopoly situation. Consequently, two main alternative future scenarios have been identified: Assuming that the actual monopoly situation is unavoidable, a solution to manage the power this monopoly situation gives to the established company has to be found; or assuming that the monopoly can be broken, allowing a competitive market, thanks to the chance the, to RES linked, micro-generation technologies are offering. In order to analyse these two scenarios, an understanding of the structure the two main companies involved in these projects have is needed. This will allow establishing a link among the specific circumstances which influences the island's electricity market and its more convenient/ foreseeable future electricity market scenario.

5.3.1 Companies structure²⁵⁸

EDA has created different sub-companies to cover their activities related to RES, such as EEG, covering wind and hydro-power, or SOGEO and Geoterceira for its geothermal activities. The progressive switch to RES is result of the headquarter-company's vision. EDA's mission is stated to be providing their customers with electricity in a quality and efficient way,

²⁵⁸ See appendix 2

assuming a main role in developing the Azores, protecting its environmental and cultural heritage. Its strategy states their growing stake in RES.²⁵⁹ The main reason for this commitment is that this company is a regional company, therefore more affected by the local acceptance and local development than UNELCO, but also result of its early contact with RES. The early introduction of RES as electricity source on Azores islands is result of the kind of RES been used: Hydropower, an old known technology. Accordingly, Flores renewable energy activities started already in 1966. On El Hierro this didn't happened until 1995, when the first wind energy farm started to produce; a much recent and, at that time, very costly technology. This RES electricity generation was only indirectly and partly linked to UNELCO, as part of ENDESA's group. One of its sisters companies was part in the mentioned farm.

UNELCO seems to be a regional company, but can't be considered as such. UNELCO has been one of the only two electricity generation companies within ENDESA's group²⁶⁰ which were not unified under ENDESA Generation in 2000. They were kept as independent company as linked to isolated island systems and therefore entailing a totally different business problem.²⁶¹ In this environment, UNELCO has its individual identity, but is steered by ENDESA's vision and strategy. Its mission is stated to be the maximization of the company's value, to serve the market beyond the customers' requirements and to contribute to their employees' development.²⁶² Although, ENDESA has its defined sustainability strategy; being a multinational, it is not so much concerned about the development and protection of a specific region as a regional company as EDA will be. ENDESA looks for the company's value maximization, under which not only economic benefit, but concepts as image and social responsibility are involved. This company's value maximization is an overall company objective: Any specific project only represents a small step towards the overall goal. That doesn't mean that their participation in this project is not sincere. It only means that their commitment is limited to the established percentage they cover. It is also true that they also expect to benefit from the innovative part of the project, if applicable in their other isolated systems, or as a marketable intangible good: know-how. Being part of the project also represents a way of assuring a privileged position to promote or to break similar changes in the other islands' systems, based in the headquarter-company's interest.

The path to the 100%RES electricity systems these projects represent has been influenced by the companies' personal attitude. In Flores, thanks to EEG's activity, RES covers already 61.9% of the electricity consumptions; 45.8% through hydropower and 16.1 through wind power. The company also seem willing to invest in biogas production and in exploiting other RES. They are being the main drivers of the change. As a consequence, EDA has kept its monopoly on the electricity generation market until now and assures itself a long lasting power position.

Contrary, El Hierro's energy market will change drastically. A new big actor is going to take over the main producer position. UNELCO's actual generation will only serve as a back up for the case that RES can't cover temporally the energy demand. Several small actors will also be added. UNELCO's role as grid controller will be enhanced if not substituted by RED ELÉCTRICA. In this case, UNELCO will be relegated to be just part of the new company's capital, with no controlling power position (30%).

²⁵⁹ Electricidade dos Açores (EDA) [Electricity of the Azores] (2004)

²⁶⁰ ENDESA is a multinational in the energy sector present in 11 countries, 3 continents. Energía de España Sociedad Anónima. (ENDESA) [Energy of Spain] (2004)

²⁶¹ Energía de España Sociedad Anónima. (ENDESA) [Energy of Spain] (2004)

²⁶² Energía de España Sociedad Anónima. (ENDESA) [Energy of Spain] (2004)

Public-private partnership (PPP) could be an interesting final aim to be achieved in the governance of the, to the 100%RES plan main linked, companies. What is for sure is that in both cases public-private ownership is being aspired. In Flores case, the public company, which has lead quite rapidly to a high RES penetrations, wants now to incorporate local investors, small and medium enterprises at local level to participate through a privatization of part of the by the local government controlled main capital share. EDA's intend to include local business into its ownership relies on the strategic importance of electricity for the local enterprises. In El Hierro's case, the discussion about the capital shares which each part should take over has been one of the main problems leading to delay the companies' establishment and through it retarding the 100% RES project. Control power in the companies' decision making process has been the core of discussion. The final 60% control of the island government to be reduced to 50% when transferring 10% of the shares to local business (following the same principle of strategic relevance of electricity for local businesses), will allow to balance business thinking with public thinking.

PPP in the academic way is meant to establish an institution which has decision taking power on the managing company. This institution should be formed by different social actors, as consumers' representatives, local NGO's, local energy agencies, municipalities, local government and capital investors, suppliers' and consumers' representatives. None of such an executive council has been established and doesn't seem to have been considered in any of the cases. Only capital investors' power has been considered as the way to establish the rules to manage the company. The advantage of considering such a body to guide the company's behaviour relies in the participation of other, to the capital alien, but to the business entailed, members, which can have a considerable influence in reducing existing barrier, providing acceptance of the project and community involvement. Through it demand growth control will easier be exert. While in El Hierro's case study countable actions regarding RES promotion, with community involvement and barrier reductions campaigns have been mentioned, no of such campaigns has been mentioned in Flores' case. And that despite no energy agency exist on El Hierro, entity which normally promotes these actions. In Flores' case, its local energy agency seems not to have gone much into the 100%RES path, but this can be just a wrong appreciation given the limited information about its action that has been obtained.

In both island's, given the demand growth tendency and the enhanced cost the system has to adapt to growing demands, a very high potential, business opportunity for an energy service company exist. The cost savings which energy savings can provide gives a high business margin to such a company, not only by the customer side, which will see its electricity bill reduced, but also of the electricity system side, which members could be interesting to pay certain amount to avoid investments in grid reinforcement and further electricity generation equipments. Even in this scenario, EDA has already a privileged starting position for considering proving such services. Its filial company SEGMA, which already provides industry with maintenance services, energy consultancy and energy project, has the required know-how to undertake such a project.

5.3.2 Scenarios analysis

The two mentioned scenarios, which will now be analyses more thoroughly, should be understood as extreme cases which will embrace the real future scenarios of both islands. Independently, which will be the final future scenario, if one or the other or any intermediate scenarios, the fact is that the whole system will benefit of a more cost efficient island electricity market.

5.3.2.1 Controlled monopoly scenario

In this scenario a unique electricity generation company will supply all electricity. As a consequence, any future RES diversification will be only linked to the internal achievement of the lowest average electricity generation cost within the electricity generation company.

In the case that this company is filial of a major company, a national or even multinational, the cost minimization strategy which it follows can be linked to island external strategies. The headquarter-company's benefit maximization strategy could distort the local decision taking process, as the, in El Hierro case study mentioned, wind turbine acquisition decision proves.

EU's directive forces to the liberalization of the energy market, which in the electricity market should lead to differentiated actors in the electricity generation and distribution market as to enhance competitiveness within each market. In this scenario no competitiveness has been achieved in the electricity generation market and, given the to costumer existing tariff setting, the island's enhanced cost, and the historically established distribution company, no competitive distribution market can either be foreseen. Historically, on both archipelagos, one unique company controlled the generation and distribution activities; as a consequence even if these activities are managed by different companies, which still are controlled by the same headquarter-company. No competitiveness increase can be won if only one producer linked in a major company structure to a specific distributor exist. No new distributor will have the option to enter the market. Not even considering the added cost, which represent to enter a new market, the surely for this company higher general transaction cost, will make it impossible to offer a competitive price to consumers. Ones more, in such a scenario, the enforcement of, in this case, EU's general regulation on island specific circumstances should be put under question mark. Is the enforcement of such a regulation an advantage or only leads to an unnecessary complexity and cost duplication within the island's electricity market?

Governmental institutions should be guardians of the social welfare. In this context, it means that they should assure the proper working of the electricity system, minimizing its negative impact on the society and the environment, as assuring that anyone obtains unusual benefits of the existing monopoly situation in detriment of others. Two are the ways to exert control in this scenario.

One option is to exert control through strict economic and technical regulations, exerting all the power policy tools can offer: governmental intervention. This means a regulated market exactly that kind of market the EU's directive is trying to avoid.

The other option is to exert control through controlling the company internally, which means controlling its capital. Also this is somehow been tried to be limited at national level by EU's directives, with the aim of avoiding the regulator, central government, to represent a significant economic actor in the electricity market. As such the optimal solution should be a local energy generation company controlled by local governmental institutions.

Basically, this has been also the company's structure chosen in both case studies to be applied to the main companies of the future electricity market. But it is EDA's singular future market scenario which seems to be more next to the defined scenario, as no other electricity generator outer EDA's group can't yet be identified. In any case, any RES electricity generation out of this company group will be confined to represent a residual share of the electricity market, totally exposed to main company's control.

5.3.2.2 Diversified RES micro-generation scenario

In this scenario a competitive electricity generation market is achieved thanks to a large number of electricity suppliers, which, thanks to the RES promotion framework and the, to many of to these sources linked, small generation technologies, has entered the market. This increased numbers of suppliers can also lead to increase the competitiveness in the

distribution market, but for this to happen a whole new market frame will have to be established, beside the actual RES promotion policy.

As argued before, the for RES promotion established renewable energy prices are not convenient for a 100%RES system. In such a system, price differences among RES will distort the market and lead to a cost-inefficient electricity generation. In the actual renewable energy pricing system promotion objectives, considering theoretical and technical potential of the RES exploitation, are established, but at national level. In Portuguese RES pricing system, individual project characteristics are also accounted. As such the final price is project specific, but readjusted, as in the Spanish model, annually regarding the achievement of the remaining national objective. As such, Portuguese model is a better starting point when it comes to these specific island systems, but the price fixing model should be even more accurate through establishing promotion objectives at island level. The objectives should be established based on the, by the planners defined, energy mix to supply the future market, based on island's RES potential and electricity system convenience. As the prices are reviewed annually, they will adjust gradually, entailing less and less promotion incentive, until a free, competitive electricity generation market can be established.

In order to achieve this split electricity generation market significant efforts in grid system and control system development will be needed. Additionally, clear and long-term technical and economic regulations regarding new incomer policies and income streams will be required.

The enhanced investment requirements/ cost of such a fragmented electricity system will be easier to be gathered, if considering this model as an experimental model to be applied in the future at mainland, European or even global level. As such funds for the required investment and research development can be obtained from the European Union, while gained back ones the acquired knowledge can be spread out.

The actually established companies are already aware about the risk new incomers by RES micro-generation represent to them. Trying to keep their actual monopoly situation they can be tempted to act against further RES promotion, but they also can decide to work with the unavoidable trend, leading the way to 100%RES systems, through internal promotion of renewable energy generation technologies. Through big investments and taken advantage of their privilege position they can try to control a high quota of the renewable energy market and thereby keep their actual position. The second option seems the better option for these companies, given the actual and future foreseeable electricity generations cost of the by them applied electricity generation technologies as the foreseeable decrease of the RES electricity generation costs. This seems to be proven in the attitude both established companies have regarding the 100% RES system, and this is the option which would lead them to the first analysed scenario. Regarding the herewith analysed scenario, the hidden power these energy companies could exert in the process to a competitive electricity market in order to assure their actual position should not be taken light-handed. In order to break down the existing monopoly, governmental intervention should establish rules in the license concession to scatter the market, as to avoid concentration processes afterwards. This means to work hardly to avoid the power influences of the monopoly company, especially in the case of the international one, where the overall objectives and strategies guiding the local filial actions can be totally contrary to the achievement of a 100%RES system. Actually, Canary Islands are suffering under such forces, leading to the promotion of natural gas applications with a very high cost in infrastructure adaptation instead of taking the chance of promoting further RES sources, technically and economically possible, but against the ENDESA's interests, moreover if Gas Natural's takeover bid is finally accomplished.

Coming back to herewith presented scenario, El Hierro's circumstances could lead to it, if Gorona del viento centres its activity in the energy storage activity it entails. The, in the 100%RES project specifies, up to 70% wind energy use, to which stability the hydropower

plant will contribute, must not necessarily be generated by Gorona del viento owned wind energy farms. Moreover, as the license concession system actually, once assuring all the technical requirements, is just a bid price issue, any offerer is supposed to be able to obtain a share of this production assigned.

5.3.3 Networking²⁶³ - Collaboration²⁶⁴

Collaboration is a magnificent tool to increase technical and economic potential of RES applications. Collaboration reduces R&D costs, as it increases its effectiveness in obtaining results. R&D investments became a source of incomes, as the results can be shared with the collaborating parties, but also sold to network members. Networks help additionally to reduce certain market barriers as representing contacts among potential demanders and suppliers, with information exchange about proven or experimental actions. Clark and Isherwood state that the time frame which R&D efforts require for its fulfilment varies depending on the institution promoting it: Industry considers short-term projects; research centres medium-term projects and universities long-term projects. Collaboration among them leads to cost efficient results of R&D development and as such should be boosted.²⁶⁵

These forms of interaction have been mentioned in both case studies. They incorporate a substantial international perspective, result of the common problems islands suffer within their national frames and as isolated areas. EU's acknowledgement of these problems is proven through their past and present support to these network and collaboration schemes. An excellent example of its results is the MORE CARE control system²⁶⁶ developed by the National Technical University of Athens (NTUA-Greece), the INESC (Portugal), the research centre ARMINES (France), the Public Power Company (PPC-Greece), the Electricity Supply Board (ESB-Ireland), Madeira's electricity company [Empresa de Electricidade da Madeira, EEM-Portugal), the Council for the Central Laboratory of the Research Councils-Rutherford Appleton Laboratory (CCLRC-RAL-United Kingdom), and the Aristotle University of Thessaloniki (AUTH -Greece), to originally be applied on Crete, Ireland and Madeira's Islands with the financial support of European Commission's DG Tren Programme.²⁶⁷ This application has being adapted by RED ELÉCTRICA to Canary Islands circumstances, by EDA and INESC to Azores ones. Now it is its 100%RES systems specific which is being developed under on and the other projects.

El Hierro's project shows a further international/inter-organizational example of collaboration under EU's DG Tren financial supports. In the development of this project a university, a research centre, two energy agencies, a governmental institution, a NGO and a private

²⁶³ Meeting people who can be of help to you and being a help to them. (Glossary of business terms, 2005)

Inter- or intra-exchange of services or information between different individuals, groups, companies, or institutions. (Satellite tv online, 2005)

²⁶⁴ A mutually beneficial well-defined relationship entered into by two or more organizations to achieve common goals. Collaboration is the process of various individuals, groups, or systems working together but at a significantly higher degree than through coordination or cooperation. Collaboration typically involves joint planning, shared resources, and joint resource management. (National Center for Children Exposed to Violence, 2005)

A process, in which two or more entities work together to achieve their independent and collective interests through a joint problem solving process. (Native Dispute Resolution Network., 2005)

²⁶⁵ Clark, W., Isherwood, W. (2004). Distributed generation: remote power systems with advanced storage technologies.

²⁶⁶ Pecas Lopes, J. A. (jpl@fe.up.pt) (2004, July 14)

²⁶⁷ NTUA, INESC, ARMINES, CCLRC-RAI, AUTH, PPC, ESB, EEM (n.d.) Preliminary results from the more advanced control advine Project for secure operation of isolated power systems with increased renewable energy penetration and storage. Handed out by Pecas.Lopes, J.A. (jpl@fe.up.pt)

company; two Greece, a Portuguese, two Canary Island's, a Swiss, as an international entity are collaborating²⁶⁸. Not only a 100% RES electricity system for El Hierro island has been the aim of the, through this collaboration implemented, project, but also the feasibility study of similar 100%RES systems on Crete and Madeira, as the analysis of the potential for its further application on other island's systems. As such not only the future application of the acquired know-how on the other related islands is undertaken, but the analysis of the future market this knowledge could have. The expected results of this specific project has been stated to be GHG emission reduction; life quality and energy independence increase on islands; as proving that RES integration is a way of providing 100% energy supply on isolated islands; that synergies between RES can highly contribute to increase RE penetration into weak grids in isolated areas and that pumped water storage is an economic way of accumulating energy. The overall goal is to optimise the available potential of RES using them together in integrated systems for local power supply.²⁶⁹

A collateral effect of collaboration is to promote social consciousness of the analysed problem, in this case the energy problem of isolated regions. The acknowledgement of the energy problem represents the first step to behaviour change, to social respond. Relying on it, the above mentioned DG Tren Project for El Hierro, also addresses aspects related to the island population acceptability of the 100%RES project, as trying to involve and integrate the population in the development of certain aspects of the project.²⁷⁰

EU's support is not limited to the financial support the two above mentioned projects has obtained. The resulting network system has gone far beyond European Community's borders. Already in the Altener programme islands as Aero, Samsøe, Gotland and El Hierro got together under its 100% island programme, which under the Altener II programme has developed to the 100% Communities on island partnership under EU's partnership programme. They also have the additional support of EU's Organization for the Promotion of Energy Technology (OPET) network, as UNESCO's International Scientific Council for Island Development (INSULA), as a recognition of the benefits which can be obtained from learning of success stories on other islands, while exporting own achievements²⁷¹ As a biosphere reserve, El Hierro also cooperates with other biosphere reserve islands, such as Minorca, Guadeloupe, Galapagos, Hiiumaa and Lanzarote.²⁷²

In Flores case, no project specific collaboration has been mentioned, but the results of EDA's collaboration with other institutions is and will continue benefiting Flores project. Strong links with the local university has been established while accomplishing projects within EDA's interest field. Azores biomass and geothermal potential studies as the hydrogen project, all still under development, are results of this relationship.²⁷³ EDA also collaborates with the ITS Lisbon in a tidal energy project, as in the 100%RES project on Corvo Islands.²⁷⁴ The

²⁶⁸ Project partners are, beside the already mentioned ITC and El Cabildo Insular de el Hierro (Canary Islands, Spain), the National Technical University of Athens (Greece), the Regional Agency for Energy and Environment of Madeira (Portugal), the Regional Energy Agency of Crete (Greece), INSULA (International Scientific Council for Island Development-UNESCO) and E4Tech (Private Company-Switzerland). (Piernavieja, Pardilla, Schallenberg, Bueno, 2003)

²⁶⁹ Piernavieja Izquierdo, G. (2003) El Hierro 100% RES

²⁷⁰ Piernavieja Izquierdo, G. (2003) El Hierro 100% RES]

²⁷¹ OPET island, Renewable Energy For Europe-Campaign for Take-off. (2001) Renewable energy partnership declaration: El Hierro Island Biosphere Reserve 100% RES Supply.

²⁷² OPET island, Renewable Energy For Europe-Campaign for Take-off. (2001) Renewable energy partnership declaration: El Hierro Island Biosphere Reserve 100% RES Supply.

²⁷³ Estrela, David L.R. (destrela@eda.pt) (18/06/04 and 20/09/04) E-mails

²⁷⁴ Estrela, David L.R. (destrela@eda.pt) (2/06/04) E-mail

previously implied MORE CARE system adaptation-project to Flores characteristics reflects the collaboration of EDA and the INESC.²⁷⁵ Thanks to EDA's participation in different RES projects and to the, by their partners established, relationships, EDA has a very spread international network within many specific fields.

5.4 The three dimensions of sustainability

5.4.1 Social dimension

Flores' 100% plan is having a much quicker implementation process, result of a unique leader with a defined vision and unique action. As the vital promoter of the system is the energy company, acting as an independent actor, a significantly low social implication in the project is achieved. If EDA's goal is a long-term sustainable system, to control the demand growth is a must. A demand increase affects negatively the company's exploitation result, as requiring grid and generation capacity increase, which means further investment. This issue should not be dismissed by EDA. The acknowledgement of the energy problem by the local population has a buffering effect on the demand, when translated in behaviour change. Involving the community is the first step to a more conscious energy use. The strongest social aspect related to this issue is the opportunity cost the above mentioned investment: Alternative uses surely would benefit the society more than its application to avoidable capacity and grid reinforcement needs.

On El Hierro, as one of the major benefits of the project, is based on the added value this system means to the island's society, El Cabildo has put a major emphasis in communicating the plan. The island community involvement has been understood as crucial to achieve a sustainable 100% RES system. Consequently, seminars and workshops with educational and training aims, for population and experts, as an annual briefing of the project development has been carried out. Also a Forum "El Hierro 100% Renewable" has been established.²⁷⁶

As a consequence, islands reputation increase is probably bigger on El Hierro, as the, by the population obtained information is spread through them. This effect is especially relevant linked to tourism, to alternative tourism. Through it the project is spread world wide, on many not scientific levels. Moreover, this project is can become a competitive advantage, when choosing among alternative tourism destinations. A 100%RES island seems to be in concordance with alternative tourist mentality; such an island represents therefore a differentiated tourism product until not generally common. This is especially relevant when the sustainable island strategy has one of its keystones in the development of an alternative tourism activity.

At scientific level, Azores is ahead in R&D of renewable energy sources not directly linked to Flores 100% RES project. Less innovation is related to this project compared to El Hierro's case. As a consequence, the social benefits which Flores society could gain due to R&D results is very limited. El Hierro's project has already established project specific capability in the local government and company's filial representatives in the island.

In none of the cases a direct employment increase should result of these projects, but a more efficient use of actual human and infrastructure resources, which actually are inefficiently use due to island's scale, will be achieved. Small electricity generation technologies represent an opportunity to diversify the activities of technical experts. Given the planned energy mix, the

²⁷⁵ Estrela, David L.R. (destrela@eda.pt) (18/06/04) E-mail

²⁷⁶ Instituto Tecnológico de Canarias (ITC), Gobierno de Canarias-Consejería de Industria, Comercio y Nuevas Tecnologías, Cabildo de El Hierro. (n.d.) Nuevos Vientos para la Isla de El Hierro [New Winds for El Hierro Island] Brochure. Handed out by ITC.

specific island RES potentials and the resulting supplier's diversification, El Hierro's society, also under this aspect benefit more than Flores' one. Given EDA's control of Flores project, few business opportunities seem to exist out of its activities. The most significant is linked to the establishment of energy-service-companies.

All above mentioned possible social benefits of the project have a high economic perspective. The social benefits are linked to social wellbeing risk diminishment, to social opportunity cost and efficient use of resources. Nothing can be said about the health related social benefit of the project, beside that they surely exist. No study trying to quantify the negative impact of the actual electricity systems is having on the islands' population's health has been found or mentioned and can't, therefore, be analysed, but just acknowledged.

5.4.2 Environmental dimension

The general acknowledgement of the negative impact the actual electricity generation systems has and comparable advantage, which RES represent, has been taken as a bases for assuming the environmental benefits of these projects. As such none of both cases has undertaken an exhaustive study of the environmental impact these projects have. In Flores case, even the amounts, shown in this thesis, of avoidable polluting gas emissions are been obtained through a rough approach to Flores scale of the, for whole Azores, to EDA's RES promoting strategy linked, expected reductions.

In El Hierro case, the impact assessment undertaken, as required for the approval of the, to the 100%RES project, specific installations isn't very specific either. It represents more a list of, in the area, existing flora and fauna, than an assessment itself: no effects on these species are being mentioned, even less quantified; no effects on indigenous, protected species are being identified; no comment is being done about the risk to their survival this project represents.

The difference of both case studies environmental impact can be simplified to a mere island scale problem. El Hierro's electricity demand is considerably higher to Flores one, and as such much more is to be gained, in absolute figures, when it comes to the archival of a 100%RES electricity generation system. It is also true that, as smaller an island is, its ecosystem becomes more sensible to changes, implying a higher risk. Also the concentration of the electricity generation to a certain RES represents a risk of enhancing the negative impacts this energy sources causes to the environment.

El Hierro's delay in the project development results in a reduced impact of wind and solar installations, as their technical development has let to require less area to achieve the same production. In this sense, the delay has represented a benefit, but at the cost of retarding polluting emissions reduction.

Concluding, that the environmental impact of the electricity system will be notably reduces has been assumed, but hasn't played a significant role in the decision of undertaken the 100%RES path. It has been seen as a collateral benefit of the project.

5.4.3 Economic dimension

In both case studies, two RES, which have proven its economical benefit in many diverse environments, with and without, an economic frame promoting RES, are the basis of the established systems: Hydropower and wind energy.

Assuming a final equivalent pricing system, under MIBEL's guardianship, on both islands, the renewable energy prices are established based on technological production costs, as on RES promoting policy objectives. One and the other are expected to decrease in the future, which represents a decrease of the income flows of RES technologies in the long-run. Given the

islands' enhanced conventional production cost and the acknowledgment that they will not decrease, but probably increase further, result of the fossil fuel price increase, and given that the above mentioned RES already lay under the conventional production cost, RES will stay in a better position also in the future. The new system will surely be more economic efficient than the actual one; that benefits can be gathered out of the system is another question: It can't be granted, but is more than foreseeable, with declining RES prices and production costs.

It is when it comes to 100% RES system, where doubts about the economic results of the whole system appear. The cost of the overcapacity or alternative storage technologies required to sustain the system has also to be accounted. If the margin between the actual production cost and RES prices is generous enough to cover, or even exceed this additional investment cost, a win/ win situation will exist. The cost of the insular electricity system will be less. The compensation system will be substituted by the RES production pricing system and thereby paid by all consumers equally, but at a lower cost, especially when accounting all the externalities the actual electricity market is not considering.

The economic benefit of a 100% RES systems get more interesting as smaller the electricity demand is, as more isolated the system is, as higher the distance to bigger systems or fuel distributing systems is, meanwhile cost efficient technical solutions for system control exist.

The economical feasibility of both projects seems to be assured, resulting in a better economic solution to the actual system. The economic problem these projects represent is the high initial investment that must be gathered.

6 Conclusions and Recommendations

6.1 Sustainable island development

Small islands limited resources have meant and will continue meaning a handicap to its development. In both analysed case studies, it has lead to service societies with a very limited numbers of activities, highly interlinked: A weak economy, very sensible to external changes. As the industrial sector is mostly testimonial and linked to basic needs, now significant change in its role is expected. The agriculture sector basically concentrated in a few, exportable crops, very sensitive to changes in the international trade markets. As such it also doesn't give ground for a solid economy. The hopes for development have been therefore centred in the service sector, with special focus on tourism. While in both cases the tourism activity represents a significant share, the kind of tourism they offer has not such social, economic and environmental impact as other kind of tourism. As such the negative environmental and social impact of this economic activity is not so sever as in other island cases.²⁷⁷ Moreover, tourism attraction is based on the islands cultural and natural asset, its protection becomes a necessity in assuring the economic wellbeing of the island society. Preserving social and natural heritage becomes a must as an input to the tourism activity. The generally controversy economic and social development, regarding cultural and natural conservation can in this case notably be avoided. To follow a sustainable development strategy is not source of following a trend, but represents a must for island's society: the way to preserve its singularity at the time of reducing its sensitivity to international market changes.

6.2 Factors influencing a sustainable 100%RES electricity systems

The existing possibilities to exert control on the demand in the long-run will have a main impact on the sustainability of the system. As proven by the analysed cases, islands tend to be less developed areas with in their countries, which leads to under the average energy intensity, not only due to the limited industrial sector, but to less use of electric appliances. The social and economic development of the island community leads to adapt its electricity intensity to the standard. The electricity demand will likely continue increasing if no control measures are undertaken, if the chance to adopt the actually most electricity efficient appliances is not taken, if the strait use of RES to cover certain energy uses is not considered, etc. Even if these measures are linked to subsidies, the cost of these measures will surely be less than continues upgrading of the whole 100% RES system.

The supply reliance will basically depend of the RES which forms the energy mix, the diversification of RES and the seasonality the chosen RES electricity generation suffers through out the year. The seasonality by itself doesn't represent any disadvantage; it will all depend on the correlation among the different RES and with the electricity demand. The same is applicable to any fluctuation of RES production and electricity demand. In any case, it is the resulting system stability which is the basis for the sustainability of the system. To assure this stability special attention has to be given at establishing the theoretical potential of the, on the specific island, existing RES. To solve or reduce the impact intermittency of RES higher correlation among RES and demand fluctuation has to be reflected in the resulting energy mix. As, in any other environment, R&D will lead to increase the technical potential of RES, but especially relevant in island's environment, are grid adaptation, cheap storage alternatives and control systems developments, as reducing considerably the investment needs of the system. El Hierro case will show that the use of hydropower as a energy storage alternative

²⁷⁷ See citation page 3, 5th paragraph, associated footnote 21.

must not be limited by the water availability. In the future, the hydrogen option will represent a significant alternative if accounting the, to its different uses related, added value.

The RES mix chosen in one and the other case study hasn't been put under question mark. This mix is obviously result not only of the renewable energy potential and stability issues, but result of the actual development of their associated exploitation technology and the political frame promoting them. As such other solutions could exist, especially if linked to more long-term R&D development with in RES technologies and synergies with RES solutions to cover other island's needs, as potable water or transport activities.

Given the small scale islands' electricity system can represent as the historical background, high probability exist that one company quite controls the whole market. Based on the analysed case studies, if the company has a national and even supranational dimension, high risk exists that other, outer island's, to the 100% RES system adverse, objective leads to withdraw the 100%RES path. As such the sustainability of the system is under a constant threat. In a regional company, as its endurance depends on the welfare of the local society, their goals will always be more accord to the society's goals. As such if the society goal is a sustainable society, the company's goal will be linked to sustainability.

The sustainability of the system seems only to be expected under a private-public company, where business thinking and public good perspective come together. This assures that not only economic profitability is considered, but other collateral benefits are additionally taken into account in the company's decision taking process.

When analysing the markets, it got clear that isolated islands create a singular electricity market which is impossible to rule commonly with a national market. A significant part of this market is represented by the RES promoting system, which assures the profitability of the innovative RES sources. They are established to increase the economic potential of RES exploitations, until technical and market development makes them unnecessary to support it. Particular market rules have to be established regarding insular electricity markets, moreover when it comes to a 100%RES systems, where the general RES promoting strategies can lead to market disturbances. This would lead to an improper energy mix, with a high, long-term negative impact on the electricity market. As such, and with the intension of assuring a proper return on investment to the RES investors, clear long-term market rules for a 100% electricity market should be established. This is one of the major priorities if the high initial investment, required to establish the system, is to be gathered. The possibility that changes in the electricity pricing system has to be undertaken scares investments away. As soon a long-term commitment, a long-term sustainable pricing system with clear rules about the price-evolution is established, this risk will disappear. In none of the analysed cases any reference to such efforts has been mentioned. This is basically due to the high concentration that in both electricity markets will endured.

Community engagement in the 100%RES project is a fundamental aspect of its sustainability. The community not only provides the system with investors, but defines the durability of the 100%RES system through its behaviour regarding electricity consumption they. It is in its hand, as individuals, to avoid unnecessary electricity consumption, to apply energy saving measures in their homes and business, when demanding energy efficiency of the by them acquired goods and services.

From an economic point of view as smaller the island is as more economically RES applications result when compared to fossil fuel based electricity generation units. The economical dilemma appears when the system leads to 100% use of RES; earlier as higher the share intermittent RES sources represents in the energy mix; as higher the resulting electricity generation fragmentation is. The need of grid reinforcement, overcapacity of the electricity generation units and/or energy storage, which a 100%RES systems requires to deal with

electricity supply fluctuations, increases the system costs. Similar effect results from the isolation the specific island has regarding remaining islands, the mainland or governmental administrative centre, especially with the fossil fuel or natural gas distribution routes. In both case studies, the electricity generation market compensates the electricity producer by them affecting increased input cost. While they result neither affected by the electricity distribution cost, the final electricity consumer is, but in a much defused way. The electricity consumer represents a much segmented group, highly representative for the island society. The electricity market regulation, while acknowledging the enhanced cost of isolated areas, breaks the relationship electricity price and production cost: the electricity price is not result of electricity supply offer and the consumer electricity demand, the link between production cost and consumer price sensibility is broken. The strongest mechanism to control the electricity demand, to influence consumer's behaviour, is in this system being annulled. No conventional supply-demand, offerer-consumer theory is applicable.

6.2.1 Driving forces

The driving forces leading to the establishment of the 100%RES electricity system can be summarized in the search of a secure, long-lasting, economic efficient electricity supply. The involved actors, planners, have seen in these projects the way to assure it. These projects carry more then enough added benefits for each of the involved actor, to lead them to post for its implementation, despite the risk innovative projects represent.

As such, on major driving force is the actual energy market circumstances and its expected future development. Fossil fuel prices have been going up and are expected to continue growing in the long-term, mainly due to its resource limits. Islands' dependency on its import and enhanced cost makes it foreseeable to be more affected by this than other territories. Already in the actual circumstances, even considering RES subsidies prices, makes RES a cheaper energy source than fossil fuels. 100%RES systems also avoid a constant money leakage from the local society, which paying the high costly fossil fuel imports represents.

The existing bias between the entrepreneurial cost and the cost for society of producing a good has been blamed on the lack of internalising environmental and social cost. As no direct expenses are linked to them, the companies have assumed them as not existing. It is mostly the governmental institution the one taking over these costs, through the social healthcare services or the environmental protection. In this sense, a strong governmental participation in RES energy project represents pay back of these costs through benefit participation, apart of the ones result of removing the externalities the actual electricity system causes.

Another driving force is the need of the actors involved in the project to follow the inevitable trend of RES promotion signals; the government because not following it would imply the non-fulfilment of international agreements and companies because it would lead them out of the future electricity market. To follow a first mover strategy allows companies to take a stand in the future RES technology market, especially considering that islands represent the biggest niche in the RES market.

The political commitment to promote an economic efficient electricity supply on the islands is reflected at different governmental level, going from the more general to more specific ones: RES prices are a general prove of this commitment at national governmental level. At EU's level the commitment reflects from the general directives ruling the national governmental actions to the most specific capital subsidies for pioneer projects. At regional level this commitment reflects more specific programmes, as in both analysed studies, in a capital participation in the project.

The, for islands common, difficulties among islands has been a further driving force of these projects. Consequence of these is the existing inter-insular/ international collaboration supporting these projects.

The additional benefit the different actors involved in the projects expected suit from social and environmental benefits of the project, to the ones result of the pioneer project these project represent, the R&D promotion they embody, the image they yield, the funds they obtained, up to the expected incomes, which thanks to sharing the, through these projects, technical and managerial won skills, can be gathered. Driving forces for energy companies are: the need of adapting to changing market circumstances, the new economic figures linked to the RES promotion, the expected future energy market development, the by the government imposed RES trend, the image than can be won, their social responsibility, to assure a proper electricity supply to its customers and to benefit as much as possible of the advantages first movers has to gain in the international market. The Government is driven by the social and environmental benefit these projects have, by their international commitment reflected in international treaties, by their responsibility to assure a proper electricity supply to their citizens and by the image that these project yield. Driving forces for the society to get involved actively in these projects is linked all: the economic, social and environmental benefit these project assure and that will rebound on it.

6.2.2 Risks and barriers

One major risk a 100%RES system has is an uncontrolled electricity demand growth. Its origin can be the still lower energy intensity and number of electric appliances to average developed regions or the possible further growth of water, heating or cooling needs. It can also be caused by a population increase, fix or seasonal, due to tourism, as be result of social change, most probably by becoming an information society.

A second significant risk relies in a resulting improper energy mix. This result could have its origin in any step taken in the path to the 100%RES system: from a wrong initial planning, to a wrong choice regarding the policy instruments to be use; from an improper implementation of policies to any other possible market disturbance. The consequences of these failures would show up in environmental, social and economic costs: stability problems would for example require storage units or additional electricity generation units, which means additional cost and environmental impact, with no additional social benefits, but the lost of the ones the, to this aim applied capital, could have generated.

The previously mentioned choice of the RES mix to be pursued in both case studies, seems to be the one with lowest risk of failure, as other possible solutions would require further R&D and therefore also more time to be implemented; issues which imply higher risk of failure. On the other hand, such activities, as undertaken by EDA on other Azores Islands with no specified 100%RES plan, imply higher social and economic benefits: qualified jobs in R&D development as marketable know-how.

The supply breakdown risk is increased as higher the number of suppliers feeding the grid is. The electricity distribution system becomes more and more complex and the grid control system requires higher efficiency. The development and adaptation needs that the actual grid system requires to manage the new electricity system, represents actually a barrier to increase the number of suppliers. Concluding, grid related aspects represent a further risk group to the system to work.

How incomers are ruled by the responsible institution when conceding the net connection has an implicit risk. Unclear concession procedure could lead hidden power to control the situation. Just the doubt about these forces acting will scare away potential investors, not willing to assume the, by it, enhanced risk of failure. This is just an additional point which

adds to the existing lack of confidence potential investors have on to them unknown or new technologies.

Market barriers are linked to the difficulty of breaking down the actually existing natural monopoly. Hidden power exerts by the established companies and annex interest groups will influence the market. The monopoly company could represent a power full actor in the above mentioned situation. Even if no monopoly forces act, the actual RES promoting frame with different prices for renewable energy source, not linked to islands specific potential and promotion objectives, not designed regarding the proper future energy mix, disturbs the market. Certain, for the island's specific case, highly relevant RES could result unattractive to investors in the actual RES promoting frame. In Flores case study, for example, the RES price is lower than the, to wind energy associated, cost; significantly higher than the, to hydropower associated, cost. The wind energy share in island's energy mix wants to be increased, but in actual conditions now investor out of EDA's group will be interested in such an activity. Involuntarily a barrier to new incomers has been created.

Eu's and, due to it, the national legislation is meant to achieve a competitive free market, with differentiated electricity generation and distribution markets. The need to adapt the islands electricity market to the regional, national and supranational normative doesn't allow searching for a singular solution which adapts to islands characteristics. These legislative frames represent a barrier to an efficient electricity island market, while its intension is contrary. One example is EU's 12% RES objective, which has been translated through Canary Island's energy plan into an institutional limitation to RES penetration, despite technical aspects and considerations: It has become a barrier, a protection of the actual monopoly situation, a further resistance to change.

The high investment needs which the new system requires embody a further economic risk. The high infrastructure investment, which RES electricity generation technologies represent, but also its associated grid reinforcement needs, calls for capital that must first be gathered.

Promoting a 100%RES electricity generation system in the actual circumstances leads to another in opportunity cost reflecting risk. Big RES exploitation technologies, actually not applicable due to economic reasons, despite technical potential, could become the best possible solution in the future, if an economic exploitation can be found to take over the excess electricity production these for island oversized generation systems entail. Hydrogen production could become such an activity. The, until that moment, already undertaken RES investments which must be gained back, will become a handicap for a switch.

6.3 Application on other environments

6.3.1 Islands

The actual high participation of different organizations from other islands or research institutes of countries with high number of islands, demonstrate not only the interest on analysing its applicability, but the interest of undertake the path to 100%RES electricity system islands. The learning curve will reduce progressively the cost of implementing such systems on islands. Skills will be gained in establishing the proper RES combination that assures a trustful system. Regardless other 100%RES islands project, Canary Islands and Azores, considerably much more isolated than other European islands, enhanced further the isolated electricity system costs, at infrastructure and input level. To promote these projects on specifically these islands is the most cost efficient way to promote its later-on implementation on other islands.

6.3.2 Continent

In developing countries, with weak or even non-existing grid infrastructure, this kind of solution is considerably more beneficial. Grid investments can be avoided; the high initial investment associated to RES electricity generation technologies can result comparatively less to the one required by a big centralized conventional electricity generation plant and its associated electricity distribution grid, as inputs distribution systems. To this, other benefits as supply security, as economic development due to RES technologies production, distribution and maintenance service has to be added. Social development is achieved through job creation of the previously mentioned activities, but mostly due to the life quality improvement a secure electricity supply can offer. All these is achieved with a very low, sometimes even positive, environmental impact. Sustainable development can be achieved when associated with RES application.

The application of the by the 100%RES electricity islands gained knowledge must not be limited to small, isolated system, but be bases of a new electricity generation model, where small systems interact among them as part of a bigger system. As described in Clark's and Isherwood's paper²⁷⁸, the growing recognition of the need to secure energy supply through local supply offers a market opportunity for small-scale applications and control systems. They justify this need as solution for avoiding blackouts as the ones suffered in California, Northeast USA and Southern Canada during the period 2000-2002, as the one suffered in Europe in the summer of 2003. These conclusions can be extrapolated to the establishment of small isolated energy systems, islands in the continent or its interconnection.

The, in chapter 5 exposed, diversified RES micro-generation scenario represent a further opportunity, as it would not only provide with technical know-how, but with know-how about how to deal a market with a very segmented electricity generation, from different RES, with the difficulty this entails.

6.4 Feasibility of 100% RES Island in the European Union context

Technically a 100% electricity generation systems will mostly be limited by the possibility the feasible RES mixes allow, economically it is clearly a chance to consider. Two have been the main obstacles identified to a more rapid implementation: the high initial investment required for such a system to work and the high risk involved, as innovative system. EU's policies have been meant to reduce these obstacles, while promoting higher RES penetration within Europe.

European Unions action promoting renewables has been on of the main factors of the increasing number of 100% RES project on European islands. The, in the introduction mentioned, needs of islands communities to achieve a sustainable society has in energy self-sufficiency a main step towards this goal. Islands added difficulties have been taken into account at national and European level. As a consequence the economic environment in which these projects are considered is very singular. Despite EU's directive has tried to harmonize EU's members energy markets, this hasn't yet been achieved, even less related to island systems. A deeper study of all the existing island market frames, its particularities, its RES promoting market tools, identifying its existing market disturbances, will help to find a for each case most efficient market frame.

It could seem that islands are profiting extremely of EU's support systems: as less develop regions, as pioneer projects, etc. This should be seen as a cost efficient way to obtain results at European level in its RES promotion strategy. In both case studies cost reduction of islands

²⁷⁸ Clark, W., Isherwood, W.. (2004). Distributed generation: remote power systems with advanced storage technologies.

enhanced electricity system benefits all their national consumers, not only the island population. As R&D is required in the RES field, it is logic that is development is done there where more benefits can be obtained. The more complex island system provides certainty about its application on other many environments. It must also be understood that just because of the size of the electricity generation units have on islands and the handicapped freedom of their electricity market, the use of many in European Continent used market-policy tools are inapplicable, as designed for continental application. Action which intent to influence the behaviour of the energy market actors has limited opportunity or even no opportunity to work in a highly regulated market. These tools work inefficiently and represent more inconvenience than benefits to the system.

Islands should take advantage of their limitations to obtain the maximum results of the European framework promoting a sustainable energy management, but also from the money flow actual schemes represent and the possibility of hold this money flow within the region.

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Abbreviations

AC	Alternating current
DISA	Distribuidora Industrial Sociedad Anónima [Industrial Distribution Company – Canary Islands’ Fossil Fuel Products Distributing Company]
CCLPC-RAL	Council for the Central Laboratory of the Research Councils-Rutherford Appleton Laboratory
CHP	Combined heat and power plant
CO ₂	Carbon dioxide
DC	Discontinuous current
EDA	Electricidade Dos Açores [Electricity of the Azores – Azores Regional Energy Company]
EDP	Energias de Portugal [Energy of Portugal]
EEG	Empresa de Electricidade e Gáz [Gas and Electricity Company – Flores main energy company]
ENDESA	Energía de España Sociedad Anónima [Energy of Spain – Spain’s main energy company]
ENI	Ente Nazionale Idrocarburi [Italian National Hydrocarbons’ Entity]
ERSE	Entidade Reguladora dos Serviços Energéticos [Energy Services Regulating Entity of Portugal]
EU	European Union
FED	Forum for Energy and Development
GALP	Portuguese petrol company
GDP	Gross Domestic Product
GW	Gigawatt
GWh	Gigawatt per hour
IDEA	Instituto para la Diversificación y Ahorro de la Energía [Spain’s Institute for the Energy Diversification and Saving]
INE-España	Instituto Nacional de Estadística [Spain’s National Statistic Institute]
INE-Portugal	Instituto Nacional de Estatística [Portugal’s National Statistical Institute]
INESC	Instituto de Engenharia de Sistemas e Computadores [Institute of Systems and Computer Engineering]
INESC Porto	Instituto de Engenharia de Sistemas e Computadores do Porto [Institute of Systems and Computer Engineering of Porto]
INSULA	International Scientific Council for Island Development - UNESCO
ITC	Instituto Tecnológico de Canarias [Canary Islands Technical Institute]

IST	Instituto Superior Técnico, Universidade Técnica de Lisboa [Advanced Technical Institute, Technical University of Lisbon]
ISTAC	Instituto de Estadística de Canarias [Canary Islands Statistic Institute]
kW	Kilowatt
kW _p	Kilowatt capacity at peak production of solar PV
kWh	Kilowatt per hour
m ²	Square metres
M€	Million Euros (1,000,000 €)
MIBEL	Iberian Electricity Market
MW	Megawatt
MWh	Megawatt per hour
NGO	Non Governmental Organization
OMEL	Compañía Operadora del Mercado Español de Electricidad [Spain's electricity market operator]
OPET	Organization for the Promotion of Energy Technology
PV	Photovoltaic
PPP	Public-private partnership
RES	Renewable Energy Sources
RIC	Reserva de Inversiones en Canarias [Reserve for investment in the Canary Islands]
R&D	Research and Development
SREA	Serviço Regional de Estatística dos Açores [Azores Regional Statistical Service]
UN	United Nations
UNELCO	Unión Eléctrica de Canarias [Electric Union of Canary Islands – Canary Islands Electricity Company]
UNESCO	United Nations Educational, Scientific and Cultural Organization
WTO	World Trade Organization

Appendix

Appendix 1:

Letter g, chapter 17 of U.N. Agenda 21 concerning islands sustainable development.

United Nations (U.N.). (1992) *Sustainable development of small islands*. Agenda 21, Chapter 17g, [Online]. Available: <http://islands.unep.ch/da21c17g.htm> [2004, May 5]

G. Sustainable development of small islands

Basis for action

17.123. Small island developing States, and islands supporting small communities are a special case both for environment and development. They are ecologically fragile and vulnerable. Their small size, limited resources, geographic dispersion and isolation from markets, place them at a disadvantage economically and prevent economies of scale. For small island developing States the ocean and coastal environment is of strategic importance and constitutes a valuable development resource.

17.124. Their geographic isolation has resulted in their habitation of a comparatively large number of unique species of flora and fauna, giving them a very high share of global biodiversity. They also have rich and diverse cultures with special adaptations to island environments and knowledge of the sound management of island resources.

17.125. Small island developing States have all the environmental problems and challenges of the coastal zone concentrated in a limited land area. They are considered extremely vulnerable to global warming and sealevel rise, with certain small low-lying islands facing the increasing threat of the loss of their entire national territories. Most tropical islands are also now experiencing the more immediate impacts of increasing frequency of cyclones, storms and hurricanes associated with climate change. These are causing major set-backs to their socio-economic development.

17.126. Because small island development options are limited, there are special challenges to planning for and implementing sustainable development. Small island developing States will be constrained in meeting these challenges without the cooperation and assistance of the international community.

Objectives

17.127. States commit themselves to addressing the problems of sustainable development of small island developing States. To this end, it is necessary:

- (a) To adopt and implement plans and programmes to support the sustainable development and utilization of their marine and coastal resources, including meeting essential human needs, maintaining biodiversity and improving the quality of life for island people;
- (b) To adopt measures which will enable small island developing States to cope effectively, creatively and sustainably with environmental change and to mitigate impacts and reduce the threats posed to marine and coastal resources.

Activities

A) Management-related activities

17.128. Small island developing States, with the assistance as appropriate of the international community and on the basis of existing work of national and international organizations, should:

- (a) Study the special environmental and developmental characteristics of small islands, producing an environmental profile and inventory of their natural resources, critical marine habitats and biodiversity;
- (b) Develop techniques for determining and monitoring the carrying capacity of small islands under different development assumptions and resource constraints;
- (c) Prepare medium- and long-term plans for sustainable development that emphasize multiple use of resources, integrate environmental considerations with economic and sectoral planning and policies, define measures for maintaining cultural and biological diversity and conserve endangered species and critical marine habitats;
- (d) Adapt coastal area management techniques, such as planning, siting and environmental impact assessments, using Geographical Information Systems (GIS), suitable to the special characteristics of small islands, taking into account the traditional and cultural values of indigenous people of island countries;
- (e) Review the existing institutional arrangements and identify and undertake appropriate institutional reforms essential to the effective implementation of sustainable development plans, including intersectoral coordination and community participation in the planning process;
- (f) Implement sustainable development plans, including the review and modification of existing unsustainable policies and practices;
- (g) Based on precautionary and anticipatory approaches, design and implement rational response strategies to address the environmental, social and economic impacts of climate change and sealevel rise, and prepare appropriate contingency plans;
- (h) Promote environmentally sound technology for sustainable development within small island developing States and identify technologies that should be excluded because of their threats to essential island ecosystems.

B) Data and information

17.129. Additional information on the geographic, environmental, cultural and socio-economic characteristics of islands should be compiled and assessed to assist in the planning process. Existing island databases should be expanded and geographic information systems developed and adapted to suit the special characteristics of islands.

C) International and regional cooperation and coordination

17.130. Small island developing States, with the support, as appropriate, of international organizations, whether subregional, regional or global, should develop and strengthen inter-island, regional and interregional cooperation and information exchange, including periodic regional and global meetings on sustainable development of small island developing States with the first global conference on the sustainable development of small island developing States, to be held in 1993.

17.131. International organizations, whether subregional, regional or global, must recognize the special development requirements of small island developing States and give adequate priority in the provision of assistance, particularly with respect to the development and implementation of sustainable development plans.

Means of implementation

A) Financing and cost evaluation

17.132. The Conference secretariat has estimated the average total annual cost (1993-2000) of implementing the activities of this programme to be about \$130 million, including about \$50 million from the international community on grant or concessional terms. These are indicative and order-of-magnitude estimates only and have not been reviewed by Governments. Actual costs and financial terms, including any that are non-concessional, will depend upon, inter alia, the specific strategies and programmes Governments decide upon for implementation.

B) Scientific and technical means

17.133. Centres for the development and diffusion of scientific information and advice on technical means and technologies appropriate to small island developing States, especially with reference to the management of the coastal zone, the exclusive economic zone and marine resources, should be established or strengthened, as appropriate, on a regional basis.

C) Human resource development

17.134. Since populations of small island developing States cannot maintain all necessary specializations, training for integrated coastal management and development should aim to produce cadres of managers or scientists, engineers and coastal planners able to integrate the many factors that need to be considered in integrated coastal management. Resource users should be prepared to execute both management and protection functions and to apply the polluter pays principle and support the training of their personnel. Educational systems should be modified to meet these needs and special training programmes developed in integrated island management and development. Local planning should be integrated in educational curricula of all levels and public awareness campaigns developed with the assistance of non-governmental organizations and indigenous coastal populations.

D) Capacity-building

17.135. The total capacity of small island developing States will always be limited. Existing capacity must therefore be restructured to meet efficiently the immediate needs for sustainable development and integrated management. At the same time, adequate and appropriate assistance from the international community must be directed at strengthening the full range of human resources needed on a continuous basis to implement sustainable development plans.

17.136. New technologies that can increase the output and range of capability of the limited human resources should be employed to increase the capacity of very small populations to meet their needs. The development and application of traditional knowledge to improve the capacity of countries to implement sustainable development should be fostered.

Appendix 2: Intelligent Energy For Europe 2003-2006, EU Energy strategy and action plan

European Commission (2003) *Intelligent Energy for Europe program 2003-2006* [Online] Available: http://europa.eu.int/comm/energy/intelligent/call_for_proposal_2003/doc/eie_detailed_description_of_key_actions_vs_1_dec03.doc [2004, September 18]

Vertical Key Actions SAVE, ALTENER and STEER²⁷⁹

FIELD	VERTICAL KEY ACTIONS		TARGET AREAS	
	CODE	TITLE	CODE	TITLE
SAVE	VKA 1	MULTIPLYING SUCCESS IN BUILDINGS	VKA1.1	Tools for the take-off of the Buildings Directive
			VKA1.2	Schemes for implementation of energy services in buildings
			VKA1.3	Public buildings as shining examples
			VKA1.4	Promotion of best practice examples of high energy performance buildings
	VKA 2	RETROFITTING OF SOCIAL HOUSES	VKA2.1	Awareness raising, education and training
			VKA2.2	Tailored financing schemes
			VKA2.3	Advanced integrated retrofitting solutions
			VKA2.4	Legal and institutional changes
	VKA 3	INNOVATIVE APPROACHES IN INDUSTRY	VKA3.1	(Instruments for) Energy management
			VKA3.2	Energy services in SMEs
			VKA3.3	Polygeneration
	VKA 4	ENERGY EFFICIENT EQUIPMENT AND PRODUCTS	VKA4.1	Enforcing the application and enhancing the awareness of EU labels and minimum energy efficiency standards
VKA4.2			Technology procurement, buyer-initiatives and other approaches to accelerate the transformation of the market	
VKA4.3			Monitoring market transformation and preparing the ground for new policy initiatives	
ALTENER	VKA 5	RES-ELECTRICITY	VKA5.1	National indicative targets
			VKA5.2	Support schemes
			VKA5.3	Grid system issues
			VKA5.4	Green electricity
			VKA5.5	Distributed electricity generation
	VKA 6	RES-HEAT	VKA6.1	Legislation, fuel standards and norms
			VKA6.2	Supply chain and market structures
			VKA6.3	Specific applications and building integration
	VKA 7	SMALL SCALE RES APPLICATIONS	VKA7.1	Solar water and space heating and cooling
			VKA7.2	PV electricity generation
VKA7.3			Biomass for domestic heating	
VKA7.4			Small scale CHP and heat pumps	
STEER	VKA 8	ALTERNATIVE VEHICLE PROPULSION	VKA8.1	Legislation, fiscal regimes and fuels standards and norms
			VKA8.2	Supply chain and market structures for biofuels
			VKA8.3	Supply chain and market structures for alternative fuels requiring separate supply chains
			VKA8.4	Market demand for alternatively propelled vehicles
			VKA8.5	Accompanying measures
VKA 9	POLICY MEASURES FOR AN EFFICIENT USE OF ENERGY IN TRANSPORT	VKA9.1	Reducing demand for transport	
		VKA9.2	Enhancing energy efficiency in a transport mode	
		VKA9.3	Encouraging transfer to less energy intense modes	
		VKA9.4	Economic instruments and incentives	
		VKA9.5	Information and awareness and education	
VKA 10	STRENGTHENING THE KNOWLEDGE OF LOCAL MANAGEMENT AGENCIES IN THE TRANSPORT FIELD	VKA10.1	Training and education of local agencies in the efficient use of energy and use of alternative fuels in transport	
		VKA10.2	Fostering collaboration and partnership: Supporting local actors in programme and project participation	

²⁷⁹ The fourth key action refers action at developing countries cooperation: COOPENER

Horizontal Key Actions

HORIZONTAL KEY ACTIONS		TARGET AREAS	
CODE	TITLE	CODE	TITLE
HKA 1	SUSTAINABLE ENERGY COMMUNITIES	HKA1.1	Promoting energy citizenship and mobilising local energy actors
		HKA1.2	Local community planning for the efficient use of RES and conventional energy, demand side management and associated mobility
		HKA1.3	Establish favourable conditions for local energy markets and services to reach a critical mass
HKA 2	THINK GLOBALLY ACT LOCALLY	HKA2.1	ManagEnergy: the facilitating instrument for local energy activities
		HKA2.2	Support for the creation of local and regional energy management agencies and for the operation of national associations of agencies
		HKA2.3	Think globally: Community added value (Reflection group)
HKA 3	FINANCING MECHANISMS & INCENTIVES	HKA3.1	Cross-country analysis of different financing mechanisms
		HKA3.2	Development and promotion of innovative financing instruments and incentives schemes for RES & RUE investments
		HKA3.3	The right to fair competition
		HKA3.4	Platform/Forum for exchange of experience on financial mechanisms & incentives
HKA 4	MONITORING & EVALUATION	HKA4.1	Monitoring and evaluation of different RES/RUE policies and measures
		HKA4.2	Methods, indicators and modelling of future trends and policy impacts
		HKA4.3	Platform for exchange of experience on monitoring & evaluation
HKA 5	DISSEMINATION & PROMOTION	HKA5.1	Dissemination of project results
		HKA5.2	Dissemination of sector best practice
		HKA5.3	Dissemination of the programme and its achievements
		HKA5.4	Public Awareness Campaign for an Energy Sustainable Europe

Appendix 3: Charter of the Regional and Local Energy Management Agencies

European Commission *Charter of the regional and local energy management agencies in Europe*. [Online] Available: http://europa.eu.int/comm/energy/library/savch_en.pdf [2004, June 1]

Charter of the Regional and Local Energy Management Agencies in Europe

We, the undersigned elected representatives responsible for administering an Energy Management “Agency” at a regional, municipal or intermediate level,

1. Whereas:

- energy management (meaning energy efficiency and energy savings and the utilisation of local or renewable energy sources) is a basic component of sustainable development;
- the solutions to most global environmental problems, and in particular the efforts to combat climate change, lie above all in energy management;
- approaching energy problems from the angle of demand from consumers, be they households, companies, or public authorities, is essential to have a significant influence on their choices and behaviour in order to limit wastage while improving the quality of life and the standard of living;
- owing to the large number of players involved and their wide dispersion the corresponding policies and actions must be decentralised to a regional, urban or intermediate level;
- even though they may not be under any legal obligation, it is the civic duty of the public authorities at the abovementioned levels to pursue a voluntary and responsible energy management policy not only for themselves, but also and above all for citizens and for companies;
- in order to instil a maximum sense of responsibility in citizens, companies (and in particular SMEs) and interest groups, they should be informed, made aware, and encouraged to take part and become involved, including in the decision-making process;
- in order to work efficiently and avoid duplication it is essential that the various levels of public authority (central government, region, province, county, department, district, municipality, etc.) become involved and work in perfect synergy;
- in order to make rapid progress it is very important to exchange experience, in particular between regional and local authorities in different Member States in order to disseminate examples of best practice and the most efficient technologies as widely as possible,

2

2. hereby declare that the Energy Management Agency for which we are responsible has aims and a *modus operandi* that are compatible with the above considerations, namely:

- its principal aim is to promote energy efficiency and renewable energy sources;
- its area of operations corresponds to a subnational administrative and policy level;
- it has political support from the regional and/or local authority or authorities within its area of operations;
- its constitution confers upon it genuine autonomy in relation to existing bodies.

In particular it has its own budget and administrative board;

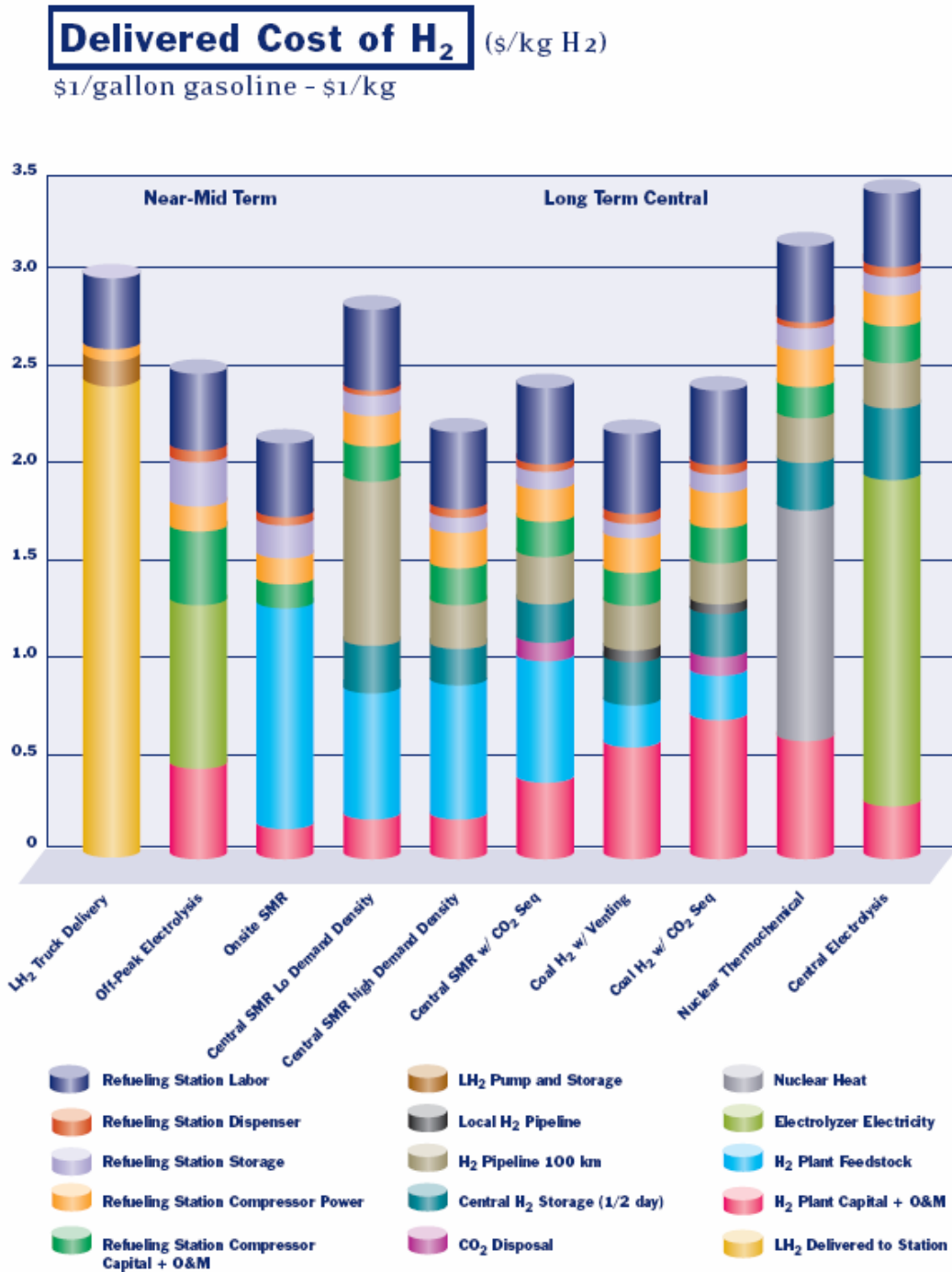
- its administrative board includes representatives of a variety of players involved in energy management, and in particular local elected representatives and representatives of consumers and local companies;
- it has an operations team with at least two permanent members, together with the necessary logistical facilities (headquarters, premises, etc. ...) needed for its tasks and for maintaining its image as an impartial body in terms of energy options.
- its strategy is first and foremost directed towards energy demand from consumers, meaning households, public authorities and SMEs.
- its activities are diverse and concern, in particular, energy planning, consumer information and advice, assistance with setting up, funding, monitoring and evaluating energy management projects, and disseminating the results obtained.
- it has sufficient will and means for forging cooperation with other European agencies.

3. hereby decide to accede to this Charter, through which we commit ourselves:

- to ensuring that our Agency pursues its aims and *modus operandi* as described above.
- to becoming members of the “SAVE Agencies Network” and to enjoying the benefits deriving from that membership, such as the use of the logo developed by the Commission, to receiving information from it and to being associated with its various energy-management activities on the same basis as the agencies that the Community has helped to create.

Appendix 4: Delivered Cost of Hydrogen

Ogden, Joan M. (2004). Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050. *The 10-50 Solution: Technologies and Policies for Low-Carbon Future*. March 2004. Washington, DC. The Pew Center on Global Climate Change and the National Commission on Energy Policy. [Online] Available: <http://www.pewclimate.org/docUploads/10%2D50%5FOgden%2Epdf>



Appendix 5: Spain's Producer Electricity Prices

Instituto para la Diversificación y Ahorro de la Energía (IDEA) [Institute for Energy Diversification and Saving] (2003) *Boletín IDAE n°5*, p.18 [Online] Available: <http://www.idae.es>

	1998	1999	2000	2001	2002
Cogeneración	5,84	5,57	5,66	6,08	6,19
Gas natural	5,75	5,48	5,52	5,90	6,04
Fuel Oil	6,18	5,86	6,10	6,97	6,92
Gasoil	6,52	6,45	6,68	7,27	7,19
Gas de refinería	5,10	4,51	4,49	4,75	4,66
Propano	8,01	7,67	6,30	7,86	7,75
Carbón de importación	4,82	4,14	4,43	4,27	4,24
Calor residual	5,57	5,15	5,29	5,74	5,93
Renovables	6,87	6,75	6,72	6,64	7,82
Solar	6,98	20,89	22,45	24,97	28,68
Eólica	6,81	6,68	6,72	6,69	7,88
Hidráulica	6,92	6,80	6,76	6,57	7,73
Biomasa primaria	6,88	6,63	6,79	6,67	7,60
Biomasa secundaria	6,40	6,22	5,49	6,69	7,63
Biogás	5,90	6,19	6,05	6,15	7,07
Residuos	5,72	5,45	5,42	5,60	5,92
Residuos Sólidos Urbanos	5,69	5,75	5,45	5,62	5,69
Residuos industriales	5,74	5,23	5,31	5,40	5,77
Gas residual	5,65	5,59	5,89	6,08	6,08
Tratamiento de residuos	---	6,11	6,26	6,97	7,57
Gas natural	---	6,11	6,26	6,97	7,57

Fuente: Comisión Nacional de la Energía.

Nota:

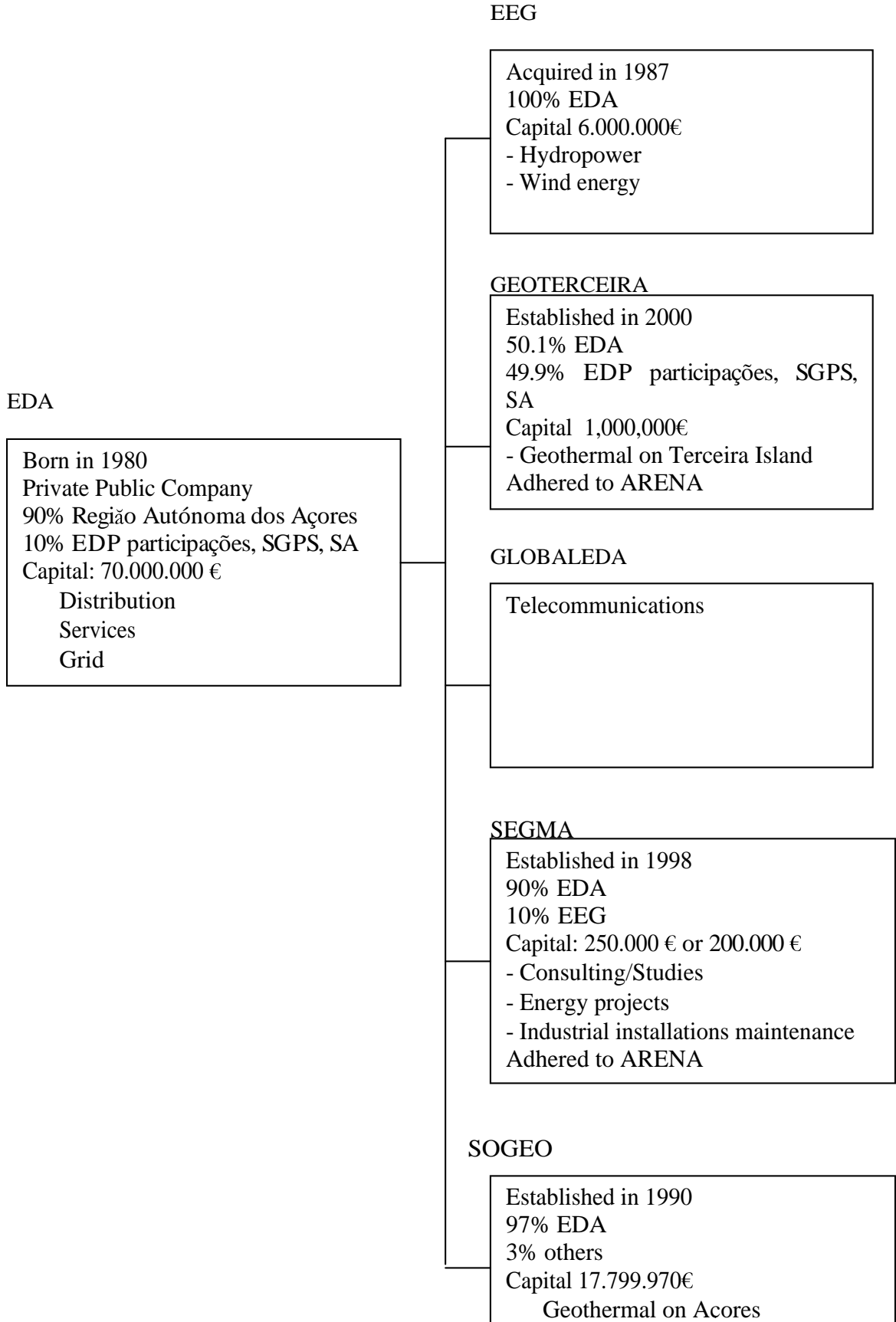
Datos de 2002 relativos al período enero-septiembre.

Precios medios ponderados de facturación de las instalaciones acogidas al régimen especial en el sistema peninsular y extrapeninsular.

Appendix 6: Companies Structure

Appendix 6.1: EEG – EDA

Elaborated based on Electricidade dos Açores (EDA) [Electricity of the Azores] (2004) [Online] Available: <http://www.eda.pt/> and Estrela, D. (September) Personal Interview.



Appendix 6.2: UNELCO – ENDESA

Energía de España Sociedad Anónima. (ENDESA) [Energy of Spain] (2004) [Online] Available: http://www.endesa.org/portal/corporate_integrity_rules/portada.asp?url=/portal/es/default1.asp&idioma=es& [2004, July 15]

