

PRIORITIZING RENEWABLE ENERGY RESOURCES BASED ON ENVIRONMENTAL AND ENERGY QUALITY CRITERIA

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À minha família

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Abstract

Energy from natural renewable resources is part of the solution for a sustainable future. However, these natural resources also have other uses and roles besides energy purposes. In that sense, a straightforward exploitation of renewable energy resources may not assure sustainable energy systems. It is important to consider them strategically in a larger scale for a careful planning of energy systems.

The traditional practice on energy planning needs to adapt to the new challenges arising from decentralized energy systems in a context of sustainability. Integration appears as a way for the development of such systems, replacing purely technical approaches by other, more comprehensive ones. Those imply considering the traditional criteria on decisions about energy solutions in a different way and include new ones.

This thesis proposes an integrated approach towards sustainable energy systems by developing a methodological framework for the energy planning process, targeted at isolated energy systems (the case of islands). In such contexts, it is compelling a more coherent treatment of the energy, particularly their renewable forms, while respecting the local environmental values.

It becomes then necessary to take into consideration the matching of the available energy resources with the specific energy demand in terms of the energy quantity and quality. That implies looking to the energy demand in a restructured way, in a characterisation according the amount of energy required by energy service (heating and cooling, electricity specific or motion). Moreover, the energy framework involves the integration of environmental and sustainability issues through the use of strategic environmental assessment as a support tool to enhance the planning process, by introducing a strategic attitude and widening the planning context.

The proposed methodological framework is developed considering a conceptual foundation that expands some concepts used in the energy field, and a restructuring about the way energy systems are understood and characterized (particularly the modelling of energy systems).

With the application to a practical case, it is illustrated that an adequate exploitation of natural resources for energy purposes is better achieved when adopting a case-specific approach based on an assessment that combines energy and sustainability criteria. Adopting an integrative approach for a qualitative and quantitative analysis, despite being time-consuming, is the key to develop tailored-made energy planning solutions, essential to achieve more sustainable energy systems.

Resumo

O uso de recursos energéticos renováveis é parte da solução para um futuro sustentável. No entanto os recursos renováveis desempenham também papéis ambientais essenciais para além do uso energético. Assim, uma exploração linear destes recursos pode não assegurar sistemas energéticos sustentáveis, sendo necessário considerá-los numa perspectiva estratégica e a uma escala mais abrangente para um planeamento cuidadoso dos sistemas energéticos. O planeamento energético tradicional está assim perante novos desafios que advêm de sistemas energéticos descentralizados num contexto de sustentabilidade. A integração parece ser o fio condutor para o desenvolvimento desses sistemas, onde as abordagens muito técnicas tendem a ser substituídas por outras, mais abrangentes. Estas últimas implicam uma nova forma de considerar os critérios de decisão tradicionais assim como incluir novos critérios.

Esta tese propõe uma abordagem integrada rumo a sistemas energéticos sustentáveis através do desenvolvimento de um enquadramento metodológico para os processos de planeamento energético, tendo como alvo sistemas energéticos isolados (e.g. o caso de ilhas). Em tais contextos é premente um tratamento mais coerente da energia, particularmente nas suas formas renováveis, enquanto respeitando os valores ambientais existentes. É assim necessário considerar a correspondência (*matching*) entre os recursos energéticos disponíveis e a procura energética existente, em termos quantitativos e qualitativos. Tal implica uma reestruturação da procura energética, caracterizando-a de acordo com os serviços energéticos requeridos (aquecimento e arrefecimento, uso específico de electricidade e movimento). Este enquadramento inclui ainda o acompanhamento pela avaliação ambiental estratégica enquanto ferramenta de suporte para a melhoria do processo de planeamento, introduzindo uma postura estratégica e alargando o contexto de planeamento.

O enquadramento metodológico proposto considera uma fundamentação conceptual que desenvolve alguns conceitos energéticos ainda pouco presentes na prática e incluiu a reestruturação dos sistemas energéticos (particularmente na forma de modelação). Com a aplicação a um caso prático é ilustrado que uma exploração adequada dos recursos naturais para fins energéticos é melhor alcançada quando é adoptada uma análise específica do caso, assente numa avaliação que combina critérios energéticos e de sustentabilidade. Uma análise integrativa, baseada em abordagens qualitativas e quantitativas, apesar de ser mais morosa, revela-se essencial para o desenvolvimento de soluções de planeamento específicas, fundamentais para alcançar sistemas energéticos mais sustentáveis.

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List of Acronyms

APS – American Physical Society

BSC – Building Science Corporation

CEC – Commission of the European Communities

CEEESA – Center for Energy, Environmental and Economic Systems Analysis

CDF – Critical Decision Factors

CSR – Corporate Social Responsibility

DECC – Department of Energy and Climate Change

DOE – Department of Energy

EA – Environmental Assessment

EIA – Environmental Impact Assessment

EMS – Environmental Management System

EP – Energy Planning

EU – European Union

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Assessment

MCDA – Multi-Criteria Decision Analysis

OR – Operational Research

PPP – Policies, Plans and Programmes

PROT – Plano Regional de Ordenamento do Território

SEA – Strategic Environmental Assessment

SRF – Strategic Reference Framework

SES – Sustainable Energy Systems

UN – United Nations

WCED – World Commission on Environment and Development

1. Introduction

The use of energy is essential to support every human activity or lifestyle. For thousand years, energy was used according its availability in the local environment, without major stresses in its use. It was only with industrial revolution that a first great transition occurred on the energy paradigm. Technologies prepared for the direct use of energy reserves (fossil fuels) become available and promoted a change of pace on human activities.

Thanks to this technological leap, great improvements take place on the development of population and human well-being. However, this direction resulted also on an “energivorous” society that faces now strong limitations on the use of energy. Such limitations include the scarcity of fossil fuels and consequently prices increases that lead to a drop on competitiveness of economic activities as well some “collateral” impacts with great consequences on livelihood worldwide, particularly from CO₂ emissions contributing to climate change and other negative social-environmental effects.

For these reasons, energy issues or energy-related issues dominate political agendas at global scale. Governments, initiating a change in what has been the traditional structure of energy supply and distribution, have announced their commitment with principles such as diversification of energy resources, decentralization of energy generation including the use of renewable energy resources or major efficiency on energy demand.

Approaching new solutions for these energy issues is imperative, however those options need to have into account the lessons learnt in the past. Having declared sustainable development as the path to follow towards the future for intergenerational equality governments assumed the compromise to think in the long-term. That means that a critical analysis on energy issues and CO₂ emissions is necessary and that solutions have to be found in the balance of social-economic-environmental parameters.

Sustainable energy systems represent a good use of energy, relying on natural renewable resources for the solution of issues such as climate change, access to energy for all and sustainable development. Two main reasons that have currently pushed for a deeper focus on the energy issue are an effective increase in fuel prices and the growing concern with climate change (Charlesworth and Okereke 2010; Helm 2005; Pohekar and Ramachandran 2004), although these concerns have been studied since the 80's and 90's. These two reasons have been so dominant on the agenda that first changes have

occurred at the highest level worldwide, with countries committing with the reduction of CO₂ emissions and mitigation of climate change effects. The issue of climate change have placed the attentions on the emissions of CO₂ and other greenhouse gas and great effort has being applied on correctly assess the emission's problem (IPCC 2007). While discussions continue about the ways of tackle this problem countries are taking effective action at global level expressed by international agreements (e.g. the Kyoto Protocol, developed under the UN Framework Convention on Climate Change) or at a more local level (at European level it can be mentioned The Covenant of Mayors).

The prominence that energy issues have on the current agenda is much due to the growth of a more participative society in political/decisional processes strengthened by media coverage. Moreover, energy is a sustainability issue and therefore it has expression in the environmental, social and economic fields, being transversal to any human activity.

It is possible to say that the energy scene witnesses today a transition between energy paradigms as we assist to "the emergence of an alternative framework of common and shared analysis" (Helm 2005). An alternative framework can be expressed in terms of new models and practical approaches, or, if the change is sufficiently deep, a reformulation on the theoretical foundations leading to new visions, objectives and goals. The paradigm shift assisted nowadays on the energy field moves from energy systems based on the combustion of fossil fuels, towards new ones, where natural renewable energy resources are seen as the main energy sources (Fernandes 2005), implying new ways of planning and modelling energy systems.

A new energy paradigm calls for sustainable energy systems as it departs from the exploitation of diverse renewable energy resources, decentralisation and conversion of proximity, efficient energy use and environmental friendliness. Several already existing energy concepts are suitable to define this new paradigm but a disambiguation and clear definition about their meaning is necessary for a correct operation of such paradigm.

An overall solution for future energy systems includes a better use of energy, which generically is linked with knowing how to use (rational use) and using less (efficiency) while meeting the same development objectives. In practice, the efficiency on the use of energy can result from a joint effort on the technological progress, the (re)arrangement of the energy supply and the way in which commercial energy is used (demand-side management). Increasing the share of renewable energies in the energy consumption, along with energy savings, is the strategy of the European Union (EU) to

address the problem of CO₂ and other greenhouse gas emissions (CEC 2010b, 2011). Such share implies an increase in the exploitation of natural renewable energy resources for energy generation. While this action contributes to attend the global emissions issue, it also triggers concerns with the local consequences from the use of natural resources that have to assure ecosystems' services and support local activities. Moreover, the way that these aspects are considered in the structure of the energy system can also influence the improvement in the use of energy. Questions about where and how much to explore the renewable resources emerge from the energy side but are also present in other contexts. In the Portuguese case these questions become relevant when the regional land-use plans needed to be developed (Fernandes 2008; Fernandes and Leal 2009).

On the development of this thesis, the energy planning process is described considering both the use of natural renewable energy resources for energy purposes and the energy services required (energy demand) as the two major concerns towards sustainable energy systems. The introduction of sustainability in the planning of energy systems pushes the process beyond an immediate arrangement between energy demand and supply but needs to be developed in close consideration with environmental aspects. An effort is made to look at energy planning as a transversal process, with a holistic vision that has to tackle diverse issues and therefore needs to incorporate some energy and environmental concepts in a way that goes beyond a simple response to the immediate use of energy, allowing for a more comprehensive understanding of the energy system.

The major goal of this approach is to contribute for the energy planning process on the support to the decisions about the main alternatives of renewable sources in isolated contexts. These contributions are systematized on a possible methodological framework.

With a stronger focus on the natural renewable energy resources from the supply side – which have direct implications on the sustainability of energy systems, it is not dismissed the importance of the demand, particularly in what regards the typologies of useful energy - heating (and cooling), electricity specific and motion.

Despite not being one of the goals of this research (focused on the planning process), it is also significant to refer the importance of transition between energy systems. To propose new concepts for the planning of energy systems will result on a new energy system for the future, distinct from a business-as-usual system. As any shift imply some kind of rupture(s), in the energy case, which have direct consequences on the social-economic system, the transition (as the way of operationalize the new energy system),

is an important aspect to consider following the planning, but that somehow it also needs to be imbedded in the planning process.

Under the umbrella of this major goal, other specific goals tried to be achieved along the research, namely in what regards a review and evaluation of the available information and its quality to support decisions about energy plans, programs or projects towards the goal of an integrated and sustainable energy planning; systematization of background information about the organization of energy systems to help the development of energy strategies and decision-making; the selection or development of environmental criteria and indicators to assess the planning of energy resources in a sustainable way; and the development of a support tool about the combination and intensity of use of the natural renewable energy resources.

The research work considers the specific focus on isolated energy systems. This is particularly relevant for the application of the concepts and methodology presented along the dissertation. It does not mean that, if any benefit can be taken, it cannot be applied to other, interconnected energy systems, on mainland. However, that is not the intent neither the effort of the research work. Some properties of isolated energy systems are presented on section 1.2.1, justifying this option about the focus on isolated energy systems.

1.1. Energy, Climate and Development

Energy is one of the major issues/challenges of current societies due to the dimension it has taken on everyday life. Daily, and for any activity, people are dependent of some kind of energy. This is particularly true for developed countries, although it starts to be also the reality on developing countries.

Currently, at the base of the global energy system are fossil fuels such as oil, natural gas or coal, completing more than 80% of total energy supply (IEA 2012a). It was thanks to these resources and their products that the world as we know it today was shaped: great technological development, high mobility and knowledge dissemination, which contributed for the improvement of living conditions and populations' wellbeing.

However, with the consolidation of this energy paradigm over time, it begun to be more evident some of its limitations and negative consequences. The dependence of few

energy resources not equally distributed geographically and limited (not renewable at a human scale) generates fragilities at a global scale, both by the way the access to energy is affected (physical availability and economic restrictions by prices structures) which conditions the development of social-economic activities as well as by the consequences at social-environmental level, resulting from the chemical and physical changes in the Earth system, generically expressed by climate change and its consequences.

It is within this triangle energy-climate-development that the great challenges of future energy systems need be beaconed, increasing the possibility of achieving more sustainable solutions.

1.1.1. Preliminary considerations about sustainability

What is or is not Sustainability differs considerably according each interlocutor. As it happens with Truth where, despite it may exist only one Truth, its interpretation varies according the system of values of each person/society, the same can be said to Sustainability. Avoiding a more metaphysic discussion on the meaning of sustainability, what seems to be accepted is that a concern with sustainability along the planning processes of development pathways will probably result into sustainable development, a more pragmatic concept. Sustainability - or sustainable development, two concepts that have been used interchangeably (Gibson 2001; Kemp and Martens 2007; J. B. Robinson and Herbert 2001) - is commonly defined based on three pillars: social, environmental and economic (UN 2002).

Sustainable development seeks a balance in the evolution of societies, where both human aspirations and natural environment can be respected, which implies considering diverging interests in planning processes. In that sense, it is perceptible the importance of integration. However, the use of three distinct aspects has contributed for an expansion of the concept under each theme, compromising the integrative quality. Sustainability then becomes a hard concept to understand, without a simple definition, which leads to distinct interpretations when put into practice. Even considering it as a static concept, the wide scope of sustainability allows for different interpretations, adjusted to each different situation and context, being used on a variety of speeches, sectors and decision-making processes, interfering with its operability (Ramos 2002).

As J. Robinson (2004) defends "If sustainability is to mean anything, it must act as an integrating concept" and distinguish two sides of integration, across fields and across sectors:

"What is needed is a form of transdisciplinary thinking that focuses on the connections among fields as much as on the contents of those fields; that involves the development of new concepts, methods and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation. In addition to integrating across fields, sustainability must also be integrated across sectors or interests." (J. Robinson 2004, p. 378)

Gibson (2006a) share this idea and builds up on the practical processes to promote sustainability, considering that sustainability assessments need to decouple from the three-pillar vision and go beyond, on an effort for integration:

"Unless sustainability considerations are addressed, together, throughout the full deliberative process beginning with the earliest decisions that frame the discussion, what comes to the approval point is likely to a business as usual proposal with damage mitigation promises, rather than a more forward looking and innovative option that has been carefully conceived, selected and designed to deliver maximum positive contributions to sustainability." (Gibson 2006a, p. 265)

In fact, perhaps the three pillar vision difficult the progress of sustainability, when considering a restrict interpretation of each one of the pillars. As Gibson (2006a) also states about sustainable development "its genius lay in recognition that combating poverty (which is not just economic) and protecting the environment (which is not just biophysical) were necessary to each other and both were likely to fail if not addressed together."

One other aspect on the complexity of sustainability is that, in practice, it is changeable, a moving target, as it has expression at different scales. Temporal and geographic scales are possibly the most important, and what was pointed as sustainable in the past is not so sustainable nowadays due to evolution on technology or processes, and what fits a reality can be inappropriate at a different place. In that sense, some authors have presented sustainability as an ideal, opposing it to a state that systems can achieve. Bagheri and Hjorth (2007) argue that "sustainability is neither a state of the system to be increased or decreased, nor a static goal or target to be achieved", which makes it "a moving target, which is continuously evolving as we understand more about our socio-environmental system". The development of this research needs to consider these contributions as it intends to develop sustainable energy systems. However, as stated by Kemp, "the notion of sustainable development (...) has emerged as a new normative

orientation of Western society”, which brings some difficulties in fitting such concept with traditional operational processes.

1.1.2. Energy, Climate and Development – links to consider for sustainable energy systems

As mentioned above, it is necessary to consider the triangle energy-climate-development to attain more sustainable energy systems. To understand how each of these components interfere with and affect each other, a brief consideration on the links established between them is presented.

The link energy-climate is greatly related with the emission of greenhouse gases from carbon intensive energy resources, destabilizing the atmosphere and resulting on global climate change. The strong media coverage and available information to public knowledge make climate change one of the current most publicized matter. The diversified consequences of climate change, such as extreme weather events, polar ice caps meltdown or long-term droughts, expressed differently in different regions, have a global impact, affecting seriously the living conditions of human population (health and environment) and representing a threat to ecosystems and biodiversity.

On the other hand, the consequences of climate change conduct to a more intensive use of technology, for instance on the acclimatizing conditions at households or offices, which are themselves energy consumers, contributing to increase the energy consumption and feeding the cycle of greenhouse gases emissions. It is then necessary to try to break this cycle and the search for the use of zero or low carbon energy resources as well more efficient technology can be one of the most effective attempts.

The link energy-development is understood when considering energy in the basis of every activity, as it was already referred. However, the different interpretations and visions about development and what it may mean increase the complexity of this relation. On a traditional approach to development, seen as economic growth, the access to energy and/or energy resources are the assurance of development, and poor access to reliable and affordable modern energy services act as a barrier to economic and social development (MEDPRO, 2013). Considering the effort that developing countries are making to pursue the path of developed countries, having these countries a more energy-intensive economy (MEDPRO, 2013) and a growing population, is possible to

foretell the potential great increase on energy demand. To follow this path leaves little hope on energy-efficiency only to solve the limitations to development. However, new paths are being uncovered towards sustainable development when efficiency is not enough. A new rational based on sufficiency can help on a different vision about development, in which are included restraint, precautionary or zero principles (Princen, 2003), may help to unlock energy demand growth from development.

After the two previous points, becomes easier to disclose a third link, between climate and development. They establish an interacting connection. In one direction, changes in climate will affect development and human livelihood, considering the impact on basic natural services (water quality or food availability), health and wellbeing. On the other way, development paths, translated on different priorities for the future will affect differently the greenhouse gases emissions, and therefore have distinct impact on climate (IPCC 2007). This link calls the attention for the importance of mitigation and adaptation, meaning that on one side is important to project development paths that minimize impact on climate, but on the other side, knowing that climate is changing, development will have to incorporate adaptation strategies to face those changes.

Despite the simple approach to the three links presented above, they hardly can be viewed isolated, on such a neat and straightforward manner. Rosen and Dincer (2001) consider this same triangle on a more scientific, profound analysis, which considers exergy as the confluence of energy, environment and development. They conclude about the substantial usefulness that an exergy analysis can have in addressing and solving energy related, sustainable development and environmental problems.

Nevertheless, and before a more in-depth approach, this tridimensional perspective allows to understand that one of the most important challenges to sustainable energy systems is to relate their natural component (the alternative renewable energy resources that help minimizing the impact on climate) with the human issues (habits and behaviors on the use of energy, underlying the aspect of development). Moreover, allow to highlight that this relation is bi-directional instead of unidirectional (where the great concern is to have a supply that respond to the demand), in a more balanced way between the two parts. Thus, it becomes more evident that it is necessary to have an effort to the adequacy amongst both parts (supply and demand) and that a sustainable

energy system will strongly depend on the way how the matching between natural renewable energy resources and energy demand is attained.

1.2. Research Problem

When the planning of energy systems departs from a principle of integration, where it is considered the transversal character of energy, it is introduced a variety of issues that increase the complexity of the problem and to which a straightforward solution is difficult to achieve. Instead, there is a need to planning for a matching (see Figure 1), providing energy planners (or planners in general) with some kind of support or guidance towards comprehensive energy solutions for sustainability. With a framework that can help about the ways of structuring the energy system and assess energy resources, they are empowered to develop the most sustainable energy options for the design of the energy system for their island (or isolated region), assuring the adequate environmental assessment of the energy options and the fine-tuning of the matching supply/demand.

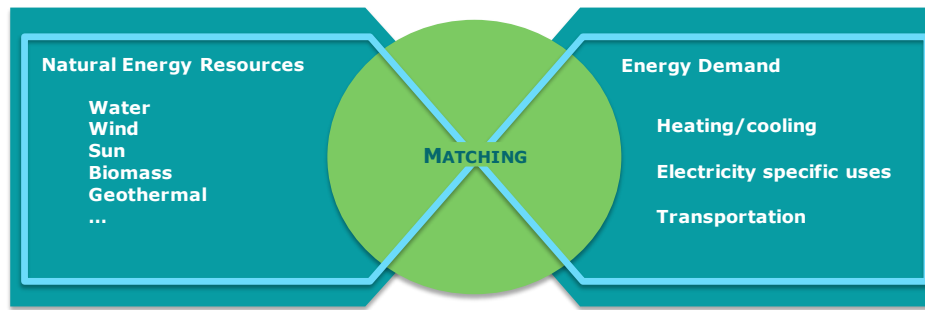


Figure 1 – Highlighting the matching exercise on the energy system

In generic terms, the problem tackled in this research can be formalized as it follows: Assuming a region with two available renewable energy resources and which initial supply S_i is given by:

$$S_i = E_T + E_{R1} + E_{R2}$$

where,

E_T = Energy from thermal power
 E_{R1} = Energy from renewable resource 1
 E_{R2} = Energy from renewable resource 2

the increase on the energy demand will require a new supply NS that can be achieved by different energy options, even when considering only the renewable resources to assure the final supply S_F . The question is then how to choose among the existing natural resources?

Should it be all with resource 1,

$$S_f = E_T + E_{R1+NS} + E_{R2}$$

All with resource 2,

$$S_f = E_T + E_{R1} + E_{R2+ns}$$

Or shared between the two resources? Moreover, if shared, in what amounts?

$$S_f = E_T + E_{R1+xNS} + E_{R2+yns}$$

This approach to the research problem puts the focus on the local aspects of the energy system, more than on the global concerns with CO₂ and other greenhouse gas emissions that are overcome by the use of the endogenous renewable energy resources, with low or no emissions at all.

The focus on the local environment highlights the concerns related with the exploitation of endogenous energy resources, as these resources also support other activities that occur in the territory. Moreover, they are also responsible for providing natural services and maintaining environmental conditions that support livelihood. These concerns are approached in a larger framework related to sustainable development, to which EU has given attention (CEC 2005, 2010a) but much is still pointed out as missing for a higher integration among subjects to guarantee a successful strategy for sustainability (ECORYS 2008). The competition among different resources uses or the effects on natural values such as landscape and biodiversity need to be somehow included in sustainable energy systems.

It becomes clear that there is a set of values, called in this context as environmental values, which need to be taken into consideration when approaching the development of energy systems. These environmental values consider ecological, biophysical and human dimensions (in terms of wellbeing and development activities).

To integrate all these values as much as possible, the question from the energy side needs to go beyond the "how to choose among the existing natural resources?" to account for an 'adequacy' on the use of the endogenous renewable energy resources regarding the real needs of energy. Therefore, the introduction of energy quality as a

concept with practical consequences is also part of the problem in that it can contribute for that 'adequacy'. By structuring the demand considering the energy services required and the resources according to their potential to respond to those energy services, the matching between both parts is promoted.

1.2.1. Specificities of isolated systems to consider

This approach considers the importance of having energy systems that strive for the independency of external (exogenous) energy resources. On this context, islands appear has the immediate practical context for application as they are isolated systems, where imports are relatively simple to control. It is a goal of any energy policy to reduce the dependence of the energy systems from external resources, which means that any region should look for its energy self-sufficiency. However, is not the focus of this work to address that issue on other regions (at mainland/continental level). On those cases, the solidarity among regions or even countries has established energy systems with an intricate network of energy supply which difficult the analysis of a single energy system at local level. The simplicity of a single, isolated energy system is easier to achieve in territories physically isolated as islands. Nevertheless, and as referred previously, it does not mean that the same objective (of independency) cannot be posed for those cases, in it can bring some benefits regarding the sustainability of such systems.

In what regards the consequences from the use of fossil fuels, the risks are higher for islands, as they are more sensitive and vulnerable to the effects of climate change and extreme weather events. Nevertheless, they are the typical case were the weakest are the ones that most suffer but can do little to change, as their contribution for greenhouse gas emissions is small. While those global consequences need to be avoided with a global effort, there are specific characteristics of islands that justify an urgent approach to their energy systems.

Islands have demonstrated great interest in resolution of problems related to the use of resources because they face a clear limitation on the availability of those resources and as by their natural isolated condition have to subsist by themselves. The International Scientific Council for Island Development states "*Chapter 17 of Agenda 21 (Rio Conference, 1992) points out that islands are a special case for both the environment and for development, and that they have very specific problems in planning sustainable development, as they are extremely fragile and vulnerable. In the context of sustainable development, energy is the cornerstone of their planning strategies.*" (Marín 2001).

Associated with the environmental vulnerability, the fragility of islands is expressed also at economic level, as they are highly dependent on international trade and have great costs on transportation (by sea or air) to import primary energy resources as oil or natural gas. This makes more expensive the production of electricity, which prices are aggravated by the small dimension of the supply system (Abreu 2004). The equity in the access to energy is lower in islands as the demand is highly constrained by energy prices.

Nevertheless, islands represent a rich context with high potential for specialisation giving their diversification of resources and specificities with high added value. At European level (CEC 2008), islands were recognized as asset and a strategy was set to overcome the disadvantages for their sustainable development considering the reduction of accessibility deficit and the effects of other constraints, increasing the competitiveness and strengthening regional integration. By considering both the environmental and economic limitations, islands have recognized that they have to loosen from "imported energy models and solutions (...) that are inflexible and inappropriate for island conditions. The fragile nature of the island environment requires ecologically rational technologies that are appropriate for the characteristics of each area and its resources, technologies that are within an island's carrying capacity." (Marín and Galván 2001). Same authors mention that most islands have the necessary resources in abundance to guarantee ample energy self-sufficiency but are still used very little.

Considering the physical conditions that islands represent for natural isolated energy systems, the urgent need to release from the over-costs of energy due to their insular context and the pressures on the environment due to the limits of the carrying capacity of their natural resources, islands represent the optimal context to apply this research, which major concern is to elucidate about the use of endogenous renewable energy resources for energy purposes.

1.3. Energy concepts for a new energy paradigm

1.3.1. Exergy – The comprehensiveness of a concept

Exergy is a rich concept, with meanings at different levels and that hardly is expressed in a short, straightforward way. Its significance can be found in the fields of engineering, natural sciences and sustainability.

From an engineering perspective, exergy is viewed as propriety of a system, as it measures the work potential of the system. Most of the times it is described shortly as the available energy of a system. Nevertheless, as the energy availability of a system depends also from the surrounding environment (from thermodynamic laws), exergy is a propriety of the system-environment combination. Considering this, exergy can change by either changing the system or changing the surrounding environment.

While the energy efficiency is the usual way to characterize the performance of a real system, which is never 100% efficient according the second law of thermodynamics, the exergy characterizes the potential energy available in the same conditions but considering a thermodynamically perfect system (a completely reversible process). As exergy “represents the upper limit on the amount of work a device can deliver without violating any thermodynamic laws” (Roy and Pradeep, 2010), the concept has particular relevance at engineering level for improvement engines or other devices towards more energy and exergy efficient ones.

The usefulness of exergy however can be expanded from the engineering context. In the field of natural sciences, and particularly related with resource accounting, Wall (1977) applied the concept to the flow of energy and matter, distinguishing this way two exergy carriers. Within his perspective, “a flow of energy and matter is driven forward by the fact that the flow all the time continuously loses in quality”. Being quality the thermodynamic meaning of exergy, and having stated that losses in quality occur in both energy and matter, the concept can be applied for both cases.

This has important consequences on the assessment of resources. As an exergy analysis always considers the combination system-environment, it may provide a more constant, stable base for the assessment by setting a reference environment, where it can be observed the loss of quality along the resources. This allows to overcome the limitations of other more variable parameters, such as the ones of an economic base, subject to prices fluctuations.

Despite Wall (1977) had stressed out that “When we apply exergy analysis to production processes and services, we should not limit the analysis to one specific part of the process, but analyse the process as a whole as well”, difficulties to broaden the analysis still subsist. In what regards the contribution for the assessment of natural renewable energy resources for energy purposes, hardly energy resources can be directly assessed using an exergy analysis. Rather that analysis tend to be applied to the different technological systems (supply technology such as solar panels or collectors, wind

turbines, biomass combustion systems, among others) that explore the natural resources. This can be found on the work of Hepbasli (2008), that despite being intensive and strongly contribute for the exergy analysis of a large number of renewable energy systems, it concludes about the exergy performance of the technologies without a reflection about the exploitation of the resources *per se*.

The efforts to apply exergy analysis to natural resources, disclose the link between exergy and sustainability. The work of Rosen and Dincer (2001) present exergy in the center of a triangle formed by energy, environment and sustainable development and builds up about the nexus established by exergy for those three elements. When saying that “activities which continually degrade the environment are not sustainable over time” the authors clearly identify sustainable development with a minor loss of quality, which can be stated by an exergy efficiency analysis.

In line with this idea, Stougie and van der Kooi (2009) conclude that “[i]n a qualitative way it could be made plausible that exergy loss is accompanied with environmental impact” but they were not able to get evidence that a higher environmental impact implies a higher exergy loss.

Given the way it links with energy, environment and sustainability, exergy is for sure a comprehensive concept that needs to be present in order to improve energy systems. These will be more sustainable when higher exergy efficiency is assured.

However, and perhaps due to that comprehensiveness, it is not yet clear how exergy can be applied as criterion for the analysis and assessment of energy systems and particularly for the use of renewable energy resources. From one side it can be viewed as a concept that supports improvement of technical supply options but is little related with the overall performance of the energy system (from the natural renewable energy resources to the final energy demand). On the other side, when considering the way natural environment is affected, the use of the concept is, most probably, not sufficient to assure sustainability.

For these reasons, the use of exergy (or energy quality) in the scope of this work is used to classify the energy vectors used to satisfy the energy services required by the demand. Table I synthesizes the quality of different energy vectors that can be provided by natural renewable energy resources, which will be taken into account for the development of this research (as presented in Wall, 1977).

Table I – Quality of different energy vectors from renewable natural energy resources (Wall, 1977)

Energy Vector	Quality index (% of exergy)	Examples of natural energy resource
Electricity	100	Sun, wind, waves, water resources
Sunlight	95	Sun
Hot steam	60	Sun, Geothermal, Biomass
District heating	30	Sun, Geothermal, Biomass
Heat radiation from earth	0	

1.3.2. The energy system

Several interpretations of energy system exist. What some times is defined as energy systems is in fact a sub-system of that system. For example, several times the mention to energy system is in fact referring only to the electric system, which although is in fact an energy system, is only part of a major framework that includes other forms of energy.

The definition of energy system is hard to accomplish giving the large number of interactions that any part can establish between themselves and surrounding parts. Even so, it is necessary to elucidate about the borders of these systems in such a way that they can be seen objectively but not so simplistic that lose their composite characteristics.

The research considers an energy system similar to the one described by Sørensen (2004, p.591). On one edge of the system is the energy demand, representing the energy needs while on the other edge are the energy resources that can provide energy to satisfy those needs. Between the two edges is the energy supply that can be more or less complex and links both extremes (see Figure 2).

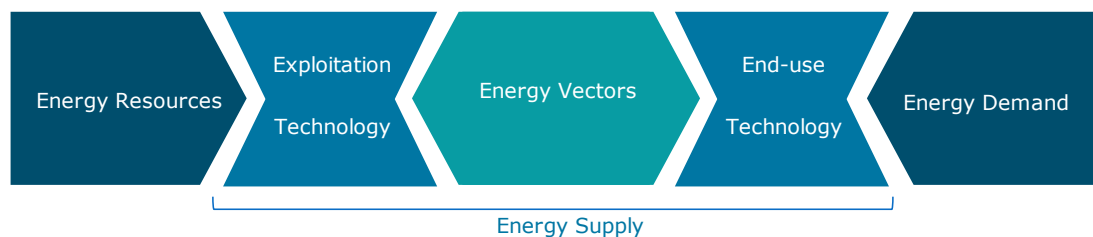


Figure 2 – Simplified diagram of the energy system

The diagram expresses in some way a tripartite system, where the focus on each component will allow understanding its proprieties, what aspects and interactions are

relevant under the new energy paradigm, and the barriers and limitations to sustainable energy systems.

Energy Demand

Energy demand corresponds to the total energy needs from human activities. The structure of energy demand depends on the type of activities developed. Similar to energy resources, it also strongly shape the energy system, once that the energy supply has to respond, and therefore adequate, to real needs. However, while the conventional energy paradigm is based on an energy demand with little restrictions to its development (development in this case is almost synonym of growth), the new energy paradigm calls for an energy demand that has to continue to satisfy the achieved livelihood and well-being but at same time has to be more efficient ("doing more with less") and where the used energy vectors are the ones available by the endogenous energy resources.

This second part of the energy system faces some difficulties on the adaptation to the new energy paradigm, namely in what regards the shift of energy vectors of some specific needs, like transportation, with few technological alternatives besides the use of fossil fuels. Thus, the fact that many of the changes at demand side are from a behavioural component on the choice of end-use technologies, depending on the awareness and intergenerational solidarity for choosing more sustainable options, the changes at the demand side tend to be very slow, even if legal regulations exist.

Energy Resources

Energy resources are the foundation of any energy system for the simple reason that energy systems would not exist if there was no source from which to withdraw energy. As energy resources are easily identifiable and limited to a few ones, many times this part of the system is excluded from the analysis. Nevertheless, the certainty about the resources on which any energy system relies on should not eliminate their consideration on the definition of those systems, regarding they different geographic distribution and availability, having different endogenous energy resources and shaping differently local energy systems.

In general terms, energy resources are divided into two groups: the conventional energy resources and the renewable energy resources. The conventional energy resources are, mainly, the fossil fuels like oil, natural gas or coal, and constitute the conventional

paradigm based on combustion of these finite resources. The renewable energy resources like the sun, wind or water are promoted by the new paradigm based on the unlimited flow of these natural resources.

Despite their infinity, renewable energy resources are not “ready to use”, being necessary its transformation into useful forms of energy, involving the use of technology (e.g. wind turbines, solar thermal or PV panels) or procedures (e.g. building a dam) to “extract” the energy that they can provide. At same time, using endogenous resources for energy purposes compete with other uses (e.g. at land-use level) and can interfere on natural services (e.g. fresh water from river courses) provided by them. It is at this point that energy resources have to be considered as singular part of the energy system, knowing that the way they are going to be use will affect the sustainability of the system.

Energy Supply

Energy supply is the third and perhaps the most complex part of the energy system. It establishes the energy chain between the resources and the demand as it ‘delivers’ the energy to the point of consumption. It potentially encompasses the processes of production/transformation, transportation and distribution of energy. At the light of the new energy paradigm, the energy supply will reduce the length of the energy chain (from primary, final and useful energy) as it is based on decentralization and proximity, where the energy production occurs near the consumption place. Thus, energy supply acts as a platform that matches the other two components of the energy system, through the energy vectors (provided by the endogenous resources and required by the demand).

Putting together the parts presented before, this work considers the whole energy system with all the inputs and outputs from a tripartite system, characterised by its energy resources, energy forms from the primary supply side, energy vectors at the transportation, final energy at distribution, and energy demand with the different energy services (electricity specific, heating/cooling purposes or transportation).

1.3.3. Energy quantity and quality

The current way of projecting energy systems considers the increase on the energy supply capacity based on the amount of energy required by the energy demand, as the major concern is to deliver to the end-users the energy they need. This way of thinking

about the energy system is represented in Figure 3, starting with primary energy resources that are transformed along the energy chain, established from the supply to demand-side, giving to the end-user the useful energy it needs.

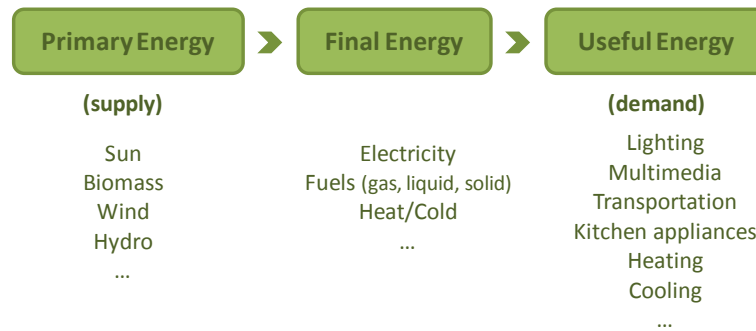


Figure 3 – Energy chain, from supply to demand

However there are different energy pathways from 'primary' to 'useful' energy to fulfil a same need (Figure 4 illustrates that for heating), but different energy vectors or final forms of energy have different levels of 'available energy', i.e., different levels of exergy. Despite being presented before, it is important to reinforce at this point that "Exergy is a measurement of how far a certain system deviates from a state of equilibrium with its environment" (Wall 1977). In other words, exergy is the parameter that qualifies energy, allowing saying, for instance, that 1 kWh at 400°C is energetically more valuable than 1 kWh at 20°C.

Nevertheless, it does not exist a clear valuation (on the prices structures) that allows distinguishing the quality of the different energy vectors (or energy carriers, expressing the different types of energy), stimulating the consumer to adopt a rational behaviour on its use. The quality of energy currently delivered to the end-users is not accounted, provided their needs are satisfied.

Then, it is necessary to make the choice among those energy vectors based on the 'quality' of their energy, being 'quality' measured as the 'available energy', of each energy vector. This means that, if it is possible to heat a house by properly burning biomass together with the actions of exploring the direct use of solar radiation and the minimisation of the energy losses, the use of electricity, an energy vector of the highest quality level, for heating purposes shall be avoided or refrained and left for electricity specific uses.

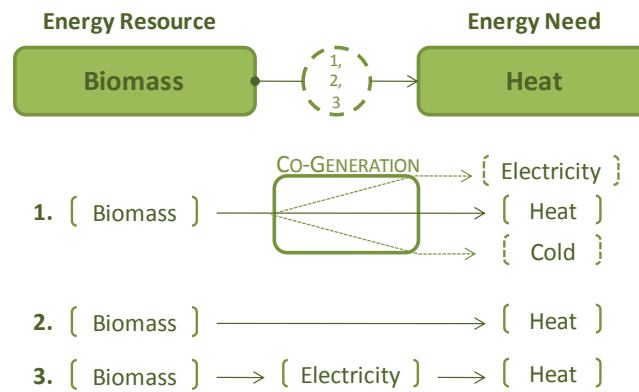


Figure 4 – Representation of different paths to provide the same energy need, from the same energy resource

The concept of energy quality is relevant for sustainable energy systems as it distinguishes the different energy vectors establishing an order of merit for their use based on thermodynamics principles as explained above. Thus, it has an environmental expression as much as it allows arranging the demand structure according to a more efficient consumption and therefore saving resources.

A practical example considering water heating illustrates quite well this point. Considering the order of merit of the energy vectors, solar heat will better fit the purpose than electricity. Therefore, the shift on the energy vector will allow saving the resources used on the production of electricity (fossil fuels or renewables), meaning that they will be available later to supply future electricity needs.

1.3.4. Decentralisation and conversion of proximity – performing the matching

Departing from the introduction of energy quality into the new approach to sustainable energy systems was possible to understand the need for a restructuring of the energy demand. Such restructuring implies an energy shift, by changing energy vectors, end-use technologies and/or processes.

Nevertheless, applying the quality criterion on the management of the energy demand has consequences also on the supply side. The change on the use of energy vectors offers the opportunity to focus the search for the new supply on the endogenous renewable energy resources, as most of them can provide heat or electricity (although in different amounts). The adequacy on the use of endogenous resources to the energy demand expresses the concept of matching. Although at the light of the new paradigm

it is considered a way of thinking of the energy system from the demand to the supply, applying the matching concept also means that an effort of the demand can occur to better fit with the energy vectors that the resources of the island can offer.

By using the resources that are near the consumption place, a conversion of proximity occurs, with decentralized energy production systems. This has an important expression on the efficiency of the system as the energy chain is shortened, taking place savings on the transformation and transport of energy. The way in which the matching is prepared has strong consequences on the environmental expression of the energy system, as it determines the type and level of use among the different endogenous energy resources.

1.3.5. Concepts in use

The concepts defined below express the way they are understood and applied on this work.

Endogenous natural renewable resources – Natural, non-fossil energy resources, available within the geographic limit defined for the planning exercise. E.g. Sun, wind, biomass, water, geothermal.

Energy Demand – Sub-system of the energy system that expresses, in an ordered structure, the energy needs required for the activities and development of the territorial context of the planning exercise.

Energy Efficiency – It refers to all the actions resulting in energy savings while assuring the same (or even improved) energy service. The idea of energy efficiency is synthesized in the motto “doing more with less” and can be expressed by conservation of energy, technological improvements or adequacy of behaviours for an efficient energy use.

Energy Quality – It refers to the available energy of each energy vector and its capacity to supply different energy needs. For instance, electricity has an infinite amount of available energy, with an extensive range of applications, being characterized as a high quality energy vector. On the other hand, heat has a lower amount of available energy (this will be higher or lower depending on the temperature difference, according the thermodynamic principles), being a vector that carries a lower energy quality.

Energy Service – It refers to the usefulness provided by the energy resources to perform a given activity. For example, one of the energy services provided the sun is the heating of domestic waters. In other words, ‘an energy service is the activity for which the consumers demand energy’ (Beeck 2003). It is important the disambiguation of this term from “energy services” used by energy companies, to refer to amenities they offer to clients.

Energy Shift – Change from one energy vector to other, more adequate. It can include a technological change at end-use devices, generation devices or even processes along the energy chain.

Energy Supply – Sub-system of the energy system, including the infrastructures of generation, transportation and distribution of energy.

Energy System – The entire energy chain, from the natural energy resources to the energy demand in terms of useful energy.

Energy Vector – Energy carrier with origin on a supply point and ending at a demand need. It displaces energy in a specific form that allows satisfying a given energy service. Example of energy vectors are electricity, heat or even pellets.

Matching – Exercise performed by the supply side, which acts as a platform, for the adequacy in energy terms between the natural resources and energy demand.

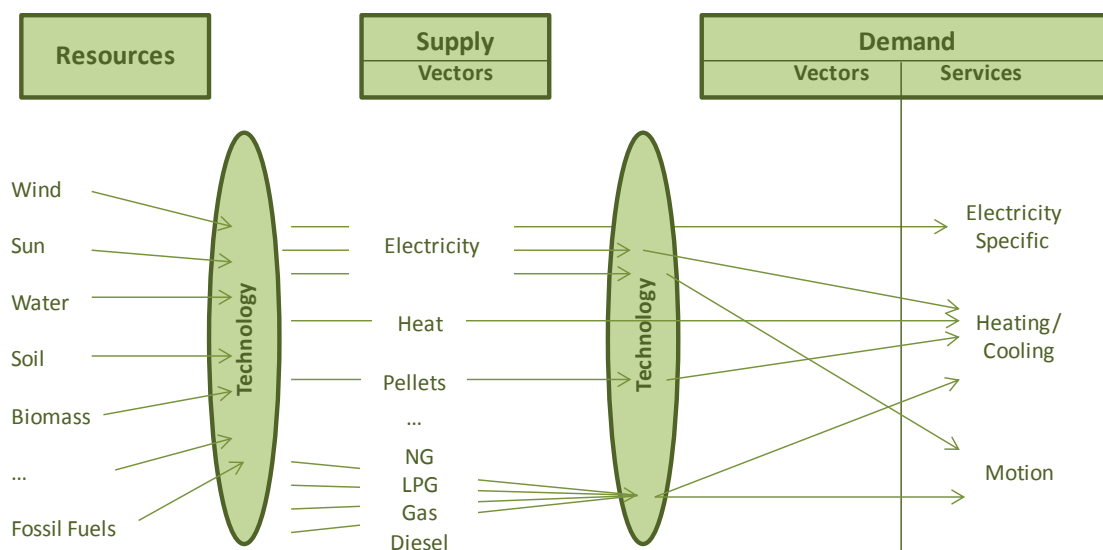


Figure 5 – Representation of the relation between energy vectors and energy services

Note: Despite the focus on natural renewable energy resources, the mention to fossil fuels helps to illustrate the distinction and relation between energy vectors (the carriers) and services (the product expected by the use of energy).

1.4. Research scope and aim

The research problem described above is approached under the scope of energy planning. Bearing in mind sustainable energy systems, the effort is on a planning process that considers the energy system structured in light of energy principles that enclosure values for sustainability. The general problem considers the case of an isolated system and the assessment about the exploitation of endogenous renewable energy resources, taking into account quantitative and qualitative energy aspects, environmental values, long-term concerns and the correspondence between energy demand and supply.

By contextualizing the problem, it becomes more or less evident that a straightforward answer would be difficult to achieve, as different options about the exploitation of renewable energy resources might be available. Moreover, sustainable energy systems will hardly be attained if sustainability concerns are considered only at late stages of the planning process. In that sense, there is a need to refine the research problem directed at the energy planning process, by considering the need for a methodology, or at least a planning framework for energy systems.

The aim of this research is to contribute for the development of a methodological framework on energy planning that allows for the transition from the current energy systems towards sustainable energy systems to achieve the new energy paradigm promoted by the decentralized use of renewable energy resources, integrating the energy and environmental considerations towards a necessary holistic and strategic vision. To do so, particular attention is given to an improved way to explore endogenous energy resources (responding to energy needs without jeopardizing environmental balance) and to the structuring of the energy system (particularly at the demand side) so it can cope with the energy principles of the new energy paradigm. This will allow developing improved solutions where the matching between the endogenous energy

resources and the energy demand is attained. To fulfil this aim, two research questions guide the investigation:

- Q1. How to design and prepare the operationalization of an energy system aimed at the matching between energy demand and supply and the sustainable use of endogenous renewable energy resources towards self-sufficiency in isolated contexts?
- Q2. What type of methodological framework can support the planning process of energy systems in a context of sustainability, providing useful guidelines and allowing for a comprehensive assessment of the solutions?

To address these questions along the research pathway, two main hypotheses are placed. The first proposes the relevance of energy concepts as presented in section 1.3, for an improved modelling of energy systems. By applying these concepts to energy systems, a new structure can be considered, oriented towards the matching of energy demand and energy resources at local level. Such structure, focused on the energy services required and the energy vectors provided locally, will provide support to a comprehensive energy planning going beyond the current one, which quantifies and projects the amount of energy demand and prepares centralized supply infrastructures to respond to those needs.

The second hypothesis considers that any methodological framework which incorporates a strategic assessment framework will better integrate the different dimensions of sustainability along the planning process of energy systems. This will allow for the development of enhanced options encompassing both demand and supply, with particular relevance on the use of endogenous energy resources. As decisions about the use of those resources need to ensure a holistic vision and long-term validity towards sustainability, Strategic Environmental Assessment, following a strategic thinking model, will be used along with the energy planning process, for the enhancement of options.

1.5. Research methodology and thesis structure

To accomplish the aim proposed above, the research was carried out considering the following stages:

- i. Literature review on the theoretical pillars identified for the development of the research, namely the planning theory, energy planning and sustainability assessment, conducting to the state-of-the-art in an energy planning oriented towards sustainable energy systems;
- ii. From the facts gathered in the literature review, it was elaborated a synthesis of evidences that define a new energy paradigm, setting the departing point to respond to the research aim.
- iii. Based on the previous two stages it was elaborated a methodological framework to be used for energy planning processes in isolated contexts, with particular emphasis on:
 - a. The way of representing and structure the energy system (applying a system's thinking approach);
 - b. The energy performance for an energy evaluation of options (through the definition of energy indicators); and,
 - c. Improving the planning process, widen its scope of analysis and making it more strategic by bringing strategic environmental assessment into the process;
- iv. Application of the methodological framework using real data for a specific case, in order to test its operability;
- v. Analysis of the results from the application of the methodological framework and synthesis of major achievements.

The methodology followed along the research combined both technical and strategic components in what regards the modelling of energy systems. Moreover, it was grounded in an analytical approach, which provides comprehensiveness when performing an integrated energy planning process.

The thesis is structured along eight chapters. The introduction sets the departing point about the concerns with energy systems and sustainability, resulting in the definition of the research questions and hypothesis presented above (section 1.4). Then, the theoretical developments are explored, based on a literature review regarding both the philosophical foundations of the current practices about planning, sustainable development and energy systems (chapters 2, 3 and 4). These reviews lead to a synthesis regarding the usefulness and limitations of those approaches to the challenges

posed by the research problem, allowing developing a group of premises that set the conceptual basis for the research (chapter 5).

After the theoretical approach, which clarified the main issues involved in planning processes and particularly in planning for sustainable energy systems, it was possible to propose the methodological framework for an integrated planning towards sustainable energy systems (chapter 6). The methodological framework is then tested in order to validate the hypotheses by considering a real case (chapter 7), which allows an in-depth reflection on the premises, concepts and indicators developed as well as to draw conclusions and highlight the relevant aspects that need to be considered and improved in future developments regarding the evolution of energy planning processes (chapter 8).

2. Inputs from Planning Theory

2.1. Planning – contributions from theory and practice

Planning theory is not unison regarding the interpretations about planning. In recent history, different typologies of planning have been presented, starting from the 70's with the contribution of Faludi (1973) that fostered developments during the 80's (Paris 1982; Reade 1987). Taylor (1999) identified three major shifts in the planning theory:

"The first was the shift from the urban design tradition of planning to the systems and rational process views of planning. The second was a shift from a substantive to a procedural conception of planning. (...) I examine a third significant change in post-war planning thought which some writers have identified – the alleged shift from 'modernist' to 'postmodernist' ways of thinking". (Taylor 1999, p. 330)

Understanding that there are several planning traditions allows accepting a wide range of planning categories and that no single approach is perfect (Hudson 1979).

When mentioning planning as a process a procedural theory is already adopted, leaving aside all the other types of planning under the substantive theory. Even now the discussion regarding the planning theory or new planning theories continues (Allmendinger 2002; Ferreira et al. 2009), but authors can now more easily accept the contribution of the different theories, which helps deconstruct a standard application, focusing on locally diverse and unique interpretations (Allmendinger 2002; Faludi 2004).

2.1.1. Planning as a process

Several authors point out different stages in planning processes. The distinction among the different classifications is somehow related to the focus of each author, agents involved or the way systems and complexity are considered in the analysis of such systems.

Ackoff is one important reference in what regards the reflection about planning principles. While departing from the operational research (O.R.) field, he has dedicated great attention to dominant doctrines and built up what he calls the 'systems age', where "we tend to look at things as part of larger wholes rather than wholes to be taken apart" (Ackoff 1974b). In that sense, Ackoff stated the limitations of O.R. in planning processes, where "breadth is more important than depth", becoming a critical of technique-

dominated approaches, advocating participative approaches and putting the emphasis on the interdisciplinary nature of decision-making (Kirby and Rosenhead 2005). These considerations allowed Ackoff to develop the concept of interactive planning, which set a base followed by other authors to explore the planning process in a range of different areas such as land-use, energy, finance or organizational (Blarke 2006; Leemann 2002; Lumbo 2007; Wollenberg et al. 2008). This interactive planning is result of an evolution of the planning process, as presented in Box 1. The definition of each type of planning evokes different postures regarding the planning process, which ultimately will deliver radically different results.

Box 1 – Three types of planning, according Ackoff (2001)

Reactive Planning
- It implies a reaction to an existing problem. - It "deals with the parts of the organization separately despite the fact that the performance of the organization and its parts depend more on how the parts interact than on how they act independently of each other".
Preactive Planning
- It is a strategically oriented planning. - Directed at predict and prepare for the future.
Interactive Planning
- This reveals an interventive posture by defining a desired vision of the future and plan to create it. - The desirable future is created "by continuously closing the gap between where it is at any moment of time and where it would most like to be."

These three types of planning can be found on current practices. The reactive planning can be classified as an outdated approach but it expresses much of what was verified on energy planning processes, leading to failures. The lack of integration of energy system's issues has originated a focus on specific problems. This is the case of CO₂ emissions and its effects, a main concern of every nation at current time that hardly will be solved if singly approached. In fact, it can be said that this is a consequence of a reactive planning, used to solve the problem of the energy supply out from the entire energy system. Without consider the interactions of the energy systems' parts, new problems arise, such as the inadequacy of the resources' use for energy purposes or the type of energy vector for the energy service required. The preactive planning represents an evolution as it is future-oriented and it overcomes the limitations of a 'fixing procedure'. However, it is limited to predict and prepare for the future and not to create a desired future. The interactive planning goes further and with its intervention attitude creates the opportunity for a desired change of paradigm as it has been advocated for

sustainable energy systems: “energy planning should not be reduced to prediction of what is most likely to happen, whether we are talking separately about supply or demand. The purpose of planning is normally to be able to shape the future” (Klevas et al. 2009).

Keeney (1994), with his value-focused thinking, also oppose to a reactive posture and propose an approach based on creative solutions. That is possible in a participative context, where the structuring of the planning problem about which is necessary to take a decision is improved by having different points of view that in practice translate underlying values. Values are the principles to evaluate the desirability of any possible alternatives or consequences. The framework has been applied at different technical planning procedures as water resources (Keeney 1996), energy (Gregory and Keeney 1994; Keeney et al. 1987) or environmental (Gregory et al. 2001) and the goal is to help create different (and better) alternatives, with goals based on values. However, value-focused thinking is yet a hard thinking process, associated to technical problems, and therefore difficult to apply on context of high complexity.

In the field of planning theory, the need to approach planning problems in a context of increasing complexity and integration contributed for the development of planning concept and practice. In this field, as stated by Roy (2011), the reflection about planning is focused on the fundamentals of planning process, deriving its theory from the philosophies of various social theorists. This allows identifying major shifts (from rational-comprehensive models to advocacy planning or communicative practice), however dominant paradigms do not mean homogeneity.

The idea of having planning as an integrative process that contributes for heterogeneity, more than the replacement of planning theories is supported by Healey (2012):

“... there has been a major shift in the past century in the planning academy and in the social sciences generally from a conception of a universally valid, linear pathway to economic and social development, linked to a set of technologies, to a recognition of the diversity of ways in which ‘development’ happens in particular places.”

The growing consciousness about the process dimension in planning contributed to a greater focus on this component, once that “the processes of articulating values and the manner in which these might become embedded in established discourses and practices were important” (Healey 2003). It is based on this idea of having planning processes,

dynamic, adaptable to each specific situation, and therefore interactive that Healey develops the collaborative planning. As she states:

"The project that became Collaborative Planning was thus inspired first by the perception of planning as an interactive process. Second, I understood planning as a governance activity occurring in complex and dynamic institutional environments, shaped by wider economic, social and environmental forces that structure, but do not determine, specific interactions." (Healey 2003)

This has provided a background to develop, at a larger scope, the latest contributions on planning theory that need to cope with growing complexity and uncertainty in planning processes. Innes and Booher (2010) state three major trends, related with the way that expertise, knowledge and reasoning are introduced and are shaping planning processes:

- The replacement of traditional linear methods and formal expertise by nonlinear socially constructed processes engaging both experts and stakeholders;
- Recognition that science and expertise have limitations and lay knowledge is also part of expertise formation as experts knowledge has a part of social construction;
- New forms of reasoning are appearing, calling for an intellectual bricolage, replacing an "instrumental reasoning from ends to means relying on logical steps and objective evidence".

The collaborative context in which planning processes seem to be progressing renews the attention in the decision-making issue. This discussion is necessary and will be approached in a further section. However, at this point, the focus was on the evolution of planning as a process and on understanding some of the major trends. Contributions from practice support this evolution towards a relational planning, enriched by a higher integration of aspects, where attention is paid to "place qualities (...) and the space-time dynamics of the relations and interactions that take place in such areas" (Healey 2007), resulting from these planning processes tailor-made solutions.

One last aspect that should not be forgotten about the evolution of planning as a process is the time factor. In fact, planning as a process is still evolving, and giving the medium to long-term period needed to assist to effective change, what is expected is a gradual transition along time, rather than having a "click" point for the shift. Having planning as learning (as supported by De Geus 1988) the process will include a time span from signal to action.

It is an integrated process, rather than the use of a technical planning (necessary, but limited in diversified contexts) that is needed in a context of sustainability. This shall apply particularly to the planning of sustainable energy systems, given the high level of interactions that such systems establish on development processes.

2.2. Planning in messy environments - contributions from system approaches

The contribution of system approaches to planning processes can be significant, as it may provide a framework to integrate different dimensions of the planning problem and express the way they interact. However, it is necessary to understand in practice what these contributions can be and, moreover, if there are also some drawbacks on system approaches that we need to be aware of.

A major momentum to systems was given by Ackoff (1974a), although he pointed out the 40's as the beginning of 'the Systems Age'. In his 'Systems Revolution', Ackoff highlights the role of systems for an expansionist approach to problems, saying that *"The systems age is more interested in putting things together than in taking them apart"* (emphasis in the original). The expansionism doctrine that considers "all objects and events, and experiences of them, are parts of larger wholes" claimed for system approaches, highlighting the importance of interaction:

"System performance depends critically on how the parts fit and work together, not merely on how well each performs independently; it depends on interactions rather than on actions. Furthermore, a system's performance depends on how it relates to its environment - the larger system of which it is a part - and to other systems in that environment and on the performance of whole" (Ackoff 1974a, p.3)

Moreover, the systemic view enabled a purposeful perspective that allowed introducing "functions, goals, purposes, choice and free will", which were not traditionally accounted on the dominant, cause-effect, deterministic perspective. This step forward provided for a new, richer perspective about real world situations, which allowed for a more comprehensive approach to existing problems.

Despite this could bring new developments on the way of approaching complex problems, there was not enough detachment from traditional O.R. methods for problem solving, and therefore did not represented a significant change for planning. In that

sense, many of the limitations of the rational paradigm which were argued against before were present on system approaches to complex problems, namely the functionalist approach (not to the parts but to the system as a whole) and the structuring needs (systems as a whole can be divided into parts or be a part of a major system).

Naturally, thinking about complex problems demanded new insights regarding subjectivity and uncertainty. By having the problem structured and the systems well defined, these concerns tended to be projected on the external environment (behaviour of decision-makers) more than in the systems behaviour. Jackson and Keys (1984), on a review about problem solving methodologies in complex systems contexts confirm the externalization of causes that increase the complexity:

"The system in which the problem exists is not the only factor which determines the character of the problem context. The nature of the decision makers will also greatly affect the type of solution needed to problems and the problem-solving methodology needed to reach that solution." (Jackson and Keys 1984, p. 476)

In view of what looked like a dead end regarding the application of system methodologies to complex problems, Jackson and Keys raise the issue of theoretical support. Therefore, they suggest that such methodologies can be used on "the particular sciences which are concerned with explaining the nature of the system(s) that exist in the different problem contexts" especially on social science and on the management of human systems (Jackson and Keys 1984).

On this polarized vision of system approaches, between operational and conceptual uses, Forrester (1994) distinguishes system dynamics and systems thinking. System dynamics is linked with the operational side that considers the "undesirable system behaviour that is to be understood and corrected" where "understanding comes first, but the goal is improvement", adopting a teleological vision. Systems thinking is linked with the conceptual sense given by Jackson and Keys, and that Forrester relates with a cognisance role at two levels: for public in general, to inform and raise awareness about systems; and as "a door opener to system dynamics and to serious work toward understanding systems".

Systems thinking and system dynamics meet each other on models, when the conceptual vision of the system is assembled, through a model, to analyse the system dynamics, or as Jackson and Keys posed it:

"... any problem-solving methodology must take into account the behaviour of the system in which the problem exists. This involves the creation of a model of that system. This model may take one of many forms but it is essentially a representation of the system. In order to create such a model, it is necessary to formulate some ideas concerning the relationships and processes which are embodied in the system." (Jackson and Keys 1984, p. 482)

Ackoff and Gharajedaghi (1996) argued for the usefulness of casting models according to the type of systems (see Table II). In their work, systems (or models) are distinguished in terms of being purposeful or not, meaning the capacity of the whole system or its parts to display choice. Particular attention was devoted to the evolution and consequences of mismatching the use of models to systems:

"Our point has been that when models of one type are applied to systems of a different type, at least as much harm is done as good. The amount of harm (hence good) that is done depends on the level of maturity that social systems have reached." (Ackoff and Gharajedaghi 1996, p. 22)

Table II – Classification of systems (and models) according to the behaviour of parts and the whole (as in Ackoff and Gharajedaghi 1996)

Systems/Models	Parts	Whole
Deterministic	Not purposeful	Not purposeful
Animated	Not purposeful	Purposeful
Social	Purposeful	Purposeful
Ecological	Purposeful	Not purposeful

The achievements of Ackoff and Gharajedaghi (1996) call the attention for the issues related to social systems - the most complex by being purposeful on its parts and as a whole (as energy systems can be considered), which need to be considered when developing a model:

- The limitations of using other than social models, namely the ones associated with deterministic models, as "optimization of parts can suboptimize the system as a whole";
- The difficulties associated to social models, in particularly the existence of "purposeful actors, individually or in groups, who pursue incompatible ends and/or employ conflicting means, generate conflict";

- The challenges of such systems “to create a type of organization that is capable of continuously *dissolving* conflict while *increasing* choice.”

Energy systems can easily be understood as social systems, when stating the way they influence the development path of societies. Moreover, all the discussion about sustainability somehow translates a system with purposeful parts and wholes, reason why complexity increases and models developed in the energy field shall have into account the considerations mentioned above.

2.3. Systems Thinking – Contributions from complexity science for the planning of energy systems

System’s approaches have been pointed out as a way of innovating on the resolution of existing problems on our social structure (Ramo and St.Clair 1998, p. 147). They allow framing the problem and therefore to search for possible solutions to solve it.

Establishing a parallelism with the strategic posture, which comprises two main components, thinking and analysis, also on a system’s approach two main components can be pointed out, one related to the way of thinking about the system and the other related with the understanding of the dynamics of the system. Healey (2007) relates and distinguish the idea of strategy and frame as it follows:

“The notion of strategy as reference frame grew (...) But concepts of 'framing' emerged separately through the recognition that what gives a strategy focus and leverage is some kind of synthetic integration. A frame is an 'organising principle that transforms fragmentary information into a structured and meaningful whole' (van Gorp 2001: 5, in Fischer 2003: 144). A frame provides 'conceptual coherence, a direction for action, a basis for persuasion, and a framework for the collection and analysis of data' (Rein and Schon 1993: 153). A strategy is thus more than a framework of principles.” (Healey 2007, p.183)

In that sense, systems thinking may provide such framework and, although do not constitute itself a strategy, it will support the development of strategies. The recent developments on the energy field have in fact verified the need to move from the system

dynamics to systems thinking, so that planning processes can be aimed at sustainable energy systems.

Meadows (1999) supported the existence of leverage points, which are “places within a complex system (...) where a small shift in one thing can produce big changes in everything”. By knowing what are and where are those leverage points, it seems that a restructure of the system can be avoided. However, these leverage points do not mean (only) physical components of the system, and include the system’s goals, the paradigm out of which the system arises and the power to transcend paradigms. Moreover, Meadows states that these non-physical components are much more effective than the physical ones (constants, parameters, numbers, negative and positive feedback loops, material and information flows, among others). Naturally, the higher the effectiveness of a leverage point, the more the system will resist to changing it. Interesting enough is the easiness/difficulty for the change of paradigm, as individually “it can happen in a millisecond” while whole societies are extremely resistant to paradigm changes.

Departing from these places to intervene in a system, Meadows (2008) explores the ways of creating change. However, one who is looking for a straight way to apply systems thinking to complex problems would be disappointed. Instead, Meadows provide a very human perspective for thinking about systems as the best way to cope with complexity. Why? First because “systems thinking makes clear even to the most committed technocrat that getting along in this world of complex systems requires more than technocracy” (Meadows 2008, p. 167). Secondly, because of the personal characteristics (almost translating human values) that she considers necessary to be developed on those who want to think about systems. These characteristics translate altruistic and humble attitudes, but also translate a pragmatic attitude when realize the importance of practical aspects, as the importance of language to be meaningful so that it can aggregate people and communities or exposing our mental models to others. Meadows concludes with the importance of system thinking as the promoter of a continuous adaptation for the future, between “the edge of what analysis can do and then the point beyond – to what can and must be done by the human spirit” (Meadows 2008, p. 185), which is perhaps the most important capacity to cope with moving targets as sustainability is.

Regarding this adaptive capacity and departing from complexity theory, Innes and Booher (2010) contribute for system thinking considering complex systems as complex adaptive systems. In order to be more effective, they advocate an approach focused on

the interactions and relationships, rather than the systems as a whole, while considering five features that need to be present when thinking about complex systems. This implies:

- To consider a large number of agents establishing multiple networks within the system;
- Understanding that interactions are dynamic, occur locally but affect the system as a whole and generate a distributed memory in the system;
- Such interactions are nonlinear, iterative, recursive and self-referential, with many direct or indirect feedback loops;
- An open system, which behaviour is not understood by analysing components but interactions where new patterns of order can emerge;
- Understanding that the system is robust and adaptive as it has the capacity to maintain its viability and to evolve.

They suggest that, to operate effectively in complex contexts characterized by uncertainty and changing environments, it is necessary to build a disperse intelligence collecting different types of knowledge and linking it in a collaborative planning process, for the necessary innovation and enhancement of systems.

A great contribution to operate under complexity is also given by these two authors, when they pose the contradictions and paradoxes as something to be embraced. Planning for sustainable energy systems will find several points where conflict may appear and where a collaborative rationality will be useful to transform those conflicts into enrichment moments for the enhancement of the outcomes.

3. Review on Energy Planning methods

Readings on scientific literature find the use of “energy planning” closely related with the field of operational research (O.R.). Pohekar and Ramachandran (2004) present an extensive review of multi criteria decision-making techniques used for energy planning. Moreover, energy planning is also used in environmental management (Ertur 1991; Mirzaesmaeeli et al. 2010; Simão et al. 2009) or environmental policy and planning (Jay and Wood 2002; Narodoslowsky and Stoeglehner 2010), just to mention other research areas.

To achieve a concise definition of energy planning is difficult, as the concept is applied in a large range of contexts. Lacking a single definition, the concept of energy planning tends to be defined according the scope of application, always within the energy field but referring to different scopes that range from general policies to the modelling of specific technical components. The broad scope of the concept can be found in practical work developed around the world (Chase and Straughan 2008; IEE 2010; LIPA 2010; OPA 2010). This lack of a single definition calls for a better understanding of the issues involved in energy planning and how far it will be necessary to change it to act as a support for a sustainable development.

This chapter intends to approach energy planning under two perspectives. Departing from practical aspects based on a review about the methods used for energy planning and lessons learn from practical cases, other energy planning issues, related decision and strategy on the process of planning are also developed in the search for an energy planning process integrated in a larger framework.

3.1. Energy planning and energy systems

Departing from a practical perspective, many authors have developed their work under the theme of energy planning. Beside the ones mentioned above, specific contributions for energy planning at a regional level have been provided by Beeck (2003), Cormio et al. (2003), Catrinu (2006), Deshmukh and Deshmukh (2009) or Kowalski et al. (2009), just to mention some recent cases, although research on the energy field is quite dynamic and intensive and new findings and contributions appear almost every day.

Despite this intensive work, a robust discussion about the meaning of energy planning and its disambiguation is difficult to find and when a definition is presented it usually occurs within a specific context of work or research. Therefore, on the issues about energy planning, some aspects are highlighted that may contribute to set a sound discussion around the concept.

A first aspect is the use of “energy planning” intimately related with “energy system”. These concepts are not used interchangeably but most of the time the allusion to energy planning leads to a technical focus on the energy system. The use of tools to model energy systems is then assumed as the entire energy planning exercise.

Naturally, approaching energy systems is essential for energy planning, once energy is the core business. However, a process aimed at sustainable development will need to go further and integrate other aspects for a broader vision on the energy system. An approach focused on a very operative component of the energy system is usually related with O.R. techniques and based on advanced analytical methods, models and tools, reflecting a technical interpretation of energy planning but a somehow compartmentalized view of the planning problem.

In these cases, a functionalist paradigm tends to prevail. The systemic view is focused on the functions established among the individual components of the system and great effort is applied on the optimization of those functions, maximizing the efficiency of the system. Ramachandra, on the development of a regional integrated energy plan (RIEP) expresses this effort on optimization when states:

“The energy planning endeavour for a particular region involves the finding of a set of sources and conversion devices, so as to meet the energy requirements/demand of all the tasks in an optimal manner. This optimality depends on the objective to minimise the total annual cost of energy. Factors such as availability of resources in the region and task energy requirements impose constraints on the regional energy planning exercise.” (Ramachandra 2009, p. 294-295)

On this RIEP, with an extensive effort to provide an integrated planning, the process is developed in a well-defined methodology with a single objective (minimise the total annual costs of energy), where other aspects that could be integrated in the planning process (availability of resources and energy requirements) appear only as constraints that frame the problem. The effort of working with these constraints as part of the system represent an alternative way of approaching the energy system, where new solutions can emerge.

At this point it is important to emphasize that some kind of structuring is always needed for problem-solving or decision-making. In an empirical way, we do it every day when immediate decisions are required. However, in the long term, the planning process cannot be limited to a strict technical approach to energy systems, having the risk of falling short on the representation of an intricate reality. The work of Wiek and Walter (2009), despite not specifically related with the subject of energy, considers the concern with the interface of O.R. with other disciplines for a transdisciplinary approach for formalized integrated planning and decision-making in complex systems. They define a Transdisciplinary Integrated Planning and Synthesis (TIPS) approach that, while “[s]triving for a sufficient level of structure and comprehensiveness (...) integrates a broad range of (soft) OR related methods, namely system analysis, scenario construction, multiattributive assessment, and formative strategy building.”

3.1.1. Defining energy planning for sustainable energy systems

The first aspect on the link of energy planning and energy systems leads to a second aspect related with the perception of energy planning, that seems to be distinguished in two different directions: an instrumental energy planning and an energy planning as a process.

The instrumental vision of energy planning was somehow developed above, when the functionalist vision about energy systems was mentioned. Kowalski et al. (2009) state that “most applications on energy issues focus on technical planning”, which leads to the use of tools, as argued before, and without considering an accompaniment of agents that can provide larger insight about the problem that is being approached. This is mainly due to the fact that energy considered, most of the time, in fragmentation from other areas and as a technical subject (McIntyre and Pradhan 2003). The concept of energy planning based on an instrumental vision is applied in many areas such as local energy and climate action plans, renewable energy planning, energy resource allocation, transportation energy management or electric utility planning (Neves and Leal 2010). Is undeniable that there is always a need to develop and improve the tools necessary to solve a given problem, but again, take them as planning is reductive. They are undoubtedly one important component of planning, as they are used to return operational results, but must be seen as only one part of a set, contributing to a real planning.

The idea of planning as a process is related with approaches that move away from functionalism, and introduce different views that “embody distinctive systems of meaning” as Healey (1994) refers to spatial planning.

This call to the importance of the variation on systems of meaning, which represent the “way social and socio-spatial relations are conceptualized, and consequently in the way issues are problematized and interventions designed, valued and implemented”, as she continues, pulls the energy planning from a single technical focus, alerting for a larger approach. As mentioned before, energy is a transversal issue on the development path of any territory and therefore, energy planning needs to be seen as a process along time.

In that sense, energy planning needs to be of a comprehensive nature and start to look at other subjects, integrating knowledge from other areas such as social or environmental sciences and approaching other types of planning as spatial or urban planning.

Explicitly or implicitly, the work developed so far considering energy planning as a process is focused on the development of methodologies, which express an effort on a combination and structure of different stages and tools, rather than the application of a single method or model. These methodologies express ongoing procedures that, by putting together different methods, allow achieving a better perception of what is involved in the problem and help reach solutions.

Despite the evolution of the concept of energy planning towards the notion of process is already perceptible, the development of energy planning as a methodology does not guarantee the distance from a functionalist energy planning. Most authors present several models combine into methodologies or even multi-methodologies (Aparicio et al. 2012; Beeck 2003; Cormio et al. 2003; Deshmukh and Deshmukh 2009; Hamm 2007; Kowalski et al. 2009; Ramos 2002; Thery and Zarate 2009), but as the underlying models and tools used on those methodologies derive from the traditional O.R. field, the limitations related to quantification and optimization of value functions continues to drive the planning process.

On an effort to go further, other authors try to combine complementary methods of different scientific areas for a more comprehensive approach of the issue. Combining scenario’s building and participatory multi-criteria analysis (Karger and Hennings 2009; Kowalski et al. 2009) is perhaps the most common way to express this effort. Approaches from other fields, applied to the energy issue can also contribute with useful principles for the planning of sustainable energy systems, as presented by Cassidy et al. (2007),

which introduce a strategic sustainable development framework for the enhancement of the planning process for local energy systems.

In fact, it is based on the idea of having the energy planning integrated in a major concept of planning that this research is aimed at. As Foell states "... the energy planning process can be effective only as an integral part of development planning" (Foell 1985). Although a challenging option, on the approach to energy planning it is necessary to broaden its application. In that sense, the effort is not only on the development of a tool to help deciding about the options and measures to be implemented, but in the importance of having a planning process for energy systems, helping bringing out new options that effectively can implement the new energy paradigm to achieve sustainable energy systems.

3.2. Contextualizing system approaches in energy problems

Energy problems have been commonly approached using models. According to Jebaraj and Iniyan (2006), energy modelling issues are as diverse as "energy planning models, energy supply-demand models, forecasting models, renewable energy models, emission reduction models, optimization models". Models always simulate a physical reality but, as they translate different parts of the whole, the real representation of the energy system is never attained. Thus, the authors also state that the "models have become standard tools in energy planning" which has been particularly true on the efforts for the transition from current conventional energy paradigm to the renewable one.

However, this widespread use of modelling tools is inhibiting an effective energy transition, as Johnson and Suskewicz (2009) state:

"So far, the bulk of investment has been in companies using conventional business models in an effort to fit clean technologies into existing systems. Sadly, history shows that this rarely works. (...) But we won't have to wait that long if we can deliberately effect a wholesale shift in our energy infrastructure. To be sure, this is an ambitious goal that requires thinking on a grand scale. The key, we believe, is to understand that in a major infrastructural shift, technologies don't replace technologies. Rather, systems replace systems". (Johnson and Suskewicz 2009, p. 2)

These achievements give a new perspective on the direction of the efforts for planning energy systems – maybe the focus should not be only on the shift of technologies (as

plenty of them already exist for the use of renewable energy resources) but on the development of new systems that can replace the existing ones¹.

The technological focus that is currently given to energy as an engineering issue, has contributed for the adoption of bottom-up approaches, leading to models that are ever more detailed. These models are mostly deterministic, searching for the one optimal solution among the different alternatives. Moreover, as they tend to depart from a positivist perspective, build upon the evidences of previous models, some premises are hardly questioned, and little improvement is taken on their structure and framework.

This way, the specificity that is attained at each of these tools is one other reason why the use of some energy models can be so inadequate, in the sense that they become context-dependent, and therefore do not fit all the energy systems. Bhattacharyya and Timilsina (2010) express this idea on their review about the adequacy of existing energy models for developing countries, when conclude that:

"(...) most of the existing models inadequately capture the developing country characteristics and that the problem is more pronounced with econometric and optimisation models than with accounting models. The level of data requirement and the theoretical underpinning of these models as well as their inability to capture specific developing country features such as informal sectors and non-monetary transactions make these models less suitable. The accounting-type end-use models with their flexible data requirements and focus on scenarios rather than optimal solutions make them more relevant for developing countries." (Bhattacharyya and Timilsina 2010, p. 508)

These concerns on the replacement of systems have already started to be considered. Schlör et al. (2012) state that the limits on energy systems "can only be overcome in the long run by a new energy system". In addition to the efforts from research, the relevance in considering new energy systems have begun to be acknowledged by some key players in the field, as the International Energy Agency, when communicate that systems thinking "is essential to explore opportunities to leverage technology deployments within existing and new energy infrastructure. Enabling and encouraging technologies and behaviour that optimise the entire energy system, rather than only individual parts of it, can unlock tremendous energy efficiency and economic benefits. (...) Moreover, "systems thinking" is key to unlocking synergies between energy, transportation, water, waste and communication infrastructure" (OECD/IEA 2012).

¹ At this point I would like to recall the importance of the variation of systems of meanings, as mentioned by Healey (1994) in section 3.1.1, as a possibility on the replacement of systems.

It seems clear that the direction towards the solving of the energy problems passes by system thinking, allowing addressing the challenge identified by Schlör et al. (2012) about the configuration of the energy system, which "is still unclear and is the subject of an intensive social discussion process."

3.2.1. Current approaches to energy systems

Giving the lack of a comprehensive response from models and operational tools to energy issues, great effort has been applied on the development of methodologies or multimethodologies for the planning of energy systems. They can be of great use, when integrating other dimensions not accounted so far, as the social or environmental ones. Nevertheless, they would fall short on their intention if resulting only from a combination of different models, without being able to cut with the deterministic approach to energy systems.

The practice shows that energy plans have shifted their focus, considering wider boundaries about the energy system (J. S. Nilsson and Mårtensson 2003), however expanding boundaries does not mean that energy systems are being addressed in a more comprehensive way. In the specific case, it refers to energy efficiency at municipal scale that consider a shift from energy efficiency at buildings level to energy efficiency in all activities, which does not imply a change on the way the global energy system is considered.

Most of the current approaches to energy systems have, as goal, to understand how the energy system works. This leads to the focus on energy models that can explain the dynamics of the current energy system. If understanding how energy systems work puts the emphasis on energy models, the fact is that, according to the focus of analysis, energy systems models can be substantially diverging. Beeck (2003), in a review on energy models uses ten different attributes along which energy models can be classified (see Table III). Considering that models can be developed by combining several of these attributes, the possibilities are countless.

Table III – Classification of energy models: a 10-attributes framework

Attributes	Definition	Classes
Perspectives of the future	Considers the way in which the models' perspective about the future is explored.	Forecasting Scenario Analysis Backcasting

Attributes	Definition	Classes
Specific purposes	Considers the case-specific definition of “energy system” to be modelled, characterizing the modelling purpose.	Including, but not limited to: Energy Demand Energy Supply Impacts assessment Appraisal of options
Model structure	Reflects the type of assumptions that shape the model and define a structure, which can be more or less flexible.	Depending on the main type of assumptions: Internal (rigid structure) External (flexible structure)
Analytical approach	Defines the way how the model “sees” the energy system, considering an aggregated view (linked with a policy level of analysis) or a detailed view (adopting an engineering approach).	Top-down (aggregated) Bottom-up (detailed)
Underlying methodology	Refers to the solving approach taken by the model developers and depends on the study field and goals of the modelling, resulting on a large variety of classes.	Including, but not limited to: Econometrics Macroeconomics Simulation Optimization Spreadsheets Multi-criteria methodologies
Mathematical approach	Refers to the way how the energy problem can be expressed mathematically, and more specifically, how the solution can be achieved using mathematical techniques	Linear Programming Mixed integer Programming Dynamic Programming Beside others under development
Geographical scale	Considers the geographical coverage on which the model is focused. It is closely related to analytical approach considering the level of detail of the information required for the analysis.	Global International National Regional Local Project
Sectoral coverage	Driven by economic activities and most of the times based on the ISIC classification, models can be focused on one or more energy-consuming activity sector.	Single sector Multi-sectoral
Time horizon	Defines the time-scale of the model analysis according to different planning objectives and the process to be analysed	Short-term Medium- term Long-term
Data requirements	Specific models require specific data types. The amount and value of data required by the model, define the type of model.	Aggregated/disaggregated Quantitative/qualitative

Based on Beeck (2003).

Despite the completeness of such classification, the characterization of energy models tends to fall into a smaller number of parameters. Schrattenholzer (2005) proposes a three-folded classification for energy planning tools, considering:

- i) the framework, being a descriptive or prescriptive (normative) model;
- ii) the type of approach to the problem, being a bottom-up or top-down model;
and
- iii) the underlying functioning of the system, being an optimization or simulation model.

Schenk (2006) notes that energy models are determined by the question that needs to be answered, and establishes three dimensions along which those models tend to be developed: mental models, empirical data and theoretical causalities.

The Nordic Energy Perspectives (Springfeldt et al. 2010) refers a two-folded classification, considering:

- i) the type of approach – top-down or bottom-up; and,
- ii) the field of energy system modelling: engineering-economic models, computational general equilibrium models; macroeconomic models, input-output models, hybrid models and integrated assessment models.

Moreover, classifications regarding energy models have a global expression as stated on reviews in the specific context of developing countries (Nakata 2004; Pandey 2002), where energy systems are classified according:

- i) the approach (also called paradigm) – top-down or bottom-up;
- ii) the geographical scale – global, national, regional or local;
- iii) underlying methodology – econometric, macro-economy, equilibrium, optimization, simulation; and
- iv) time horizon – long, medium or short-term.

This aggregation into a smaller number of parameters also expresses an evolution that have been observed on the existing models towards a higher integration and comprehensiveness (see Table IV). This integration among models resulted on a new generation of models, called the 3E models that combine energy-environment-economy (Capros 1995). More recently, new approaches to the improvement of such models have also included the importance of society and technology, resulting in SE³T models: society-energy-environment-economy-technology (Y.-M. Wei and Liang 2009).

Table IV – Identification of the type of integration verified on some examples of energy models

Model	General description	Type of Integration
MARKAL (Seebregts et al. 2001)	MARKet Allocation – Energy system model that interconnects technology (supply and demand side) in an optimization routine based on economic constrains.	Energy-Economy
PRIMES (Capros)	General-purpose energy model, demand- and market-driven, that searches for an equilibrium solution.	Energy-Economy
ENEP-BALANCE (CEEESA 2007)	Energy and Power Evaluation Program - model for energy simulations based on market equilibrium algorithm (includes environmental costs)	Energy-Economy

Model	General description	Type of Integration
HOMER (Lambert et al. 2006)	Energy Modelling Software for Hybrid Renewable Energy Systems – for the comparison of different design options for micropower systems and optimal integration, based on their technical and economic merits.	Energy-Economy
RETScreen (RETScreen)	Modelling tool for “clean energy projects”, analyses and evaluates the technical and financial viability of possible projects	Energy-Economic
LEAP (Heaps 2008)	Long-range Energy Alternatives Planning System – Integrated modelling tool enabling the design of energy systems for analysis and simulation on an overall accounting framework	Energy-Economy-Environment
EnergyPLAN (Lund 2011)	Modelling tool for analysis of energy systems on an hourly base, returning results at technical and market-economic level (optimization).	Energy-Economy
TIMES (Uwe et al. 2008)	The Integrated MARKAL-EFOM System – With a systems engineering approach, allows detailed technical description and economic evaluation, based on linear equations for the economic balance, without searching for optimization.	Energy-Economy
NEMS (DOE 2009)	National Energy Modelling System – Integrates energy supply and demand in a macro-economic approach that searches for general market equilibrium.	Energy-Economy
POLES (Kitous 2006)	Prospective Outlook on Long-term Energy Systems - econometric, partial-equilibrium world model that allows projections of energy supply and demand by prices	Energy-Economy
WEM-ECO (Roques and Sassi 2008)	World Energy Model - takes into account macroeconomic feedbacks in the WEM energy scenario and introduces interaction with policy and decision makers, in a general equilibrium model	Energy-Economy
GEM – E3 (Capros)	General Equilibrium Model-E3 – considers the interaction of energy, macro-economy and environment (atmospheric emissions and pollution abatement)	Energy-Economy-Environment

Note: Most of the energy-economy represented in the table considers an environmental dimension, which is represented by CO₂ emissions

3.3. Adopting a strategic posture for the enhancement of energy planning processes

It was given more attention to strategy and strategic issues since 70's within planning and management fields, with research on strategy formation. Mintzberg (1978) defines strategy as "a pattern in a stream of decisions" that can be explicit from the beginning (intended strategy) or inferred from the practice (realized strategy). These two patterns are not exclusive and depending on the way they occur, it can result a deliberative

strategy (intended and realized strategy), an emergent strategy (not intended but realized) or an unrealized strategy (intended but not realized). However, what is clear along his work is that strategy formation is not a neat process as “a strategy is not a fixed plan, nor does it change systematically at pre-arranged times”. Moreover, denounces the false dichotomy between formulation and implementation of strategies “because it ignores the learning that must often follow the conception of an intended strategy”.

It is the strategic intent that may have a distinctive input on the enhancement of planning processes. This does not deprive emergent strategies from a relevant role, as it draws attention to the importance of learning along the planning process. Nevertheless, strategic intent acts as the driving force for the entire planning process, maintaining the improvement effort along time, as Hamel and Prahalad (1989) stated (for a business context):

“(...) they created an obsession with winning at all levels of the organization and then sustained that obsession over the 10- to 20-year quest for global leadership. We term this obsession 'strategic intent'”. (Hamel and Prahalad 1989, p.64)

In their work, Hamel and Prahalad (1989) highlight that strategic intent differs from strategic planning, approaching a distinction that is later stated by Mintzberg (1994) as strategic thinking and strategic planning:

“(...) strategic planning is not strategic thinking. Indeed strategic planning often spoils strategic thinking (...). Planning has always been about analysis – about breaking down a goal or a set of intentions into steps, formalizing those steps so that they can be implemented almost automatically, and articulating the anticipated consequences or results of each step. (...) Strategic thinking, in contrast, is about synthesis. It involves intuition and creativity. The outcome of strategic thinking is an integrated perspective (...) a not-too-precisely articulated vision of direction (...)” (Mintzberg 1994, p. 107-108)

As Heracleous (1998) states “the relationship between the two ideas of strategic planning and strategic thinking is by no means clear in the literature, which is in a state of confusion over this issue” but notes a difference between the them, when observes that strategic thinking should precede strategic planning. This distinction is important as the two concepts have different roles, nevertheless they are related and sometimes used as synonyms as verified in Schoemaker (1995).

If strategic thinking expresses intuition and creativity for the future, strategic planning gives a real shape to that future. Moreover, when tools for strategic planning are correctly used, they can also stimulate imagination, giving inputs to strategic thinking

(Godet 2000). This contribution of strategic planning to strategic thinking is highlighted by Liedtka (1998) when defines planning as dialogue: "The most valuable role strategic planning processes play is to legitimize a developmental dialogue around strategic issues (...)". Idea supported by Eisenhardt (1999) when sets, among others, "building collective intuition through frequent meetings" and "stimulate quick conflict by assembling diverse teams, challenging them through frame-breaking heuristics" as a keys to strategy.

Thus, strategic thinking does not withdraw importance to strategic planning and both concepts are reconcile by Liedtka (1998) that addresses the elements that constitute strategic thinking and point out strategic planning as a support to strategic thinking. She states that "the scientific method accommodates both creative and analytical thinking sequentially in its use of iterative cycles of hypothesis generating and testing", unifying synthesis and analysis used before by Mintzberg (1994) and embracing both strategic thinking and planning.

Such considerations find echo outside organizational management field and are reflected at public level and governance issues as presented by Healey (2006):

"In short, episodes of strategic spatial planning (...) should be judged in the long-term in terms of their capacity to enrich the imaginative resources, creative energies and governance cultures (...)." (Healey 2006, p. 543)

All these aspects contribute for the enhancement of planning processes, towards a future that is desired, more than a future that can be predicted by the use of models or analysis tools. Thus, what is then a strategic posture? What can be withdrawn from these thoughts about a strategic posture is that it is a permanent and dynamic behaviour: permanent in the sense that an 'obsession' about the future accompanies all activities; dynamic because that 'obsession', to be accomplished, needs to have present real conditions (the interrelationship between strategic thinking and planning).

3.3.1. Exploring strategy on practical cases of energy planning

Giving the importance that a strategic posture has on the enhancement of planning processes, understanding if it has being applied and how in energy planning is necessary to draw some conclusions on what has failed on achieving sustainable energy systems. In that sense, a short number of cases selected from a larger collection reviewed were used to illustrate the way strategy is claimed on energy planning. Considering the two elements of a strategic posture, as explored above, some major conclusions are outlined and presented as outcomes.

Case 1 – “Renewable energy strategies for sustainable development”

Lund (2007) presents a methodology for energy planning based on an analysis model (EnergyPLAN) and “discusses the perspective of renewable energy (wind, solar, wave and biomass) in the making of strategies for a sustainable development”. The study presents strategies as:

“Sustainable Energy Development Strategies typically involve three major technological changes: energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy”

The work is developed under a technological approach, where four different alternatives - savings, efficiency, renewable energy sources and a combination of the three, are modelled. Considerations about other relevant issues for sustainability are not mentioned. The results express the combination of the technological alternatives that assure 100% renewable energy consumption.

Outcome #1	Often what is presented as strategies refers only to alternatives, missing the strategic thinking component.
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Case 2 – “Strategic analysis methodology for energy systems”

Krumdieck and Hamm (2009) propose a methodology for the planning of energy systems in island countries, considering sustainability by incorporating “aspects of the local social, economic and environmental sub-systems into the engineering design and optimization project”. The main work is placed on a “functional model that captures the complexity of the local energy system while providing a relatively simple representation of the system dynamics”, allowing to develop alternatives for future developments based on feasibility analysis and risk assessment. The result is a strategic analysis methodology based on an engineering approach, emphasizing optimization.

Case #3 – “Renewable energy planning at regional level”

Terrados et al. (2009) combine different planning techniques in a single methodology “for the sketching of strategies and action lines for renewable energies development”. Similarly to Krumdieck and Hamm, they include sustainability criteria for the analysis of energy alternatives to the planning context. The result is the ranking of energy actions

and targets that can be implemented, based on the maximization or minimization of 11 criteria used for evaluation.

Outcome #2	Detailed structuring of a problem can result on a strategic posture limited to the strategic analysis component, in quantitative terms.
Outcome #3	As a consequence, planners fall on the 'optimal solution' trap.

Case #4 – "Planning for Local and Regional Energy Strategies"

Narodoslawsky and Stoeglehner (2010) propose an evaluation of energy strategies based on the ecological footprint as an indicator that can be applied at all stages of the planning and decision-making processes. They present the creation of a vision for the energy future as a result of the planning process and defend the direct use of the footprint "as assessment tool for visions, goals and measures". The result is the presentation of the ecological footprint indicator as a tool for evaluation of different energy alternatives, with a "strong potential for strategic planning of energy-related issues".

Outcome #4	Decisions about strategies can be supported by a one-indicator assessment
Outcome #5	Planning and assessment results tend to define the probable future instead of supporting a desired future (the vision).

These four cases presented above, they all present contributions to different aspects of energy planning, in an incremental way to enrich the planning process, by combining complementary methods, increasing comprehensiveness or provide better assessment. Thus, they all claim energy strategies despite their focus are limited to specific parts of the energy systems or stages of planning processes. Regarding the use of multi-criteria decision analysis (MCDA), a great variety of research and studies is available and many examples can be found in literature, however on the strategy subject they would only support these outcomes.

On a review about energy planning methodologies and tools, Schrattenholzer (2005) presents a wide range of models used on the planning of energy systems, alerting for the GIGO situation (garbage in – garbage out). Putting the emphasis on the stage of 'garbage in', one can realize the importance of strategic thinking before strategic analysis.

To a certain extent, the threat to strategic thinking on energy problems can be explained by having different agents responsible for decisions at different levels. The European context illustrates quite well this situation, when member-states are compelled to present their renewable energy action plans under the structure of UE requirements:

"Article 4 of the renewable energy Directive (2009/28/EC) required Member States to submit national renewable energy action plans by 30 June 2010. These plans, were prepared in accordance with the template published by the Commission, and provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption." (Build Up 2012)

As presented before, both components of a strategic posture (thinking and analysis) should not be dissociated once they mutually benefit from each other. However, centralized decisions confine the development of local strategies, or from another perspective, local decisions have not been able to escape from centralized frameworks that may inhibit the development of new solutions. As J. S. Nilsson and Mårtensson (2003) conclude about a study of 12 municipal energy-plans in Sweden, "the municipal energy-systems have evolved with the Swedish national energy-policy for the past three decades".

The global dimensions of energy-related problems may have contribute for these global, centralized guidelines on energy planning, but as Patt (2010) states, "regional governance is what is needed to set in motion a transformation of the energy system away from fossil fuels".

3.4. Decision-making: When and what for in energy planning

Decision-making and planning are closely related, although the way the connections are established can be rather fuzzy and not as neat and hierarchical as we would like they were, for the sake of rationalization. Lyhne (2011) argued against these hierarchical assumptions between policy-making and planning, highlighting both processes as interactive activities (p. 119). In practice these two concepts (planning and decision-making) are frequently used interchangeably, as in a case of land and natural resource management (Lessard 1998). This is mostly because decisions occur at different levels and moments regarding the planning process, with different purposes.

The reason why it happens is that decision occurs before and during the planning process and it is important to understand that decision can have different interpretations. In 1976, Mintzberg et al illustrated this situation as it follows, when dealing with what they called 'strategic decisions' as opposed to 'operating decisions':

"Researchers of administrative processes have paid little attention to such decisions, preferring instead to concentrate on routine operating decisions, those more accessible to precise description and quantitative analysis. As a result, the normative models of management science have had a significant influence on the routine work of the lower and middle levels of organizations and almost no influence on the higher levels." (Mintzberg et al. 1976)

These two decision moments are distinct. At a first moment, decisions have place in what regards the identification of goals or objectives that one wants to achieve and, on public government, they are stated as policies. These types of decisions are faced as resolutions, directions to follow to attain a desirable future and trigger the planning processes. Then the planning process combines those intentions with current reality and search for possible solutions to reach the desirable future. This leads to the second decision-making moment, when it is necessary to choose among options that, in different ways, respond to the overall objective.

It is difficult to have a linear representation on the way these processes occur. It is not a cycle insofar as decision does not represent the same before or in the planning process; the first one is related with strategy formation while the second one with the selection of alternatives. Thus, it is not a linear process from decisions to the choice of alternatives, as planning results may be conflicting with initial objectives (in what respects the definition of primary objectives, considering the work of Ralph Keeney on Value-Focused Thinking, referenced on previous chapter). The first moment is characterized by visions for the future while the second moment is characterized by the ways to operationalise those visions.

When a development process is concluded and the way that it has evolved is analysed, it is difficult to say, most of the time, where decisions or planning started, as probably they do not have independent origins but have evolved together. However, first and second decision moments cannot be mistaken since if operational decision-making is considered at very early stages of the planning process, this will be limited to the operationalization of selected alternative, with little chance to be integrative and improving the quality of initial decisions.

3.5. Strategy, decisions and energy planning - Understanding the failures of traditional approaches and emerging solutions

Despite the efforts for a culture of strategic posture, in practice they tend to fall short, as identified above. All the outcomes point out a lack of strategic thinking. This is mainly due to the absence of the dynamic aspect of strategy on decisions, merging the different types of decision in a single (or few) moment(s), after some kind of strategic analysis.

To deal with the dynamics of strategy is difficult simply because most of the time they are not explicit. Moreover these dynamic are threatened by what Kurtz and Snowden (2003) call the “universality of three basic assumptions that pervade the practice and to a lesser degree the theory of decision-making”:

- The assumption of order;
- The assumption of rational choice;
- The assumption of intentional capability.

These three assumptions characterize the rational paradigm. What Kurtz and Snowden state is in fact a criticism on the dominance of this paradigm, present in all knowledge areas. The rational paradigm is closely linked with:

- The utility theory, based on measurements that allow choosing the correct answer among different alternatives;
- The believe that is possible to have a complete knowledge about the problems and uncertainty and risk about choices are possible to determine;
- Positivism, explaining practical results or observations based on logical functions.

It is perhaps on O.R. that rationalism reaches its highest expression, much because of the utility theory underlying to almost all problem-solving approaches. Having strategy closely related with the dynamics of the decision, is possible to say that some characteristics of rationalism may be causing the difficulties on achieving a strategic posture. In fact, that is disclosed on Ackoff's reflection on the use of O.R. when he states that “(...) OR has been and is almost exclusively concerned with organizational self-control. (...) Its method is analytic and its models are predominantly of closed mechanical systems, not of open purposeful systems. This is clearly revealed when one considers OR's use of two concepts: *optimization* and *objectivity*” and in that sense OR could be of little use when approaching systems that are complex and “are wholes which lose their essential properties when taken apart” (Ackoff 1979).

These criticisms were useful as they challenged O.R. to overcome the rigid norms of problem-structuring, allowing for the development of a great variety of new supporting methods to decision. The effort was, initially, on broaden the system's boundaries and cope with the higher needs of quantitative data than on a paradigm change regarding the optimization and objectivity highlighted by Ackoff. However, later on contributions from critical theory started to be reflected by the development of new approaches. As Daellenbach (2001) states in a useful review on O.R. evolution (see Table V):

"OR has expanded from its originally quantitative systems focus in various directions that encroach on or straddle other disciplines, such as critical philosophy, social and human behaviour fields, and areas traditionally seen as business administration, such as organizational behaviour and strategic management" (Daellenbach 2001)

Table V - Types of approaches on O.R. according the problem situation (based on Daellenbach 2001)

Approach	Group
Functionalist systems approach: High technical complexity and objective view of the systems (low human complexity and low diversity of interests)	Hard O.R. or Hard Systems Approach
Interpretative systems approach: Pluralist view about the system and low diversity of interests. Promotes cooperation among stakeholders. Greater difficulty in dealing with complexity.	Soft O.R. or Soft Systems Approach
Emancipatory systems approach: High technical and human complexity with conflicting interests about the system. Characterized by involve a rupture with traditional approaches	Methodological Pluralism
	Multi-methodologies
	Critical Systems Thinking

At same time, the consequences of rational paradigm were also reflected at planning level, both by the dominance of the rational paradigm as universal philosophy and the expression of O.R. on planning processes. Alexander (1984) advocated for a 'search response' to the rationalist breakdown, considering it the logical reaction: "if a paradigm is revealed as flawed to the point that it becomes useless for any conceptual or practical purposes, look for another." He presented a number of alternative approaches to rational paradigm that were arising, but stated that the majority were essentially modifications to the rational model, without a genuine rupture with the principles that caused the very limitations of the model. One of the alternatives was Habermas' critical theory as philosophical contribution on the domain of planning and decision-making, to which Alexander notes:

"Many stimulating ideas have resulted from such cross-fertilization, and some of these models offer promise. But none has yet been sufficiently developed or, indeed, generated enough interest or debate to present itself as a candidate for recognition as a potential dominant paradigm." (Alexander 1984, p. 66)

Generically, critical theory is characterized by “its ability to disrupt and challenge the status quo” (Kincheloe and McLaren 2011), probably the major reason of its success. One other important aspect of critical theory is that it is “particularly sensitive to the kind of philosophic error embodied in positivism” (Geuss 1981). The empirical focus of positivism and the importance of demonstration are of particular relevance on planning research as the lack of empirical evidence conditions the adoption of valid approaches, confirmed by Dalton (1986) “(...) academics cannot expect practicing planners to adopt alternative approaches unless they demonstrate them effectively.”

Despite the doubts about the significance of critical theory, recent years have shown its importance to overcome the limitations of rationalism on the approach to our complex world. When Innes and Booher (2010) identify the three trends in the evolution of planning (already mentioned on previous chapter) they implicitly illustrate the contribution of critical theory (see Table VI).

Table VI – Contribution of critical theory for the evolution of planning (based on Innes and Booher 2010)

Relativity of rationalism
“(...) traditional linear methods relying primarily on formal expertise are being replaced by nonlinear socially constructed processes engaging both experts and stakeholders. (...) They may start with some general shared concerns, but collectively they do not start with specific goals. They do not operate on the assumption that there is an optimal solution”
Relativity of positivism
“(...) ideas about appropriate knowledge for planning and policy are changing. (...) the public and decision-makers are recognizing the limitations of science and expertise (...). The use of expertise itself depends on lay knowledge, but many experts do not publicly acknowledge that their knowledge is socially constructed.”
Adoption of a critical posture
“(...) new forms of reasoning are beginning to play a larger role and gain scholarly recognition and legitimacy. (...) participants in policy processes, especially in collaborative planning, rely on a variety of other methods of making sense of issues and persuading others. ”

Back to the dynamics of strategy, the adoption of critical theory also brings some of the necessary ingredients to improve the strategic posture, as it supports complexity science.

When Kurtz and Snowden (2003) identify the three assumptions that affect strategy, they then assume a critical posture, questioning what is order, rational choice or intentional capability, and find that the solution can be, respectively, on the expansion

of such concepts by relaxing the idea of order, objectivity and context. Accordingly, to make sense of things is more relevant for strategy than logical or rational explanations:

" . . . whatever we perceive is organized into patterns for which we the perceivers are largely responsible. . . .As perceivers we select from all the stimuli falling on our senses only those which interest us, and our interests are governed by a patternmaking tendency, sometimes called a schema. In a chaos of shifting impressions, each of us constructs a stable world in which objects have recognizable shapes, are located in depth and have permanence. . . . As time goes on and experience builds up, we make greater investment in our systems of labels. So a conservative bias is built in. It gives us confidence." (Mary Douglas 1966, cited in Kurtz and Snowden 2003)

The critical theory seems to bring a deconstructed context, difficult to work in, but Kurtz and Snowden present interesting notions that provide some guidance on this necessary new approach, namely with the notion of 'un-order', "not the lack of order, but a different kind of order, one not often considered but just as legitimate in its own way". Therefore, sense-making, about which we need to understand that substitutes a universal order, does not imply total disorder, as they state:

"Boundaries are possibly the most important elements, in sense-making, because they represent differences among or transitions between the patterns we create in the world we perceive" (Kurtz and Snowden 2003, p. 474)

This use of patterns (resulting from nonlinear relations) to make sense of things is somehow related with the two models ("seeing first" and "doing first") that Mintzberg and Westley (2001) advocate as supplement to the rational model of decision-making, insufficient to explain (rationally) most of the decisions, result of the integration from the three approaches.

4. The importance of assessment in planning processes

4.1. Introduction

Currently, many contributions for assessment procedures in planning processes have emerged in the environmental field (Emmelin 2006; Richardson 2005; Sheate 2009) and that explains why lately most of the assessments are environmental assessments (EA). These procedures have also recently developed in parallel with the communicative component in planning processes. Healey (1993) stated that "Planning is an interactive and interpretive process (...) Planning processes should be enriched by discussion". This contribution, known as the communicative turn in planning theory, placed the attention on the discussion about the possible developments of planning processes.

"Thus the narrative mode should accompany and intersect with experiential expression and the analytical mode. But in the end, the purpose of our efforts is not analysis, telling stories, or rhetoric but doing something; that is, "acting in the world." For this, we need to discuss what we could and should do- why and how." (Healey 1993, p. 238)

According to this way of facing planning, assessment is intrinsically related with the planning process. However, the way of developing assessment procedures can vary significantly in practice and results can be very different. The main relevant distinction in the context of this work is to consider assessment as an *ex ante* or *ex-post* procedure. In this context, assessment (or appraisal) is understood as the consideration of the dimensions and deliberation about effects from different strategies in the elaboration of a plan. This close link with strategies pose the emphasis on an *ex ante* procedure, as have been recognized to be more effective on the challenges about integration in planning processes (Abaza 2003). Thus, the assessment is not limited to a specific moment in time but assists along the planning process, opening space to collaboration and contributing to the learning capacity (Owens et al. 2004; Richardson 2005), making planning reflective about its own processes (Healey 1993). This way, strategic assessment procedures are having an increasing role on the way of moving beyond deterministic approaches to energy systems, overcoming the results of quantitative evaluations and their limitations on complex contexts.

Despite the importance of assessment procedures in the environmental field, in recent years concerns are directed at sustainability, which imply the inclusion of other topics and the reshape of the usual procedures.

Considering the connexion of assessment procedures with strategy, planning and decision-making, particular attention is given to strategic environmental assessment (SEA) as a procedural instrument that contributes for sustainability. The growing application of SEA to policies, plans and programmes allowed to identify the potentials and drawbacks of the instrument. Its connection with energy planning is considered in the development of sustainable energy systems. All these aspects are developed in this chapter.

4.2. Sustainability assessment and insights on the energy field

The focus on the development of new ways to measure and assess progress toward sustainable development emerged in 1987, from the WCED (Hardi and Zdan 1997). This idea of assessing sustainability was reinforced in 1992 during the Rio summit, calling for the need to “review the status of the planning and management system and, where appropriate, modify and strengthen procedures so as to facilitate the integrated consideration of social, economic and environmental issues” (Quarrie 1992). As George (2012) states, “The concept of sustainability appraisal of policies, plans and programmes has grown out of these Rio commitments.” And Gibson complements with the observation that “The last few years have brought many experiments with forms of sustainability assessment, applied at the strategic and project levels by governments, private-sector firms, civil society organizations and various combinations” (Gibson 2006b).

Having sustainability assessment being applied, the question is then if it has allowed to attain a higher sustainability level, in particular in the energy field. Gibson (2006b) says that “conventional assessment and planning processes today are not often well designed for addressing human and ecological effects within complex systems”, which is precisely the case of energy systems. Moreover, he continues stating that “most (assessment processes) fail to ensure effective integration of sustainability considerations in the key early decisions on purposes and preferred options”.

Once again, we find the lack of integration as the major limitation of sustainability, there are passed on to sustainability assessment. If integration does not occur at the conceptual stage, the consequences extend along to the operational processes (as planning and assessment). The contribution for the improvement of these processes

towards sustainability is on the watchword **integration**, materialized in the words of Gibson as:

"The challenge, then, is to design a sustainability assessment approach that is true to the integrative genius of the concept, but that also ensures attention (maybe even special, corrective attention) to the usually neglected factors, and is minimally vulnerable to damaging implementation. The working premise here is that no single assessment design feature is likely to be sufficient for this, but that a package of linked features might succeed." (Gibson 2006a, p. 267)

Moreover, there is one other challenge in sustainability assessment, as conception about sustainability is moving from 'a target' to 'a driver'. This means that sustainability assessment cannot be a simple evaluation of decisions and actions at a given moment, otherwise little could be expected on the contribution towards sustainability. Devuyt (2000) states "sustainability assessment initiatives should start from the knowledge that sustainable development is not a 'fixed state of harmony' and therefore "sustainability assessment only makes sense when linked to an assessment framework". This concern finds echo on the considerations of Pope et al. (2004) about current sustainability assessment "as 'direction to target' approaches. While these kinds of assessment have their place, it could be argued that they do not go far enough to make a significant contribution to sustainability."

In what regards energy, it is recognized as a core issue in sustainability due to its role on social, economic and environmental conditions (Voß 2006). Reddy (1998) calls for the contribution of energy towards sustainable development and the need to overcome some installed paradigms that constrain sustainable energy strategies. That supports the effort on the evolution on energy planning processes, as discussed before, where attention is given on approaches that integrate other than technical concerns and where sustainability assessment can perform an important role. However, current approaches to energy problems still adopt an 'engineering approach' to the issue of sustainable development (Afgan et al. 1998). This 'engineering approach' entails a deterministic approach, based on the paradigms of rationalism and functionalism and framed by operational research, with a range of limitations already discussed above.

The large amount of research work developed under the definition of multi-criteria methods (Kleivas et al. 2009; Kowalski et al. 2009; Lahdelma et al. 2000; Polatidis and Haralambopoulos 2004; Stirling 2010; Thery and Zarate 2009) or development of

sustainable energy indicators (IAEA 2005; Neves and Leal 2010; Patlitzianas et al. 2008; Streimikiene et al. 2007; Vera and Langois 2007) reveals the functionalist posture adopted on the claimed sustainability assessments.

Despite these tools may be necessary at some stage on sustainability assessment processes, their use is not sufficient to assume that an assessment is made, especially when considering sustainability as a driver on energy planning processes. As Voss and Kemp (2005) put it “sustainability cannot be translated into a blueprint or a defined end state from which criteria could be derived and unambiguous decisions be taken to get there” (cited in Bagheri and Hjorth 2007).

4.3. Environmental assessment in planning processes

Planning has evolved towards a democratic process, involving power conflicts and different arenas of discussion. There is a growing need to discuss values and develop enhanced planning solutions and “most actors - planners, politicians, and stakeholders - see EA as an opportunity to persuade, to mediate, and to contest” (Richardson 2005). It is not clear however if these efforts are being effective as EA is being applied with a great diversity of tools and in different ways.

Participation is one of the assets of EA as most of these procedures allow a planning application to be communicated to the public before a decision is made and therefore collect and integrate diverse points of view about the planning object. It is however recognized that “there is the tendency for EA to concentrate on the provision of public participation” (Richardson 2005, p. 359) leaving aside the potential to integrate values along the planning process.

It is in this balance of a bottom-up and top-down approaches that assessments are being developed. For sure, public participation is an added-value on planning processes as shifts for new planning options, especially in the energy field, need the acceptance of general public (for instance, the adherence to energy efficiency measures that depend on the user’s behaviour). Nevertheless, purely bottom-up approaches take the risk of become meaningless if driven by public concerns rather than the fundamental values underlying the planning process:

“While both representative democracies and public involvement in decision making represent systemic acknowledgements that societies consist of different values and

discourses, they also represent a rationalisation of 'the pluralist democracy' that has to be regulated and governed in order to overcome the 'never ending' line of interests and interpretations" (Fischer 2003, p. 158)

In that sense, inasmuch EA is dealt with as a procedural issue at a specific moment in time for the planning, linked with a perception of ex-post approach, there are clear limitations to the potential to enhance the planning process. Elling (2003) express the concern with the instrumental character that is given to EA tools, stating the risk of environmental assessment to become "an instrumental 'tool' that is simply part of a technocratic and expert ruled practice far from the original ideas of involving all democratic parties and legitimate interests in an attempt to avoid unintended environmental damage".

The issue is then to know how to conciliate the engagement and communicative component of EA around the discussions about the values involved in the planning process on the support to better decisions, without having the assessment procedures emptied of meaning. From the information that can be provided by environmental accounting, two phenomena are distinguished by Larrinaga-Gonzalez and Bebbington (2001): organizational change – which considers the power of environmental agenda to change organizations, and; institutional appropriation – that organizations will change the environmental agenda so that their activities do not need to change. In this perspective, environmental assessment is effective when an organizational change occurs. More recently, and also under the communicative component of EA, Sheate and Partidário (2010) focus on knowledge brokerage as one of the main contributes of strategic assessments in planning processes, based on stakeholder dialogues. The authors claim a vital role of knowledge brokerage on decision making as it helps delivering better capacity building. In that sense, they frame the social and communicative capacity of such procedures as facilitators for exchange and transference of existing knowledge among stakeholders, which is particularly relevant at higher levels of decision-making for strategic planning processes.

However these facts regarding the potential of assessment procedures developed at a theoretical level still have some difficulty on being accepted by a wider audience, giving the lack of demonstration and distance to current practice.

Having planning and EA as parallel processes that can learn from each other is a possible point of view but it would be probably more useful to have them integrated as the calling for persuasive planning processes would benefit from the characteristics of any

assessment procedure. In an integrated approach, where the planning process is developed in the dynamics between strategies to achieve a vision and the assessment of the decisions about the necessary action, environmental assessment could communicate and elucidate about the values and powers at stake and necessarily be clear about the identity (position) that the planning process defends.

Meanwhile, the meaning of environmental assessment has evolved. Environmental concerns was a first step in assessment towards sustainability, and currently, in many cases, the expression is being replaced by sustainability assessment (SA) reflecting the increasingly consideration of other, non-environmental, issues.

The efforts on SA were intensified after the Rio summit and the use of the concept grew exponentially from 1994 to 2011 (Bond et al. 2012). The practice towards a sustainable development has led to a diversification of assessment procedures and under the umbrella of SA can be included in at least 17 tools (Sheate 2009). Considering such diversity, opinions are not unanimous on what SA really means (Hacking and Guthrie 2008; Pope et al. 2004), however the importance of the environmental assessment background seems consensual (Bond et al. 2012; Pope et al. 2004; Scrase and Sheate 2002).

Despite the easiness on the use of both concepts in some situations, within technical approaches the reference to one or other type of assessment express distinct meanings. This is particularly relevant as in those contexts the word environment is taken literally. Therefore, an EA in the specific context of energy planning is interpreted as impact assessment of energy projects in the natural environment. On the other hand, within the environmental field, and particularly in development planning, environmental assessment is increasingly related with other sustainability dimensions, detaching from a simple impact assessment and considering the effects at larger scale for policies, plans and programmes (PPP).

There are challenges ahead for SA, distinguished between practical and conceptual ones (Pope 2006), being necessary to understand the full potential of the tool. Bond et al. (2012) recognize that SA is only at the beginning of its development, being expected a broadened practice in the future.

4.4. Strategic Environmental Assessment

Taking into account the comprehensiveness that is necessary in SA and the ability of SEA for integration and to deal with different dimensions, it is possible to understand why authors tend to present it as the main tool for sustainability assessment (Scrase and Sheate 2002; Sheate et al. 2003; Thérivel and Minas 2002). The evolution of SEA has allowed it to be considered a SA tool, especially because it overcomes some of the limitations of the preceding instruments based on EIA. These first tools that were developed for impact assessment are related with a traditional reactive posture at project level, focused on pragmatic decisions, technical and rationally oriented (Partidário 2003). SEA, on the other side, has been increasingly applied at PPP's level, overcoming the challenges to the technical-rational model of appraisal and the positivist forms of policy analysis (Owens et al. 2004) by acting as a "facilitator of strategic decisions, which aims to ensure the integration of environmental issues in a context of sustainability" (Partidário 2006).

At institutional level, SEA is a legal requirement in European countries (EU 2001) and recognized as "contributing to the adoption of innovative solutions more effective and sustainable and the control measures to prevent or reduce significant adverse impacts on the environment that arise from the implementation of the plan or program" (MAOTDR 2007). However, to take SEA as a legal requirement has, sometimes, limited the scope of SEA in its strategic essence by convert it on an instrumental tool acting on an ex-post posture as discussed above.

Being related with higher levels of decision, SEA has been challenged for an approach that can deal with the strong interactions between policy-making and planning, as Lyhne (2011) presented for the Danish energy sector. This is the point that this work also advocates, having a more fruitful use of SEA if applied at an earlier stage, not just for the environmental assessment of the planning of energy systems but as a helper in the development of those plans towards sustainable energy systems.

4.4.1. Different ways of understanding SEA

Having a strategic approach and with an active role on the development of planning processes may be the great ideal of SEA, acting as a sufficiently flexible tool establishing a framework for sustainable decision-making (Partidário 2000), but in practice different versions of SEA are recognized and applied, as it has evolved from traditional impact

assessment. Most authors are unanimous on a fundamental distinction in what regards SEA practice according the way it relates with EIA. Partidário illustrates this situation as SEA moving between two poles, policy development (linked to a planning rationale) and project assessment. When SEA practice is closer to the planning rationale the strategic role of SEA is more evident, while the opposite direction considers an SEA procedure closer to traditional EIA, identifying respectively a decision-centred SEA and an EIA-based SEA (Partidário 2000, 2007b). This perspective is shared by Sadler (2000) that distinguishes SEA between the procedures that have an “impact assessment” track (linked with EIA approaches) and the procedures that have a “policy appraisal” track. Moreover, the OECD uses seven attributes to define such procedures, including the relation established with planning, policy and decision-making processes, the focus on environmental or sustainability aspects, the type of agents involved and the goal of the procedure (OECD 2006). Regarding the space within SEA can be developed and similarly to SA, authors tend to consider SEA as an overarching concept or a family of tools rather than a single technique family (Tetlow and Hanusch 2012).

Despite the effort towards decision-centred SEA’s, practical examples are yet attached to a normative use, which does not promote the integrative role for the improvement of solutions, being the SEA process limited to an informative role (see Box 2).

Box 2 – Example of SEA practice illustrating the difficulty of the process to influence and enhance the decision-making

“However, the Government’s guidance on conducting SEA is clear ‘that it is not the purpose of the SEA to decide the alternative to be chosen for the plan or programme. This is the role of the decision makers who have to make choices on the plan or programme to be adopted. The SEA simply provides information on the relative environmental performance of alternatives, and can make the decision-making process more transparent’.” (Olympic Delivery Authority 2011)

These situations occur most of the time due to a well-defined structure within which SEA is developed (the instrumental version of the tool). In order to overcome the shortcomings of such approaches and to become a comprehensive and strategic tool, SEA needs to be understood as a process (Finnveden et al. 2003; Seht 1999). Such assessment process links with the PPP’s development processes and has the opportunity to change those development processes, as it can integrate in the plans sustainability issues, influencing the choices towards sustainable outcomes (Partidário et al. 2009; Seht 1999).

Considering the previous discussion on the importance of systems thinking and system dynamics for energy planning, SEA can bring into the planning context the dimensions that, although not directly related with the planning object (the energy system), surround and interact with the planning context and therefore need to be accounted to develop integrated and more sustainable options for the planning problem. As Sheate et al. (2003) mentioned, “the role of SEA is dictated by how and where it fits into the decision making process”, which if promoted from the beginning of the planning process it can effectively contribute to the integration amongst planning dimensions, consistency in objectives and improvement of solutions for the decision. Moreover, the analytical tools used by SEA also affect the outcomes, as Finnveden et al. (2003) states in an energy context, where quantitative tools are needed for assessment of alternatives while qualitative results are adequate to more strategic approaches on the critical aspects of alternatives.

Bearing in mind the need to think about energy systems and to attempt a new approach to the planning of sustainable energy systems, which needs to break with the limitations of traditional way of planning. A SEA that relies on a more strategic attitude and less quantitative tools seems to be a valid option to accompany the planning process.

4.4.2. The nexus between SEA and decision-making

It was mentioned above the potential of SEA to enhance sustainable decisions when adopting decision-centred SEA approaches. Even so, there has been some difficulty to transform this potential into a real result of the practice, given the lack of methods considering this purpose (Bardouille 2001, cited in Finnveden et al. 2003). Since the first attempts to define SEA that a strong nexus has been established with the decision-making:

(SEA is) "a systematic, on-going process for evaluating, at the earliest appropriate stage of publicly accountable decision making, the environmental quality, and consequences, of alternative visions and development intentions incorporated in policy, planning, or programme initiatives, ensuring full integration of relevant biophysical, economic, social and political consideration." (Partidário 1999)

The way in which that nexus is established however is not clear. From a long time it has been advocated the importance of critical points in decision-making to ensure the effectiveness of SEA (Partidário 1996) but when SEA is faced as just one other compulsory requirement – usually with an informative role by the production of

environmental reports, to validate decisions, the linkage that could be established between SEA and decision-making is revoked.

If, from one side, having clearly defined an SEA procedure is necessary, as it reminds the decision-makers of the importance to assess options in a larger context, on the other side it can limit the effects of strategy:

"Some level of legal requirement will certainly be necessary at an initial stage, but in a way that does not undermine the necessary flexibility and adaptiveness that the EA of strategic decisions intrinsically requires." (Partidário 1996, p. 45)

Considering the discussion about strategy in decision-making on the previous chapter, namely regarding the importance of creativity as "real strategic change requires inventing new categories, not rearranging old ones" (Mintzberg 1994) SEA can in fact be the accompanying agent that allows to introduce the strategic thinking in the planning processes and, particularly, in the case of sustainable energy systems. Partidário (2000, 2007b) conceptualizes a framework that, answering to the legal requirements, also considers core strategic elements that can in fact influence the decision-making. They allow decision-makers to keep a track of "satellite" issues that, by being considered in the decision processes (in terms of effects or consequences and without the need of being quantitative), help improving the quality of their decisions towards sustainability. Among others, can be distinguished the importance of the objectives (vision), the values and the policy framework. Consensual to this flexible approach required for SEA, M. Nilsson and Dalkmann (2001) add that, given the critiques of rationalism and the limitations of rationality in real decision-making processes, SEA needs in fact to be adaptative and flexible to cope with variations in the decision rationality and so become effective on the support to decision-making.

Further ahead on the nexus of SEA and decisions, Nitz and Brown (2001) introduce the importance on policies and support the influential role that SEA can have, by influencing the decisions that are intrinsic in policy making. Despite the importance of SEA "to inform the decision-maker (...) of the level of consistency in objectives" (Sheate et al. 2003), Kørnøv and Thissen (2000) justify the advocative role that SEA can have by the relations of power established among stakeholders and taking SEA as a stakeholder itself, since it has its own intents of promoting sustainability. Yet, they recognize that "SEA practitioners would prefer to consider themselves as being objective scientists". Regarding this objectivity, many times interpreted as a result of predictive approaches, there is the effort of SEA to be autonomous from quantitative data. Despite the

difficulties posed by high uncertainty associated to less data available, SEA has been increasingly accepted in this perspective, helped by the different perception that professionals have about predictions in a changing world (Partidário 2007a). In the context of SEA, data is associated to the scale and time of decisions:

"Any moment is a good moment to decide on data needs. There are moments of debate and brainstorming, moments of analysis, moments of interaction, moments of decision. In all these moments new data may need to be found, and a decision made on whether the data is really indispensable" (Partidário 2007a, p. 476)

In that sense, the meaning of data in SEA includes "any element that enables you to respond to critical questions and to move on in assisting decision-making by reducing uncertainty" as Partidário (2007a) notes.

Getting back to the idea that SEA needs to be adaptive and flexible, Nitz and Brown (2001) also state that it is SEA that has to fit policy making and not the other way around. Applicable as well to the planning process, this is important to be digested by SEA practitioners since it is strongly related with the learning component necessary for strategy formation and improvement of solutions, as discussed before. Moreover, it is necessary to have an adaptable SEA to each specific planning context and not a rigid tool acting as a panacea independently of the planning cases.

4.5. Review on current energy planning-related SEA

In order to understand how SEA has been applied in energy-related planning processes, a review was carried out. From on-line available databases, twenty-six SEA reports were considered, which were directly related with energy plans.

The analysis of SEA procedures developed in each case considered:

- The classification of SEA type (according to Partidário and Vale 2012);
- The identification of planning dimensions related with the energy planning field: natural resources, territorial aspects, temporal and social concerns and governance;
- Identification of the assessment elements and their function in the assessment procedure.

Furthermore, SEA procedures were classified according to the level of integration between energy and environment, as expressed in Table VII, and the level of improvement brought to the energy planning process as expressed in Table VIII. The results are synthesised in Table IX.

Table VII - Levels of integration regarding Energy-Environmental nexus

Low	Medium	High
The energy measures are evaluated per se, perceiving their impacts generated by the plan and preparing for mitigation	The energy measures are evaluated under the environmental factors legally defined for an assessment of the different alternatives for the plan	The energy goals are considered under different energy related planning dimensions being assessed in a transversal way

Table VIII – Level of improvement according SEA contribution to Energy Planning

New developments (++)	Enhancement of alternatives (+)	No significant changes (0)
After the SEA, new alternatives are considered for the energy planning process	With SEA, energy planning drawbacks are identified allowing the improvement of alternatives	The assessment takes place but no changes on the alternatives occur, only proposing monitoring and mitigation measures

Table IX – Review of energy planning-related SEA procedures according the classification parameters

Note: NR – Natural Resources; Tr – Territorial; S – Social; Te – Temporal; G – Governance

LI – Level of integration; EPI – Energy Planning improvement

SEA Report	SEA Type	Assessment Object	Planning dimensions					Assessment elements		LI	EPI
			NR	Tr	S	Te	G	Type	Function		
Dublin City Sustainable Energy Action Plan 2010 – 2020 (McCormac 2010)	SEA based	Alternatives (scenarios)				x		Environmental Factors	Assessment of scenarios according possible effects	M	0
								Criteria	Assessment of actions for environmental protection objectives		
Vietnam Hydropower Master Plan (Soussan et al. 2009)	EIA based	Alternatives (projects)	x		x			Criteria	Economic evaluation of impacts	L	0
An Energy Policy for Malta (Adi Associates Environmental Consultants Ltd 2011)	SEA based	Policy	x	x	x			Indicators	Assessing impacts on environmental objectives	L	0
Energy National Plan for Dominican Republic (TAU Consultora Ambiental 2010)	SEA based	Plan	x					Indicators	Evaluation of pressure on the environmental factors	M	++
Energy Efficiency Action Plan for Scotland (Scottish Government 2009)	SEA based	Plan			x		x	Environmental Factors	Assess the possible contribution of plan's actions for the goal (energy efficiency)	M	+
Scotland's Climate Change Adaptation Framework (Land Use Consultants 2009)	SEA based	Adaptation Framework						Environmental Factors	Assess effects from the plan's measures	L	+
Renewable Energy Planning Framework for Orkney (David Tyldesley and Associates 2005)	SEA based	Plan framework	x	x	x			Criteria	Assess the effects of renewable energy development on the environmental objectives	M	0
Strategy of the Nuclear Decommissioning Authority – UK (NDA Strategy Consultation 2005)	EIA based	Strategy				x		Environmental Factors	Assess their influence on the nuclear sites, on the long-term	L	0
Electricity Development Programme - Costa Rica (Jiménez et al. 2007)	EIA based	Programme						Criteria	Establish the framework for the impact assessment of the projects	L	0

SEA Report	SEA Type	Assessment Object	Planning dimensions					Assessment elements		LI	EPi
			NR	Tr	S	Te	G	Type	Function		
Hubei Road Network Plan (2002-2020) (SEA Centre 2005)	EIA based	Plan		x				Indicators	Evaluation of impacts for each scenario	L	0
Sustainable Development Programme for the North Region of El Salvador (Albarracin-Jordan 2008)	SEA based	Programme				x	x	Environmental Priorities	Assess effects and propose adjustments	M	0
III Energy Plan – Horizon 2012 – Navarra (EIN SL and Namainsa 2011)	EIA based	Plan		x				Indicators	Evaluation of scenarios	L	0
Renewable Energy Plan 2011-2020 for Spain (Secretaría de Estado de Energía 2011)	EIA based	Plan	x	x	x	x		Indicators	Evaluation of alternatives	M	0
Transport Plan for the London 2012 Olympic and Paralympics Games (Olympic Delivery Authority 2011)	EIA based	Plan						SEA objectives	Assess alternatives considering their contribution to the goals	L	0
Montenegro Energy Strategy (Land Use Consultants 2007)	SEA based	Objectives of the Strategy	x		x	x	x	Sustainability criteria	Assess strategy assumptions and identify conflicts	M	++
								Technical indicators	Assess performance of scenarios and develop alternatives		
Polish Nuclear Program (Szkudlarek 2010)	EIA based	Results of the implementation of the Polish Nuclear Programme						Indicators	Evaluation of impacts	L	0
National Programme for Dams with High Hydroelectric Potential (COBA and PROCESL 2007)	SEA based	Programme	x	x	x			Strategic options	Ranking dams according the goal of strategic option (quantitative or qualitative)	M	+
								Critical Factors	Assess the different strategic options		
National Electric Transmission Grid Investment and Development Plan 2009-2014 (2019) – Portugal (Partidário 2008)	SEA based	Alternatives	x	x				Critical Factors	Assess the different strategic options	M	+

SEA Report	SEA Type	Assessment Object	Planning dimensions					Assessment elements		LI	EPi
			NR	Tr	S	Te	G	Type	Function		
SEA Biofuels Policies, Plans and Programs in Colombia (Lozano 2008)	EIA based	Environmental effects of policies, plans and programmes for biofuels	x	x				Criteria and Indicators	Ranking resources options for biofuels Evaluate impacts from resources' options Development of scenarios	L	0
Fundy Tidal Energy (OER Association 2008)	EIA based	Effects and factors associated with potential marine renewable energy (technology)						Questions and issues	Generate recommendations	L	0
In-Stream Tidal Energy Generation Development (Jones 2008)	EIA based	Tidal in-stream energy technology	x					Public concerns	Generate recommendations	L	0
Hydro Power Plan in the Vu Gia - Thu Bon river basin (ICEM 2008)	EIA based	Hydropower development plan 2006 – 2010 of Quang Nam Province	x		x			Critical Concerns	Assess effects and drive mitigation measures	L	0
Energy Efficiency and microgeneration Strategy for Scotland SEA (Estrata 2007)	EIA based	The Draft Strategy						SEA objectives	Assess environmental effects of each area of influence	L	0
Offshore Renewable Energy Development Plan - Republic of Ireland (METOC 2010)	SEA based	Scenarios of the Plan		x				Criteria and indicators	Select areas of greatest potential for future development	L	0
								Criteria and Indicators	Assess effects from the development of energy projects		
Northern Ireland Offshore Wind and Marine Renewables Strategic Action Plan (METOC 2009)	SEA based	Offshore wind and marine renewable energy developments		x				Criteria and consenting procedures	Identify potential zones where development could occur	L	0
									Assess the potential effects		
SEA UK Offshore Energy (DECC 2009)	EIA based	Draft plan of offshore wind leasing and offshore oil and gas licensing		x				SEA Objectives	Assess the effects of alternatives	L	0

The analysis of Table IX reveals that planning dimensions considered in each report vary considerably, from plans that have almost all dimensions present to plans that do not mention a single dimension. Regarding the assessment procedures, it is verified that assessment elements may vary but the majority relies on criteria and indicators for a final assessment of the plan's options, resulting sometimes on a type of ranking of those options. Finally, it is verified that more than half of the cases reviewed perform an SEA that is based on an EIA logic approach. When that is the case, the level of integration between energy and environment tend to be lower and with no significant changes for the improvement of the plans. The use of an SEA based approach generically contributes for better results, although it does not happen in all cases.

To synthesize the different SEA procedures that were reviewed, two situations are distinguished: when SEA is applied to action plans and when SEA is applied to policies or strategies. In the first case, the assessment tend to be focused on the effects of the measures adopted and risks to fall into an EIA, given the very practical level of the options. In the second case, the assessment is attentive to the potential effects of the guiding lines of plans and strategies, adopting an approach closer to the strategic positioning of SEA. Nevertheless, two different situations were identified regarding the practical results from a strategic SEA:

- a) a situation of environmental accompaniment – when the SEA procedure supports the strategies defined in the plan assessing the potential effects, identifying weaknesses and contributing for the enhancement of the alternatives proposed by the plan;
- b) a situation of development – where the SEA procedure is able to bring new alternatives into considerations, by setting a strategic framework for the assessment.

From the review of these energy-related assessment procedures, it was possible to draw the following points:

- SEA reports can vary substantially, from an EIA base (more exhaustive) to the SEA base (more succinct);
- A SEA based approach does not assures a higher level of integration, principally if it follows a strict interpretation of SEA directive, with a compartmented approach by environmental factor;

- The object of assessment reveals great importance for the development of SEA procedure, as it conditions the scope of the assessment. For instance, it is different to assess alternatives for a plan, which are more flexible to enhancement, or the plan itself, more rigid and with less flexibility for strategic changes.

4.6. Summary

To introduce in a conscious way some kind of assessment in planning processes implies to understand how assessment procedures have evolved. In the context of this research, that includes the evolution from environmental assessment to sustainability assessment and the need to adapt existing instruments, as SEA, to transform its potential into practical action.

The role of SEA has been interpreted and applied in very distinct ways, but when considering its strategic component, it starts to be clear a tendency to face such procedures as integral part to the decision and planning process and furthermore, to reject the innocuous function of informing to adopt a much more advocative role.

Integration, claimed as necessary for sustainability, can produce inaction when incorporates diverging interests, but by focusing on values it is expected from SEA to increase the quality of alternative visions and the development of perspectives for (energy) plans that will serve as framework to future (energy) projects.

The contributions that are expected from the application of SEA in energy planning processes can be summarizing as:

- Introducing a holistic approach to the planning process;
- Acting as magnifying lens that allow energy planning to look in different directions, search for new hypothesis to be explored and increase the insights necessary for the decision making;
- Structuring a framework of the involved dimensions, vision and goals, and accompany the planning process, standing up for the operationalization of comprehensive/enhanced planning solutions.

Yet, there are challenges to overcome in the practice of decision-based SEA, namely regarding the balance between qualitative and quantitative requirements to perform the assessment. These requirements however cannot be seen as opposites or contradictory, rather they help to keep in mind the different arenas in which SEA can be performed. Similarly to the notion of un-order (Kurtz and Snowden 2003), it allows to consider a larger space of development for SEA, facilitating a critical approach to complex contexts.

It is then expected that SEA can contribute to the new energy paradigm, supported by its strategic component, identifying and taking advantage of windows of opportunity for the development of case-specific solutions that can assure the adequacy between endogenous resources and energy consumption, in a logic of decentralization, proximity and self-sufficiency.

5. Defining conceptual guidelines for a new approach to the planning of energy systems

Being noticed the importance of having an enhanced energy planning process towards sustainability, with tangible implications such as becoming a more integrative process (meaning considering the different energy related dimensions) and aimed at a better matching between the different parts of the energy system, this chapter first presents a review on current practices for sustainable energy systems and afterwards proposes an enhanced energy planning process considering the lessons learnt.

5.1. Reference cases on best practices for sustainable energy systems

Preparing the transition towards sustainable energy systems implies a previous knowledge of current practices, in order to understand what are the best practices and lessons learnt for future developments.

For this section, a number of plans and projects related with energy transition (and with a particular effort to find it for isolated systems) was collected and analysed, to set some guidelines regarding the best available practices, always considering the focus on natural renewable energy resources.

5.1.1. The technological focus

At a first level, it is important to systematize the available technologies for energy systems based on renewable energy resources². The natural resources considered are the sun, wind, water, geothermal, biomass and biofuels. To help on that systematization, a review on conversion technologies by natural renewable energy resource was conducted. Despite not exhaustive, the main purpose is to give some insights about their

² The focus is on natural renewable energy resources based on the assumption that they represent the future of sustainable energy systems. In that sense, technological development on fossil fuels or nuclear are not approached in this work. However, there is not the intention of withdraw the importance of such developments as they can represent, during a transition period, improvements towards sustainability, on the current energy systems.

performance in different aspects, such as the supply-demand relationship, the performance on the use of the natural resources and the business model.

Sun

- Photovoltaic (PV)

Photovoltaic conversion consists on the conversion of radiant energy from sun into electrical energy. It is a direct conversion of sunlight, where PV cells convert solar energy into electricity. The unit of such technology is the PV cell that uses semiconductor materials and are interconnected to form the PV module. It is based on these cells that PV technology can be distinguished, being available different types of PV cells. Single crystalline silicon and multi-crystalline silicon are the most common technology, representing 85 to 90% of the PV market while thin film PV cells represent 10 to 15% and recent trends show that PV has registered an average annual growth rate of 40% over the last decade (Hearps and McConnell, 2011). With this trend, it is expect a cost reduction over time, with increased production capacities, improved supply chains and economies of scale (see Figure 6). However, other factors can soften prices reductions, such as the need of storage.

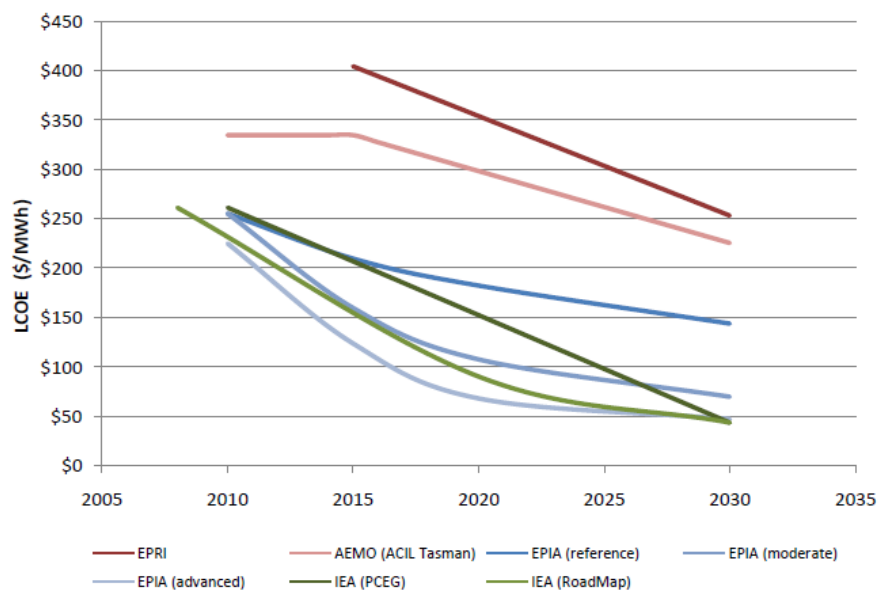


Figure 6 – Cost projections for PV electricity (LCOE) for a Direct Normal Irradiation of 2445 kWh/m²/yr (Hearps and McConnell, 2011)

PV technology have evolved from first generation (crystalline silicon cells), second generation (thin-films solar cells) and third-generation technology, which includes four

emerging types: Concentrating PV (CPV); Dye-sensitized solar cells (DSSC); Organic solar cells; and Novel and emerging solar cell concepts (IRENA, 2012a). This evolution has given PV high flexibility on its supply-demand relationship, being applied at residential level for direct supply of electricity needs or at utility scale, for distribution and commercialization of electricity, with direct implications on business models (individual investments or corporate business model).

The type of technology within PV options has also different expression on the use of the natural resources. Here, more than its technological efficiency (see Table X) which major consequences are on the payback of the investment, some attention needs to be given to land-use, once that it is always necessary to have available an implementation area. That can be less important at residential level, where module areas are small and rooftops can be a solution. However, when considering a utility scale, the territorial expression can be significant and other implications need to be accounted, such as conflicts with the agricultural system, geological resources or other natural assets.

Table X - Comparison on the characteristics of PV technologies (adapted from IRENA 2012)

	Units	1st Generation	2nd Generation	3rd Generation
Commercial PV Module efficiency	%	15 – 19	5 – 11	1 – 30
Confirmed solar cell efficiency	%	14 – 24	6 – 12	8.3 – 41
Area needed per kW	m ²	1 – 8	10 – 15	-
State of commercialisation	-	Mature with large scale production	Early deployment phase, with medium scale production	R&D phase or just commercialised at small-scale production

Note: Values at Standard Testing Conditions, temperature 25°C, light intensity 1000W/m², air mass 1.5

- Solar Thermal

Thermal energy from sun has been used since ever by humankind for heating or acclimatization purposes. Nowadays, the thermal potential from sun is being explored on two sides: directly for heating and acclimatization (e.g. using solar thermal storage or passive acclimatization systems) but also in parallel with PV to supply electricity, by concentrating solar power (CSP) technology.

Passive acclimatization systems are commonly present on building techniques and have as major objective to minimize energy consumption for heating or cooling indoor environments. Despite not directly comparable with other types of technology, they need to be seen as an important instrument on the supply-demand relationship about the use of energy, as they allow important savings and efficiencies on energy services related with heating or cooling the buildings. They therefore have a relevant role on natural

resources by way of energy savings (or negawatts), alleviating the pressure on natural renewable energy resources. This concept has been explored under the term of Solar-Active-House solutions, where the contribution of solar energy fraction is increasingly higher, making possible to meet more than 50% of a house heating and cooling needs.

Solar thermal storage has become a mature technology in what regards the sensible heat storage, having water as the usual option of storage³. The major effort currently is to develop combined systems to maximize the possibilities of this heat storage. In that sense, several alternatives are already explored, such as domestic hot waters combined with building heating systems (Solar-Combi-Systems) or large hot water tanks used for seasonal storage of solar thermal heat in combination with small district heating systems (IEA-ETSAP and IRENA 2013).

In terms of supply-demand relationship, this type of technology allows a response at the level of energy service for heating purposes, representing a shorter energy chain from primary to final energy and it is easily decentralized. Moreover, by being a system of energy storage, it can help managing the energy system by balancing energy demand and supply, reducing some peak demand and energy costs. In what regards the use of natural resources, and similarly to PV technology, solar thermal technology represents low impact on environment as it is more appropriate to respond to heating human needs on a built environment and therefore, most of the time, does not require other than the built areas. This type of distribution, highly dispersed according to the end-use location, contributes for a business model focused on the commercialization of the technology at the end-user, which traditionally means a high number of installed units of small or medium capacity. Table XI summarizes some major characteristics of available technologies for domestic hot waters.

Table XI - Comparison on the characteristics of PV technologies (based in ESTTP 2012 and BSC 2002)

Technology	Area (m ²)	Storage capacity (L)	Efficiency (%)
Solar thermal DHW systems (thermosiphon)	2-3	150	50-60
Solar thermal DHW systems (forced circulation)	4 – 6	300	60
Combi-systems (DHW and space heating)	10-15	600-1000	60-70

³ There are other means of thermal energy storage particularly important for electricity storage, but at this point the focus is on technology for heating purposes. In what regards the conversion to electricity, such theme is approached at concentrating solar power (CSP).

In terms of energy costs, the price of heat from solar technologies is, most of the times, competitive when compared with the fossil fuels alternatives, as shown in Figure 7.

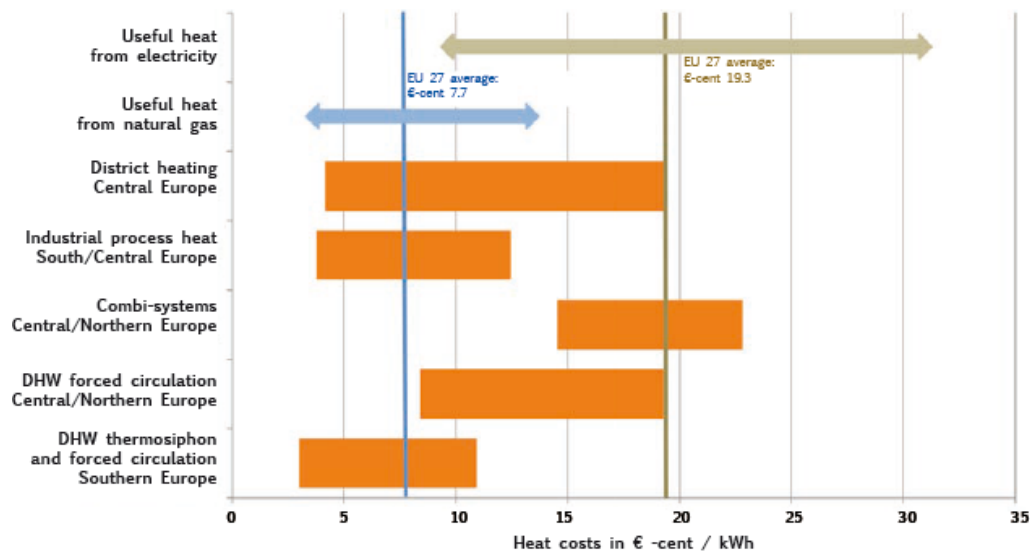


Figure 7 – Heat costs by type of solar thermal technology (ESTTP 2012)

In what regards the use of solar thermal energy for other purposes, it shall be considered also the use of solar thermal technologies for process heat systems necessary in agriculture or industry. Depending on the level of heat required, there are available adequate solar technology to provide low (<50°C), medium (50°C - 95°C) or high (> 120°C) temperature process heat, being an important contribute for a renewable supply on others than domestic uses.

Despite the importance of sun for heating purposes, lately, the main developments on solar thermal have being related with CSP technology, for electrical conversion. The basics of a CSP facility consists on the concentration of sun heat at very high temperatures. Two main ways are used to do so: using a number of mirrors that reflect the solar radiation to a central receiving tower (with heat storage) or using a parabolic trough plant (with or without thermal energy storage). By having superheated water and through a Rankine cycle, on conventional steam turbines generations, conversion to electricity is obtained (Hearps and McConnell, 2011).

Even though less mature than other solar technologies, this type of facilities have being implemented commercially since 2011. By its characteristics, this solution contributes for a centralized supply model, responding to a large scale demand and therefore representing a corporate business model on electricity conversion and distribution.

The different available technologies (parabolic through plant or solar tower) represent different performances and price structures, as expressed in Table XII.

Table XII – Capacity factor and Levelized Cost of Electricity (LCOE) according the different types of CSP technologies (adapted from IRENA 2012b)

Technology	Capacity factor (%)	LCOE (2010 USD/kWh)
Parabolic trough without storage	20 – 25	0.14 – 0.36
Parabolic trough with storage (6h)	40 – 53	
Solar tower (6 to 7.5 hours storage)	40 – 45	0.17 – 0.29
Solar tower (12 to 15 hours storage)	65 – 80	

Note: LCOE assumes a 10% cost of capital

Wind

Wind turbines are the basic unit of technology used to explore wind for energy purposes. Several variables affect the efficiency of this technology, being the most relevant the height of the tower, the wind velocity and the length of the blades. The rotation of the blades drive a generator, for the conversion to electricity. There are different wind turbine and wind farm designs, expressing different impact on the supply-demand relationship, energy and environmental performance and business model.

When considering onshore or offshore wind farms is assumed a large scale, centralized model of wind power generation. As any centralized model, there is a longer chain between supply and demand and the system is less flexible in what regards the response to the required energy service (electricity as final energy will be used for distinct energy services that can be others than the electricity specific ones). The implementation of wind farms tends to be controversial, environmentally and socially, as it raises issues related with acceptance at local level and loss of some social-environmental values (landscape value and avifauna mortality are the most usual aspects mentioned when considering new wind farms). Nevertheless, wind power has being one of the most important contributions for a more renewable electricity mix, which has contributed for better consensus about its use. In terms of energy performance, the technology remains a key driver, with direct implications on efficiency and cost of energy. One of the main challenges is to deal with the intermittence of this natural resource, but the developments on prediction and management models are trying to minimize the negative consequences of such characteristic. These type of options (large scale wind farms) are based on a corporate business model, considering the commercialization of energy to the grid. The main characteristics of onshore and offshore technologies are expressed in Table XIII.

Table XIII – Capacity factor and Levelized Cost of Electricity (LCOE) for wind farms (adapted from IRENA 2012c)

Technology	Capacity factor (%)	LCOE (2010 USD/kWh)
Onshore wind farms	20 – 45	0.06 – 0.11
Offshore wind farms	40 – 50	0.14 – 0.19

Note: LCOE assumes a 10% cost of capital

At a different scale, small wind technology (< 100 kW), is a less used option but it represents an alternative to centralized wind farms. In that sense, it is particularly relevant to off-grid contexts, enabling an *in situ* conversion and consumption. The main drawback is the cost of electricity comparatively to the centralized model.

Water

Based on the water cycle, and particularly on the natural movement of water courses, this resource is used since ancient times to provide energy to human activities. The first type of technology was based on the transference of kinetic energy, to provide motion. This fact is mentioned only to state the importance of water to provide other type of energy than electricity. Of course water has being used on the modern age to provide energy by using hydropower technology. It is one of the oldest sources of electricity, and as such it presents some of the most mature technologies.

The types of hydropower applications are generically defined according their installed capacity, being classified as large-hydro (>100 MW), medium-hydro (20 – 100 MW), small-hydro (1 – 20 MW) and even mini, micro or pico-hydro, these ones varying from 1 MW to just a few hundred watts (IRENA 2012d). The hydropower technologies are also classified according the existence of water reservoir or lack of it (run-of-river technologies) and, for the first case, with or without pumping system.

All these possibilities represent distinct supply-demand relationships. Large and medium hydropower systems (with or without pumping systems) are used to supply the electricity grid and therefore feed a centralized model, focused on deliver a type of final energy rather than a specific energy service (that means a type of energy that can be adequate or not to the required energy services). On the other hand, micro or pico hydropower systems are implemented using a decentralized rational, usually for isolated contexts, enabling a better matching with the energy service required by the demand.

Small and mini hydropower systems, giving their intermediate dimension, can support both a centralized or decentralized model, with different consequences on the supply-demand relationship.

Hydropower systems are very effective systems, particularly the large-hydro or medium-hydro with an important role on grid management as one of the key-advantages is its enormous "load following" capability, meaning that it can meet load fluctuations minute-by-minute. Despite this important advantage, projects related with hydropower also have important drawbacks related with sustainability, once they strongly interfere with land-use, due to large flooding areas (for water reservoirs), with strong consequences for the social-environmental system.

Giving the great variety of options regarding hydropower systems, the business models differs according a centralized or decentralized energy model. Large projects usually can be more competitive in terms of cost of energy, while small, decentralized projects tend to present higher energy costs. Table XIV summarizes some characteristics of hydropower technologies.

Table XIV – Capacity factor and Levelized Cost of Electricity (LCOE) for hydropower systems (adapted from IRENA 2012d)

Type of hydropower system	Capacity factor (%)	LCOE (2010 USD/kWh)
Large-hydro	25 – 90	0.02 – 0.19
Small-hydro	20 – 95	0.02 – 0.10
Pico-hydro	20 – 95	>0.27

Note: LCOE assumes a 10% cost of capital

Most recently seen as an energy resource, the ocean has gained importance as a contributor to the energy system. Marine renewable energy (MRE) technologies have been developed and tested to explore this resource, with significant progress in recent years, namely wave and tidal stream energy technologies. However, they have not yet being applied at commercial level (until now, full scale prototypes have being tested and plans for implementation are being developed). Important information have been developed to support policy makers (see CPMR 2013 and SI OCEAN 2013). Summing to an initial, immature state of these technologies, significant constraints are reported on MRE installation related with environmental, legal and other barriers (CPMR 2013). A preliminary cost projection for these types of technology are summarized in Table XV.

Table XV –Levelized Cost of Electricity (LCOE) for marine technologies (based on SI OCEAN 2013)

Technology	LCOE (€/kWh) (early array costs)
Tidal	0.23 – 0.48
Wave	0.32 – 0.62

Biomass

Being a renewable energy resource, biomass includes any type of organic matter which are available on a renewable basis. The most usual types of biomass for energy purposes are wood, agricultural crops, organic wastes and manure. Biofuels are included as a specific type of energy resource from biomass as they represent liquid and gaseous forms resulting from biomass. While solid biomass resources can be used for electricity conversion or thermal purposes, biofuels have a more specific application, particularly in the transportation sector⁴.

Biomass is pointed out as “the most versatile of renewable energy sources” (IRENA 2013a), being a highly disperse resource. This versatility explains the different relationships between supply and demand or business models that can be found for bioenergy.

The sustainability on the use of biomass for energy purposes, however, tends to be questioned as some type of uses lack efficiency and can have negative effects both on environmental and social systems (biodiversity, land-use and competition with food production or even human health), which alerts for a careful planning of biomass energy resources.

When considering biomass for thermal purposes (usually to provide heat for acclimatization although, depending of some contexts, for cooking as well), is possible to have a closer relationship between supply and demand as the use of the resource can be direct as is the case of wood for fireplaces. However, depending on the heating technology, the resource may have different transformation degrees, increasing the distance between supply and demand, as is the case of pellets for end-use or even biomass district heating. Different, and more complex, business models accompany these types of supply-demand relationships, from the simple commercialization of wood or pellets for a very decentralized consumption, to a complete conversion and distribution systems, where the level of centralization increases.

⁴ Considering that the main use of biofuels is on the transportation sector, complementary to fossil fuels, they are not further developed at this point.

Electricity conversion represent a longer chain between supply and demand on the use of biomass for energy and have a particular concern with the transport of biomass to the conversion places, which have an important role on the economic feasibility of some options. Nevertheless, relationship between supply and demand and the level of centralization will depend strongly on the type and dimension of conversion units, which translate in different costs of energy as presented in Figure 8.

Regarding the high versatility of biomass, it is also relevant to call the attention to its potential for combined heat and power systems, which can contribute to increase the efficiency on the use of these types of resources.

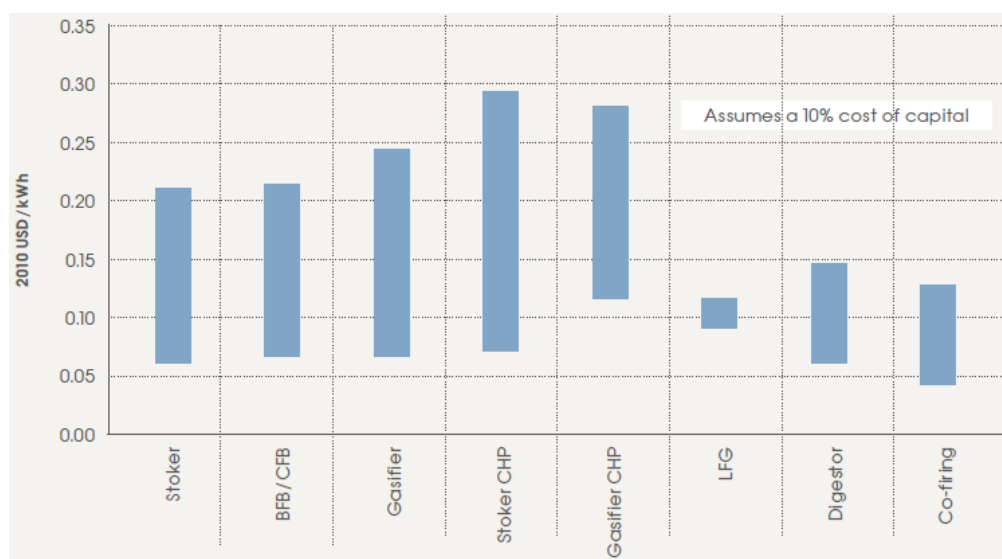


Figure 8 – Levelized Cost of Electricity for biomass power generation technologies (in IRENA 2012e)

Geothermal

The natural heat available from the Earth's interior is a resource with energy potential that can be used as alternative to fossil fuels. Geothermal energy consists of the thermal energy stored in the Earth's crust, distributed between the constituent host rock and the natural fluid that is contained in its fractures and pores at temperatures above ambient levels (Geothermal Program 2006). Depending on the fluid and temperature, this energy can be used either to provide heat or electricity to the demand.

Extensive work has been developed about geothermal (see IEA 2012b, Geothermal Program 2006), regarding its developments, contributions for the global energy system and possible environmental impacts, as this is seen as one of the important energy

resources of the future. At this point, however, just a brief overview about geothermal is given to understand the role it can have for energy systems. In that sense, two levels of geothermal are distinguished – high temperature geothermal, which is available on specific sites associated with a more intense geological activity; and low temperature geothermal, with a higher geographic dispersion.

At high temperatures, geothermal is usually considered for electricity, supporting a centralized model. This means that conversion and consumption occur separately, in a longer supply-demand chain, which can result in a final energy less adequate to the required energy service. This type of model also implies infrastructures for electricity conversion and distribution designed under a corporate business model. The levelized cost of electricity in these cases can vary between USD 0.03/kWh and USD 0.10/kWh, but depending on some capacity factors lower than expected, these costs can attain USD 0.14/kWh (IRENA 2013b).

At low temperatures, geothermal sites tend to be exploited on a small scale, and mainly for heating purposes. For instance, greenhouses heating or hot water to spa buildings are some of the main uses of this resource in the Mediterranean area (Guzman and Marquez 2005). Even the thermal gradient of soil can be used as a source of heat, with the use of heat pumps. This high dispersion allows a high decentralization in what regards the use of low temperature geothermal, which supports a closer relationship between supply and demand, promoting the energy service (heating) rather than a final energy at end-use.

5.1.2. Understanding renewable energy options on islands' action plans

Knowing the potential of the different renewable energy resources according the available technologies for its use and exploitation, it is also necessary to have a better comprehension about the way they can be combined in order to design a reliable renewable energy system.

Given the scope of this work, where the focus is on islands, as they represent isolated energy systems, more effort was put on the study of energy plans for islands. At this level, the European Union has developed the Isle Pact Program (2009-2012), which evolved at a second stage to the SMILGOV program, with the objective of implementing sustainable energy plans in islands by addressing multilevel governance issues. Several sustainable energy action plans (SEAP's) were developed, for the islands within the Isle Pact Program, which constitute a good resource to understand how the renewable energy

options are being considered on energy planning processes. In order to diversify the analysis, were also considered other energy plans for islands out of European context.

A great concern on islands, given their isolated context, is the need to assure complementarity among energy resources to provide energy without major restrictions. On Table XVI are presented some energy plans for islands, having as object of analysis the renewable energy resources considered for supply, the overall energy scenario chosen for the island (at project level) and specific actions considered at demand-side level that can contribute for sustainable energy systems.

Table XVI – Resume-table on the benchmark of some energy plans for islands, considering the renewable energy resources to explore, the energy options to supply the energy systems and energy demand's role in the evolution of the energy system.

	Renewable Energy Resources	Proposed Energy scenario (supply options for the energy system)	Energy Demand Role
Sustainable Energy Action Plan of Madeira Island (Madeira ISEAP 2012)	Water Wind Sun Biomass Geothermal Ocean -	- Hydro-storage, hydroelectric plants and reversible hydroelectric plants. - Wind farms and micro and mini production regimes - Solar photovoltaic parks and micro and mini production regimes. - Biofuels production (solid, liquefied and gaseous) from plants, agricultural biomass, from livestock farms and selected waste. - Installation of an induced geothermal pilot power plant. - Installation of wave energy power plants. - Adopting CHP, using the waste heat from electricity production.	Increasing energy efficiency: - More efficient practices (citizens); - Acquisition of better energy performance's equipment and systems. 64% of the investments to be carried out are in the hands of citizens or private companies and organizations.
Island Sustainable Energy Action Plan of Samso (Samso ISEAP 2011)	Wind Sun Biomass -	- Increase the number of private wind turbines and replace stepwise land- and offshore wind turbines with new and more efficient ones - Expansion of PV solar and heating with solar collectors - Biogas plant run on manure, energy crops and organic waste - Expand the net of district heating to more homes - Heating with oil gradually replaced (with heat pumps, solar collectors and biomass) - Fossil fuels phased out until 2030	Technological shift: - Heat pumps, private solar collectors and PV; - Local fleet of cars becoming electric (50%) Efficient consumption: - Heat; - Power.
Energy Action Plan of Mariana Islands (Conrad and Ness 2013)	Not considered	- Installing one waste-to-energy power plant (1 MW), using island's residues	Demand-side management program (utility, residential, and commercial sectors) Energy conservation in government agencies and businesses

	Renewable Energy Resources	Proposed Energy scenario (supply options for the energy system)	Energy Demand Role
Guernsey Energy Resource Plan (Guernsey ERP 2011)	-	Promote small scale renewable power (not specified) and ensure that Guernsey Electricity is able to deviate from the merit order (electricity imported by the cable link with France) to facilitate the supply of low carbon and renewable energy.	Using energy wisely and efficiently, at individual or community level and encourage energy conservation and the use of high efficiency and low carbon energy technologies.
The Cook Islands Renewable Energy Chart Implementation Plan (Cook IRECIP 2012)	Sun Wind Biomass	Solar PV with battery storage (all 12 islands) Wind Mini Grid with battery storage (2/12 islands) Biomass and waste to Energy Network (1/12 islands)	No designated actions for energy demand side.

These five energy plans are, for sure, a small sample. They, however, represent the diversification that can be found when considering islands and therefore to distinguish some important features to take into consideration:

- There are islands with a considerable number of inhabitants and there are very low populated islands. That translates into more or less complex energy systems. This is particularly visible in the case of The Cook Islands, where complexity of the energy systems increases from just solar PV with battery storage in the smaller islands to solar PV plus wind minigrid and biomass and waste to energy network in the biggest island. And when considering Madeira island, is possible to notice a rather complex energy system, where six different energy resources are considered and the energy scenario includes seven different options (without considering the remaining solutions based on fossil fuels). Of course there is a limitation to the complexity of the energy system, which does not depends only on the dimension and energy demand on the island, but also on the available renewable energy resources. And one of the factors that most contributes to that availability of resources is the geographic location of the islands.
- Despite all islands translate the common concern with a higher independence from fossil fuels, the option of using renewable resources is not clear. At this point it may be particularly important the existing policies and legal frameworks. From the cases analysed above, it is possible to observe that European islands of Madeira and Samso translate a greater

concern with the exploitation of renewables than, for instance, the Mariana's that considers a reduction on fossil fuels by using the wastes produced in the island. However, this can be not enough to assure an effective turn towards renewables; as

- The distance to mainland conditions the type of evolution for the energy system. The vast majority of island is distant enough from mainland, so that isolated energy systems need to be developed. Nevertheless, some islands are not so distant, which allows them to establish interconnections with the mainland energy system. This type of cases is illustrated by the Guernsey island, which despite being on the European context does not considers immediate action on the use of renewable energy resources, as it shares a grid connection with France, and is therefore dependent from the energy mix from the grid.

Finally, a shared concern to all plans that consider isolated energy systems is also the reliability of the energy system. When depending on renewables, which tend to be unpredictable in the medium/long-term, the management of the energy system more difficult.

The solutions to these concerns are, usually, the combination between complementary resources and/or energy storage. A common example of complementarity between renewable resources is wind and solar PV power. However, this type of solution is never 100% secure, because days of no sun and no wind are possible to occur. Energy storage is then more reliable, once that it represents a reserve of energy that can become available at any time. Great research has being applied on battery technologies and particularly hydrogen fuel cells, have being pointed out in many cases as important solutions to overcome some limitations in isolated energy systems (Krajacic *et al* 2009). These solutions however, need to be assessed in terms of life-cycle, and some of the chemicals and residues used on these technologies are dangerous and can have important negative impacts (water contamination with heavy metals is one of the most usual). Moreover, there is always a loss of energy associated to the efficiency of the batteries or fuel cells.

One other solution that can be more interesting on the scope of this work is the use of water as energy storage. Bélanger et Gagnon (2002) state that, to face high variation on energy production, other transformation facilities are necessary, working as backup and able to increase or decrease production very quickly. Hydropower is the most

probable possibility to assure the electrical service in these cases, especially when has reversible capacity that allows to absorb electricity fluctuations, once that is the most flexible type of facility.

The basic idea is to use exceeding electricity from intermittent renewables to pumping water from a lower to a higher water reservoir. By maintaining the water level at the higher reservoir, it is assured an energy storage that can be used to respond to peak needs. For instance, in Portugal, this type of option has been a strategy regarding wind power facilities, once that the major wind production occurs during the night (better wind velocities), and the needs for electricity are low (Carlos 2007).

The analysis of the previous plans also allowed for a comparison on the different energy planning processes. In short, it is possible to state that all the plans consider, with more or less detail, three major parts:

- a) A first part related with the strategy, which includes contents such the vision for the future of the energy system, the mission and the major objectives/targets to attain.
- b) A second part related with energy modelling, which includes the characterization of the current energy system (the baseline situation) and the projection of energy scenarios (typically two scenarios – the business as usual and the proposed alternative).
- c) A third part, related with the integration of other aspects such as stakeholders involvement, financing and monitoring.

In what regards the first part, about strategy and goals, it can be noted that energy plans for islands translate commonly a great concern with the independency of the energy system (or, as stated in Madeira's ISEAP, "reduce independency from abroad"), the energy efficiency and CO₂ emissions (and therefore introducing the focus on endogenous and renewable energy resources).

Regarding the energy modelling process, the way-of-doing stated on the most developed plans (those that consider more complex energy systems) generically follow a similar structure to the one presented by the RenewIslands methodology (Duic *et al* 2008), where there is a mapping of the needs and resources, creation of scenarios to use the available resources to cover the energy needs and the modelling of the energy system according those options.

On a final consideration, regarding the integration of other aspects important to the implementation of energy action plans, it is noticed that usually this integration is translated by a description about the way the different issues can be or need to be present to the fulfilment of the energy plan. Nevertheless, a different type of integration can be considered, understanding integration as an inclusion of boundary issues to the energy system along the energy planning process.

5.1.3. Other learnings from energy plans and programs on energy transition

Although the focus on islands, learning from experiences on other geographic contexts can contribute to address the underlying concern with the energy transition towards sustainable energy systems.

Some feedback at European level show that the main challenges are related with the coherence of energy networks and infrastructure giving the increasing decentralisation of energy production, the adaptive capacity at the local level to cope with the changes to the energy system and the evolution of roles on energy systems' players towards a greater proximity between consumers and producers, where demand and supply are "all potential 'prosumers' of energy" (McGowan 2014).

Such challenges have inherent barriers or difficulties that impede or delay action towards transition. From practice, they have been identified and systematized in order to be understood and overpassed. Table XVII synthetises such difficulties according major themes.

Table XVII – Barriers/difficulties for an energy transition, by theme

Theme	Barriers/Difficulties
Policy	Policy conflicts, when diverging energy interests and goals are reflected at same local level. (McGowan 2014)
	Policy stagnation, when goals are not accomplish or their realization takes more time than expected. (Leeuw 2014)
	Policy uncertainty, when the development of relevant policy and regulations is not clear, inhibiting the implementation of energy measures. (McKinsey and Siemens 2013)
Participation	Resistance from institutional framework towards transition in general. (Leeuw 2014)
	Lack of communication and familiarity, where the different stakeholders (decision maker, investors, consumers) are not aware of the benefits from specific actions towards transition or have no interest in implementing it (do not value the measure's potential). (McGowan 2014; McKinsey and Siemens 2013)
	Lack of acceptance, when measures represent a direct or indirect impact on third parties, resulting into resistance those who are affected. (McKinsey and Siemens 2013)
Knowledge	Deficient professional expertise, conducting to an incomplete implementation of measures/actions (McKinsey and Siemens 2013)
	Incipient development of the measures, with implicit cost reduction in the future (McKinsey and Siemens 2013)

Theme	Barriers/Difficulties
Finance	Economic unattractive measures, due to low/inexistent economic benefits or long amortization periods for investors. (McKinsey and Siemens 2013)
	High costs and risks, associated to the process chain (information, planning, coordination, and decision making processes). (McKinsey and Siemens 2013)
	Lack of capital for implementation, despite the attractiveness of action/measure and the interest of the investor. (McKinsey and Siemens 2013)

The recognition and characterization of these hurdles for the execution of plans and programs for energy transition is only a necessary stage that allows to call the attention to the possible solutions and search for practical aspects to overcome such difficulties and implement the plans. Moreover, some important lessons were already learnt from practice, about factors for success on energy transition. Table XVIII compiles some of the most recurrent factors pointed out as needed for success.

Table XVIII – Factors for success in energy transition, by theme

Theme	Factor for success
Policy	Thinking about the long term, both in terms of vision and impacts, to create certainty, consistency and stability when addressing energy structural issues. (McGowan 2014, Ecofys 2013)
	Having a national policy framework, organised in packages and well-articulated, as complex issues cannot be addressed with single policies. (Fangmeier 2012, Ecofys 2013)
	Permanent institutions that can ensure continuity and “consensus building amongst stakeholders, translation of the vision into medium term strategies and monitoring of progress”. (Ecofys 2013)
Participation	Encourage cooperation, both internally or transnational, as it contributes for success on energy transition through the learning process. (McGowan 2014, Ecofys 2013)
	Promote transparency and communication of information to all parts involved in the process, to overcome problems and points of criticism. (Wüste and Schmuck 2012)
	Sense of ownership, bringing together different groups by sharing results. This allows consensus building and involves people towards the (McGowan 2014, Ecofys 2013)
Knowledge	Having available technologies and motivated people informed and capable of using and adapt it according the available renewable resources. (Fangmeier 2012)
	Visibility and accessibility of pilot projects for “learning effects” (Wüste and Schmuck 2012), with clear focus on the necessary activities for results while maintaining the necessary flexibility for adequacy (McGowan 2014)
Finance	The importance of “price fluctuations on the global market as supporting factors” for the acceptance of a new vision and energy transition. (Wüste and Schmuck 2012)

An illustration of these factors of success is the practical case of the Bioenergy Village Jühnde. This village, nowadays aimed at 100% renewable energy, began the transition in 2001 and the implementation lasted for almost four years. The energy production started at the end of 2005 and after seven years of experience the results were expressive in what regards an integrated approach to the region, namely (according Fangmeier 2012):

- About 5 million kWh of electricity produced per year;

- Heat supply for the village through the cooperative, that counts with a 70% participation of the people;
- Reduction of approximately 60% CO₂ emissions;
- An economy operating with approximately € 1.3 million turnover and where 80% of revenues remain in the region;
- A pilot project with many visitors.

Giving the characteristics of the village, where 61.5% of the fields were of wood production, the bid was on the use of biomass for heating and electricity supply. Despite the use of a single resource, the project clarified the importance of having an integrated process in a strategy for energy.

At a policy level, the national policies have evolve in a way that confirmed the option for the village, namely on the feed-in tariffs for biomass, which allowed to implement with more certainty the project, as well as, later on, the objective of increasing the share of renewables in electricity supply. The project also had the ability to set together the community around common energy and environmental goals. The efforts on participation and knowledge areas resulted in the build of a cooperative society responsible for the investments and the biomass business.

This pilot project has been used as an example to inspire other regions to become self-sustained communities, particularly in Germany (the European Network of Self-Sustained Communities counts with four German communities), which calls the attention to the importance of having plans adaptable to local contexts.

The challenges, difficulties and factors of success presented above, give important contributions for the development of an integrated energy planning. From practical cases, is stated that energy transition is possible and that the overall system (energy but also social and economic systems) can be self-organized towards a common goal, so is a fact that it can result. Nevertheless, to do so, planners and persons responsible for the development and implementation of such plans or programs need to be aware of all the dimensions involved in the planning process, such as the policy agenda, the participation and communication about the process in the covered territory, the available knowledge and expertise for the necessary interventions or the financial and economic conditions that can affect investments, as all these dimensions can affect positively or negatively the energy planning process.

5.2. Proposing an integrated energy planning process

Based on the final considerations of the previous review, an effort is made to approach a possible integrated energy planning process. It is taking into account the need to move beyond a straightforward process with well-defined technical actions in order to start tackling the complexity that characterizes energy systems. This includes considering in the same process moments of exploitation of strategies, integration of different goals and objectives, moments of decision and of technical planning, assuring this way the integrative role pursued for the energy planning process.

5.2.1. An enhanced energy planning process

The focus is given on the importance of having a strategic attitude and to consider it in particular decision moments. The strategic intent, as presented by Hamel and Prahalad (1989), can contribute to the planning of sustainable energy systems (SES) when a vision of the future is developed based on the new energy paradigm. This way, SES acts as the driver of the energy planning process pulling the energy system towards that vision, as schematically represented in Figure 9.

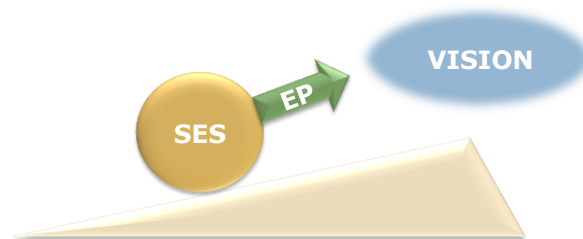


Figure 9 – Vision acting as driving force for the energy planning process

Moreover, contributions from critical theory in planning and decision-making as explored by Kurtz and Snowden (2003) and Innes and Booher (2010) promote the necessary strategic thinking dimension for the strategic planning process in the energy context, allowing for creativity and emergence of genuine strategic options. They give freedom to accept qualitative information as valid as quantitative data and confidence to deal with complexity, overcoming the risk of simplifications (linear assumptions). Finally they comfort planning/decision agents with the prospect that several good strategies exist, rescue them for the endless search for the one optimal solution (that rarely exists).

Adopting such type of approach is useful to respond to the limitations identified before as outcomes from the different cases observed in section 3.1.1 for the energy planning processes. Table XIX was elaborated to synthesise the contributions from critical theory.

Moreover, they also respond to the needs of change for sustainable development as an evolutionary process, supporting the planning for sustainable development beyond traditional planning and strategy making.

Table XIX – Identification of the critical theory characteristics that contribute to overcome the limitations identified on the outcomes of energy planning cases as referred in section 3.1.1

Outcome	Identified Limitation	Contribution from Critical Theory
#1	Miss strategic thinking component	Legitimizes a 'un-order' that stimulates creativity
#2	Approaches limited to well-structured problems and quantitative analysis	Capacity to deal with complexity recognizing the importance of qualitative information
#3	Assume that there is one optimal solution	Collaboration among agents search for common concerns and assumes several good solutions
#4	Based on linear assumptions	Recognizes patterns (nonlinear assumptions) and validates sense-making
#5	Predictive approach to formulate technical visions	Creativity and sense-making stimulate strategic thinking to formulate strategic visions

5.2.2. Introducing SEA in the planning of sustainable energy systems

As previously discussed SEA is considered a procedural but flexible instrument that acts as a mediator by establishing a context of discussion and assessment to enable the integration of the several planning-related issues, while at same time it is advocative and interventive, pursuing sustainability. Such versatility gives SEA the comprehensive character necessary to approach complex planning processes but introduces the question about the way that SEA can effectively be applied in energy planning. The answer is not exclusively given from SEA procedure but includes the planning process and the energy systems.

Previously it was stated that for energy planning, different scopes could be found in practice, mostly at a technical level and in relation to specific parts of the energy systems. In that sense, when SEA is applied to these cases, as the planning context do not represent a comprehensive vision of the energy systems, the amplitude that SEA introduces is limited and cannot be compared to the one that could be possible if a broader framework regarding the energy system was considered (Jay 2010). It can also be said that SEA benefits from the development of assessment criteria to assess a specific energy problem (e.g. energy security developed by Chen 2011) but its contributions became threatened if limited to single and well defined aspects.

Connelly and Richardson (2005) deal with these issues when they centred SEA on values rather than goals, alerting for two situations. The first is the importance for researchers of planning processes to reject the notion of value-free processes. The second situation, deriving from the first, is the abandon of SEA as a mediator on the planning process, as values should not be left for a trade-off situation dominated by power relations about goals.

Despite the focus on values, Connelly and Richardson (2005) are rather pragmatic, and do not get lost on the idyllic principles of participation and democracy pointed out to SEA, which can be pretty useful when approaching a planning context that is traditionally quite technical. Two aspects are pointed out from their work with relevance to the context of this research:

- Sustainability is not acceptable to express values as a great variety can be considered under this concept and generally it is only useful to set a general direction for policy. Therefore, with everything else open for debate, "pursuing the ideal of genuine, unforced, and inclusive consensus as a goal for deliberative processes within any sustainable development process, including SEA, is fraught with practical and theoretical difficulties which are seldom addressed by theorists or practitioners."
- Deliberation is possible and can be faced in the planning process, but "problems of value difference and conflict cannot be addressed satisfactorily by using procedural approaches within the decision making process. They require the addition of some external, independent criterion or criteria by which to make decisions."

This last aspect follows the idea to which Fischer (2003) calls the attention, to not abandon prematurely structured and normative/objectives-led SEA approaches.

It is based on the conjunction of these, sometimes diverging, characteristics of SEA that the tool can go further and reveal its potential on the development of new options for the planning process. The flexibility claimed for SEA finds echo on Connelly and Richardson (2005) when stating that the role of a good SEA is to redress systematic imbalances. If promoted from the beginning of the planning process on a strategic base that can support a planning process towards a vision about the planning problem, it can effectively contribute to the integration amongst planning dimensions, consistency in objectives and improvement of solutions for the decision. The scheme elaborated in

Figure 9 can thus be completed with the presence of SEA, which acts as a wedge in the planning process energy (see Figure 10).

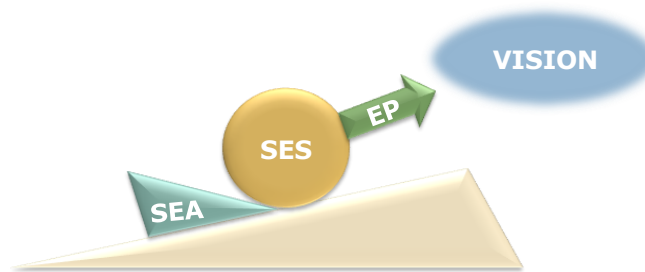


Figure 10 – The role of SEA in energy planning process: acting as a wedge for the support of SES

5.2.3. Towards a new energy paradigm

A common understanding on the objective of energy systems is the supply of the necessary energy that is demanded by human activities. This has resulted in a unidirectional representation of such systems, from energy supply to energy demand, consequently focusing on a quantitative analysis (see Figure 11) of the energy supply subsystem:

"The decisive feature of such systems is, of course, the purpose they are meant to serve, i.e. the end-point of the energy conversion processes." (Sørensen 2004, p. 591)

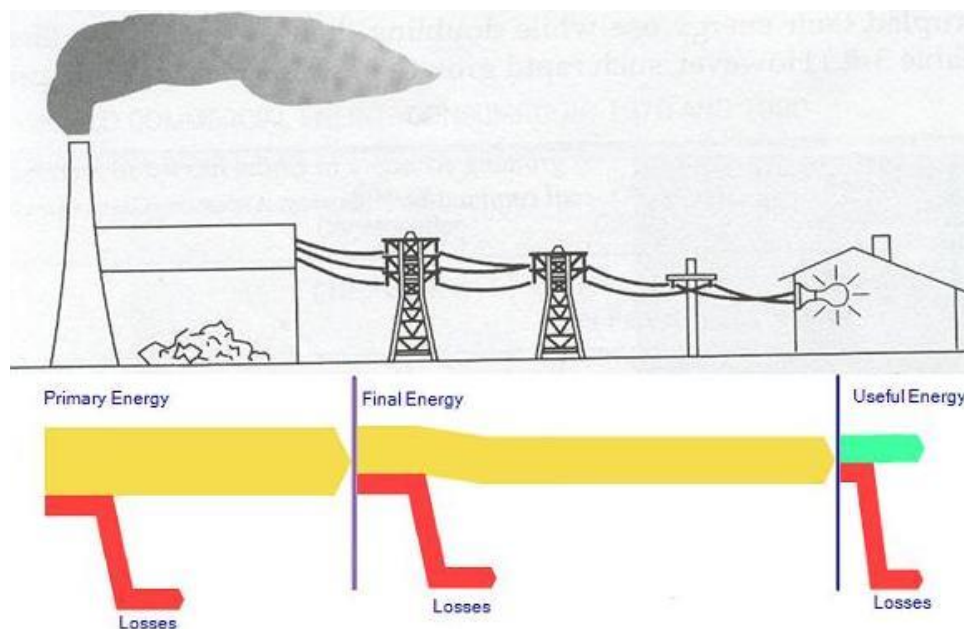
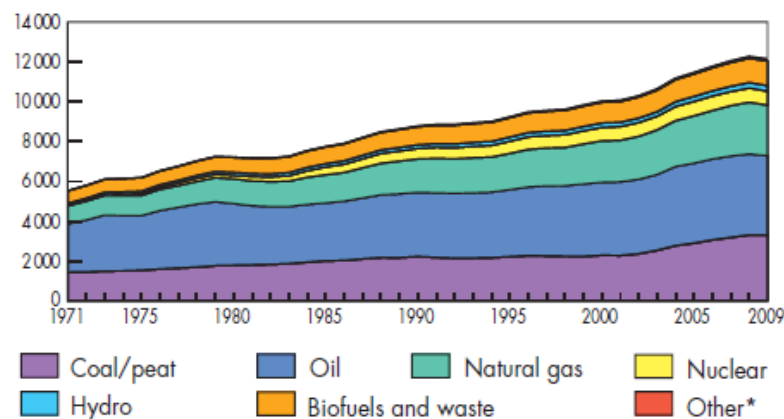


Figure 11 – The quantitative analysis of the energy system in the logic of supply chain (based on Hinrichs 1996; Sousa and Carlos 2007)

However, there are several reasons that justify the consideration of the energy system in a larger framework:

- It is recognized that the real demand is not the energy itself, but rather a provision of a service or product (Sørensen 2004);
- The energy resources upon which current energy supply is based are predominantly fossil fuels (see Figure 12) that, by being finite, cannot support indefinitely the energy system;
- The economic perspective of a liberalized market determines a prices escalate on those fuels, making them available only to those who can afford it;
- Natural renewable energy resources are recognized as alternatives to fossil fuels;
- Natural renewable energy resources contribute with several services, not only related to energy but also to other environmental services such as the provision of air and water quality, as well as support services that are the base of all ecosystems.



*Other includes geothermal, solar, wind, heat, etc.

Figure 12 – World total primary energy supply from 1971 to 2009 by fuel (Mtoe) (IEA 2011)

These reasons enable the formulation of five premises that support the proposal of a new energy model based on a different paradigm:

Premise #1	Energy supply, in the long-term, will have to rely on renewable energy resources
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Natural renewable energy resources tend to be more diversified and their availability depends from the geographical context, as sun, water or wind (just to mention the main renewable energy resources) do not occur equally in all regions. Moreover, different

resources imply different technologies for energy transformations, originating a diversified supply system, moving away from the single-minded and centralized combustion paradigm. In that sense, a second premise can state that:

Premise #2	Energy supply will have to rely on decentralized infrastructures, adapted to the existing natural renewable energy resources
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The decentralization of energy supply infrastructures enables shortening the energy chain, adopting a regional context for energy systems and increasing efficiency from the supply side. However, that efficiency is attained only if the demand side is prepared to accommodate the energy that can be provided at regional level. Thus, at the demand side, efficiency results from a combined action of:

- Energy efficiency of end-use equipment;
- Energy shift, promoting the adequacy between the energy vector used and the energy service required;
- Energy Demand Management, assuming the importance of each consumption sectors to perform the necessary measures to attain the two previous points.

The concepts presented in chapter two – energy quality and shift of energy vectors, find here their application. The first, as an energy criterion to structure the energy consumption based on the concept of energy service instead of the energy vector, which introduces a 'rational' demand (in the sense that is more intelligent or careful in the use that makes from energy) and preparing it for the matching. The second, expressing the operationalization for the matching between demand and supply.

From this, other hypotheses are taken:

Premise #3	Demand side needs to be prepared by energy service , ensuring the use of adequate energy vectors based on their energy quality
Premise #4	The adequacy to the energy that can be provided regionally implies a shift on the use of the energy vectors at end-use, to operationalise the matching between demand and supply

When considering the energy system in the context of sustainable development, as a subsystems of all activities at regional levels, it is necessary to consider how the energy system influences the availability (and quality) of the natural resources it requires. The sustainability of the energy system needs to be assured, in the long term, but the same

natural resources also need to provide, sustainably, for other natural services that support livelihoods.

Premise #5	Energy systems need to be planned in close consideration of the context-specific environmental conditions to assure the sustainability of the energy systems
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The premises above support a new energy paradigm needed for the planning of future energy systems, and that can be expressed as presented in Box 3.

Box 3 – Description of the energy paradigm

"The energy scene witnesses today a transition between energy paradigms. The shift assisted nowadays moves from the current paradigm based on the combustion of fossil fuels, towards a new one, where natural renewable energy resources are seen as the main energy sources. The new energy paradigm calls for 'sustainable energy systems' as it departs from the exploitation of diverse renewable energy resources, decentralisation and conversion of proximity, efficient energy use and environmental friendliness.

The introduction of sustainability in the planning of energy systems pushes the process beyond the current organization of the energy demand and supply.

Environmental assessment is a cornerstone in the development of energy systems under the new paradigm as it is essential to consider the perennial environmental values in the assessment of energy options based on the use, and sustainability, of natural renewable energy resources, to guarantee solid, long-term and a strategic vision of the planning process."

In order to verify the value of the energy paradigm proposed in this research work and consequently the premises as presented above, an analysis of perception has conducted for several agents including energy agencies, energy companies and other energy and environmental professionals, via a survey conducted in April of 2012 (see Annex I for more detail). Globally, the results show the concordance with the lexicon used to describe the proposed energy paradigm. Nevertheless, important feedback was also obtained on the gaps that current practice still presents and the need to incorporate the concepts presented (and others referred by the respondents) on real energy planning processes, namely the importance of bringing some premises (energy shift and efficiency) as main pillars for planning processes or the importance of a more broad analysis including social and regional development. From all these contributions, perhaps one can be used to synthesized the goal of this work, as one of the respondents stated:

“Developing appropriate criteria and using appropriate impact assessment methodologies with which to evaluate options”

In line with the perception of the survey’s participants, the new energy paradigm proposed here places relevance on the role of less used energy concepts (such as energy quality or energy services), and introduces a concern with the contextual environmental conditions (including the “perennial environmental values”) in a logic of sustainability. Moreover, it helps elaborating on principles that might drive the planning process, such as self-sufficiency, decentralized exploitation, technological efficiency, the adequacy and matching of the energy system.

The energy concepts, concerns and planning principles included in this paradigm can be assembled together in a proposal for a planning vision for sustainable energy systems, as expressed in Box 4.

Box 4 – A vision for sustainable energy systems

Sustainable energy systems are based on renewable energy resources, where supply infrastructures are decentralized and consumption occurs in a logic of proximity. In that sense energy demand is structured by energy service and prepared for the matching between the resources by the adequate use of energy vectors. This will contribute to increase self-sufficiency of these systems. Moreover, strategies for the development of such systems will have into consideration dimensions that, not being directly related with energy issues, introduce sustainability concerns in the planning process.

Having these premises, paradigm and vision for sustainable energy systems, is then possible to elaborate a proposal for a methodological framework on the planning process of such systems.

6. Methodological Framework for an Integrated Energy Planning

6.1. Overview of the Methodological Framework

Previous chapters presented the main pillars for the development of an integrated process for the planning of sustainable energy systems. The methodological framework proposed in this chapter has as main purpose to respond to the major goal of this research work – to be a support instrument for energy planning processes, particularly on the decisions about the main alternatives of renewable sources in isolated contexts, and therefore contribute for a truly comprehensive integrated energy planning process.

Based on all the contributions collected and exposed above on the chapters of literature review, it is designed a framework that has as fundamental elements:

- An energy planning model aimed at the matching between supply and demand;
- The SEA according to the strategic thinking model proposed by Partidário (2012).

Auxiliary tools and techniques are used along the process for the development of specific practical stages. The articulation of the methodological framework is represented in Figure 13.

The methodological framework initiates with the development of an integrated strategic framework for energy planning and SEA. This includes the development of the energy vision that will drive the planning process (section 6.2.1.1) the establishment of strategic issues and dimensions in section 6.2.1.2 and the definition of the strategic elements that will be considered in the SEA. The SEA involves the strategic reference framework in section 6.2.1.3 and the assessment framework, based on critical decision factors, assessment criteria and indicators, in section 6.2.1.4.

The second stage is related to the modelling of the energy system. It starts with the conceptual representation of the energy system (sections 6.2.2.1) expressing the articulation of the vision in terms of elements of the system and relationships established between them. This provides a structure for the modelling of the energy system (section 6.2.2.2), which occurs afterwards, giving a baseline about the status of energy system to be planned. This is followed by the analysis of the energy system, which includes the analysis of the systems' performance in relation to the energy concerns expressed in the

energy vision (section 6.2.3) and the analysis of trends in the wider context established by the assessment framework. When this stage is complete, it is possible to initiate an exploratory stage about which strategies need to be followed to attain the vision. This fourth stage includes developing energy strategies for the components of the energy system (section 6.2.4) which are combined to form images of the future that are finally modelled as planning proposals.

The final stage is the assessment of the proposals (section 6.2.5), using the assessment criteria and indicators developed under each critical decision factor. The results are the identification of an overall preferable planning proposal as well as the mapping of opportunities and risks that need to be taken into account to enhance the planning process and assure the progress towards the energy vision.

The development of the methodological framework is supported by inter-related spreadsheets to enable the performance of the integrated energy planning tool.

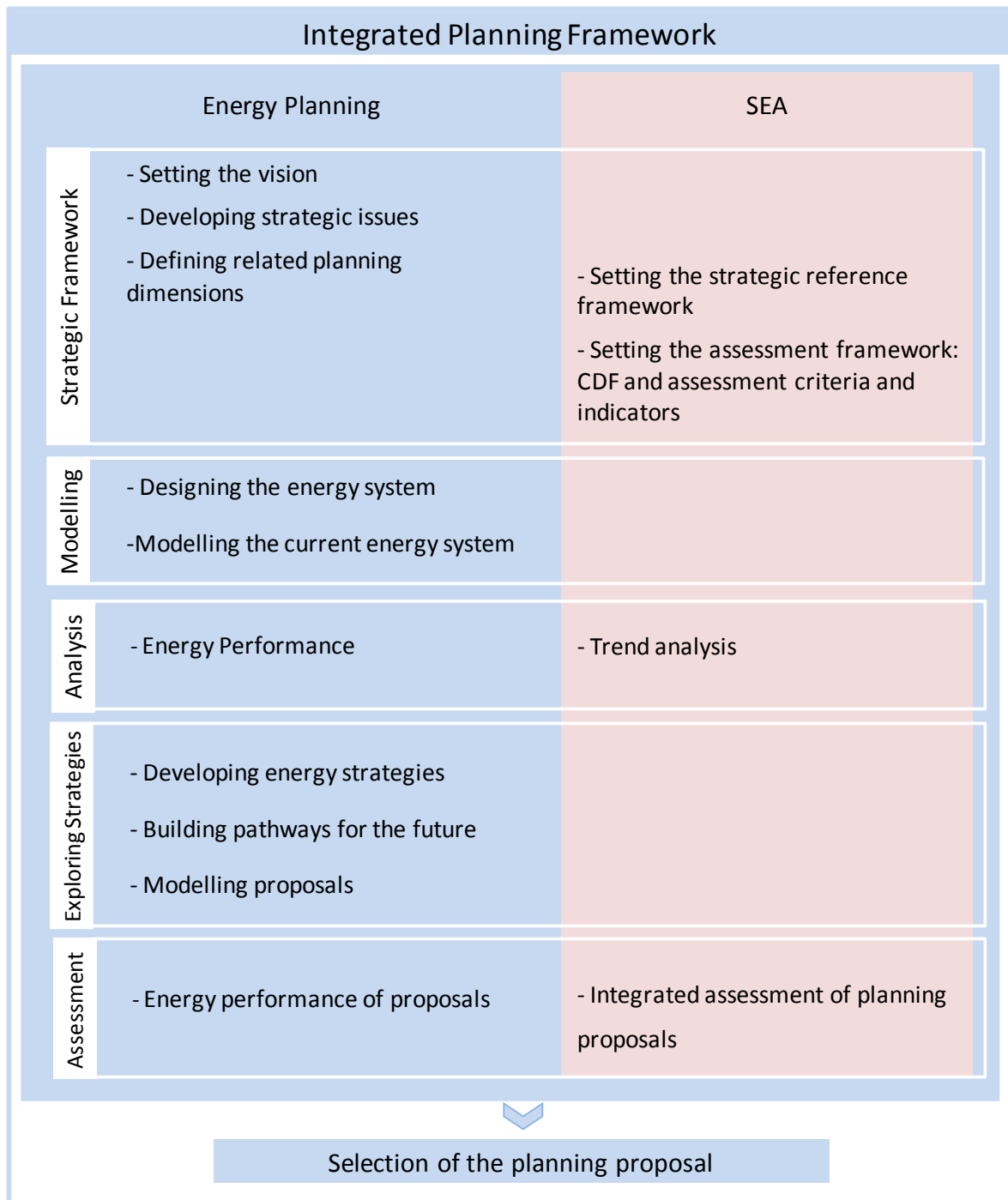


Figure 13 – Schematic representation of the methodological framework for the planning of sustainable energy systems

6.2. Detailed description of the methodological framework

6.2.1. Stage I – Strategic Framework

The first stage consists of setting the strategic framework for the development of the integrated assessment. The strategic framework is the departing point for the energy planning process as it gathers the vision for the energy planning and the strategic elements according the SEA methodology, as defined by Partidário (2012), resulting into the development of the strategic guidelines that will be present along the planning process. The process starts with the definition of a vision for the energy system, which is complemented by adding energy-specific concerns expressed by the strategic issues and the related planning dimensions. With the contribution of SEA, through its strategic elements such as the strategic reference framework and the assessment framework (CDF, criteria and indicators), the strategic framework is widen for a more comprehensive development of the planning process.

6.2.1.1. Setting the energy vision

The effort when elaborating the energy vision is to make sure that it expresses the image of the future that we want to achieve in a short description. For the development of such vision, support can be found in section 5.2.3, which gives a general description of an energy planning vision under the new energy paradigm. Departing from that generalized vision, a contextualization and a detailed description will be necessary according each case of application.

6.2.1.2. Developing the strategic issues and related planning dimensions

In light of the SEA methodology, to define the strategic issues is fundamental, both for the expression of the critical challenges to achieve in the long term and to set the critical decision factors (CDF). The definition of strategic issues departs from the energy context, as they need to clearly state the objectives and the challenges that will be faced by energy system and to which the energy planning need to help respond, in terms of its own performance as well as on the interactions established with surrounding environment. Box 5 presents a set of generic strategic issues for sustainable energy systems.

Box 5 - Strategic issues regarding the planning of sustainable energy systems

Energy supply system based on the endogenous energy resources
An energy system based on the available energy resources allows for a greater independence of a region from external sources, which have to be imported, need storage infrastructures and stock management and are subject to prices instability. To base the energy supply on the endogenous energy resources also means to explore the natural energy resources at a level where the natural values and the sustainability of the island are not threatened.
Smart energy consumption based on the management of the energy demand
Adopting sufficiency as a planning principle calls for an effort on a smart energy usage that can be characterized both by efficiency and adequacy. Therefore, the planning of the energy system shall include measures at the demand side, to better structure the type of demand in order to obtain more adequate and efficient patterns of consumption.
Assuring the matching between the energy needs and the natural energy resources
It is critical for the energy system to articulate the natural energy resources with the energy demand in the territory, i.e. the matching (as illustrated in Figure 1, section 1.2) between both sides of the energy system.
Promote a sustainable development model, ensuring the welfare of the populations
A sustainable territory will only be achieved if the energy system is integrated in the territory development pathway. The energy system is a consequence of the organization of the activities in the territory, but at same time, the way the future of the energy system is perceived will condition the development model. Therefore, in what concerns the possibilities and evolution of the energy system, the consequences of the energy system on the development model of the territory regarding the welfare of populations and the competitiveness of the region becomes a strategic issue.

Related energy planning dimensions

Related to the strategic issues different dimensions involved in the energy planning process can be identified. The identification of these dimensions is important as they give context to the sustainability concerns. By having a clear identification of these dimensions the trend analysis can be better structured, while also improving the definition of the assessment elements, assuring that important aspects are not left behind.

The main dimension is the energy driving the planning process and to which the objectives are targeted. Then, five other dimensions were identified as relevant to the energy planning process: natural resources, territorial, social, governance and temporal dimensions, which allow keeping attention on other relevant aspects of an integrated approach (see Figure 14).

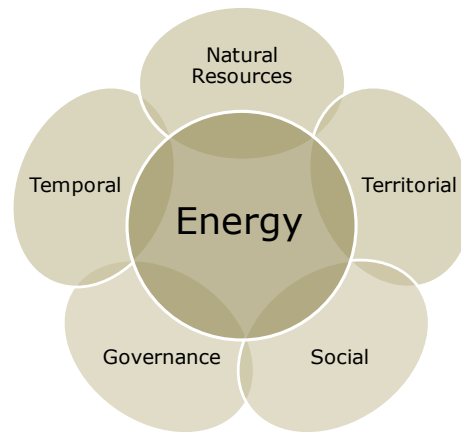


Figure 14 - Representation of the dimensions involved in the planning process

The energy dimension expresses anything directly related with the energy use, the rationality of use, the principles of efficiency and adequacy, the design of the energy system considering the energy quality and quantity from the natural resources and the demand's management, and all that directly regards energy goals.

The natural resources' dimension highlights the role of the existing resources and biophysical conditions in the region as the base matrix for all the development that occurs in the territorial context, emphasizing the importance to respect the environmental values, and the ecological services provided by those resources. Those environmental values can be expressed, in a tangible and physical way, as a natural capital expressed as good quality biodiversity, air, water and soil, landscape and protected natural areas, among others.

The territorial dimension relates to the way in which activities are physically organized in the territory, regarding their spatial distribution and their allocation, as it conditions the development path in the geographic context.

The social dimension relates to the livelihood in the territorial context and all aspects important for the human existence, introducing other aspects of development, including the social cohesion and fairness, socio-economic well-being, attractiveness and living conditions.

The governance dimension is related to the decision process and introduces the importance of having energy solutions tailored to the needs and expectations of the stakeholders. By involving all agents and giving them responsibility to be actively involved in the development and implementation of the model, it would be easier to achieve more comprehensive energy solutions.

The temporal dimension contributes to the energy model with the long-term concern making present issues such as intergenerational equity and the balance between immediate and long-term performance of the solutions by taking a precautionary and adaptive approach.

6.2.1.3. Setting the strategic reference framework

The strategic reference framework identifies the relevant macro-policies that can influence the planning process, with particular attention to the energy, environmental and development goals for the region. The energy planning has to respond to these goals set by policies and legal documents of wider scope. This way, it is possible to identify existing goals that frame the development of the energy system and that need to be accounted for in the development of possible strategies for the energy system.

In order to help the definition of such strategic reference framework, the generic content of the main documents to consider in this case is mostly related with:

- Energy policies and plans;
- Strategies for sustainable development;
- Land-use plans;
- Renewable energy action plans;
- Climate change adaptation and mitigation plans;
- Sectoral (buildings, industry, transportation, ...) policies, plans and directives related with energy performance: energy efficiency, use of renewables, energy technology, among others.

6.2.1.4. Establishing the assessment framework

After the strategic framing of energy issues, it is necessary to have a more technical approach to the planning process in order to ensure an objective discussion about the strategic options for the energy plan. The goal of the assessment framework is to establish factual and coherent guidelines (expressed ultimately into indicators) that will allow to assess objectively the energy scenarios created for the energy planning and support the decision about a final option.

Achieving that assessment framework implies departing from the strategic framework for the planning of sustainable energy systems and then trying to synthesize the environmental and sustainability concerns related to energy planning into a limited number of critical factors that will analyse and assess the process with the purpose of assisting more integrated decision-making. These critical decision factors (CDF) will support the choice of energy strategies within the energy planning and the establishment of guidelines to assist the planning process. CDF are structured according to criteria and indicators that are used along the assessment process (see Figure 15). The CDF, criteria and indicators set the assessment framework, which needs to be refined according to each planning context, by particular considerations and specificities so that it can be consistent with the case involved. In generic terms for the planning of energy systems three CDF are presented (see Box 6), according the contextual framework of the planning process.

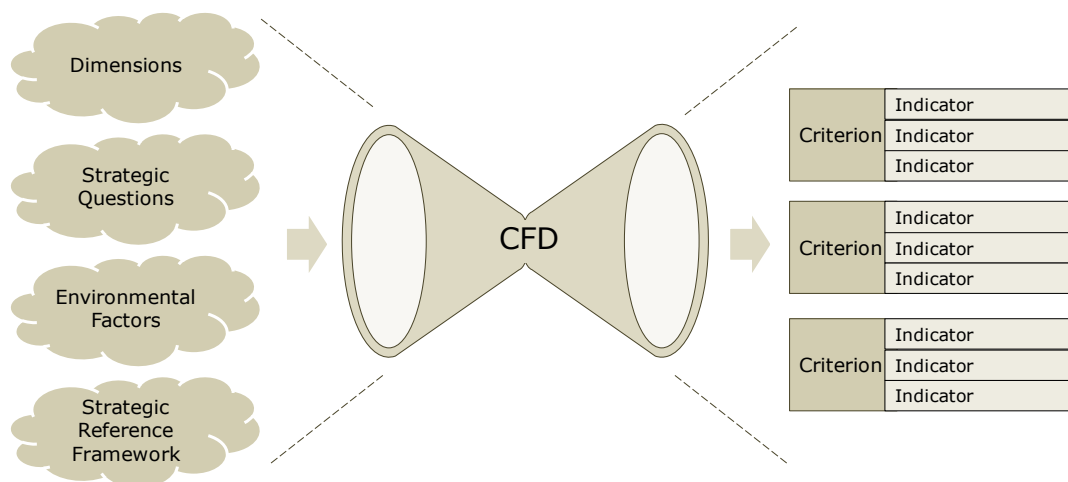


Figure 15 – The role of the Critical Decision Factors

Box 6 – Generic CDF for sustainable energy systems' planning process

Energy Shift
It translates the importance of the energy options on the shape of the energy system and as promoters of change. Those energy options that promote the shift can be grouped as: use of different energy vectors, promotion of energy efficiency along the entire energy chain (supply and demand sub-systems) and adequacy of the energy use to the required energy services. The main goal is to assess the way in which the shift occurs and if it promotes the matching between the energy needs and the energy that can be provided endogenously.

As the changes at this level are related to behavioural changes from the stakeholders and citizens in general, the governance dimension is put in evidence, in what regards pointing out the direction to follow. This CDF is crosscutting to almost all the strategic reference framework, as it relates with the different energy goals, CO2 emissions' reduction and, ultimately, combating climate change.
Natural Resources and Territorial Shape
It translates how different energy uses of natural renewable energy resources affect differently the evolution of the energy system and have different expressions in the territory. The use of a resource for energy purposes inhibits its use for other purpose (e.g. the biomass case) or it has a territorial expression of that use (e.g. wind power and landscape link). The main goal is to assess the way that the natural resources are used and the territorial organization of activities is shaped. This factor expresses the physical effects of the energy system's planning, linking the natural resources and the territorial dimensions by assessing how the territorial organization is shaped by the use of the resources. It is related to the environmental values present in the territory, which constitute the basic matrix that supports all the activities.
Energy and Development Nexus
The development within a delimited region is more than the physical expression of activities. This CDF translates how the energy system influences the access to energy and the availability of different energy types allow or inhibit the development of economic activities and the improvement of living conditions. The main goal is to assess how the different energy options promote the development path for the region. The nexus between energy and development allows to introduce the social and temporal dimensions in the planning process, particularly important to assure an integrated vision for sustainability.

The criteria and indicators associated to the CFD must be defined according to the conditions of the practical case. However, Table XX provides some general criteria and indicators that may be considered, or used as an illustration of possible criteria and indicators for the assessment of the energy planning options.

Table XX – Generic criteria and indicators for the assessment stage of the energy options

CDF	Criteria	Indicators
Energy Shift	Shift on energy supply	Resources' diversity Adequacy to energy services Self-sufficiency Decentralization
	Shift on energy demand	Shift on energy vectors in use Level of matching
Natural Resources and Territorial Shape	Energy intensity regarding the use of natural resources	Energy exploitation of natural resources Total installed capacity for energy purposes
	Affection on the global use of natural resources	Competition among other uses Competition for same territorial areas
Energy and Development Nexus	Contribution to SD path adopted for territorial context	Adequacy to territorial strategy Amelioration of natural sensitiveness
	Competitiveness related to the use of energy in the territorial context	Access to energy for all Jobs creation CO2 emissions Percentage of renewable electricity

Even though the assessment framework is defined within the first methodological stage, the expected outputs are primarily practical. Therefore, its implementation is achieved in a later stage of analysis (presented in section 6.2.3).

A relevant aspect to have present along the planning process is the importance of having an iterative process that helps building and defining enhanced alternatives. In that sense, the assessment framework, which at this point is defined strategically, may be detailed from practice, being possible to define, within the CDF and criteria, new or more adequate indicators. This application of the assessment framework allows both a “learning from practice” and the involvement of stakeholders, to become a real iterative and participatory process, as proposed by SEA methodology.

6.2.2. Stage II – Modelling

The modelling stage initiates with the representation of the energy system, which can now be framed by the strategic elements defined in previous stage. It is used the concept mapping technique to achieve a comprehensive representation of the system regarding the relationships established across its components. This provides the insight to structure and model the energy system, the second step of this stage, to which is required a data collection, and then is used a spreadsheet-based modelling. The final result is an image of the current state of the energy system under analysis.

6.2.2.1. Representing the energy system

Regarding how energy systems are understood, the approaches at systems level are diverse (Ramage 1997; Sørensen 2004; Tester et al. 2005). A representation of energy systems was already presented in the introductory chapter, mentioning a tripartite system. Although it establishes a departure point, it is necessary to expand the representation of the energy system to clarify the inherent complexity of a system that is not linear and unidirectional and where complexity is increased by the diversity of energy resources and energy vectors that are available to be used in different ways. The goal is to set a common understanding about the parts of the energy system and relationships established among them, resulting into the development of an adequate structure for the energy model. The technique used to support the representation of these systems was the concept mapping (CMap tool - free software available at <http://cmap.ihmc.us/> and propriety of the Institute for Human and Machine Cognition).

To achieve a final, comprehensive representation of the energy system, the contributions from previous representations were incorporated, as the matching exercise, the tripartite energy system and the way how the different components are linked in energy terms through energy vectors and services (Figure 16).

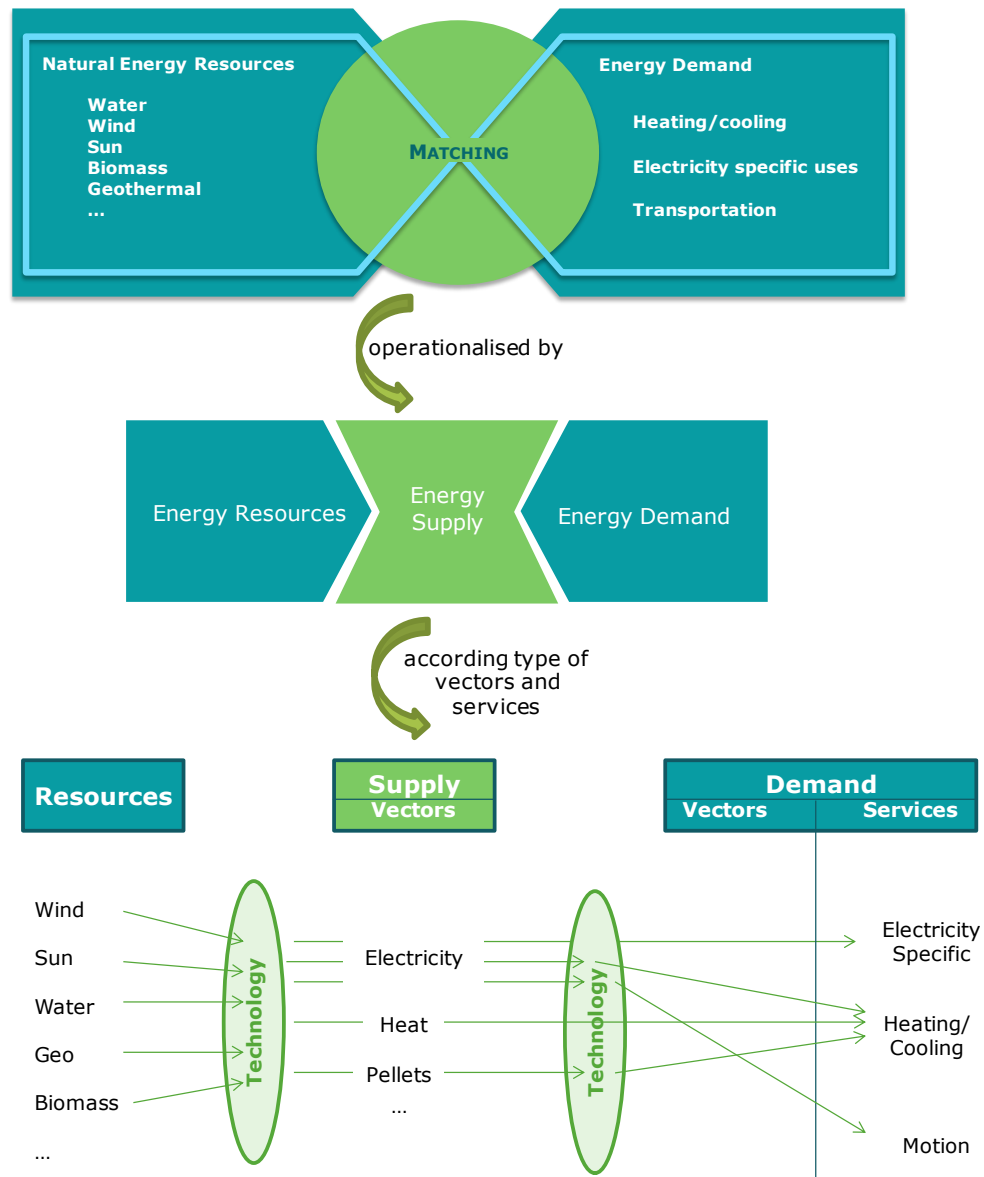


Figure 16 – Expliciting the matching exercise: from energy system's components to energy vectors and services

The first step was to elaborate a concept map that expresses the generic view of the system, relation among components and its link with external components that support the energy system (see Figure 17). The greater contribution is to express the

interconnectedness among all components, which was not evident on the previous linear diagrams.

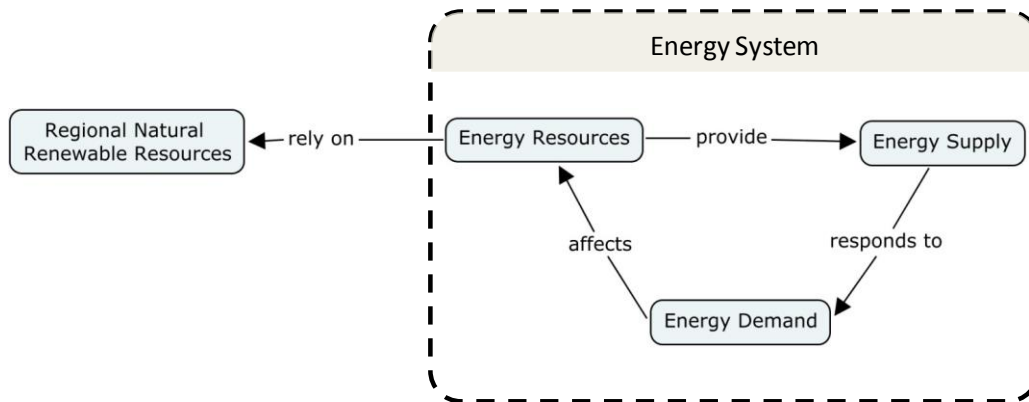


Figure 17 – Concept map of the generic view of the energy system

From this first representation, the chart is expanded, entering in more detail regarding exclusively the energy system (see Figure 18). Having as departing point the new vision about the energy system, the five planning principles are introduced (represented in bold) and becomes more explicit the way they affect the system.

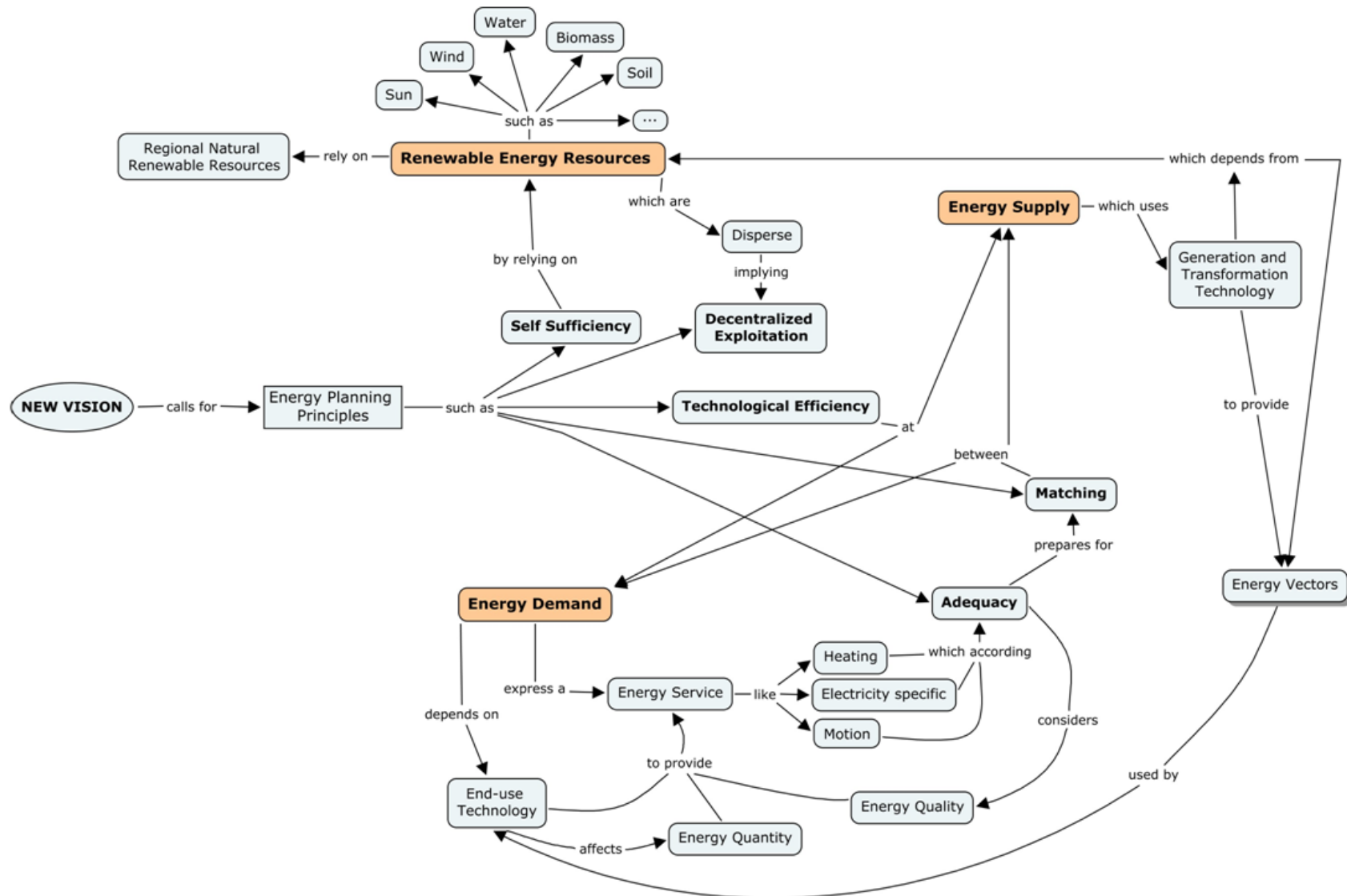


Figure 18 – Concept Map of the energy system departing from the principles for a new vision towards sustainability

6.2.2.2. Modelling the energy system

The modelling of the energy system is developed separately for its three components and is based on the collection and organization of available information, where spreadsheets are used for this purpose aimed at the elaboration of an image of the energy situation. This will provide a static picture of the energy system that allows describing the conditions at the departing point, by the quantitative characterization that is made. At this point particular attention must be given to the units of the data used, assuring the uniformity of data among components and preferably detached from fossil fuels-related units.

Energy Demand

For the modelling of the demand, it is followed the traditional structure of existing energy models, as shown in Figure 19. Usually the system is structured according the main activity sectors: domestic, services, industry, agriculture and fisheries, construction and transportation and each of these sectors are unfolded into other, energy consumption actions, which may vary according the context of analysis and available data, resulting in a more or less disaggregated analysis.

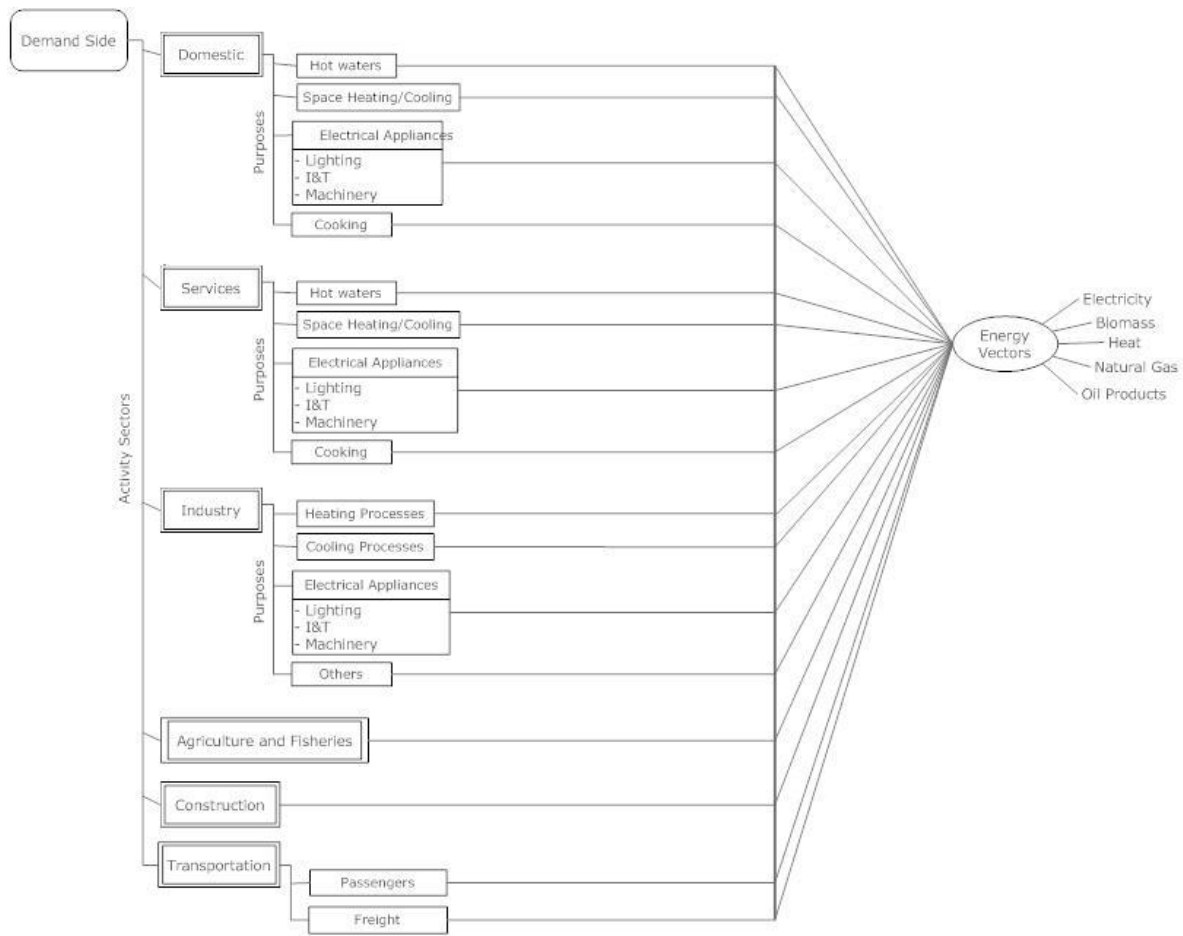


Figure 19 – Demand-side tree

One extra step is then required to structure the consumption of energy by the final energy service (heating, electricity specific or driving force), resulting in a characterization of the energy demand as expressed in Table XXI.

For each specific activity, the energy vectors used are identified allowing understand, considering the energy quality principle, what is really necessary and what can be shifted or improved, in order to be more efficient.

This organization of the demand side allows having the energy needs identified according to the energy vector to assure a given service, which prepares the demand side for a direct comparison with the energy vectors that endogenous renewable resources of the region can provide.

Table XXI – Structure according the new organization for the characterization of an energy demand sector

	Purpose	Energy Vector	Quantity (MWh)*		
HEAT	Water Heating	Electricity			
		Solar Heat			
		Fossil Fuels			
	Space Heating/Cooling	Electricity			
		Fossil Fuels			
	Cooking	Electricity			
		Fossil Fuels			
	Others	Electricity			
		Fossil Fuels			
EE SPECIFIC	Lighting	Electricity			
	I&T				
	Others				
MOTION	Transportation	Fossil Fuels			
	Other engines				

* To be fulfilled with the quantity of energy consumed

Supply

For the modelling of the supply is also followed the traditional structure that includes the characterization of the existing supply infrastructures, and the energy vectors provided, as showed on Figure 20.

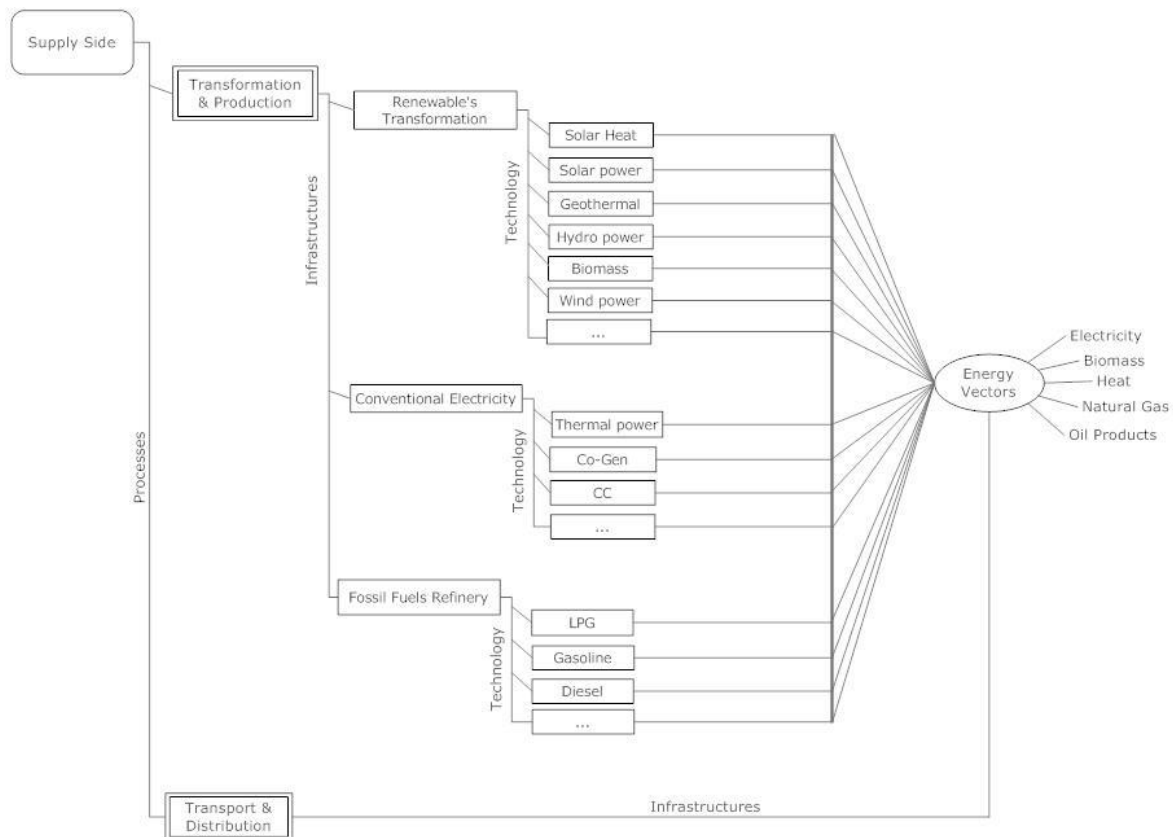


Figure 20 – Supply-side tree

Moreover, it identifies the primary energy that needs to be introduced in the system from outside the region. This allows to understand in what extent the energy supply in the region is dependent from external energy resources and what is the potential to increase the exploitation of the endogenous energy resources based on the existing infrastructures.

Endogenous renewable energy resources

The modelling of the endogenous renewable energy resources has two phases. The first includes a survey for the identification of the natural energy resources that exist in the region and the second phase regards the characterization of the resources. The preparation of the energy resources, aimed at the matching with the demand need to consider the following aspects:

- The characterization of the existing energy resources in terms of the energy vectors that they can provide. This implies a qualitative characterization of the natural resources for energy services. At same time is also dependent on the available technology for the exploitation of the resources;

- The characterization of the available the energy potential of the resources. It entails a quantitative characterization of the resources for energy purposes (already considering existing legal/environmental restrictions to full exploitation).

Considering the aspects mentioned above, is possible to build a matrix where energy quality and quantity intersect, facilitating the description of the region's energy potential (see Table XXII).

Table XXII – Matrix for the qualitative and quantitative characterization of the resources existing in the region

		Energy Vector		
		Heat (MWh _t)	Electricity (MWh _e)	Motion (MWh _m)
Resources	Solar	X	Y	-
	Wind	-	Y	-
	Geo	X	Y	Z
	Water	-	Y	-
	Biomass	X	Y	Z
	Biogas	X	Y	-
	Biofuel	X	Y	Z
	Air	X	-	-

6.2.3. Stage III – Analysis

The analysis of the energy system considers two perspectives. The first from an energy point of view, that analyses the performance of the system taking into consideration the principles proposed by the new vision, which are detailed below in section 6.2.3.1. The second perspective considers a wider analysis, following the SEA methodology that proposes a trend analysis based on the elements developed along the strategic framework. The combined analysis gives a comprehensive insight about the energy system that will allow developing the energy strategies.

6.2.3.1. Energy Performance

As the proposed methodological framework envisions a change regarding current energy planning processes considering new principles, the analysis and assessment of the energy system will have be done at the light of new elements different from the ones traditionally used. At this phase are developed those energy elements to be used on the analysis of the energy system, from a direct energy perspective. Table XXIII presents those elements, explaining how they contribute to the transition towards sustainable energy systems and translate them into indicators that can be applied for the assessment of the system's performance in energy terms.

Table XXIII – Description of the elements for the energy assessment of the energy system

Energy Principle - Diversity	
Rationale	Energy diversity in the region depends both on the type of energy vectors that existing natural resources can provide to the energy system as well as the type of energy vectors used at demand side to satisfy the energy services. Diversity can be assessed regarding real vectors provided (attained diversity considering real situation - D_R) and potential vectors of the region (attained diversity considering the potential - D_P).
Elements under consideration	Indicators
- Energy vectors supplied in the region (EV_s) - Energy vectors used by the demand in the region (EV_d) - Potential energy vectors provided by the endogenous resources (EV_p)	$D_R = \frac{EV_d}{EV_s} \times 100$ $D_P = \frac{EV_d}{EV_p} \times 100$ (units: %)
Energy Principle - Adequacy	
Rationale	Adequacy considers the relation between energy services required by the demand and the energy vectors used to respond to those needs. When vectors respond in the exact amount to the energy service, they fit exactly in adequacy terms, otherwise a distance to adequacy (A_d) is observed, which can be positive (if the vectors exceed the energy service needs) or negative (when the amount of adequate vectors for the energy service is used below the needs).
Elements under consideration	Indicators
- Amount of energy demanded by energy service (E_s) - Amount of energy delivered by the adequate energy vector (E_v)	$A_d = \frac{E_v}{E_s} - 1$ (adimensional)
Energy Principle - Self-sufficiency	
Rationale	Self-sufficiency (or energy independence - E_i) of the region in energy terms depends on the energy that can be provided by endogenous resources and the level of energy demand.
Elements under consideration	Indicators
- Total amount of endogenous primary energy ($P.E_{end.}$) - Total amount of primary energy ($P.E.$)	$E_i = \frac{P.E_{end.}}{P.E.} \times 100$ (units: %)
Energy Principle - Decentralization	
Rationale	Decentralization (Dec) expresses the dispersion of supply infrastructures and the logic of production near to consumption places. It accounts for the energy consumption that derives from large scale, centralized origin and the energy consumption produced at end-use place.
Elements under consideration	Indicators
- Amount of primary energy provided by decentralised energy vectors ($P.E_{Dec}$) - Total amount of endogenous primary energy ($P.E_{end.}$)	$Dec = \frac{P.E_{Dec}}{P.E_{end.}} \times 100$ (units: %)
Energy Principle - Efficiency	
Rationale	The efficiency (η) relates the inputs and outputs of the energy system. The inputs refer to primary energy at the supply side while the outputs express the final energy used by the demand. An efficient energy system tries to have as close as possible the values of primary and final energy. The efficiency can be assessed to the global energy system or to specific cases (e.g. the electric sub-system)
Elements under consideration	Indicators
- Total amount of final energy ($F.E.$) - Total amount of primary energy ($P.E.$) - Total amount of electricity vectors ($F.E_{EE}$) - Total amount of primary energy for electricity ($P.E_{EE}$)	$\eta = \frac{F.E.}{P.E.} \times 100$ $\eta_{EE} = \frac{F.E_{EE}}{P.E_{EE}} \times 100$ (units: %)

(Table XXIII – cont.)

Energy Principle - Matching	
Rationale	The matching is both a qualitative and quantitative principle that expresses the relationship between endogenous energy resources and demand. Qualitatively it is assessed by the adequacy. Quantitatively, it relates the energy provided by the endogenous resources and the energy required by energy services in the region, expressing a response rate to the matching (M_R)
Elements under consideration	Indicators
- Total amount of endogenous primary energy (P.E. _{end.})	$M_R = \frac{P.E._{end.}}{E_S} \times 100 \quad (\text{units: \%})$
- Amount of energy demanded by energy service (E_S)	

In addition to the use of these indicators for the assessment of the energy system, it is highlighted the importance of using some other commonly indicators proposed by international institutions for the benchmark of energy systems (see Table XXIV).

Table XXIV – Overall energy indicators for benchmark

Benchmark element (based on IAEA 2005)	Type of result
Energy consumption per capita: expresses the level of energy consumption (primary and final) in the region considering the total number of inhabitants (resident population).	MWh/inh toe/inh
GHG emissions: giving the importance of climate change policies, one of the most common energy indicators is the emissions of GHG from energy production (per unit of energy or per capita)	Tonnes of CO ₂ eq./MWh Tonnes of CO ₂ eq./inh

6.2.3.2. Trend Analysis

The trend analysis gives particular attention to the dynamics of the systems, analysing the driving forces that give impulse for the development of possible pathways to attain the desired vision. The analysis considers the evolution of each component of the energy system according the directions established by energy policies and goals (to which the SRF provides a good base) and the past and future trends on the different planning dimensions that influence the course of the energy system.

This phase is based on the collection of facts about all dimensions related with the energy planning problem and that act or have a role on the system's performance towards the future. A SWOT analysis is used to summarize the trend analysis resulting in the identification of those possible pathways that are then used on the next stage for the exploitation of strategies.

6.2.4. Stage IV – Exploring Strategies

After having an image about the current state of the energy system and the identification of the possible directions that it may follow according to the trend analysis, this stage explores the strategies for the energy system, providing the planning options (or proposals) to be assessed.

The first step is to materialize the possible pathways into structured energy strategies, as presented in section 6.2.4.1. These energy strategies consider both the demand and supply side of the energy system which then need to be assembled together to create images of the future (section 6.2.4.2) by using scenario's building techniques. The third step consists in modelling these scenarios (section 6.2.4.3), giving them a quantitative content for a more robust assessment.

6.2.4.1. Developing energy strategies

The strategies regarding the energy system are developed separately for the demand and supply, following the approach to the energy system based on its components. Endogenous energy resources do not admit the consideration of strategies as they are considered a constant over the territory. This way, strategies related with the endogenous energy resources are reflected on the supply, when different exploitation strategies are considered.

At demand level, strategies are related with the structure of the demand, which can reflect different requirements according:

- Changes on energy services at end use, resulting from different types of efficiency (including technological improvements, rational use of energy and behavioural changes)
- Changes on the use of energy vectors, according the principle of quality and adequacy to the energy service required, implying changes at end-use technologies.

For the development of strategies from the supply side, the strategies are aimed at the matching between resources and demand. Possible solutions for the regional matching emerge from the intersection between the energy vectors provided by the resources and

the energy vectors required by the demand, performed in a matrix that links these two dimensions (see Table XXV). Such matrix allows identify possible solutions that respects the limitations and respond to the needs of the energy system.

Table XXV – Matrix of solutions for the matching between resources and demand

			Resources (technology)											
			Solar		Wind (EE)	Geo		Water (EE)	Biomass		Biogas	Biofuels	Air (thermal)	(...
			Thermal	EE		Thermal	EE		Thermal	EE				
Demand	Heat	DHW												
		H&C												
		Cooking												
		(...)												
	Electricity Specific	Light.												
		I&T												
		E App.												
		(...)												
	Driving-force	Motion												
		Transp.												
(...)														

Note: Yellow shade considers the possibility of using the resource for the energy service depending on the heat degree.

Moreover, the new vision introduces some challenges to the energy supply. Solutions that, at a first view, can be equally valid as strategies may generate conflicting options about the use of energy resources. Two generic cases set the context to explore the aspects that need to be considered on the prioritization of energy resources and vectors.

Allocation of a resource to provide different energy vectors

The question of how to allocate a resource to the different energy vectors that it can supply is relevant, as it affects the type and quality of energy that can be provided to the demand. The objective behind such decision is the efficient use of the energy resource (which is dependent from the transformation technology) and the satisfaction of the demand in terms of quantity and quality.

The situation can be translated in practical terms, by a region that has electricity as the main energy vector to satisfy its needs, although the main energy services required are for heating purposes. The use of the resource Sun can provide both heat and electricity,

according the type of technology use. The question is then to decide about the possible solutions to explore the Sun as an energy resource. Which aspects need to be applied on such analysis? Box 7 presents the aspects that allow assessing the options regarding the energy resources that support the energy system.

Box 7 – Description of the main aspects energy-relevant for the assessment of the options

Quality of the vector provided
The quality of the energy vectors affects the allocation of the resource, where the goal is to provide the one with higher quality. Electricity has always a higher quality, once it is a form of energy with the highest level of exergy. This confers to electricity a plasticity of use that overpasses all the other vectors. In other words, electricity is the only available energy vector so far that can substitute all the other vectors.
Vector's adequacy for the energy service
Following the previous aspect, a vector with a lower quality can be more adequate for the energy service than other with higher quality, regarding the adequacy principle. Adequacy translates a new organization of the energy system that privileges the matching of the energy vector and the energy service (e.g. heat for heating purposes).
Answer to the Demand status
In terms of structure, the demand status tends to be lagged from the goal of the new organization. Nevertheless, it is necessary to respond, on time, to the energy needs. In a balance between the desired future for the energy system, expressed by the two previous aspects, and the present situation, it is necessary to privilege the vector that assures the supply of the energy vector in which relies the energy supply. In other words, if the current demand requires more electricity than heat (as vectors), then the allocation of the resource should consider that to assure the answer to the demand needs.
Characteristics of the transformation technology
Different technologies have to be used to provide different energy vectors from the same resource and those available technologies present different efficiencies according the type of transformation. The use of the resource to provide a given energy vector will be as good as higher is the efficiency of the technology.
Exclusivity of the resource
The existence or inexistence of other energy resources that can provide the same vectors helps deciding about the allocation of the resource to one or another energy vector. For instance, having heat and electricity as alternatives for the use of solar energy in the island but considering that electricity can also be provided from the wind, the use of sun for electricity purposes is not as urgent as for heat purposes.

A simplified assessment of the options about these two resources can be performed as synthesised in Table XXVI, for the specific case presented. By adopting this rationale, strategies become easier to draw, knowing that in terms of priority of exploitation, energy principles are being safeguarded.

Table XXVI – Assessment table of different vectors provided by the same resource

Resource	Possible Vectors	Energy Aspects				
		Vector's Quality	Vector's Contribution	Answer to current Demand	Transformation technology	Resource's exclusivity
Sun	Heat	+	++	-	++	+
	Electricity	++	+	+	+	0

Legend: + positive impact; 0 without significant impact; - negative impact

Choosing among different resources to generate the same energy vector

A second issue relates with the choice of the most appropriate resource to provide a specific energy vector, when several are available. The main goal is to choose, for that specific vector, the energy resource with higher merit of exploitation, meaning that it can better contribute for the independence and reliability of the energy system and the decentralization logic adopted by the energy vision. The use of a resource over another has also an important effect on the incentive to solutions of exploitation, in terms of procedures and technologies, affecting the direction of the future energy system.

To use a practical situation can be assumed a region where the electricity needs can be clearly supplied by either sun or wind. Sun is the most abundant resource, followed by wind. Although both resources respond equally well to provide the energy vector, it is not indifferent, in the future of the system, the option for one or other resource. Again, which aspects would help to support a decision? Box 8 presents some analysis lines that can elucidate about strategic moves in energy terms, anticipating the possible effects and aspects of the options, with a simplified assessment synthesised in Table XXVII.

Box 8 – Main aspects to consider on the analysis of different resources providing the same energy vector

Contribution to independence
Considering the availability of two resources to provide the same energy vector, the amount of energy provided from one or the other can differ, which means that they contribute differently for the independence of the energy system from external resources. The resource with a higher potential of supply is better positioned to answer to the future energy needs.
Single-vector's Resource
The exclusivity or not regarding the energy vector that the competing resources can provide allows deciding about the choice between either one or the other, where the single-vector resource must be privileged. In a practical way, considering the case of an island where all the natural resources can provide electricity, the first strategic move will consider the use of wind for electricity, giving it exclusivity regarding the vector that can provide while at same time frees the sun and biomass to provide other energy vectors.

Resource's Reliability
Giving the intermittence characteristic of most of the renewable energy resources it is important to consider the consistence of the energy resource's occurrence (e.g. wind regimes or solar exposure) and the capability to manage its stock, which contributes for the reliability of the supply.
Contribution to decentralization
The contribution for the decentralization of the supply infrastructures and the proximity between production and consumption is promoted as higher is the access to the resource and its distribution in the territory.
Technological readiness
The quality of the technological solutions for the exploitation of energy resources affects the availability of energy options. A resource that has available mature technological solutions for its exploitation, reliable, with high performance and easy maintenance it will be preferred over the others.

Table XXVII – Assessment table of different resources to provide a single energy vector

Vector	Possible Resources	Energy Aspects				
		Contribute to Independence	Single-vector Resource	Resource's Reliability	Contribute to Decentralization	Technological readiness
Electricity	Sun	++	0	+	+	+
	Wind	+	+	+	+	++

Legend: + positive impact; 0 without significant impact; - negative impact

6.2.4.2. Building pathways for the future

This step considers scenario's building by putting together the strategies defined before. By inserting in a matrix the strategies from the demand and the strategies from the supply, different scenarios are generated for the energy system (Table XXVIII). The generated scenarios correspond to pathways for the region, in energy terms, which need to be characterized at this point qualitatively.

Table XXVIII – Matrix for the generation of scenarios

		Supply	
		S1	S2
Demand	D1	A	B
	D2	C	D

When the number of scenarios become too high due to a great number of strategies at demand and supply side, being unfeasible to model all of them, other methods for the

development of scenarios can be applied such as the two axes method, branch analysis method or the cone of plausibility method (Foresight 2009).

6.2.4.3. Modelling Scenarios

SEA recognizes backcasting techniques as central to a strategic approach to sustainable development (Partidário 2012) to better cope with high levels of uncertainty and complexity. This way, SEA can work on the gap between where we are and the expectation on a desirable future, searching for the risks and opportunities of optional pathways, or strategies. As the scenarios are based on energy strategies for demand and supply, they can be associated to possible energy planning pathways aimed at a new vision for the energy system allowing the assessment of opportunities and risks based on the CDF. The modeling of scenarios for the region provide substance to these pathways with a quantitative characterization.

As the scenarios represent the matching between the demand and the resources in the future, through the supply, this step includes an iterative process, where demand and supply are progressively adjusted to each other. This means that departing from a demand that is quantified on the base year and based on assumptions for the scenarios, installed capacity for the supply can be computed to respond to those needs. However, that capacity is limited to the region's potential and therefore the first supply obtained may need adjustments until the use of endogenous resources respects the region's capacity.

The result of this stage is the characterization of the scenarios, expressing different pathways followed for the planning of the energy system towards an intended vision.

6.2.5. Stage V – Assessment

The pathways that were explored above express the different planning proposals that can be adopted for the energy system. Those planning proposals are assessed in terms of its risks and opportunities taking into account the modeling results for each scenario. The assessment considers the energy-specific perspective and also the integration of the proposals in the context of the region. At a first level, a restrict energy analysis based on energy indicators can be made regarding the performance of the scenarios (section 6.2.5.1) providing a common base for comparison among scenarios. The final

assessment (section 6.2.5.2) uses the SEA assessment framework to help with the choice of the planning proposals.

6.2.5.1. Energy performance of scenarios

Following the guidelines for the energy performance in section 6.2.3.1 for the base year, also the scenarios are analysed regarding their energy performance, both in terms of the indicators related with the energy principles as well with the benchmark indicators. At the end of the analysis is possible to compare scenarios and considering that each scenario represents a pathway to achieve the vision, is possible to identify the one that has a better performance towards that vision. However, the selection of a proposal based only on the energy performance is insufficient when a larger framework in a context of sustainability, being necessary a last step for the assessment and choice of proposals.

6.2.5.2. Integrated assessment of planning proposals

As the final goal of the methodological framework is the integrated assessment of planning proposals, to help on the choice of a planning option for sustainable energy systems, it is necessary to introduce other than the energy-specific indicators. As developed in section 6.2.1.4, regarding the assessment framework, other indicators were defined that can now be applied to assess the different scenarios created. These indicators are now developed in Table XXIX. By considering together the results obtained for the energy performance and the remaining indicators now specified, is then possible to finalise the assessment process.

Table XXIX – Specification of the remaining indicators mentioned on the assessment framework for an integrated assessment of planning proposals

Shift on energy vectors in use	
Description	The energy shift (E_{shift}) represents the change from one energy vector to another, being the result of end-use technology changes or different energy transformation processes along the energy chain (from supply to demand).
Elements under consideration	Calculation method
Energy Service (ES_n), where n = electricity specific, heating/cooling and motion	It is accounted in terms of final energy by energy vector for an energy service, considering the absolute difference between the traditional demand (resulting from a business-as-usual scenario) and the alternative scenarios under analysis. $E_{shift} = \sum (BAUF.E_{EVn} - SCxF.E_{EVn})_{ESn} $
BAU Final Energy (BAUF.E.) by energy vector (EV): BAUF.E.EV1, ..., BAUF.E.EVn	
Scenario X Final Energy (SCxF.E.) by energy vector (EV): SCxF.E.EV1, ..., SCxF.E.EVn	

Energy exploitation of natural resources			
Description	Considers the level of exploitation ($L_{Exp.}$) of the natural energy resources based on the overall existences and the number of resources that are being explored near their limit. Implies knowing the energy potential of each natural resource, which can be estimated based on available supply technology.		
Elements under consideration		Calculation method	
Total number of natural energy resources (NER_T)		$L_{Exp.} = \frac{NER_{Limit}}{NER_T}$	
Number of natural energy resources explored near their limit (NER_{Limit})			
Total installed capacity for energy purposes			
Description	Takes into account the total installed capacity (TIC) for energy supply from renewable resources. Implies knowing the energy potential of each natural resource and depends only on the considerations taken to build each scenario.		
Elements under consideration		Calculation method	
Installed capacity from each available renewable energy resources (ICR_n)		$TIC = \sum ICR_n$	
Competition among other uses			
Description	This indicator is applied to the natural renewable energy resources that can have other uses (e. g. water or biomass resources). It tries to assess the affection that energy purposes can have on the use of those resources for other purposes, in a qualitative way.		
Elements under consideration		Calculation method	
As a qualitative indicator, the elements under consideration are qualitative and depend from the analysis of existing plans, goals and trends for the use of natural renewable resources		As a qualitative indicator, it is not based a calculation method. Three levels are defined: 0 = low affection on other uses 1 = medium affection on other uses 2 = high affection on other uses	
Competition for same territorial area			
Description	Considers the natural renewable energy resources that have a territorial expression on their use (e.g. sun or wind) and is translated in terms of total occupied area (TOA).		
Elements under consideration		Calculation method	
Occupied area on the use of natural renewable energy resources (OAn)		$TOA = \sum OAn$	
Adequacy to territorial strategy			
Description	Assesses the contribution of energy planning proposals to the strategy followed for territorial development.		
Elements under consideration		Calculation method	
As a qualitative indicator, the elements under consideration are qualitative and depend from the analysis of existing planning strategies, goals and trends for the island (or territory).		As a qualitative indicator, it is not based a calculation method. Five levels are defined: -2 = global negative contribution for the development path -1 = partial negative contribution for the development path 0 = without specific contribution for the development path 1 = partial positive contribution for the development path 2 = global positive contribution for the development path	
Amelioration of natural sensitiveness			
Description	Accounts for the positive or negative effects that energy planning proposals can have on the overall environmental context of analysis, particularly regarding specific measures about the most susceptible natural features.		
Elements under consideration		Calculation method	
As a qualitative indicator, the elements under consideration are qualitative and depend from the analysis of existing environmental plans and goals.		As a qualitative indicator, it is not based a calculation method. Two status are defined: + with positive effect - with negative effect	

Access to energy for all	
Description	The access to energy for all considers factors such as intra-generational access to energy, intergenerational access to energy or energy costs, so that energy as a component of development can be assured for all, at short and long-term and transversal to all society levels.
Elements under consideration	Calculation method
Intra-generational access to energy	Relates with the effort that current generation has to apply to accomplish the planning proposal. Affected by the shift at the demand side, it is considered that the efforts to attain a higher shift imply the change of end-use equipment, resulting in higher intra-generational inequalities and difficult access to the energy vectors considered in the planning proposals. This effort can be expressed in terms of % of energy to shift.
Intergenerational access to energy	Based on the dependency of islands from external energy resources, it assumes that the intergenerational access to energy is higher when the island reduces its energy dependency and can be expressed in terms of % of external energy required.
Electricity costs	The electricity costs allow to compare the economic effort to access a widely used energy vector. According technologies and resource availability, different electricity costs are achieved, which contribute for the global cost of the electricity mix. These values can be obtained from existing studies and databases or calculated into more detail for each specific case.
Jobs creation	
Description	Considers the number of jobs created by each energy scenario. These values can be obtained from existing studies and databases or gauged in more detail for each specific case.
Elements under consideration	Calculation method
-	-
Percentage of renewable electricity	
Description	Accounts for the renewable electricity in the electricity mix (% Elect. _{Ren}). Despite focusing a specific energy vector (electricity) it is an important indicator both internally for the assessment among options as externally for the benchmark with other energy systems.
Elements under consideration	Calculation method
Electricity from renewables (Elect. _{Ren})	$\% Elect_{Ren} = \frac{Elect_{Ren}}{Elect_T}$
Total electricity consumed (Elect. _T)	

This is a strategic assessment as it is based on the CDF, criteria and indicators defined in the assessment framework, where risks and opportunities associated to the strategic options are identified. Also it allows, as referred before, the enhancement of the energy planning process by improving the existing proposal or helping elaborating new ones even at a final stage of the process.

6.3. Final remarks

The methodological framework for the planning of sustainable energy systems was described along this chapter. Although the part related with energy can be more specified

giving its technical characteristics, all the methodological steps present an effort to define the elements to be applied along the methodological framework, from the energy planning side as well as from SEA methodology. This provides a departing point for the application of the methodological framework to practical cases but also assures the necessary flexibility for a critical analysis of the energy situation in each specific case and the development of a tailored made planning process.

At the end of the description of this integrated planning framework it is important to highlight the learning cycle introduced by the “continuous stage” considered in the SEA methodology, consisting on an on-going routine of follow-up, monitoring, evaluation and communication. In a more conceptual way, this means that, despite the methodology described in this chapter is presented in a linear way and in a progression of steps, the results at each stage can be improved by the achievements of the following stage. Windows of opportunity can be identified and initial solutions (in terms of strategies or planning proposals) can be enhanced. Moreover, in practice for energy planning, it means that it makes the process more sensitive to the real circumstances that affect the trajectory of the energy planning process, allowing for a continuous adjustment of the chosen proposal to achieve the vision about sustainable energy systems.

7. Applying the methodological framework - The energy planning process in Gran Canary

7.1. Introduction

This chapter performs the practical application of the methodological framework in a real context. This allows testing the applicability of the energy concepts under the vision for the planning process and all the changes proposed for a new planning of energy systems, especially the restructuring of the energy model.

The island of Gran Canary was chosen to apply the methodological framework and concepts presented in the research, given its current situation. Gran Canary, as an island, presents the boundary conditions of the problem of being an isolated system. Also allows for the free application of the methodology once it presents some independence at national level as an autonomous regional authority and for being a territory that already has some strategic guidelines for its sustainable development but where options for action are still open. The fact that it fairly represents the context of developed countries and their energy issues as stated on the description of the problem, with the need to improve the energy demand structure and with endogenous renewable energy resources easily identifiable, facilitates the energy planning exercise.

7.2. The context - Gran Canary

Gran Canary belongs to Spain and is one of the seven islands that constitute the Canary archipelago (Figure 21). The archipelago has a volcanic origin, which Gran Canary is representative, with a characteristic morphology and geology that develops from the sea level on coastal areas to a great vertical dimension in the inner centre that reach the maximum altitude of 1950 meters. The island has an area of 1560 km² and a coastal length of 256 km.

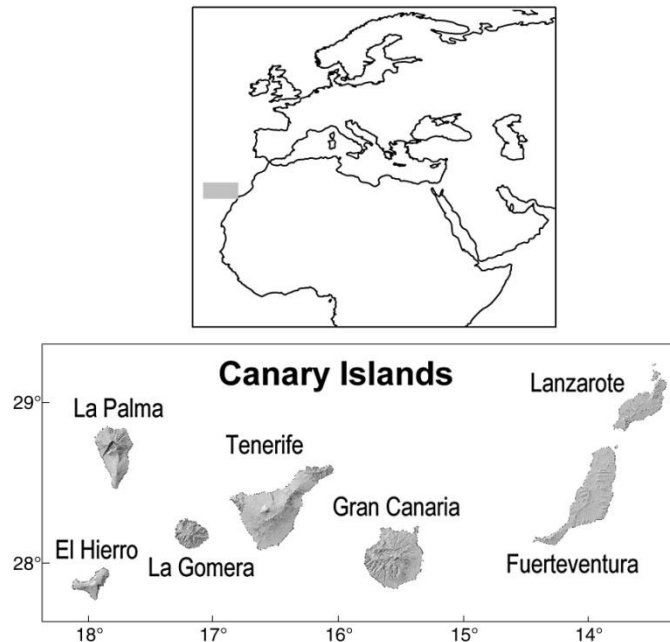


Figure 21 – Location of the Canary Archipelago (adapted from Alcover et al. (2009))

Being Spanish territory, it locates in the south-western end of Europe, in the Atlantic Saharan platform (Castranys and Blanco 2003), presenting a semitropical climate due to the influence of the Gulf Stream and trade winds regime. It is characterized by a dry climate where most of the rains are orographic, occurring along the slopes of the mountains. There is a dualism between the north facade, wetter, and the south facade, drier. Winter registers the rainiest periods, although with a low mean precipitation and average temperatures are mild. Nevertheless, high temperatures are recorded during summer season reaching 40°C (due to heat waves) and low temperatures near 0°C are common in almost all territory in the cold season, resulting in frost (Cabildo de Gran Canaria 2010; García-Blanco et al. 2003a).

The current population slightly surpasses 850000 inhabitants according the last available data at ISTAC, being registered a constant growth on resident population over the last years. The distribution on the territory is heterogeneous depending on the type of municipality (metropolitan, urban or rural area) and the land use has changed giving the evolution of the dynamics of the population from rural to urban areas. In a global way, the traditional agricultural model of the island has changed to an island where (García-Blanco et al. 2003b):

- The north and northeast is characterised by a combination of housing areas, industry, warehouses and other urban uses;

- The south and southwest areas are dedicated to touristic activities and infrastructures, with a great speculation and lack of planning. Some agro-tourism exists also in this area although roughly integrated in the economic activities;
- The phenomena of second housing and agriculture at partial time is generalised in the inland areas, causing some desertion.
- The territory at high altitude and the occidental coastal area have the highest environmental protection, giving the difficult access and low human density.

Additionally to the resident population of the island, is of relevance the significant floating population, mainly represented by tourists.

Regarding the activities developed in the island, the Gran Canary is characterized as a dual island (old island versus new island) according its southeast-northwest axis, where the traditional and environmentally preserved part is located in the south-eastern side opposed to the anthropogenic developed part of the island located on the north-western part (Cabildo de Gran Canaria 2010). The evolution of the economic activities in the island is characterized in global terms by a transition from the primary sector (agriculture) to the tertiary sector (tourism). Gran Canary presents an open and dependent economy, where production of goods and services is targeted to exportation and the domestic market dependent on importation. This type of evolution on the development model of the island was posed by the limits of the available natural resources, giving origin to a geographically and sectoral polarized island (Castanys and Blanco 2003).

In energy terms, Gran Canary, as all the other islands of the Canary archipelago is almost totally dependent from external energy. Based on the energy statistics for the island (EEC 2005 and EEC 2006, modelled using LEAP), the energy system of the Gran Canary is based on fossil fuels, used as final energy mainly for transportation needs, besides the generation of electricity.

The main renewable resources used in the island are wind and sun, for electricity generation and thermal uses.

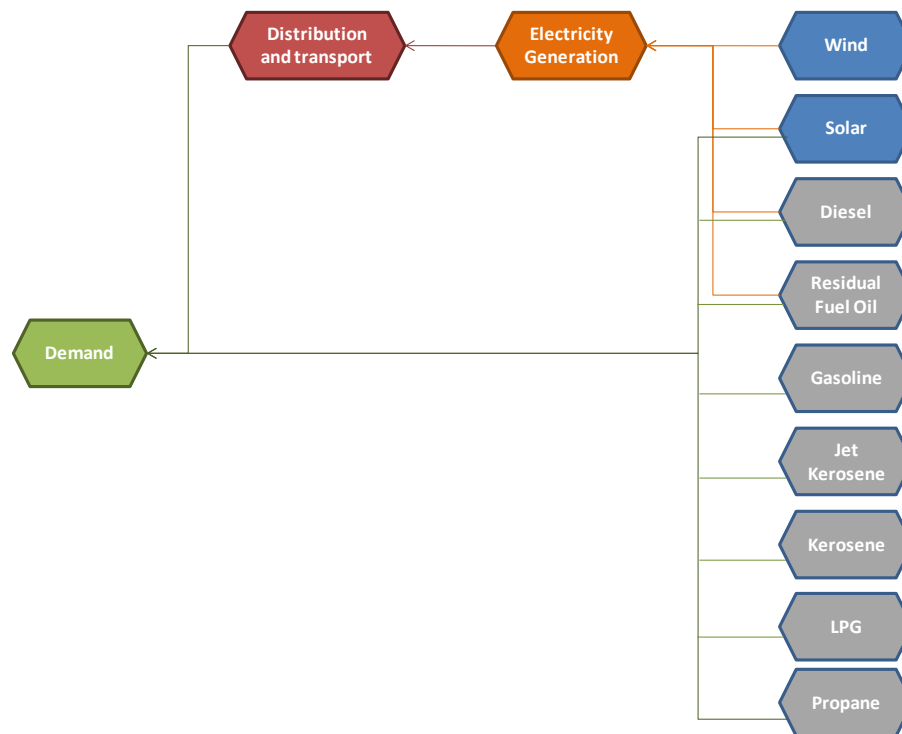


Figure 22 - Simplified diagram of energy resources in use in Gran Canary

The energy demand, considering the year 2006, is mainly for transportation (86%), followed by buildings (10%; includes domestic and services sectors) and industry (3%), as shown in Figure 23. Excluding fuel consumption for air and water transportation from the analysis, transportation continues to be the major sector of consumption (50%), but the other sectors gain a new dimension, with buildings representing 33% of the consumption and industry 12% (see Figure 24).

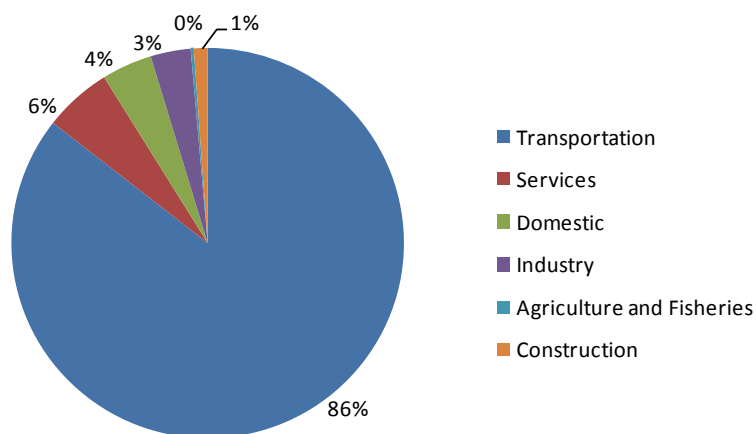


Figure 23 - Final energy demand in Gran Canary, by activity sector

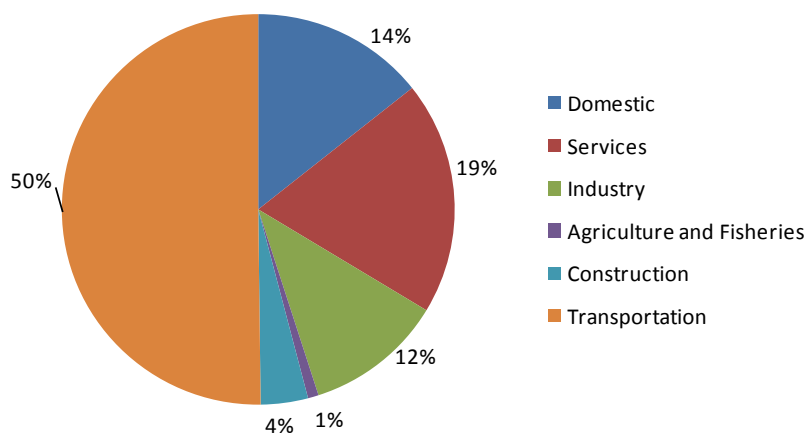


Figure 24 - Final energy demand in Gran Canary, by activity sector, excluding air and water transportation

To respond to the energy demand presented above, the main energy vectors used in Gran Canary are fossil fuels (see Figure 25 and Figure 26), consumed directly for end-use by several activity sectors, to which the transportation sector has articular relevance. These energy vectors are followed by electricity, itself coming from 98% of fossil fuels (see Figure 27).

The high consumption of fossil fuels brings important concerns related with CO₂ emissions that, for the year 2006, were about 13.2 ton/capita.

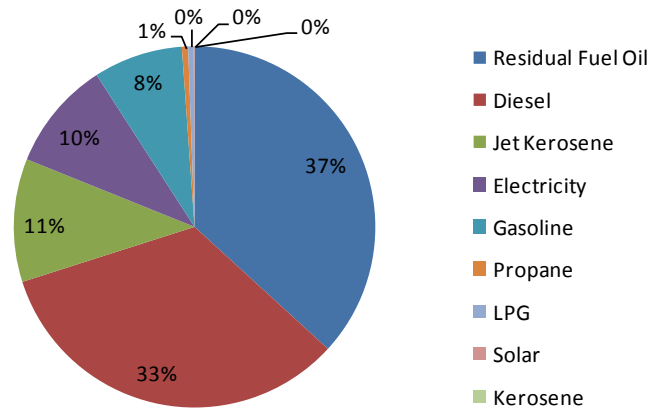


Figure 25 – Energy vectors in use by energy demand in Gran Canary

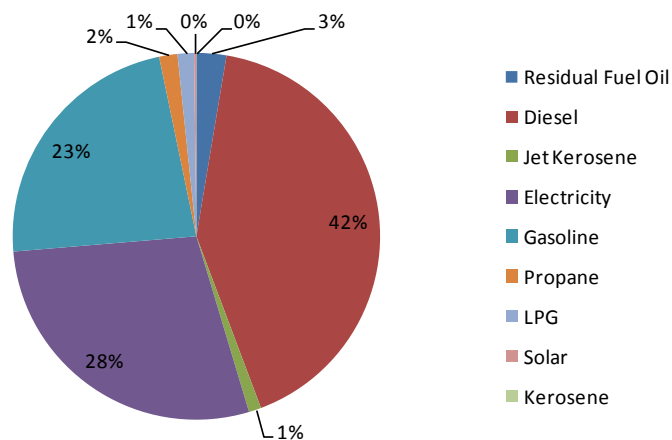


Figure 26 - Energy vectors in use by energy demand in Gran Canary, excluding air and water transportation

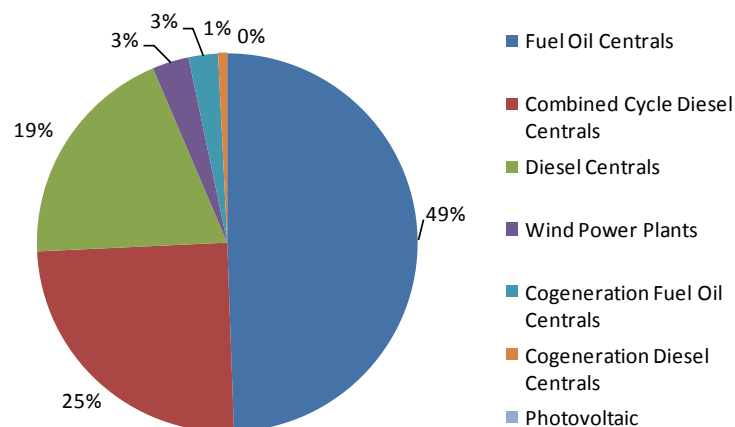


Figure 27 – Energy vectors in use for transformation into electricity, in Gran Canary

From the previous social-economic characterization, the overview about the energy system in Gran Canary and also considering the energy context of the Canary archipelago (Izquierdo 2005), is possible to understand Gran Canary as an island with a constant increase of energy demand, while dependent from external energy resources. To intensify the energy dimension, the water-energy binomial has a great weight as the lack of water resources implies artificial water production systems through desalination. Given the geostrategic location and attractiveness for tourism, both human and freight transportation aggravate heavily the energy needs.

All these factors contribute for an increased concern with the sustainability of the energy system, which translates into a will to diversify energy sources considering the endogenous capacity (despite not being used yet) and potentiated by qualified research centres in the field. Moreover, is recognized the need to act at demand level for demand side management and energy efficiency, as well as to contribute for the minimization of environmental effects of energy and energy installations.

Considering the bottlenecks and opportunities for improvement exposed above, Gran Canary constitutes a real example to which the methodological framework for sustainable energy systems can be applied.

7.3. Applying the Methodological Framework

The methodological framework for the energy planning process, departing from the establishment of the strategic framework, distinguishes afterwards four major practical stages:

- i) The modelling of the energy systems - according the tripartite vision and a new structure based on the energy services;
- ii) The analysis of the energy system – assessing the system’s status at the light of the energy planning principles and understanding the major trends expected to drive the energy system;
- iii) The development of options and creation of future scenarios – thinking about energy strategies in an integrated approach supported by SEA elements for sustainable energy systems

- iv) The assessment – elucidating about the best options according the integrated vision for the energy system.

For the practical application, a common working base was set for the areas identified above, using several spreadsheets, constituting the “Integrated Energy Planning” (see Figure 28).

INTEGRATED MODEL - Microsoft Excel		
METHODOLOGICAL FRAMEWORK FOR SUSTAINABLE ENERGY SYSTEMS PLANNING		
1. MODELLING THE TRIPARTITE ENERGY SYSTEM		
» 1.1. RENEWABLE ENERGY RESOURCES		
1.2. ENERGY DEMAND		
» 1.2.1. DOMESTIC SECTOR		
» 1.2.2. SERVICES SECTOR		
» 1.2.3. INDUSTRY SECTOR		
» 1.2.4. AGRICULTURE & FISHERIES and CONSTRUCTION SECTORS		
» 1.2.5. TRANSPORTATION SECTOR		
» 1.3. ENERGY SUPPLY		
» 2. ANALYSIS OF ENERGY SYSTEM'S COMPONENTS		
2.1. RENEWABLE ENERGY RESOURCES		
» 2.2. ENERGY DEMAND		
» 2.3. ENERGY SUPPLY		
» 2.4. TRENDS, STRENGTHS AND WEAKNESSES		
3. DEVELOPING STRATEGIES AND CREATING SCENARIOS		
» 3.1. DEVELOPING ENERGY STRATEGIES		
3.2. MODELLING DEMAND STRATEGIES		
» 3.2.1. DOMESTIC SECTOR		
» 3.2.2. SERVICES SECTOR		
» 3.2.3. INDUSTRY SECTOR		
» 3.2.4. AGRICULTURE & FISHERIES and CONSTRUCTION SECTORS		
» 3.2.5. TRANSPORTATION SECTOR		
» 3.2.6. OTHERS		
» 3.3. SCENARIOS' BUILDING		
» 3.4. MODELLING SCENARIOS		
4. INTEGRATED ASSESSMENT		
» 4.2. ENERGY PERFORMANCE		
» 4.3. INTEGRATED ASSESSMENT		
» INTEGRATED ENERGY PLANNING	1.1 RENEWABLE ENERGY RESOURCES	1.2.1. DOME

Figure 28 – Index sheet for the “Integrated Energy Planning” - Framework for the planning of sustainable energy systems

7.3.1. Setting the strategic framework

The strategic framework for Gran Canary is developed based on the strategic elements already defined along section 6.2.1. The scope of application of the framework was the

inland energy system, which left out of the energy system the energy consumptions related to maritime activities or air transportation.

The energy vision and strategic issues, adapted to Gran Canary are presented in Box 9 and the related planning dimensions defined in section 6.2.1.2 were maintained for the practical context.

Box 9 – Energy vision and strategic issues that drive the energy planning process in Gran Canary

VISION Gran Canary's energy system will be based on endogenous renewable energy resources contributing for the island's energy self-sufficiency. In that sense, supply and demand will be adequate to each other, where supply is decentralized and consumption occurs in a logic of proximity. Energy demand will be structured by energy service and prepared for the matching with existing resources by the adequate use of energy vectors. Moreover, the planning process of the system will consider and contribute for a sustainable development of the island. STRATEGIC ISSUES 1. Development of the energy supply based on endogenous renewable energy resources. 2. Smart structuring of energy consumption based on a quantitative and qualitative analysis of the energy demand. 3. Respect the intrinsic natural value of Gran Canary while exploring its endogenous renewable energy resources. 4. Contribute for a sustainable development model, taking into consideration welfare of Gran Canary people.

The strategic reference framework (SRF) for Gran Canary collected the energy and sustainability macro-policies affecting the island and identified the orientations and targets established in energy and environmental terms. The results and references are presented in Annex II.

The assessment framework was developed based on the elements described in the methodological framework (see section 6.2.5.2), resulting in three CDF specific for Gran Canary to assess each planning proposal:

1. Energy Shift: expresses the transformation of the energy system of Gran Canary, assessing the energy performance according to the energy vision and the requirements of the strategic reference framework;

2. **Natural Resources and Territorial Shape:** assesses the use of natural resources for energy purposes in the wider context of the territorial shape, meaning the physical, ecological and social expression in the territory.
3. **Energy and Development Nexus:** considers the adequacy and contribution to the development path proposed by the land-use plan in the island, assessing Gran Canary competitiveness.

According these three CDF, criteria and indicators were defined to perform the assessment, as presented in Table XXX. These criteria and indicators introduce the concerns related with the other dimensions affected by the energy planning process and their effectiveness is higher when resulting from participatory processes. However, being the participatory process out of the scope of this exercise⁵, criteria and indicators used for this case were developed considering the specific case and based on the literature review.

Table XXX – Criteria and indicators according CDF, defined for the integrated assessment of the energy planning proposals

Energy Shift	
Criteria: - Shift on energy supply - Shift on energy demand	Indicators: - Diversity - Adequacy to energy services - Self-sufficiency - Decentralization - Shift on energy vectors in use - Level of matching
Natural Resources and Territorial Shape	
Criteria: - Energy intensity regarding the use of natural resources - Affection on the global use of natural resources	Indicators: - Energy exploitation of natural resources - Total installed capacity for energy purposes - Competition among other uses - Competition for same territorial areas
Energy and Development Nexus	
Criteria: - Contribution to SD path adopted for Gran Canary	Indicators: - Adequacy to territorial strategy - Amelioration of natural sensitiveness - Intra-generational access to energy

⁵ Despite not being developed at this work, the participatory process is of great importance, particularly at this first stage of the planning process, where the intervention of diversified agents and stakeholder strongly contribute to build the processes as a real strategic one.

- General SD concerns related to the use of energy	- Intergenerational access to energy - Energy affordability - Jobs creation - CO2 emissions - % of renewable electricity
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From the indicators presented above for the integrated assessment, the ones related with the energy performance were explained on previous chapter (see Table XXIII) and can be directly applied on the analysis. The other indicators used for the integrated assessment were also detailed before (see Table XXIX), but as they are more context-dependent, Table XXXI recalls their definition with some adjustments for the specific case of Gran Canary.

Table XXXI – Definition of indicators used for the integrated assessment of energy planning proposals

Shift on energy vectors in use
Evaluates the shift capacity of the demand by adopting the energy vectors adequate to the energy service required. The higher the shift, the higher the contribution from the demand side for the energy vision.
Energy exploitation of natural resources
Considers the exploitation of the natural energy resources on each planning proposal, regarding the thresholds of the natural resources in the island for that purpose, according the values: 0 = all the energy resources are explored below their energy threshold]0 ; 0.5[= less than half of the energy resources are explored near their energy threshold [0.5 ; 1]= half or more of the energy resources are explored near their energy threshold
Total installed capacity for energy purposes
Considers the total installed capacity of the endogenous renewable energy supply in order to evaluate the planning proposals regarding the intensity of use of the island's natural energy resources.
Competition among other uses
Applied to the energy resources that can have multiple uses (e. g. water or biomass resources), this indicator considers the affection of those resources according three levels: 0 = low affection on other uses 1 = medium affection on other uses 2 = high affection on other uses
Competition for same territorial areas
Considers the physical expression of the planning proposals (translated in terms of land areas) assuming that planning proposals with higher occupied land areas for energy purposes represent higher pressure/competition with other uses of land-based resources in the island.
Adequacy to territorial strategy
Assesses the contribution of the planning proposals to the development strategy followed in the island. This contribution is based on the strengths that each proposal represents, according five levels: -2 = global negative contribution for the development path -1 = partial negative contribution for the development path 0 = without specific contribution for the development path 1 = partial positive contribution for the development path 2 = global negative contribution for the development path

Amelioration of natural sensitiveness
Accounts for the overall positive or negative effects that energy planning proposals can have on the global environmental context of the island: 0 null effect + positive effect - negative effect
Intra-generational access to energy
Relates with the effort that current generation has to apply to accomplish the planning proposal. Affected by the shift at the demand side, it is considered that the efforts to attain a higher shift imply the change of end-use equipment, resulting in higher intra-generational inequalities and difficult access to the energy vectors considered in the planning proposals. It is calculated in terms of percentage according the amount of energy that responds to the shift in the total final energy required by the demand.
Intergenerational access to energy
Based on the dependency of Gran Canary from external energy resources, it assumes that the intergenerational access to energy is higher when the island reduces its energy dependency. It is translated in terms of percentage of external energy dependency, being the best proposal the one that represents the lower value.
Energy affordability
Considers the access to energy based on its global cost for unit of energy, assuming that the lowest the cost, the higher the energy affordability. It accounted the levelized cost of electricity for electricity at current prices (\$/kWh) according NREL database (NREL 2012).
Jobs creation
Considers the contribute of each planning proposal to create jobs and boost economic activities in the island, assuming that a more decentralised energy system contributes for more jobs creation (regarding installation and maintenance) and a diversified system contributes for the creation of value (through creating expertise and know-how that can be exported). It accounted the number of jobs created according M. Wei et al. (2010).

7.3.2. Energy modelling of Gran Canary energy system

For the first step of the modelling stage, regarding the representation of the energy system, it was adopted the representation expressed in section 6.2.2.1 taking into consideration the scope of application mentioned above, where it is considered for the exercise the inland energy system (excluding energy consumptions related to maritime activities or air transportation). The energy system was modelled considering the three distinct parts: the endogenous renewable natural energy resources, the energy demand and the energy supply.

Regarding the energy resources, the characterization was based on a survey about the existing endogenous natural renewable energy resources and their energy potential considering:

- a) natural energy potential (e.g. solar irradiation or wind velocities);
- b) available exploitation technologies;
- c) direct restrictions to the use of resources (e.g. exclusion of protected areas).

Both demand and supply were modelled for an annual basis (2006 was the base year considered, giving the completeness of data available), following the structures presented in section 6.2.2.2. For the demand, it was considered the consumption on inland, which exclude consumptions associated to external activities, such as air transportation to/from mainland or other islands and fuel supply to ship crossings. The inland consumption was disaggregated for each activity sector and category of end use, followed by a restructure by energy service (Figure 29), and under energy service, by purpose and vectors used (see Figure 30, Figure 31 and Figure 32). For the supply, the model considered the installed capacity and energy produced in the island by energy resource and energy vector (Figure 33).

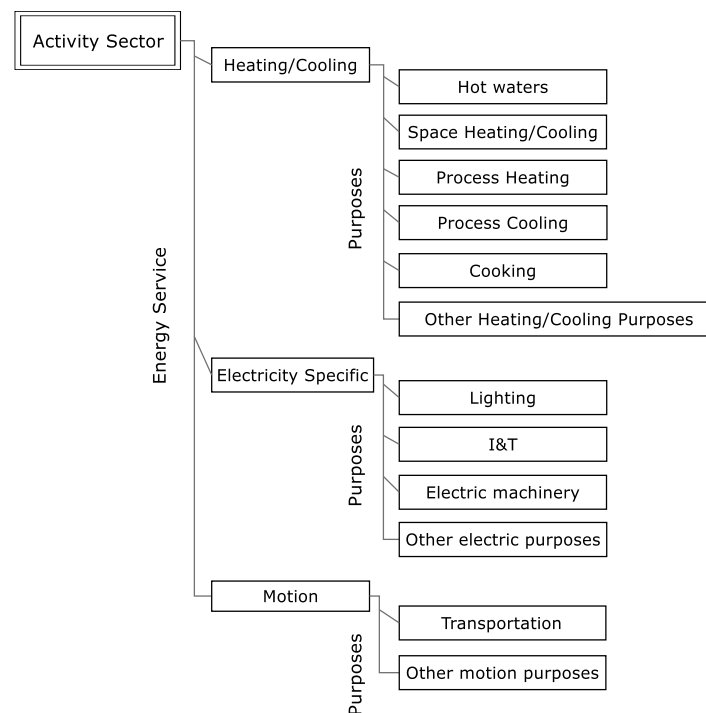


Figure 29 – Structure of energy demand by energy service, according each activity sector

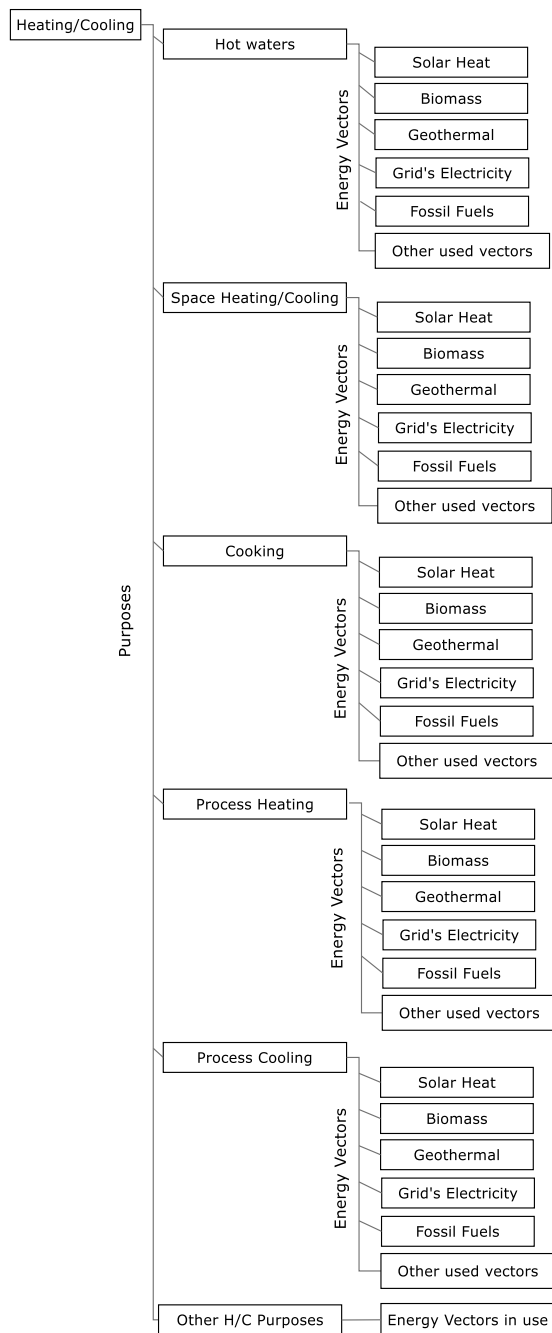


Figure 30 - Energy demand by energy vector, according energy service – specific case of Heating/Cooling

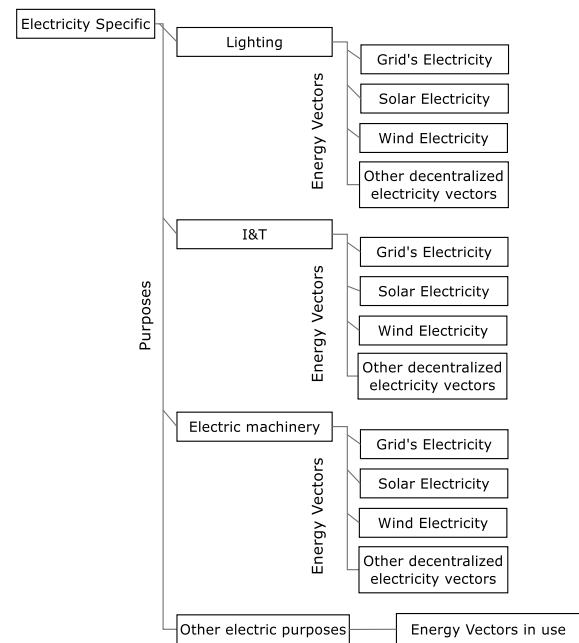


Figure 31 – Energy demand by energy vector, according energy service – specific case of Electricity Specific

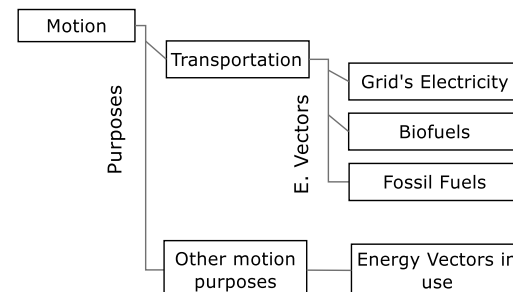


Figure 32 - Energy demand by energy vector, according energy service – specific case of Motion

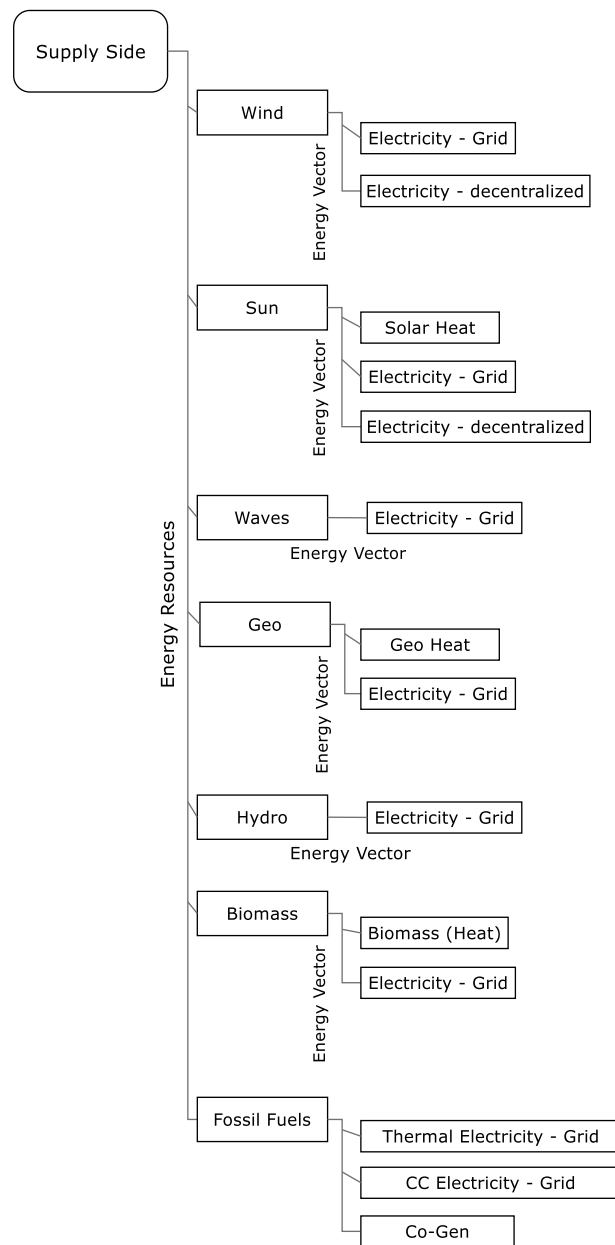


Figure 33 – Energy supply structure by resource and vector provided

The major data resources used to fulfil the data requirements are synthesised in Table XXXII, although the collection have occur along research time and several other sources have been used to support and verify the main information. The level of detail of the model (and therefore the quality of the results) is strongly affected by the availability of data, which pose great importance on the stage of gathering information. This can be time consuming giving the disperse scope of the information, which not always is directly

available but sometimes can be deducted with some accuracy. Moreover, energy-related information, particularly from the supply side, tends to be confidential and access is difficult.

Table XXXII – Data needs and sources used for the modelling of Gran Canary energy system

Data Requirements and Sources	
General	Energy units conversion factors (APS 2012)
	Specific conversion factors for Gran Canary energy system (Gobierno de Canarias 2006)
	Demographic and economic indicators (ISTAC 2005a, 2007a, 2009b; Muñoz and Falcón 1998)
Resources	Qualitative energy potential of renewable resources in Canary archipelago (A. Garcia and Meisen 2008)
	Land use – territorial statistics (ISTAC 2005b)
	Protected natural areas statistics (ISTAC 2007b)
	Canary archipelago wind resource areas (ITC 2007)
	Wind power capacity density (Denholm et al. 2009)
	Solar irradiance in Gran Canary (Schillings 2005)
	Biomass crops and areas (ISTAC 2009a)
	Biomass energy potential (Oliveira et al. 2005)
	Wave potential in Gran Canary (Cortadellas et al. 2011)
	Calculation methodology for Waves energy potential (EPRI 2011)
	Geothermal energy (Guzman and Marquez 2005)
	Geothermal energy potential in Gran Canary (Guzmán et al. 2011)
Demand	Characterization of energy demand in Spain
	Energy consumption in Gran Canary – base year (Gobierno de Canarias 2006)
	Characterization of demand among final users (ULL 2008)
	Domestic sector (INE 2009b, 2009c; ITC 2008)
	Economic activities sectors – Services, Industry, Agriculture and Fisheries (EIA 2006; INE 2009a; ITC 2002b; Servicio de Desarrollo Rural n/a)
	Transportation sector (DGPCT 2004; DGT 2010; M. Á. F. Garcia 2002; Luis 2006; Martínez and Cáceres 2006)
Supply	Fossil Fuels (CORES 2006, 2008)
	Supply Infrastructures and electricity production (Gobierno de Canarias n/a; ITC 2002a; REE 2006)

7.3.3. Analysis of energy system for base year

The results from the modelling effort allow for an analysis and assessment of the status of the energy system for the base year. As the planning process is not aimed at predicting the future, the results obtained give a snapshot of the energy panorama for the base year (2006).

7.3.3.1. Energy Performance

In general terms, Gran Canary reveals an overall natural energy potential that could satisfy the energy demand verified in the island (see Table XXXIII and Figure 34). In fact, the saturation of endogenous capacity, which represents the ration between the annual energy demand and the energy potential of endogenous resources, is 39%, which suggests that endogenous energy resources in the island could easily satisfy the demand in quantity terms.

Table XXXIII - Matrix of the global energy potential by resource and according exploitation technology for Gran Canary

		Technology	Energy Potential (MWh/y)	Global Energy Potential
Resources	Sun	Solar Thermal	91355000	H
		PV	25000000	H
	Hydro	Hydropower	n/d	L
	Wind	Windpower	935000	H
	Sea	Waves	398475	M
		Tidal	n/a	L
	Geo	Geothermal	3460000	H
	Biomass	Biofuels	n/d	L
		Thermal	77638	M
		Power	19409	L

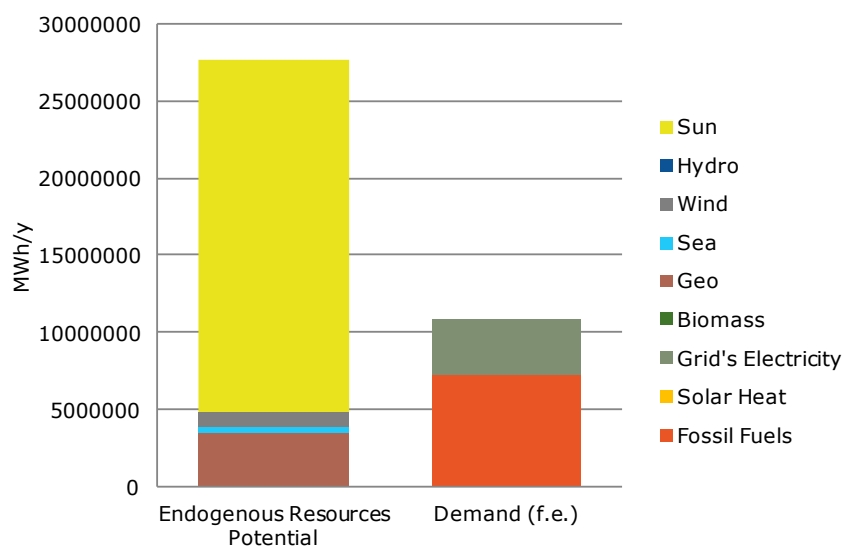


Figure 34 – Comparison between the potential energy from endogenous resources and final energy consumed

Entering in more detail regarding energy demand, the global consumption within Gran Canary was 10800 GWh and it had a distribution by activity sector as presented in Figure 35. When excluding transportation, domestic and services sectors are the most consuming activities.

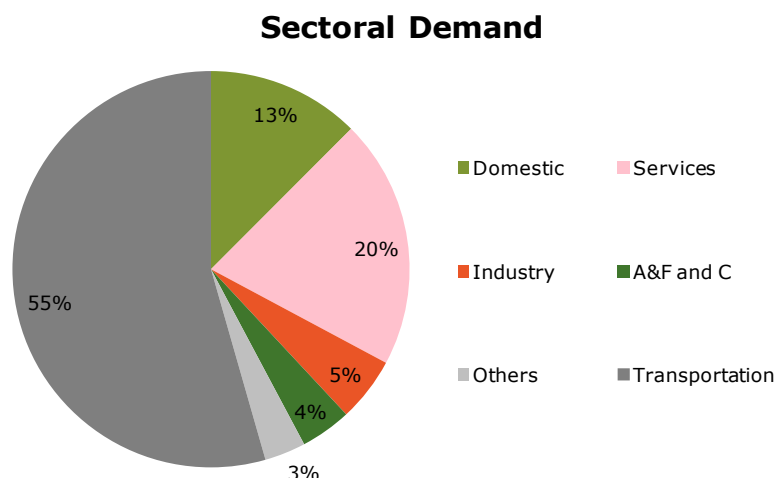


Figure 35 – Partition of energy demand by activity sector in Gran Canary

Taken into consideration the analysis focused on the energy services (Figure 36), the demand in Gran Canary is predominantly dependent from motion, which makes sense giving the weight of transportation sector in total demand. However, the importance of electricity specific services (lighting, I&T equipment and other electric devices) is expressive, representing also an important fraction of the demand.

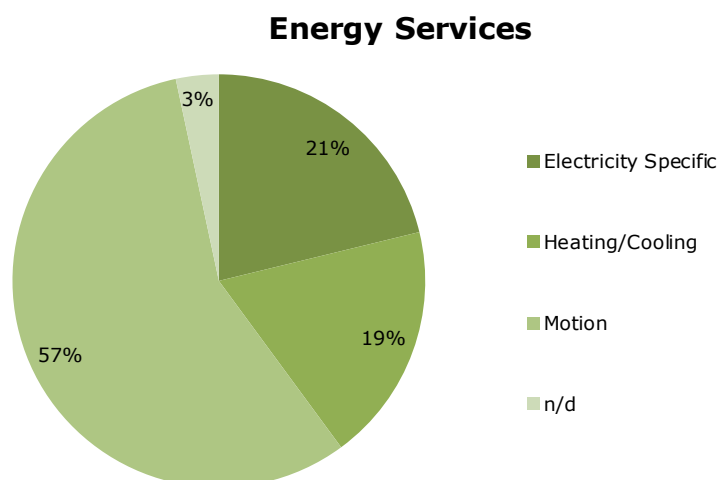


Figure 36 – Distribution of energy demand by energy service

To satisfy those services, the demand currently uses three vectors – electricity from the grid, heat from solar panels and fossil fuels. Their use is uneven as fossil fuels tend to deliver the majority of the energy required, followed by grid’s electricity and finally solar heat with almost no expression (Figure 37).

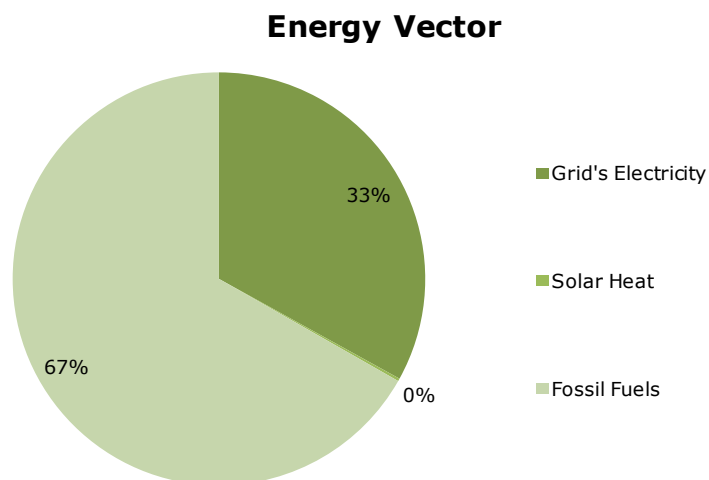


Figure 37 – Partition of energy vectors used in Gran Canary to satisfy energy demand

Considering the energy supply in Gran Canary, the total installed power accounted 1001 MW shared among wind power, solar (heat and PV) and fossil fuels as Figure 38 presents. The primary energy used was 16820 GWh resulting in 10995 GWh of final energy, which is delivered to the demand under the form of grid’s electricity, solar heat and fossil fuels on the proportions represented in Figure 39.

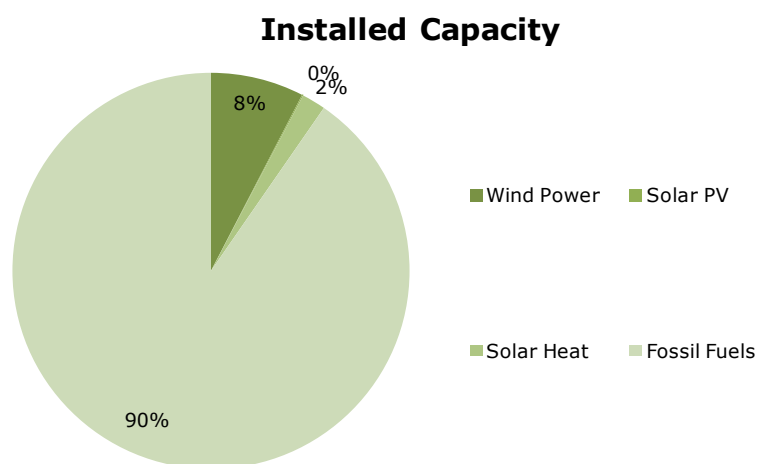


Figure 38 – Share of installed capacity in Gran Canary, by energy resource

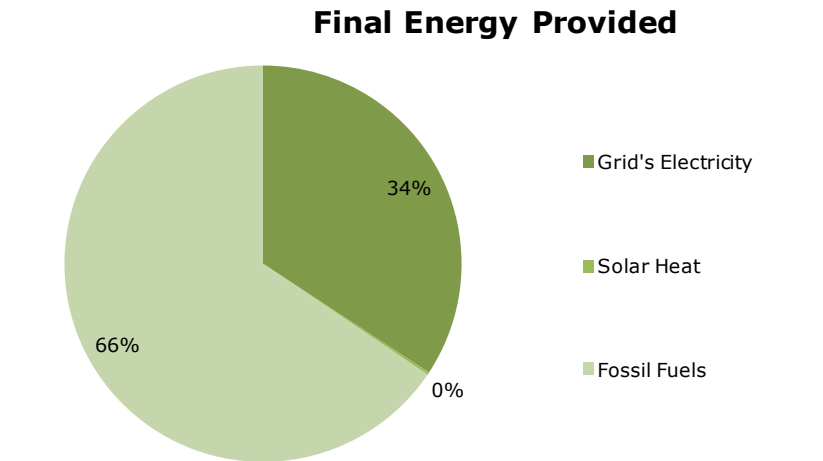


Figure 39 – Partition of energy vectors provided by the supply in Gran Canary

When analysing the situation of Gran Canary, by comparing energy supply and energy demand in terms of energy vectors and services, it is possible to note that is electricity and fossil fuels that supply almost fully the energy requirements (Figure 40).

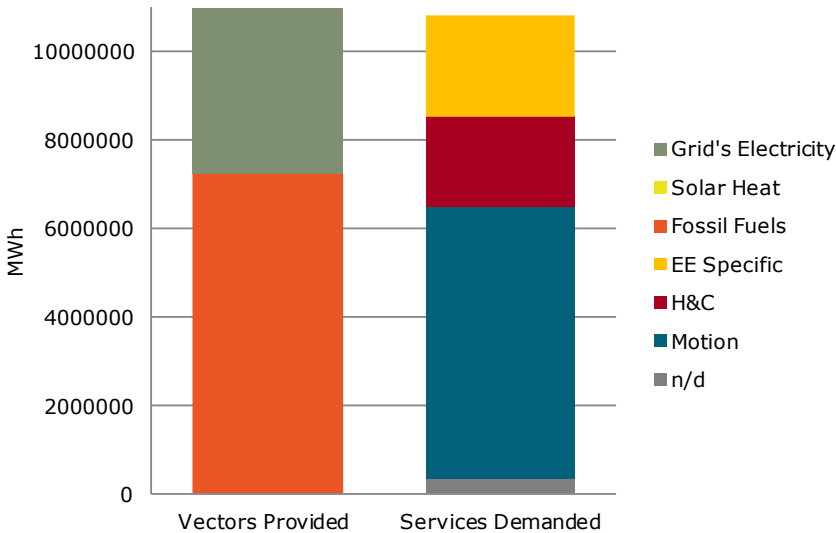


Figure 40 - Comparison between energy vectors provided and Energy services demanded in Gran Canary

By performing the energy analysis according the indicators defined in section 6.2.3.1, it is possible to obtain a characterization of the baseline status of the energy system in Gran Canary. The results of the indicators are presented in Table XXXIV. The energy image of Gran Canary at this starting point is of an island that despite being use all the available energy vectors, is half-way on the use of the potential energy vectors that it

can provide to energy consumers, as there are several natural renewable energy resources that are not being used and that otherwise could provide a higher diversity in terms of energy vectors. Moreover, considering the energy services required by the demand, the island presents a potential to better adequate the use of energy vectors, as it shows a deficit in the use of vectors adequate for heating and cooling purposes, while having a surpassing offer in what regards electricity specific services. In that sense, the response to the matching also presents a high improvement potential, as quantitatively the use of energy from endogenous resources is, for the baseline situation, 2% of the total amount of energy required for the energy services in the island.

In terms of self-sufficiency, the energy analysis shows a very small value (1.3%), which supports the idea expressed in the introductory energy context about the much dependence of Gran Canary from external energy resources. This situation is aggravated when analysing the efficiency of the energy supply, which in general terms loses globally 35% of the energy imported to the island. When reporting only to the efficiency of the electrical system, which depends from the transformation technologies used in the island for electricity production, losses reach values on the order of 61%. This means an energy systems that, while depending strongly from external energy resources, also wastes the resources imported due to its internal inefficiency.

Regarding the level of decentralization of the energy system, the baseline situation shows an island that relies on a centralized model, once that only less than 1% of the energy provided has its origin near the end-use place.

The indicators related with the performance of the energy system from direct use of energy (primary energy), complete the image of the island as a territory of medium-high intensity in the use of energy, particularly when considering the global consumption⁶ in the island (4.3 toe/inh, surpassing the national average of 3.2 toe/inh and the European average of 3.6 toe/inh according the World Bank 2006). When considering the inland consumption, the number is reduced to 1.8 toe/inh. Both these consumptions can be translated in terms of CO₂ emissions according the energy mix in the island, which represent for the global consumption the emission of 13 tCO₂ eq/inh and for the inland consumption, the emission of 5.7 tCO₂ eq/inh. Bearing in mind the importance of accounting the demand impact, it was also calculated the CO₂ equivalent

⁶ Global energy consumption includes all energy in use, while the inland energy consumption excludes energy consumption from air and water transportation.

emissions per unit of final energy consumed in Gran Canary (inland), being the value of 0.428 tCO₂ eq/MWh⁷.

Table XXXIV – Results for the assessment of the energy system according the indicators for planning principles

Indicator	Results
Attained diversity considering real situation (D_R)	100 %
Attained diversity considering the region's potential (D_P)	50%
Distance to adequacy (A_d) according energy service	Electricity specific: $A_d = 0.558$
	Heating/Cooling: $A_d = -0.989$
	Motion: $A_d = 0.177$
Self-sufficiency (E_I)	1.3%
Decentralization (Dec)	0.6%
Efficiency (η)	Global supply efficiency: $\eta = 65\%$
	Electricity specific efficiency: $\eta_{EE} = 39\%$
Response to matching (M_R)	2.0%
Energy consumption per capita	Inland: 21 MWh/inh (or 1.8 toe/inh)
	Global: 50 MWh/inh (or 4.3 toe/inh)
CO ₂ eq. emissions per capita	Inland: 5.7 tCO ₂ eq/inh
	Global: 13 tCO ₂ eq/inh
CO ₂ eq. emissions per unit of final energy	Inland: 0.428 tCO ₂ eq/MWh

7.3.3.2. Trend analysis

Departing from the elements of the strategic framework (strategic issues, dimensions and the SRF) it is possible to perform a trend analysis with the SEA, regarding past evolutions of the energy system and future possible pathways. The analysis includes the identification of policy intentions and goals that conditions the evolution of the elements of the current energy system to which the SRF contributes (Table XXXV) and the driving-forces (past and future trends) acting in the evolution of the energy system according the related planning dimensions (Table XXXVI), which are then synthesized in terms of strengths and weaknesses considering the desired vision for the energy system (Table XXXVII).

Table XXXV – Policy intentions and goals regarding each component of the Gran Canary energy system

Natural endogenous energy resources	Energy supply	Energy Demand
- Increase exploitation of wind resource	- Increase installed wind power to 411 MW in 2015	- Global energy demand registers a growth at small rates, after a period of regression
- Increase exploitation of solar resource	- Increase installed PV to 61 MW in 2015	- Electricity has a growing trend at small annual rates (between 2% and 3%)

⁷ It are use the units MWh in order to be more adequate to an analysis that has the focus on the energy services instead of final energy.

Natural endogenous energy resources	Energy supply	Energy Demand
- Exploitation of inland water resources	- Create a 1 MW hidropower project	Fossil fuels at end-use register an overall decrease, driven by: - LPG's (between 3.5% and 4%) - Gas (between 1.8% and 3%) - Industrial fossil fuels (between 0.5% and 2%)
- Exploitation of sea	- Create other renewable supply infrastructures (thermosolar centrals and wave power)	
	- Increase solar thermal (20-30% annual rate)	- Diesel consumption, after a regression period, tends to grow (between 3% and 3.5%)
	- Implementation of renewable supply tend to be below the annual goals	
	Exploitation goals (2015) on renewables register: - A positive trend regarding solar PV (+33%) - Keep wind power - A negative trend on other renewable supply (-85%) - Negative trend on solar thermal (-20%)	- Biofuels' demand with a slow growing trend - Increasing energy efficiency at end use
	- Achieve 30% renewable electricity in 2015	
	- Develop energy recovery from biological wastes (biogas)	
	- Increase co-generation	
	- Increase access to energy by the development of new energy (electricity) transportation infrastructures	
	- Introduction of biofuels and natural gas from exterior	
	- Decrease energy dependency of Gran Canary	

Table XXXVI – Driving-forces for the energy system verified on the five related planning dimensions

Natural Resources	Territorial	Social
- General growing vulnerability to human pressures deriving from the increasing energy demand and aggravated by the insular context	- General growth of built environment following two distinct trends, expansion around urban centres (particularly Las Palmas) and construction on isolated contexts, meaning an increase on the energy demand with diverse territorial expression	- Growing population
- Water as a limiting resource		- Demographic aging
- Biomass losses due to soil erosion, urbanization and forest fires	- Adequacy of transportation system and multimodal connections to the increasing mobility in the territory	- Increasing social dependency
- Improvement on the management and development of natural protected areas	The insular land-use plan points out a development path based on: - Urban renovation and	- Loss of competitiveness (particularly in tourism)

- Increasing pressure on littoral areas (landscapes and ecosystems) from concomitant uses (fishery and port infrastructures, tourism, agriculture and mining activities)	requalification - Conservation and enhancement of natural resources, landscape and cultural heritage - Preservation of territorial integrity while assuring territorial cohesion	- Negative growth on economic activities
		- Effort on diversifying and specialize the industrial sector
		- Growing costs of energy
Governance		Temporal
- Recognized the importance of education, awareness and training to transform attitudes and social habits for an energy change	- Recognized the concern with the future development path in the island	
- Increasing availability of information on-line	- Development and energy-related PPP's have short to medium-term time horizons (2015, 2020, 2025)	
- Energy decisions tend to be a highly hierarchical process (national, archipelago, island)	Search for solutions based on an expectable image of the island: - reactive planning to solve existing problems rather than forearm future ones;	
- Lack of evidence of participatory processes regarding energy	- threaten to intergenerational equity by privileging the present	

Table XXXVII – Strengths and weaknesses for the energy system in Gran Canary

Strengths	Weaknesses
- Contribution of biomass developments to combat soil erosion	- Increasing the competing demands for natural resources
- Growing effort on a supply based on mature renewables' technology	- Stress on inland water resources
- Willingness to explore emerging renewable technologies	- Low diversification of energy vectors, focused on electricity developments
- The use of co-generation to promote heat as an energy vector	- Lack of promotion of decentralized solar thermal
- Stable demand abandoning fossil fuels and searching for energy savings	- Dependency from a centralized supply
- Territorial development aimed at a rational use of resources and respecting endogenous characteristics	- Energy rising prices by infrastructures development
- Mobilize agents (population, stakeholders, local government) for the future of the energy system	- Increase dependence from exterior: by importing biofuels and natural gas
	- High requirements of transportation
	- High sensitive territory
	- Sensitive social context associated to a degradation of economic activities

In global terms, the analysis to the current state of the energy system in Gran Canary shows a considerable distance to the intended vision but the trend analysis reveal that there are possible pathways that can contribute to achieve that vision towards a higher

self-sufficiency and biophysical enhancement of the natural conditions in the island, namely by the policy intentions and goals that promote the use of endogenous renewable energy resources and the increase of energy efficiency at end use.

Nevertheless, other planning principles and concerns are not so evident on the pathways identified in the trend analysis such as decentralization and diversity of energy vectors or even the reduction on fossil fuels solutions, as stated by the SRF for supply infrastructures, when new external energy resources are considered to be introduced in the island (biofuels and natural gas).

7.3.4. Exploring strategies

The energy strategies were developed separately for the energy supply and demand allowing for the specific application of the energy issues (see section 6.2.4.1) with the concern to promote globally an energy system, structured by energy services and adequate energy vectors from resources to end-use.

7.3.4.1. Developing strategies

The final integrated assessment envisions the overall performance of the different proposal for the energy system with the common goal of achieving the vision. However, those proposals result from different strategies that can be developed for the distinct components of the energy system (particularly the demand and supply, giving the immutable character of the natural resources). Energy strategies both for supply and demand were developed at a macro level and in an iterative way to form final scenarios, translating the proposals to be assessed.

Three distinct strategies were considered for demand and supply, which are described in Table XXXVIII and Table XXXIX.

Table XXXVIII – Description of possible strategies for energy demand in Gran Canary

1 – Traditional demand structure
The demand follows its traditional structure in terms of energy services and vectors, meaning that no significant changes occur and being the consumption affected only by the efficiency at end-use. In that sense there is no particular distinction about the adequacy of the resources for the service provided.
2 – Adequate use of existing energy vectors
The demand considers a new distribution among the existing energy vectors according the principle of adequacy. In that sense, solar heat and electricity from the grid (based on the existing renewables) are promoted whenever they are adequate to the energy service and fossil fuels are used only when no other solutions are available.

3 – Introducing new energy vectors
This strategy considers an answer to the energy services required by the demand, based on all the potential vector of the island: solar heat, electricity from the grid (wind, waves, hydropower), decentralized electricity (solar PV), geothermal heat and biomass and again considering as last resource the use of fossil fuels.

Table XXXIX – Description of possible strategies for energy supply in Gran Canary

A – Current Supply Structure
The energy supply based on renewables, follows the existing structure in terms of priorities already considered for the island, in terms of priority of exploitation and energy vectors provided. In that sense, the structure of the supply adopts the following order for the exploitation of the natural resources: 1. Wind – providing electricity 2. Sun – providing electricity 3. Hydro – providing electricity 4. Sun – providing heat 5. Other resources – providing both electricity and heat
B – Supply structure according resources potential
This strategy follows the endogenous potential of the renewable energy resources existing in Gran Canary. It distinguishes the potential of the resources according the possible vectors provided and assumes the exploitation of the ones that have medium or high potential, leaving aside the natural resources with low potential or already overexploited. Therefore, it considers the following order of exploitation: 1. Sun – providing heat 2. Sun – providing electricity 3. Geo – providing heat 4. Wind – providing electricity 5. Sea – providing electricity 6. Biomass - providing heat
C – Supply structure according energy issues
The energy supply considers an order of exploitation of the natural energy resources resulting from an energy assessment, according the energy issues defined in section 6.2.4.1. The distinction considers a focus on the energy vectors provided and on the resources itself (see annex III) resulting on the following order of exploitation: 1. Wind – providing electricity 2. Geo – providing heat 3. Sun – providing heat 4. Sun – providing electricity 5. Biomass – providing heat 6. Sea - providing electricity

The development of the strategies at demand or supply sides have particular inputs from the strengths and weaknesses identified before, particularly the ones that can be directly expressed at an energy level such as the diversification of energy vectors, the rational use of resources, and the promotion of self-sufficiency and of renewable energy resources.

7.3.4.2. Creating scenarios

After the development of strategies, was then possible to combine them to build scenarios, expressing different pathways for Gran Canary's energy system. Using a matrix approach, the combination of strategies from demand and supply side originated nine different scenarios (see Figure 41). From all these scenarios was necessary to choose a shorter number to proceed for the assessment. A distinction was made between the ones that constitute the main diagonal of the matrix, which were selected for the assessment, following a similar logic to the two axes method to generate contrasting scenarios, as they represent changes in the system both from demand and supply side, while the others represent intermediate scenarios. The scenarios on the main diagonal are described in Table XL.

		Supply Strategies		
		A	B	C
Demand Strategies	1	A1	B1	C1
	2	A2	B2	C2
	3	A3	B3	C3

Selected scenario

Figure 41 – Snapshot of the matrix of strategies for the creation of scenarios and identification of the selected ones

Table XL – Description of the scenarios selected for the assessment

A1
This scenario considers a demand side evolving according the efficiency targets but without considering structural changes and the options for a supply based on the island's renewables follows the existing alternatives already considered for the island. In that sense, the scenario corresponds to a business-as-usual pathway regarding the energy system, where the main image of the future is an energy system that struggles for the affection of the resources to the demand (in other words, the matching) through the conventional goals adopted for the renewables' supply.
B2
This scenario considers a demand side that promotes the adequacy of the energy vectors to the energy services and the supply relies on the use of endogenous energy resources according their energy potential in the island. It represents the result of a pathway based on structural changes from the demand side and a growing exploitation of the most abundant natural resources resulting into an image of the future of an island that looks for a self-sufficient energy system.

C3
This scenario considers a demand side that promotes the adequacy of the energy vectors to the energy services but also balances this adequacy with the most common energy vectors in the island. At the supply side, the exploitation of the endogenous energy resources considers a prioritization of the resources based on an energy evaluation that accounts for more than only their energy potential. It represents the result of a pathway that involves a higher effort when approaching the energy issue than the two previous ones. This results in an image of the future of a Gran Canary that breaks traditional paths in energy and believes in a structural change of the energy system both at the demand and supply side, where all the planning principles (self-sufficiency, diversity, adequacy, matching and efficiency) are put in evidence.

7.3.5. Integrated assessment of scenarios

The first step for the assessment was to model the scenarios. Scenarios were modelled for the year 2030 as it includes all the temporal horizons considered on the strategic reference framework and introduces a medium to long-term analysis. The modelling process considered the structure followed for the characterization of the energy system as in section 7.3.2 for the demand and supply. Regarding the natural endogenous energy resources, they are implicit on the supply but were not subject to any special consideration, as their occurrence is assumed constant along time in Gran Canary.

The demand for 2030 considered a stable, slow growth trend on the consumption according the existing projections (mainly due to increasing efficiency and even the reduction of the consumption in some uses) and a partition among activity sectors that remains similar to the base year, resulting in a consumption for Gran Canary in 2030 as presented in Table XLI.

Table XLI – Structure of energy consumption in Gran Canary, 2030

Partition by activity sector		Total Consumption 2030 (MWh)	Partition by energy services	
Domestic Sector	1573304	12579290	2667001	Electricity Specific
Services Sector	2552792		2352724	Heating/Cooling
Industry Sector	659390		7137429	Motion
A&F and C Sectors	523048		422136	N/d
Others	422136			
Transportation	6848620			

The supply, being the interface between resources and demand, depends from the strategies adopted, both according the exploitation of the natural resources, which considers different priorities, and the energy vectors used by the demand, which assume a change towards the vectors that can be provided by the endogenous resources. This

means that the modelling of the supply considers a response to the required energy vectors and not to the energy services. The detailed results regarding the modelling of the scenarios are presented in annex IV.

The analysis of the scenarios followed the aspects used on the analysis of the energy system for the base year, based on an energy perspective and allowing comparing the three scenarios. However, considering the focus of the energy vision on the use of the endogenous renewable energy resources and the weight that transportation sector represents on the overall demand, while relying principally in the use of fossil fuels, it was performed a two-folded analysis of the scenarios. First, it was considered the analysis of the energy system including the global energy demand and after a second analysis considered the exclusion of the transportation sector from the energy demand in the island.

7.3.5.1. Energy performance of scenarios

First part – considering transportation

In terms of energy services, the partition remains the same, as expressed in Figure 36, regardless the scenario considered. The structure of the energy vectors, however, changes, as expressed in Figure 42, where the diversity of the vectors in use grows from A1 to C3. Between A1 and B2, the attained diversity considering the island potential remains the same (50%) although solar heat gains more expression in scenario B2, with 17% against near 0% in scenario A1. Scenario C3 attains 100% of the potential diversity of energy vectors in the island. The major consequences between scenarios is a progressive lower end-use of external resources (fossil fuels). Moreover between scenarios B2 and C3, the use of electricity (from the grid and from isolated production) takes greater role in C3, explained by a change on the demand at transportation sector, moving from traditional transportation based on fossil fuels to a higher electric transportation.

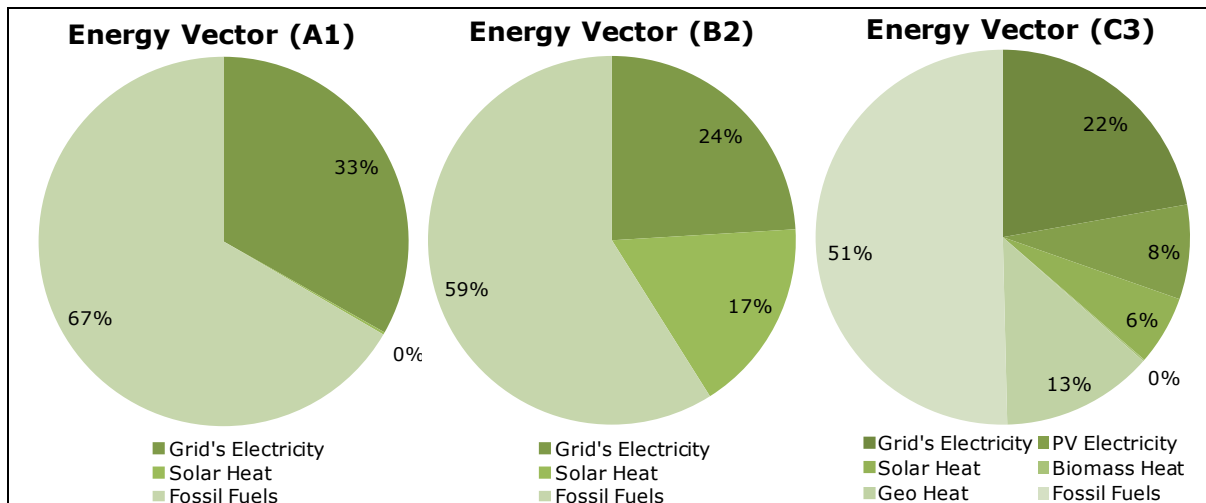


Figure 42 – Energy vectors in use by the demand, according each scenario

The evolution registered on the diversity is also translated on the adequacy according the energy services along the three scenarios. While scenario A1 maintains a deficit in the use of vectors adequate for heating and cooling purposes and a surpassing offer in what regards electricity specific services, as observed for the baseline situation, B2 and C3 are able to minimize the distance to adequacy. Scenario B2 shows a similar trend as A1 for electricity specific and heating and cooling services but the distance to adequacy is lower, meaning that despite using electricity in excess and heat in defect, is closer to the goal. Moreover as the fossil fuels' consumption is lower for this scenario, it registers the best adequacy of all three in what regards the use of energy vectors for the energy service "motion". Scenario C3 distinguishes from the two previous scenarios, being the one that registers an almost total adequacy for heating and cooling services ($A_d=0.03$, a slight surpassing offer of energy vectors to supply heating and cooling needs). As it uses the existing natural energy resources in the island, a major consequence is to use electric transportation, which increases again the distance to adequacy in what regards electricity specific services, although not exceeding the value in A1, and consequently translated into a deficit of adequate vectors for the energy serve "motion".

Regarding the supply in terms of installed capacity, all scenarios are aimed at the matching between demand and supply based on the endogenous energy resources. The effort for the matching resulted from an iterative process where first was verified that, to respond to the demand based only on the endogenous energy resources, wind power was always exceeded in all three scenarios. Being necessary to respond to the needs of

electricity from the grid, it was assumed that the remaining electricity would have to be supplied based on conventional production. The final installed capacity for Gran Canary was computed resulting in diverging results as shown in Figure 43. Scenario A1 still relies heavily in conventional production to satisfy energy needs while the contribution of renewables is mainly for electricity production (wind, solar PV, hydro and other renewables), being the exploitation for purposes of heating and cooling very low, based on solar heat. Scenario B2 presents an opposite picture, where despite not all the existing renewable resources are explored (e.g. geothermal capacity), there is a Gran Canary committed on the exploitation of endogenous resources, reducing the installed capacity of fossil fuels to 10% of the total installed capacity. Finally, in scenario C3 despite increasing the variety of endogenous resources explored, it is registered again a higher level of installed capacity from fossil fuels (39%), resulting from the need to respond to a higher demand of electricity.

Still regarding the installed capacity, it is verified that the total installed capacity does not varies much among the scenarios but the variation on the renewables' installed capacity is significant, with A1 registering the lowest value and B2 the highest (see Table XLII).

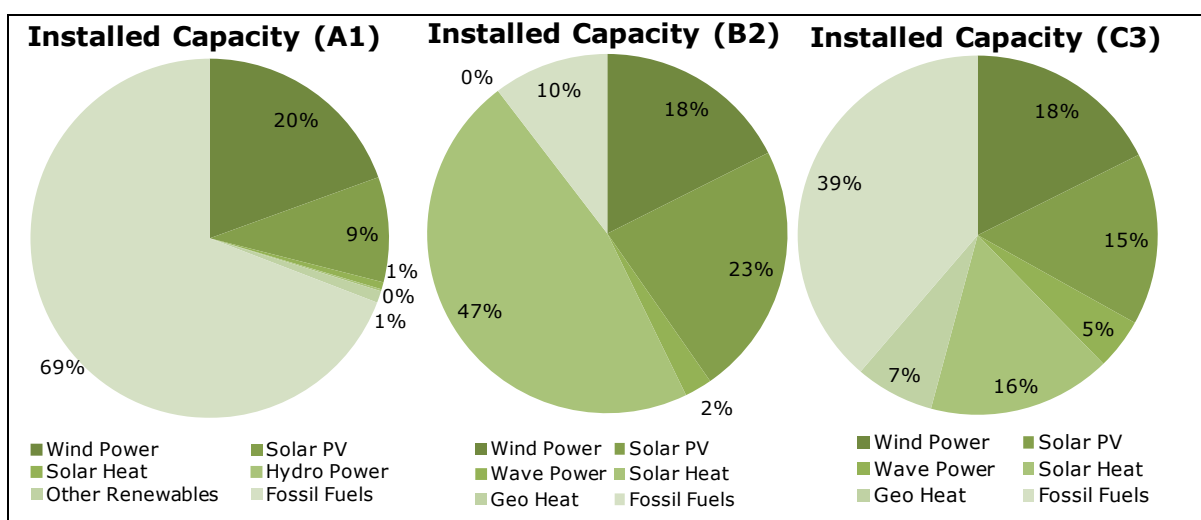


Figure 43 – Installed capacity in the different scenarios

Table XLII – Installed capacity by resource and type of technology, according the scenarios considered for assessment

Resources/Technology	Installed Capacity (MW)		
	A1	B2	C3
Wind Power	467.5	467.5	467.5
Solar PV	227.2	602.8	488.3
Solar Heat	15.3	1243.0	306.0
Geo Heat	-	0.0	152.8
Wave Power	-	65.8	136.2
Biomass Heat	-	-	**
Hydro Power	4.2	0.0	0.0
Other renewables*	25.5	-	-
Fossil Fuels	1660.0	276.8	-
Total	2399.7	2655.8	2649.4
(from which renewables)	(739.7)	(2379)	(1624)

*Other renewables refer to an undefined installed capacity of wave power, biomass and geo heat.

** Considers the direct use of wood to supply the needs required by the demand

Finally, for a global analysis regarding the matching between demand and supply on each of the scenarios created, the results are expressed graphically in Figure 44, Figure 45 and Figure 46.

Scenario A1 shows an energy system that still relies heavily on fossil fuels for all the energy services required by the demand.

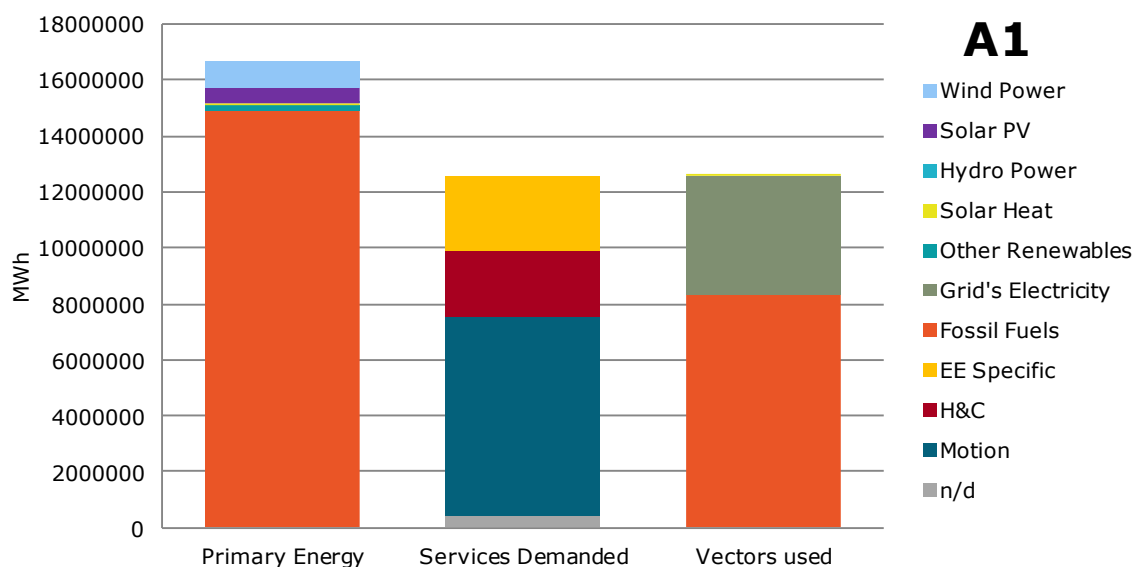
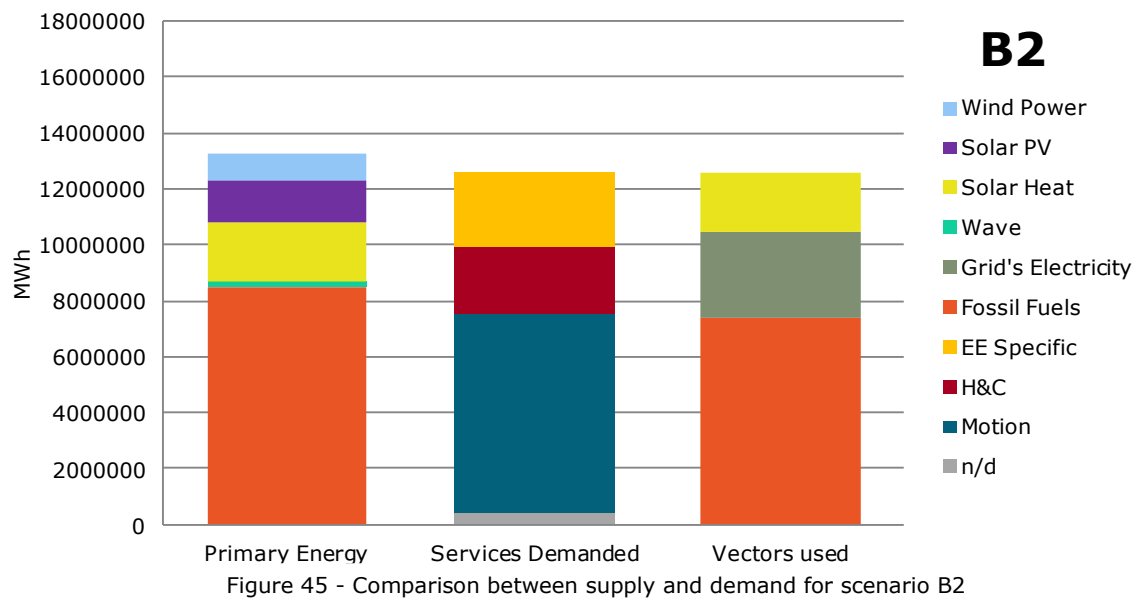
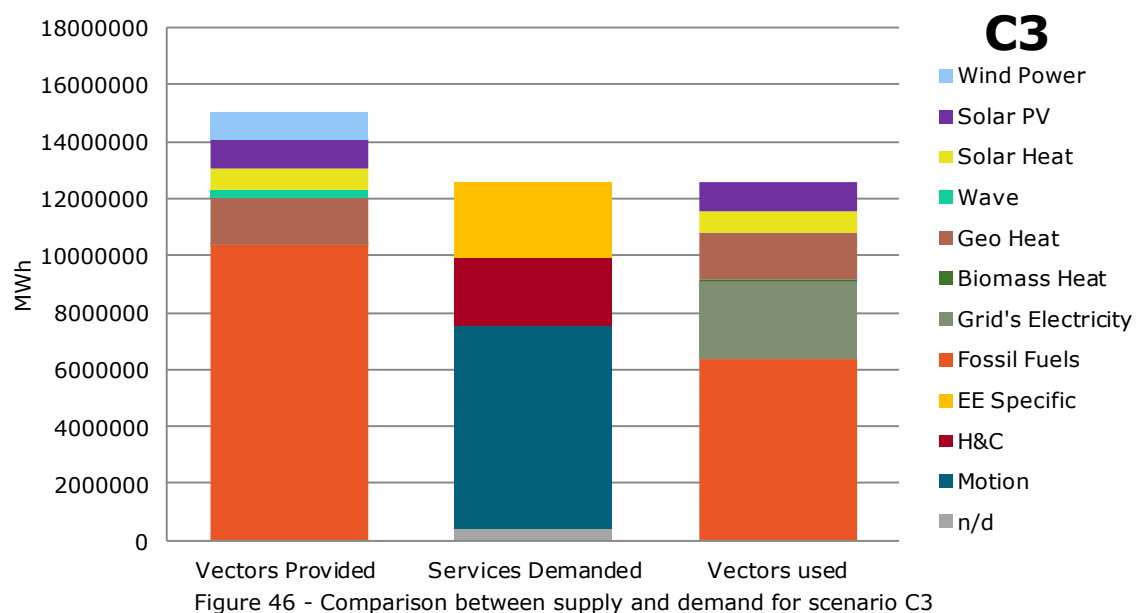


Figure 44 – Comparison between supply and demand for scenario A1

Scenario B2 presents a higher adequacy between supply and demand which also express higher energy efficiency of the system. The major drawback for the matching is the lag between supply and demand, in the sense that the demand is not prepared to diversify the heat sources according the potential considered for the supply.



Scenario C3 presents an energy system with a demand using directly the island resources for its energy needs end-use, reflecting on a lower end-use of fossil fuels, but with higher electricity requirements, leading to a supply that still relies on conventional electricity production, decreasing the energy efficiency of the system.



In that sense, the response to the matching is very similar in scenarios B2 and C3 (37.7% and 37.1% respectively) which are the best results when comparing to A1, with a response to matching of 13.9%.

In terms of self-sufficiency, the three scenarios register an improvement of the baseline conditions, denoting the concern with a future less dependent from external energy resources. Again scenario B2 and C3 are closer (35.8% and 31% respectively) while scenario A1 represents a self-sufficiency of 10.5%.

The level of decentralization of the energy system for the different scenarios is progressively higher, with A1 representing a highly centralized energy system (1.5% of decentralization) while B2 and C3 represent decentralized systems (45.1% and 52.9% respectively). With some connection with the level of decentralization, is verified an increase on the efficiency of the energy system from scenario A1 to scenario B2, both when considering the global supply or only the electrical system (from 75% in A1 to 95% in B2 for global efficiency and from 50% to 82% for the efficiency of the electrical system). Nevertheless, when comparing the efficiency of B2 and C3, it is verified that the increase on decentralization does not correspond to an increase on efficiency (scenario C3 shows a global efficiency of 84% and an efficiency of the electrical system of 61%, against 95% and 82% of scenario B2), which can be explained by the lower efficiency of emergent technologies for the exploitation of alternative natural renewable energy resources.

In what regards the intensity in the use of energy and its environmental consequences at global level, is possible to state that all three scenarios register an improvement of the current status, having scenario B2 the best performance. Scenario A1 represents a decrease of 23% on the energy consumption per capita and a decrease of 33% on the CO₂ emissions per capita. Scenario B2 reaches a reduction of 38% on the energy consumption per capita and a decrease of 68% on the CO₂ emissions per capita. Scenario C3 represents a reduction of 33% on the energy consumption per capita and a reduction of 52% on the CO₂ emissions per capita.

In a synthesis for the three scenarios at the light of the planning principles and the vision proposed, Table XLIII presents the comparison among the scenarios according the indicators for the energy performance of the system.

Table XLIII - Results for the assessment of the energy system according the indicators for planning principles, for each scenario

Indicator		Scenario A1	Scenario B2	Scenario C3
Attained diversity considering the region's potential (D_P)		50%	50%	100%
Distance to adequacy (A_d) according energy service	EE Specific	$A_d = 0.566$	$A_d = 0.134$	$A_d = 0.432$
	H&C	$A_d = -0.989$	$A_d = -0.091$	$A_d = 0.030$
	Motion	$A_d = 0.174$	$A_d = 0.039$	$A_d = -0.112$
Self-sufficiency (E_I)		10.5%	35.8%	31%
Decentralization (Dec)		1.5%	45.1%	52.9%
Efficiency (η)	Global supply	$\eta = 75\%$	$\eta = 95\%$	$\eta = 84\%$
	EE. specific	$\eta_{EE} = 50\%$	$\eta_{EE} = 82\%$	$\eta_{EE} = 61\%$
Response to matching (M_R)		13.9%	37.7%	37.1%
Energy consumption per capita (inland)		16 MWh/inh 1.4 toe/inh	13 MWh/inh 1.1 toe/inh	14 MWh/inh 1.2 toe/inh
CO ₂ eq. emissions per unit of final energy (inland)		0.318 tCO ₂ eq/MWh	0.151 tCO ₂ eq/MWh	0.223 tCO ₂ eq/MWh
CO ₂ eq. emissions per capita (inland)		3.8 tCO ₂ eq/inh	1.8 tCO ₂ eq/inh	2.7 tCO ₂ eq/inh

Second part – excluding transportation

When the transportation sector is excluded from the energy demand, the structure in terms of energy services provided in the island changes, resulting on a strong reduction on the needs for motion. Without the transportation sector, energy services of Gran Canary rely, almost equally, on electricity and heating (see Figure 47).

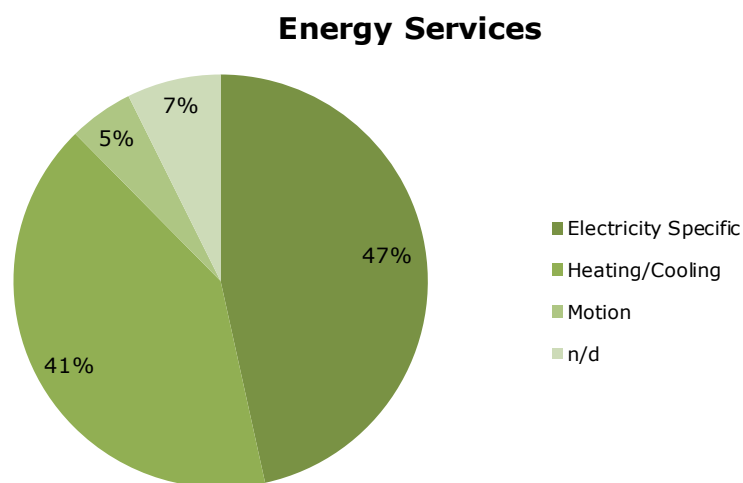


Figure 47 – Distribution of energy demand by energy service, when transportation is not considered

Regarding the structure of energy vectors in use to respond to the new structure of the energy services, is possible to observe that in this case the reduction of the dependency on fossil fuels occurs equally for scenarios B2 and C3, where fossil fuels represent 10% of the final energy consumed by the demand, against the 23% registered in A1. Also from scenarios A1 to C3, there is an increase diversification on the number of energy vectors at end-use as well as a proximity to the distribution of energy vectors. In fact,

scenario B2 registers a partition between electricity vectors and heat vectors of 53% versus 37% while scenario C3 registers a partition of 48% of electricity vectors and 42% of heat vectors, closer to the partition of 47% electricity specific and 41% for heating/cooling purposes registered for the energy services (see Figure 48).

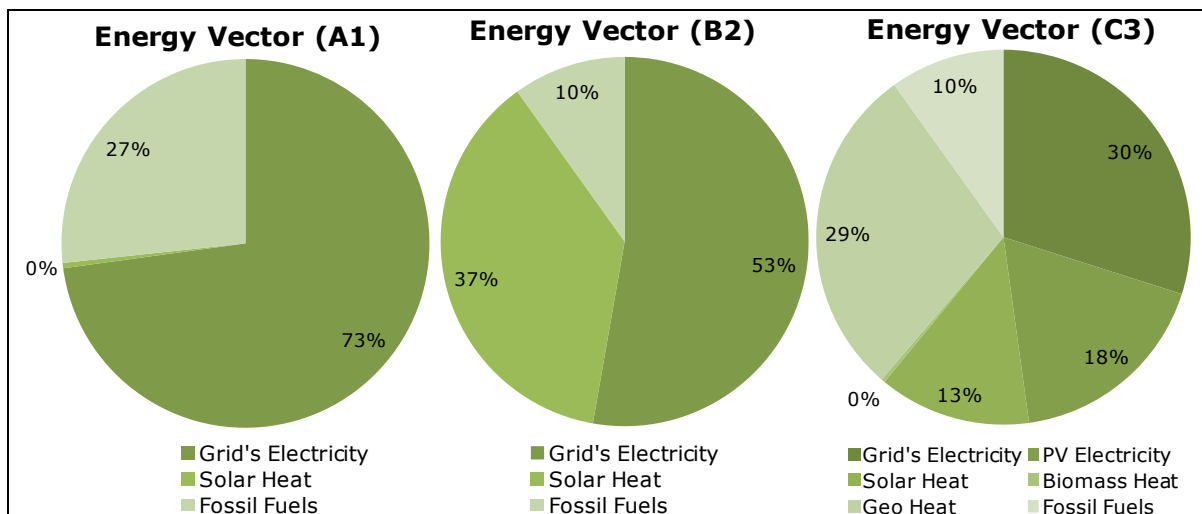


Figure 48 - Energy vectors in use by the demand (except transportation), according to each scenario

The exclusion of the transportation sector affects particularly the structure of the energy supply in scenario C3, as less electricity is necessary by the demand. When considering the installed capacity to respond to an energy demand that does not account with transportation it is more easily stated the contribution from the endogenous resources of Gran Canaria (see Figure 49).

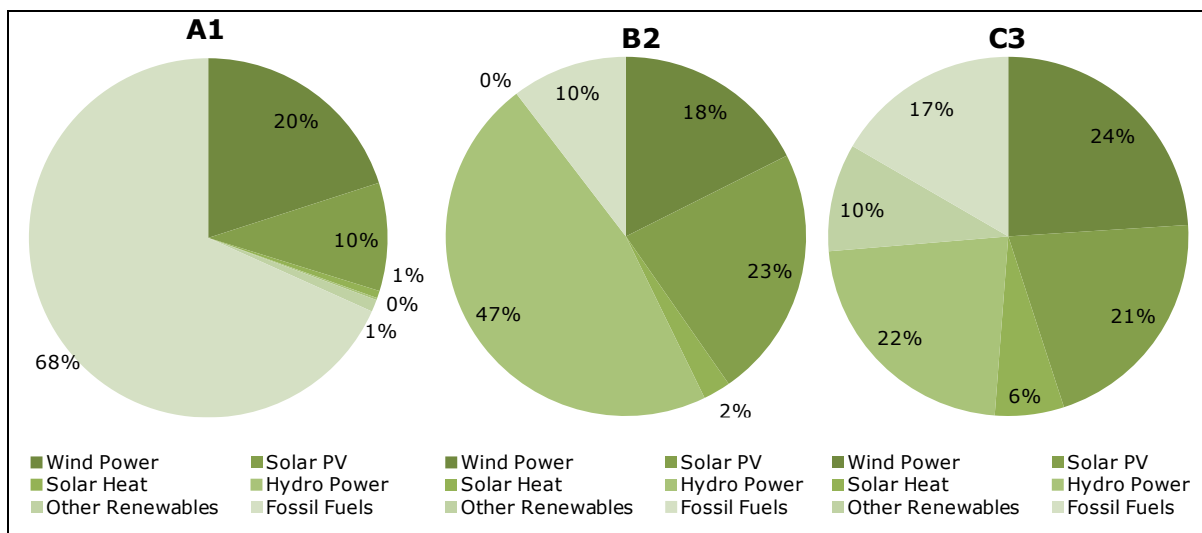


Figure 49 - Installed capacity for the three scenarios considered, when transportation sector is excluded

The results are consistent with the ones obtained in the analysis of the Gran Canary inland energy system, as expressed in Table XLIV. When excluding transportation, the self-sufficiency is increased, as the demand is less dependent from fossil fuels. On the other hand, the distance to adequacy suffers an increase for this case as, despite the requirements of fossil fuels are lower, the needs for the energy service “motion” are much lower, resulting on a greater distance to adequacy for this case.

Table XLIV - Results for the assessment of the energy system without transportation sector, according the indicators for planning principles, for each scenario

Indicator		Scenario A1	Scenario B2	Scenario C3
Attained diversity considering the region's potential (D_P)		50%	50%	100%
Distance to adequacy (A_d) according energy service	EE Specific	$A_d = 0.565$	$A_d = 0.134$	$A_d = 0.027$
	H&C	$A_d = -0.989$	$A_d = -0.091$	$A_d = 0.030$
	Motion	$A_d = 4.297$	$A_d = 0.966$	$A_d = 0.966$
Self-sufficiency (E_I)		18.3%	74.1%	71.6%
Decentralization (Dec)		1.5%	45.1%	52.9%
Efficiency (η)	Global supply	$\eta = 60\%$	$\eta = 90\%$	$\eta = 88\%$
	EE. specific	$\eta_{EE} = 52\%$	$\eta_{EE} = 82\%$	$\eta_{EE} = 78\%$
Response to matching (M_R)		30.5%	82.7%	81.4%
Energy consumption per capita (inland)		9 MWh/inh 0.8 toe/inh	6 MWh/inh 0.5 toe/inh	6 MWh/inh 0.5 toe/inh
CO ₂ eq. emissions per unit of final energy (inland)		0.388 tCO ₂ eq/MWh	0.083 tCO ₂ eq/MWh	0.093 tCO ₂ eq/MWh
CO ₂ eq. emissions per capita (inland)		2.1 tCO ₂ eq/inh	0.5 tCO ₂ eq/inh	0.5 tCO ₂ eq/inh

7.3.5.2. Exploring a new scenario

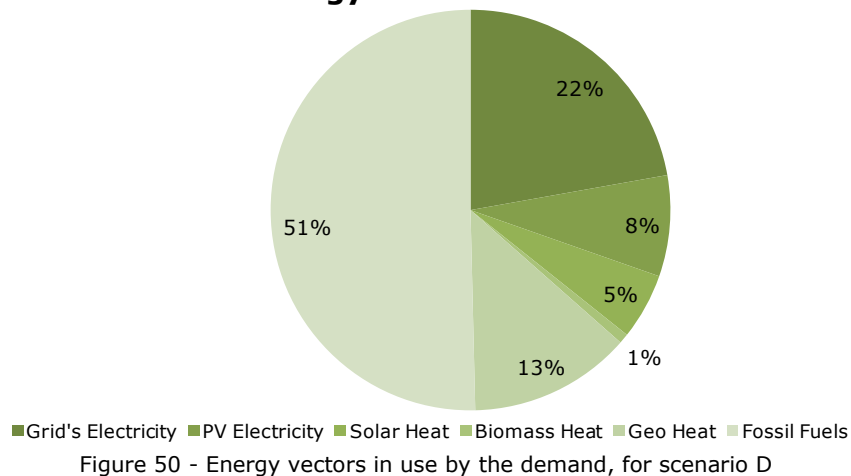
The analysis of previous scenarios allows identifying the strengths and weaknesses of each one regarding the energy vision proposed. It is stated that some of the opportunities and risks identified at the beginning of the planning process were not fully represented on the three previous scenarios. The major points to take into consideration are:

- To fully use the biomass potential by the demand (77638 MWh from which only 17936 MWh were considered for heating purposes at domestic sector);
- To increase the biomass potential by promoting some crops for both energy purposes and prevention of soil erosion;
- To satisfy the electricity needs based on the existing renewables resources, without considering the supply from fossil fuels.

By incorporating these considerations on the exercise is possible to elaborate a forth scenario – scenario D, that can compete with the other three, as a planning alternative for Gran Canary. This last scenario translates the effort at the supply side to improve the exploitation of the natural energy resources, considering the increase of installed capacity of some resources which were not explored at their full potential (biomass and sea) and also taking into account the efficiencies of some technologies (centralized solar power plants).

The results show an energy demand that is almost half satisfied by its own, endogenous energy vectors (Figure 50), attaining the full potential of the island’s energy diversity (100%), which contributes for a self-sufficiency of 49.6%. Moreover, as fossil fuels are consumed at end-use, this new scenario translates a supply side based on a totally endogenous installed capacity (see Figure 51 and Table XLV), with a major role of solar resources for electricity and heating vectors.

Energy Vector Scenario D



Installed Capacity Scenario D

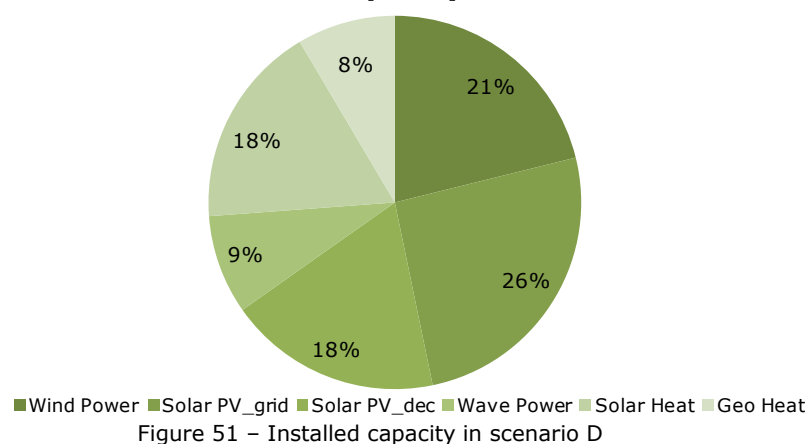


Table XLV – Installed capacity by resource and type of technology, according the scenarios considered for assessment

Resources/Technology	Scenario D Installed Capacity (MW)
Wind Power	467.5
Solar PV - Grid	566.2
Solar PV - Decentralized	408.9
Wave Power	190.1
Solar Heat	390.4
Geo Heat	188.5
Biomass Heat*	-
Fossil Fuels	0
Total	2211.6
(from which renewables)	(2211.6)

* Considers the direct use of wood to supply the needs required by the demand

By having a good endogenous supply capacity and also a demand that incorporates the available endogenous energy vectors, this scenario presents a high level of efficiency (100%) and matching (49.6%). Figure 52 illustrates such conditions by comparing the supply (in terms of quantity of primary energy and diversity of energy resources explored) and the demand (in terms of quantity and final energy vectors used) to respond to the energy services required in Gran Canary.

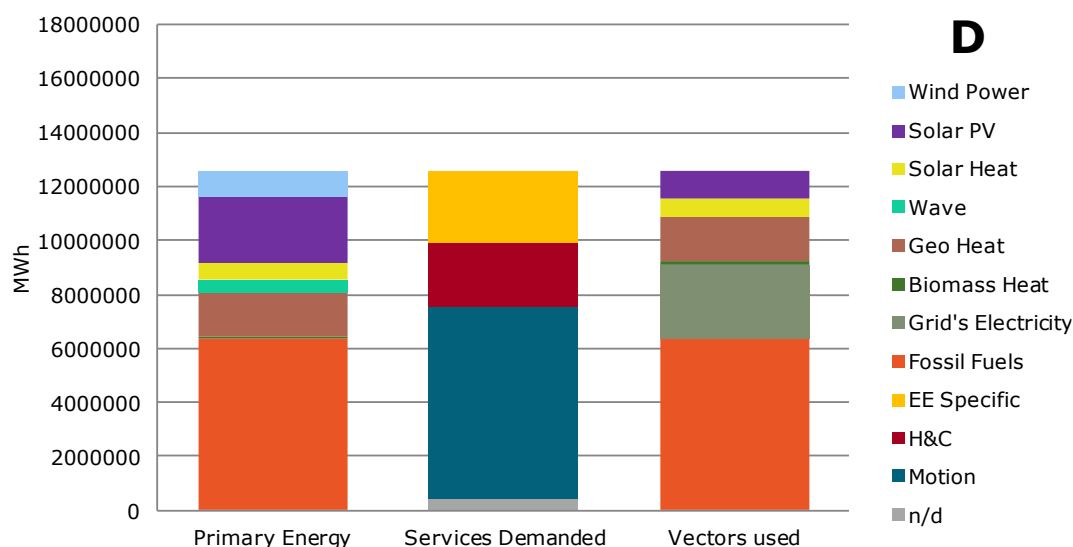


Figure 52 - Comparison between supply and demand for scenario D

The adequacy to the energy services in this scenario is identical to the performance of scenario C3, being almost totally adequate for heating and cooling services but with a lower performance on the adequacy to electricity specific or motion services. These results can be understood again by the use of less adequate but more abundant energy vectors (e.g. electricity for motion) according the availability of the endogenous resources in the island.

The level of decentralization for this scenario represents 55.3%, meaning that from all the endogenous energy supplied in the island, more than half is supplied at local level, without requiring grid support.

Regarding the intensity in the use of energy and its environmental consequences at global level, this scenario represents a decrease of 44% on the energy consumption per capita (annual consumption of 1.0 toe/inh) and a decrease of 73% on the CO₂ emissions per capita (annual emissions of 1.5 tCO₂ eq/inh). Table XLVI summarizes the indicators used for the assessment of the energy performance of scenario D.

Table XLVI - Results for the assessment of the energy system in scenario D, according the indicators defined under the planning principles

Indicator		Scenario D
Attained diversity considering the region's potential (D_p)		100%
Distance to adequacy (A_d) according energy service	EE Specific	$A_d = 0.432$
	H&C	$A_d = 0.030$
	Motion	$A_d = -0.112$
Self-sufficiency (E_i)		49.6%
Decentralization (Dec)		55.3%
Efficiency (η)	Global supply	$\eta = 100\%$
	EE. specific	$\eta_{EE} = 100\%$
Response to matching (M_R)		49.6%
Energy consumption per capita (inland)		12 MWh/inh 1.0 toe/inh
CO ₂ eq. emissions per unit of final energy (inland)		0.124 tCO ₂ eq/MWh
CO ₂ eq. emissions per capita (inland)		1.5 tCO ₂ eq/inh

7.3.5.3. Integrated assessment of planning proposals

The analysis allowed distinguishing four planning proposal for Gran Canary in the 2030's horizon, towards the vision defined: scenario A1, scenario B2, scenario C3 and scenario D.

Their assessment in terms of energy performance was carried out, being scenario D the one with the best scores, as it results from an improvement after the analysis of the other three scenarios.

However, the planning proposals need to be assessed in an integrated framework, where the energy vision and principles are accounted together with other sustainability concerns. In that sense, the integrated assessment takes place making use of the assessment framework elements set in the strategic framework - CDF, criteria and indicators.

The first CDF approaches the energy shift to which contributes the use of the energy resources towards the vision (based only on energy performance indicators, already analysed) and the effort that the demand can have for the necessary shift. Scenario A1 represents no effort for the shift while B2, C3 and D stated a concern with the shift, being C3 and D the scenarios with a higher shift in energy consumption (a total of 6844965 MWh of energy shifted, representing 54% of the total energy consumed).

The second CDF considers the relation between energy resources and territorial shape, translated into the intensity of use of natural resources and the global affection of those resources for the territory. In terms of intensity, the installed capacity is a good indicator as higher it is, higher is the pressure on the natural resources and for this exercise, A1 is the scenario with the lower installed capacity presenting the best performance for this indicator. Nevertheless, the exploitation of the natural resources, when relying on a few number of them, can represent a higher weight for the intensity even if the installed capacity is lower, as it happens in A1. In this sense, B2 presents the best alternative at this criterion as it offers the higher installed capacity with the lowest impact on the exploitation of natural resources.

Considering the global affection of the natural resources, scenario A1 represents the highest competition once it envisions inland water resources as one of the alternatives for energy supply, being water a scarce resource in the island. Scenario D, by considering an intensive use of biomass, also represents some level of affection of the natural resources, particularly in what regards the competition for other land-uses.

Regarding the third CDF, which approaches the nexus between energy and development, also two criteria are considered for the analysis: the contribution for sustainable development path for Gran Canary and other general concerns of sustainable development related with the use of energy.

For the first criterion, the indicators express the results from the trend analysis and how they are incorporated in the design of the scenarios. According the regional plan for Gran Canary, the strategy with best performance is the "Development by renovation and integral requalification" path. Crossing the energy scenarios with this development path is possible to state that scenario A1 does not contribute for the desired future as it does not consider any changes at demand side and the supply makes use of some resources that already register stress, being classified as -1 on the adequacy to the territorial strategy and with a negative effect on the amelioration of the island sensitiveness. Scenario B2 does not consider any changes at the demand side but the supply makes the effort to use some of the most abundant resources, being classified as 0 (zero) on the adequacy to the territorial strategy and without any significant effect on the amelioration of the island sensitiveness. Scenario C3 registers a change at the demand side, on the use of energy at end use, that can express an effort in renovation and the supply makes use of the existing renewable resources, being considered the value 1 on the adequacy to the territorial strategy, while being neutral on the amelioration of the island sensitiveness. Finally scenario D registers a change at the demand side at energy end-use, and the supply makes use of the existing renewable resources, allying their use with the improvement of some biophysical aspects, being considered the value 2 on the adequacy to the territorial strategy and a positive effect on the amelioration of the island sensitiveness.

The second criterion of this CDF reflects a diversity of issues that try to express the remaining dimensions related with the energy planning that were not mentioned before, namely temporal and social dimensions. In that sense, the effort for the energy shift made by current generation increases along the four scenarios, meaning that scenario C3 and D are more exigent and therefore less socially "fair" at intra-generational level. The exigency of such scenarios translate, in the opposite direction, the burden on future generations, once there is an increase on the energy independence at intergenerational level.

Other social-economic indicators show that while scenario A1 is the one that can provide energy at lower cost, the price of energy tend to grow on the other scenarios, which consider higher shares of renewables on the energy system, being B2 the worst scenario with respect to prices. Nevertheless, the scenarios that rely more in renewables are the ones that, inherently, have a better environmental performance (scenario D presents the lowest CO₂ emissions and the highest renewable electricity mix, followed by B2 and then C3) and that can contribute to the stimulus of social dynamics through jobs creation

as the increase on renewables for the supply corresponds to a greater need for hand labor (scenario D leads the number of job creation, followed by scenario B2 and C3).

All the results for the analysis expressed above are summarized in Table XLVII and the details of the assessment procedure are presented in Annex V, by CDF.

The CDF, as by their own designation, are considered critical for the choice among the options under assessment, and therefore need to be seen equally important for a final analysis, with the same weight for the decision. Bearing this in mind, the integrated assessment by CDF shows scenario D as the best option under analysis, as it appears as the first choice both for CDF 1 - "Energy Shift" CDF and CDF 3 - "Energy and Development Nexus". Contrasting to the leading position on these two CDF, scenario D is the only option that has the worst performance for CDF 2 - "Energy Resources and Territorial Nexus", explained by one of the options with greater exploitation of the existing natural renewable resources. Nevertheless, it is also important to highlight that under this factor, none of the other scenarios take the lead.

Thus, from all the proposals considered, scenario D is the one that presents the best response to the vision aimed for sustainable energy systems in Gran Canary. It translates an exploitation of the endogenous natural energy resources that considers a different order from the single energy potential of the resources. Moreover, it also presents a different prioritization of the natural resources from the one expected from the energy principles, helping illustrate the need to have both energy and environmental criteria applied together on the assessment of the energy planning options.

Table XLVII – Results of the integrated assessment, by CDF, criteria and indicator

		Planning Proposal				Best Scenario
		Scenario A1	Scenario B2	Scenario C3	Scenario D	
CDF 1 - Energy Shift	C1 - Energy resources towards the vision					
	Diversity (D_P , %)	50	50	100	100	C3, D
	Distance to adequacy to energy services (A_d)	1.728	0.264	0.574	0.574	B
	Self-sufficiency (E_I , %)	10.5	35.8	31.0	49.6	D
	Decentralization (Dec, %)	1.5	45.1	52.9	55.3	D
	C2 - Demand side effort for the shift					
	Shift on energy vectors in use (MWh)	0	4224961	6844965	6844965	C3, D
	Response to matching (M_R , %)	13.9	37.7	37.1	49.6	D
CDF 2 - Energy Resources and Territorial Shape	C3 - Energy intensity in the use of natural resources					
	Energy exploitation of natural resources	0.4	0.2	0.2	0.4	B2, C3
	Total installed capacity for energy purposes (MW)	739.7	2379.0	1624.4	2211.6	A1
	C4 - Global affection of natural resources					
	Competition among other uses	2	0	0	1	B2, C3
	Competition for same territorial areas (km ²)	95.41	100.30	97.53	102.18	A1
CDF 3 - Energy and Development Nexus	C5 - Contribution for SD path adopted for Gran Canary					
	Adequacy to territorial strategy	-1	0	1	2	D
	Amelioration of island's sensitiveness	-	0	0	+	D
	C6 - General SD concerns related with the use of energy					
	Intra-generational access to energy (effort % of energy to shift)	0.0	33.6	54.4	54.4	A1
	Intergenerational access to energy (% of external energy required)	89.5	64.2	69.0	50.4	D
	Energy affordability (\$/kWh, for electricity at current prices)	0.141	0.192	0.176	0.183	A1
	Jobs creation	852.8	2738.6	1981.9	3041.0	D
	CO ₂ emissions (t CO ₂ eq/inh)	3.8	1.8	2.7	1.5	D
	% of renewable electricity	41.2	85.9	58.7	100.0	D

7.4. Discussion

The methodological framework allowed to develop the energy planning process in a comprehensive way, first by setting a strategic framework from which departs the planning process and then by providing several images of the future that in energy terms reflect always an effort towards the energy vision. Following this framework it was possible to have an integration of energy aspects in a larger scope of sustainability, promoting an integrated energy planning process, responding to the aim of the research.

On the specific aspects regarding the energy planning and the effort for the matching between the demand and the renewable endogenous energy resources, the exercise revealed that the contributions towards that matching are limited, as the best result obtained considers a response to matching of 49.6%. The difficulties to achieve higher matching levels are linked with the logic between energy services and energy vectors. To illustrate this, it can be given the example of transportation sector where the common energy vector that can replace fossil fuels is electricity. Giving that the island's potential is higher to provide heat than electricity, there is a lower matching in this situation.

From a methodological point of view, the complete practical application and the intermediate results obtained along the several stages (definition of strategic elements and modelling results) of the methodological framework allow highlighting two major aspects. The first aspect is related with the importance of having SEA to accompany the planning process. It allowed to contextualize the planning process by introducing in an early stage (strategic framework) some energy-related issues that were not clear in the energy vision proposed. The energy vision, which was primarily driven by energy-specific principles, became more attentive to other sustainability issues. This was decisive for awareness about the possibilities of improving the planning proposals, which was particularly evident when an extra scenario emerged (scenario D) and that has revealed to be the most adequate alternative in two of the three CDF used for the assessment. Although SEA appears to be diluted along the planning process, it does not loses its strength, present in the strategic elements that continuously introduce concerns with the dimensions related with the energy planning.

The second aspect refers to the adoption of a new modelling structure for the energy system. The new structure, that put in evidence the energy services and vectors within the energy system and the way they relate among the components of the system, allows for the operationalization of the energy principles that guide the planning process. By giving a practical meaning to concepts such as diversity, adequacy or matching, they

gain substance and are seen valid, along with other traditional concepts in use, to drive the planning process.

While the first aspect evidences the procedural characteristics of the methodological framework (less quantitative), the second aspect calls the attention to the modelling steps, which are of quantitative nature and may have an important influence in the results. The demand side is the most data intensive component from the model and it is verified that results are particularly sensitive to changes at this level. When the energy performance considers the entire inland energy system or when excludes the transportation sector, the results change considerably. Despite such type of simulation may not be of great usefulness for the reality of the energy system, it helps understanding the variability of the indicators according the base conditions and increasing a critical analysis of the results, approaching in a way a sensitive analysis. It also calls the attention for the particular importance of a detailed characterization of the demand in order to explore more consistent strategies at this level that may conduct to a better matching.

In what regards an effective prioritization of the natural resources existing in the island for energy uses, the methodological framework contributes to a balanced design of options that does not follows exclusively an exploitation order based on the energy potential of the existing resources (supply strategy B) neither the order of merit attained by applying the energy issues (supply strategy C). The solution that responds better to the energy vision while also respects the sustainable development of the island has important inputs from the structured and quantitative analysis used for strategies B and C but was developed having into consideration a qualitative, case-specific approach to the planning process in the island.

This focus on the prioritization of the natural resources for energy purposes is perhaps the major contribution that the framework brings to a more sustainable planning of energy systems. To illustrate this aspect, the results of the application of this framework can be compared with the actual Action Plan for Sustainable Energy Island of Gran Canary (ITC 2012). Despite considering different horizons (the exercise is projected for 2030 while the Island Sustainable Energy Action Plan – ISEAP, for 2020), the order of exploitation of the resources needs to be, in a certain way, fixed as it implies investments on technology and installed capacity in a long-term perspective. It is verified that the order of exploitation is not coincident between the proposed framework and the ISEAP, as other energy resources are included in the framework (such as geothermal or wave power) while hydropower is not considered giving the environmental conditions. The

order of exploitation is similar, when are considered only the core resources (wind, sun and biomass).

Regarding the contributions at a quantitative level, the different time horizon constrains a direct comparison of the results. However, an island that increases its independence from external energy resources is a common goal to both exercises, and is verified that the ISEAP continues to rely strongly on fossil fuels (87.8% on the scene of the action plan) while the framework exercise tries to drive the energy system towards a higher level of endogenous renewable resources (scenario D depends 50.4% on fossil fuels).

On other aspects that were introduced along this methodological framework, it becomes difficult to find equivalence when analyzing other approaches, as the focus on a new structure of the demand based on the energy services is not reflected on the other planning exercises. At this level, the ISEAP considers the role of energy services companies (ESCO's) as major players at demand side.

In a more global view, the comparison between the exercise presented above and the Gran Canary ISEAP illustrates two other major differences. The first one related with the scenarios exercise, to which the framework contributes for a discussion among several possible strategies corresponding to different scenarios. At an action plan level, it is not strictly necessary to have present all the different options under analysis in a detailed way, but is important the systematization of lessons learnt from the consideration of different scenarios, which is not clear in this case. Having an integrated framework allows to have present those lessons and facilitates adjustments along the implementation process.

Finally, it is also important to highlight the robustness that an integrated process, as the one presented above, brings on the environmental sphere and for sustainability. The protection of the environment is seen by Gran Canary ISEAP as a complementary and necessary element to ensure sustainable development of the island, being translated on the reduction of CO₂ emissions. Along the methodological framework it was possible to address other environmental and sustainability issues that, combined since the beginning in the planning process, allowed to take into consideration the sensitiveness of the island, resulting in a different combination for the exploitation of the existing natural resources, respecting both the local and global environment, as a necessary prerequisite to sustainability.

In what regards the participation in the planning processes, along the methodological framework there was a particular attention to identify these moments, with higher

consideration on the initial stages. This concern is less evident on current practice, and in particular for the case study, as participation for Gran Canary ISEAP is considered for the implementation stage. Such attention to participation at early stages is important to assure a standardization of language and concepts as well as to build consensus along the planning process, so that the vision can be accomplished in practice. This also allows to overcome some gap felt on energy plans between the definition of strategic goals and the indicators used to express the performance of future energy scenarios.

Giving due consideration to energy action plans, in the sense that they establish measures to implement a vision, it is emphasized their development within a methodological framework as the proposed one, considering that improved energy action plans can result from this application.

The methodological framework contributes particularly to introduce a more strategic approach to the planning of energy systems, as it allows to elaborate images of a desirable future and identifies possible strategies to develop pathways towards that future. Thus, this methodological framework can be a powerful tool to support the development of energy action plans, at both demand and supply side.

8. Conclusions

The aim of this research is to contribute for the development of a methodological framework for the planning of sustainable energy systems, enclosing on this definition a number of concepts and premises about a new energy paradigm to which society is shifting, or at least recognizes the need to do so. As been noticed along the work developed here, the main effort was applied on the elaboration of the conceptual framework for the energy planning process with the introduction of SEA as well on a practical approach to the development of enhanced planning solutions, through scenarios' building and modelling, translated by a better exploitation of the natural resources for energy purposes.

After the theoretical and practical work developed previously, this chapter presents a summary of the main achievements and puts forward a reflection about some of the contributions of this research. Finally, it states some areas that may require further developments.

8.1. Main achievements

The departing point of this research put the focus on the planning of energy systems towards the matching between energy demand and natural energy resources at local level. It was given emphasis to the role of environmental instruments to elucidate about the best way of exploring the natural endogenous energy resources in the direction of sustainable energy systems. With an in-depth knowledge about SEA and the effort to merge it in the energy planning process, it became clear that innovative results would be achieved only if the identity of both processes was preserved, which sometimes was not easy to accomplish.

As these two processes have evolved from very distinct backgrounds, it was necessary to conciliate and clearly define concepts to set a common basis for the development of the methodological framework. While the energy planning departs from a strong practical background, where practice drives theory and relies strongly on empirical and quantitative results that can be shown in a relative objective way, the strategic background, brought to this work by SEA, relies much in conceptualization and

qualitative approaches, where practical results occur slowly and in a more gradual way. However, it is from the differences between these two elements that the process is enriched, by considering their complementary characteristics in a single methodological framework.

From this aspect, a first conclusion is formulated: “energy” cannot expect “environment” to pave the way for a clear prioritization list on the resources to explore. This means that, in terms of planning energy systems, it will be the “energy” side to pose the question, not asking “how much” can be explored but proposing different exploitation alternatives and asking about the potential to implement and the drawbacks to overcome, helped by the “environment” side.

Furthermore, related with the quality of the options explored, it is verified the importance of SEA to incorporate the strategic component into the planning process. Along the practical application, SEA was the vehicle to consider both critical and creative components of strategic thinking as defended by Liedtka (1998), conducting to the formulation of a fourth alternative that was not achieved simply by the energy vision and that revealed the most adequate option according the integrated assessment.

These achievements confirm the hypothesis advanced to respond to the research question related to the type of methodological framework that could respond to the planning of sustainable energy systems (the second hypothesis advanced in section 1.4). In fact, it was confirmed that having an energy planning process that keeps in mind an integrated assessment procedure produces better options, not in terms of the most efficient energy options but on an overall better adequacy to the local/regional conditions (social and environmental). This, however, shows that great effort is at the human side, requiring from the planner a continuous attention to a qualitative analysis rather than relying on optimal solutions returned by well-structured computational situations. In addition, if having a planning process that considers the accompaniment of SEA from the very beginning hinders the identification of benefits obtained by this procedural tool, there are specific moments where the contribution of SEA in the planning process is evident. The introduction of SEA allowed to include specific stages such as the definition of the energy-related planning dimensions, strategic elements such the strategic reference framework, the identification of risks and opportunities and the definition of critical decision factors for the integrated assessment. These elements were defined in global terms in a way that can be applied to any planning situation, giving to planners a basis for the definition of their own case-specific planning dimensions and critical

decision factors, where different aspects for sustainability regarding the energy issue are already merged and can be globally considered.

Along with the conceptual developments for the methodological framework, the energy planning exercise developed in this research allows to draw the following achievements that confirm the hypothesis placed for the research question related with the operationalization of the energy system (the first hypothesis advanced in section 1.4):

- The energy concepts introduced in the conceptual framework (e.g. matching or adequacy) can in fact be translated in practical terms through the indicators defined in section 6.2.3.1. Thus, it is not necessary a great change for the characterization of energy systems according the new concepts than restructuring the usual way of modelling the energy system, being possible to use the current available energy information and data.
- The energy concepts, as they are developed considering a vision that searches the balance between energy and environment, already enclosure other than energy concerns, which allow developing a planning process prompted to search for solutions with better performance those energy indicators.
- The energy perspective is widen regarding the prioritization of natural resources, being possible to explore different strategies, from a simple ranking based on the energy potential of existing resources to a prioritization based on energy issues (as defined in section 6.2.4.1) according the response of the energy resources to the energy system.
- Despite the relative easiness to restructure the information provided by current energy models, opening the path towards the energy vision centred on energy services is not immediate. It is necessary to consider the planning process as a iterative process, based on quantitative and qualitative information both from demand, resources and supply, to achieve different strategies and energy options to be considered for the planning process and to identify the areas where the system could evolved and be enhanced.
- It is necessary to consider the tripartite energy system as a whole. Only by taking into consideration the interactions established among its components is possible to respond to the vision of the new energy paradigm. Therefore, having a supply

based on natural resources not enough if demand is flexible to change, as illustrated by scenario A1 or B2.

- Despite the increasing efficiency on energy systems with higher adequacy between energy vectors and services, when a region decide to explore its renewable energy resources it might have to opt by the available energy vectors even if they do not correspond to the best adequate ones for the energy service. That means that adequacy and self-sufficiency, in energy terms, can be conflicting concepts for the energy system.
- The set of indicators developed under the new vision establishes a useful basis for a critical discussion about current energy systems and emerging solutions, regarding their energy performance, allowing identifying risks and opportunities in energy terms.

It is then possible to conclude that the restructuring of modelling of energy systems aimed at a better adequacy between energy vectors and energy services contributes for a better matching between resources and demand, allowing designing better solutions to achieve sustainable energy systems.

8.2. Future effects

This research work is developed in the energy-planning field and based on planning theory, resulting on a methodological framework. As such, there are limitations at the outset that cannot be overcome. The methodological framework can be tested for a practical case, to verify its applicability in operational terms and advance some of the difficulties that can be expected. However, to verify practical results of such type of intervention on a real context and on a time-horizon compatible with the development of the research it would be very difficult in what regards measurable effects in the energy system. If there is a major lesson from planning theory, is the delay between theory and practice. Therefore, the immediate future effects expected from this research are not so related with the application of the planning process as presented, but the transformation on the way of thinking about the energy issue and on the involvement of local agents. Making planners perceive that there are concepts and indicators, different from the

traditional ones, that can start to be included on the analysis and modelling of energy systems and conduct to equally good results in terms of global goals (considering CO₂ emissions) will promote the transition towards sustainable energy systems. Considering the premise of integration this will include the participation among agents (hopefully in a constructive dialogue) for the formulation of a vision at local/regional level that is then accomplished by the develop of energy planning proposals based on the methodological framework proposed here, where the different parts of the energy system are mobilized for the same common goal.

8.3. Further research

Considering the achievements of this research work and the desired contribution to the future, the following areas are identified that could provide starting points for further research:

- Sensitivity analysis of the performance indicators regarding the characterization of the energy system based on the new structure (energy services and vectors) and concepts (matching);
- Integration of a more robust demand model that could consider detailed end-use strategies to better promote the matching towards the vision. In this case, it was considered a generic efficiency improvement at the demand side, but the work would contribute from other complementary research as the one being developed by Neves (2012);
- Develop the role of SEA in the methodological framework, namely in what regards its potential as a tool for governance, empowering agents and increasing the quality of the planning process;
- Testing the involvement of local agents for the development of improved energy strategies and pathways for the energy future.

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Annex I – Survey Results

The preliminary considerations were able to materialize the conceptual considerations made for the planning methodology. With some practical definitions prepared to be applied, was necessary to understand how generically accepted those definitions were. A survey was design online and sent by e-mail to agents of the energy and environmental areas in order to understand the level of agreement with the work developed so far. The design of the survey is presented below.

The survey - Towards sustainable energy systems

The survey considered two parts. The first part presented a short description of the energy vision for sustainable energy systems and the concepts that characterize that vision. The second part exposed the critical decision factors defined under the SEA methodology, as well as some criteria and indicators that could be used for the assessment.

Research Survey

Survey – Sustainable Energy Systems

The survey that follows has as main goal to collect the opinion of several energy stakeholders on the assessment of planning options for energy systems.
 You will be contributing for a research work under the MIT|Portugal Program that intends to develop a methodology where the planning of the energy systems is accompanied by the strategic environmental assessment in order to collect in a single process the main aspects for the sustainability of the energy systems.

1. Please indicate your category:

▼

Governmental Organization

Energy Company

Energy Agency

Researcher

Environmental Organization

Energy Professional

Environmental Professional

Research Survey

The Energy Vision

***2. Please indicate your level of agreement with the description of the new energy paradigm:**

"Society witnesses today a transition between energy paradigms. The current paradigm based on the combustion of fossil fuels is shifting towards the use of natural renewable energy resources as the main energy sources, based on decentralization, proximity of user to energy source, efficient energy use and environmental friendliness. This calls for a different approach in the structure of energy demand and supply."

Environmental assessment is a cornerstone in the development of energy systems under this new paradigm. It helps to keep a long-term, strategic sustainability vision in the planning process, the assessment of energy options based on the use of natural renewable energy resources, the adequate matching of energy sources versus energy uses that will ensure the enhancement of environmental values."

	1 (totally disagree)	2	3	4 (agree completely)
The new energy paradigm	☐	☐	☐	☐

***3. Which 3 words would you apply to sustainable energy systems?**

- ☐ Efficiency
- ☐ Rationality
- ☐ Matching
- ☐ Quality
- ☐ Adequacy
- ☐ Shift

Other, please specify

Prev

Next

Research Survey

Strategic Environmental Assessment - Part I

***4. Three major aspects are advanced as critical for the assessment of the energy options under the new energy paradigm.**

Please indicate your level of agreement for each one (from 1 - totally disagree to 4 - agree completely).

You can comment the aspects in the comments box.

	1	2	3	4
Energy shift - Translates the importance of the energy options on the shape of the energy system (e.g. moving from electricity to solar heat in case of domestic hot waters).	☐	☐	☐	☐
Natural Resources and Territorial Shape - Translates the expression that different uses of natural renewable energy resources have on the physical organization of the territory.	☐	☐	☐	☐
Energy and Development Nexus - Translate the relation between the energy uses and the development of economic activities and the improvement of living conditions within the territory.	☐	☐	☐	☐

Comments Box

5. Which other aspects would you consider of most relevance for the assessment of the energy options?

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Research Survey

Strategic Environmental Assessment - Part II

***6. Criteria and indicators are also necessary to operationalise the assessment of the energy options. Please indicate your level of agreement for the ones presented below.**

	1	2	3	4	5
Diversity of energy vectors	☐	☐	☐	☐	☐
Use of endogenous resources	☐	☐	☐	☐	☐
Ratio of the amount of the resource for energy uses to the total amount of the resource	☐	☐	☐	☐	☐
Ratio of the endogenous energy use to the total energy use	☐	☐	☐	☐	☐
Cooperation for sustainable development	☐	☐	☐	☐	☐
Livelihood	☐	☐	☐	☐	☐
Energy consumption per capita	☐	☐	☐	☐	☐
Energy-related jobs	☐	☐	☐	☐	☐

7. Which criteria and/or indicators would you add for the assessment of the energy options?



Prev

Next

Research Survey

This survey is complete.

Thank you for your time and collaboration.



Prev

Done

Powered by **SurveyMonkey**
Create your own [free online survey](#) now!

The survey – Results from the answers collected

The survey was built on-line at the surveymonkey platform (www.surveymonkey.com) and distributed via e-mail to a list of contacts elaborated from personal contacts and contacts of energy and environmental agents available online, with particular incidence on European countries. Table A 1 characterizes the sample invited to answer to the survey, according seven different categories. The main objective was to try to gather as much diversity as possible, considering the type of stakeholders or agents involved on energy planning processes. Nevertheless, major incidence was given to energy agencies (representing 51% on the invitations sent) as they have being responsible for the energy action plans at local level.

Table A 1 – Distribution, by category of the respondent, of the requests to participate on the survey

Categories of the respondents	Number of invitations	Weigh on the total sample
Energy Companies	3	5,9%
Energy Agencies	26	51,0%
Researchers	6	11,8%
Environmental Organizations	3	5,9%
Energy Professionals	4	7,8%
Environmental Professionals	1	2,0%
Governmental Organization	7	13,7%
Others	1	2,0%

From the surveys sent, only 37% accused the reception of the request for the survey and from those, 80% initiated the survey. Further details are expresses in Table A 2.

Table A 2 – Resume of surveys sent and answered

	Number	Percentage
Total surveys sent (e-mail)	51	100%
Total e-mails read (receipt)	19	37%
Surveys initiated	15	80%
Totally answered surveys	9	47%

The results for each of the questions present on the survey above are expressed below.

Q1. Categories of the respondents

The majority of the respondents were energy agencies, researchers or environmental organizations. When comparing the distribution by category of the respondents with the distribution of the invites sent, is possible to state that the segmentation changes considerably, being notice the great involvement of researchers (energy and

environmental field). The representation of energy agencies is equivalent to environmental organizations, both with a 20% weight.

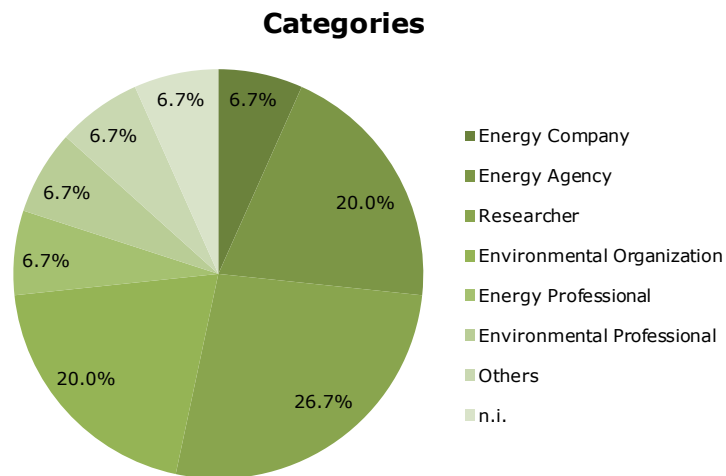


Figure A 1 – Distribution of the respondents by category

Q2. Level of agreement with the description of the new energy paradigm

A total of 85.7% respondents agree with the new energy paradigm described in the survey, where 57% have answered "Agree completely".

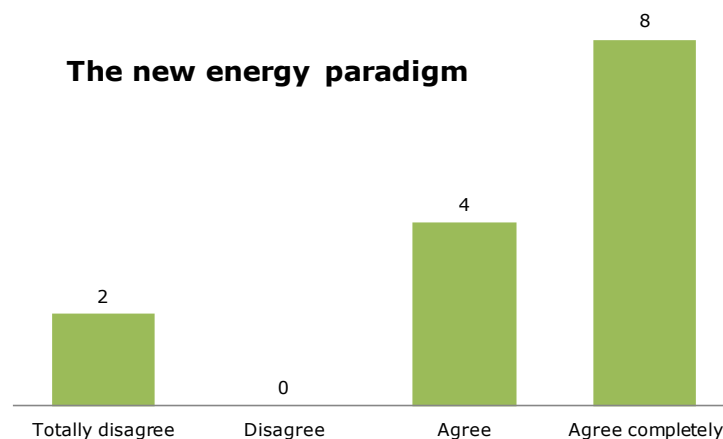


Figure A 2 – Level of agreement with the description of the new energy paradigm

One of the respondents answering "totally disagree" justifies that position regarding the current practice of energy planning: *"totally disagree that EA is a cornerstone in the development NOW, but I partly agree that it has the potential to be so in the future"*.

Q3. Words applied to sustainable energy systems

From the list of concepts available to characterize sustainable energy systems, the vast majority of respondents answered 'efficiency', followed by 'rationality', 'matching', 'quality' and 'shift'. The concepts applied to define energy systems probably can take different meanings according the perception of each participant, expressing different perspectives about these systems and the ways that related problems can be approached. In that sense, a justification for the outstanding of 'efficiency' may be the different interpretations that can be given to the concept.

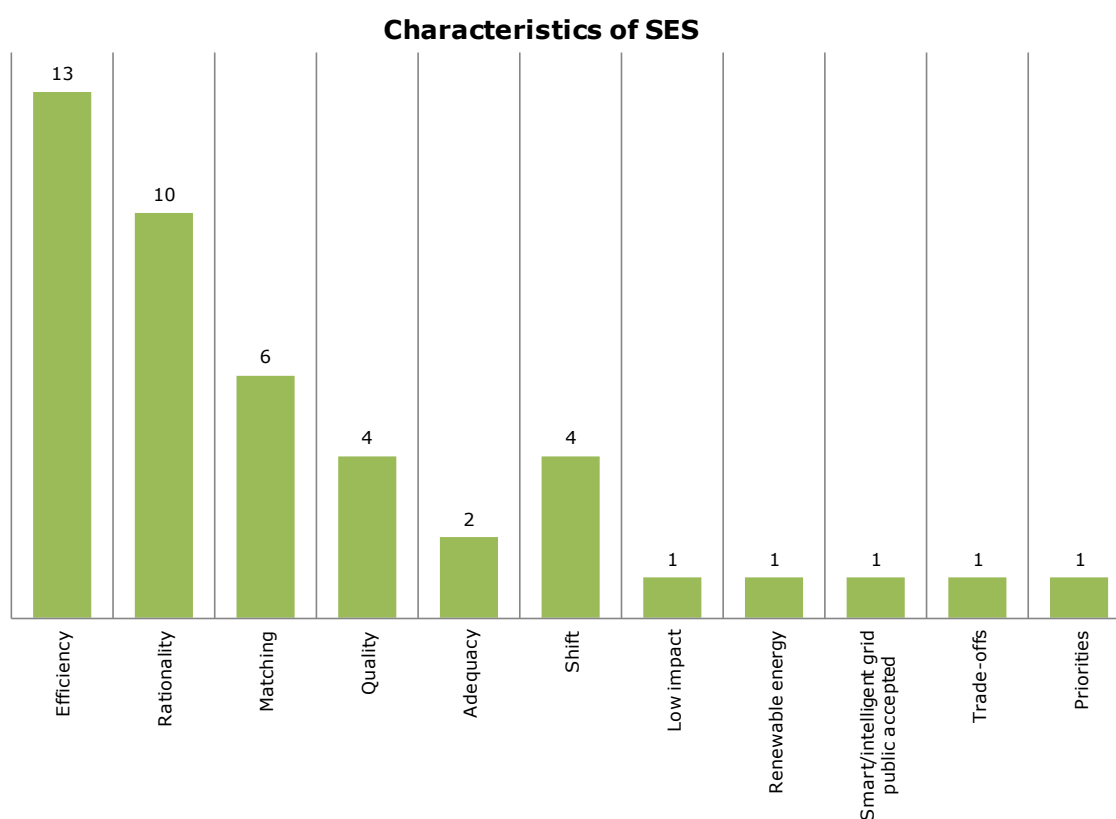


Figure A 3 – Concepts that characterize sustainable energy systems

Q4 – Level of concordance with the critical aspects advanced for an assessment of energy options

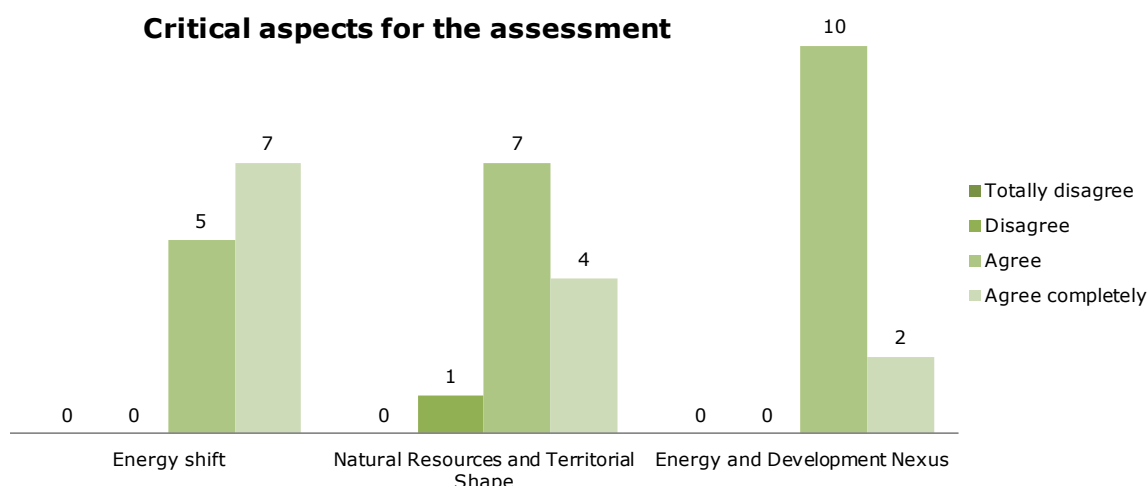


Figure A 4 – Level of concordance with the critical aspects for the assessment

Q5. Other aspects of most relevance for the assessment of the energy options

Six respondents mentioned other aspects that consider relevant for the assessment of energy options, although some can be quite specific, contributing better for the definition of criteria and indicators for the assessment.

Table A 3 – Collection of other aspects mentioned for option's assessment

"Economic feasibility"
"Developing appropriate criteria and using appropriate impact assessment methodologies with which to evaluate options."
"The intelligence of the grid in the complex relations between consumption and production; The public ownership/acceptance"
"public acceptability"
"- Introduce efficiency and fuel shift as the main pillar of the energy options assessments and strategies, and not secondary as currently is, when compared to generation technologies (renewable energies, nuclear, natural gas)."
- More broad analysis of the impacts of energy technologies, from the Environmental analysis (to much focused on CO2 these days) to the social and regional development impact."
"Energy mix, security, cost-benefit analysis"

Q6. Criteria and indicators to operationalise the assessment of energy options

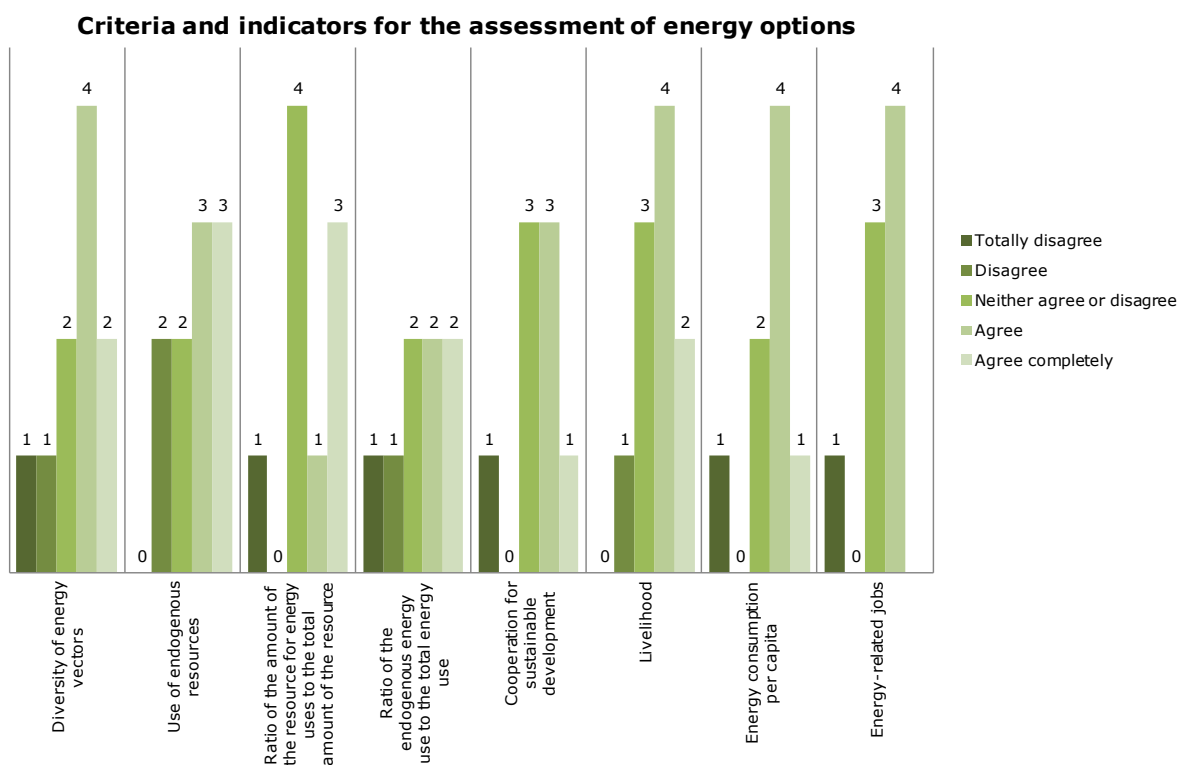


Figure A 5 - Level of concordance with criteria and indicators advanced for an assessment

Q7. Other criteria and indicators for the assessment of the energy options

Results regarding this question allowed to state the importance of clearly define the concepts (see comment 2), as they can even be understood in a completely opposite way, as comments 1 expresses:

Comment 1 – *“What does endogenous mean in this context exactly? Renewable or non-renewable? In theory, it means a resource that comes from within an organism/place, so I'm going to assume it means non-renewable. You might want to explain what these criteria mean, specific to your particular context.”*

Comment 2 – *I don't know what you mean by the questions "ratio of the endogenous ... ", "Ratio of the amount..." and "Cooperation for ..."*

Table A 4 - Collection of other criteria and indicators mentioned for option's assessment

Ratio on energy and added value
Environmental protection (biodiversity, air quality)
Greenhouse gases emissions per capita
Energy consumption per unit of gross domestic product
Energy consumption per unit of household disposable income
Energy savings relative cost compared to energy production cost
Saved costs

Annex II – Strategic Reference Framework – Gran Canary

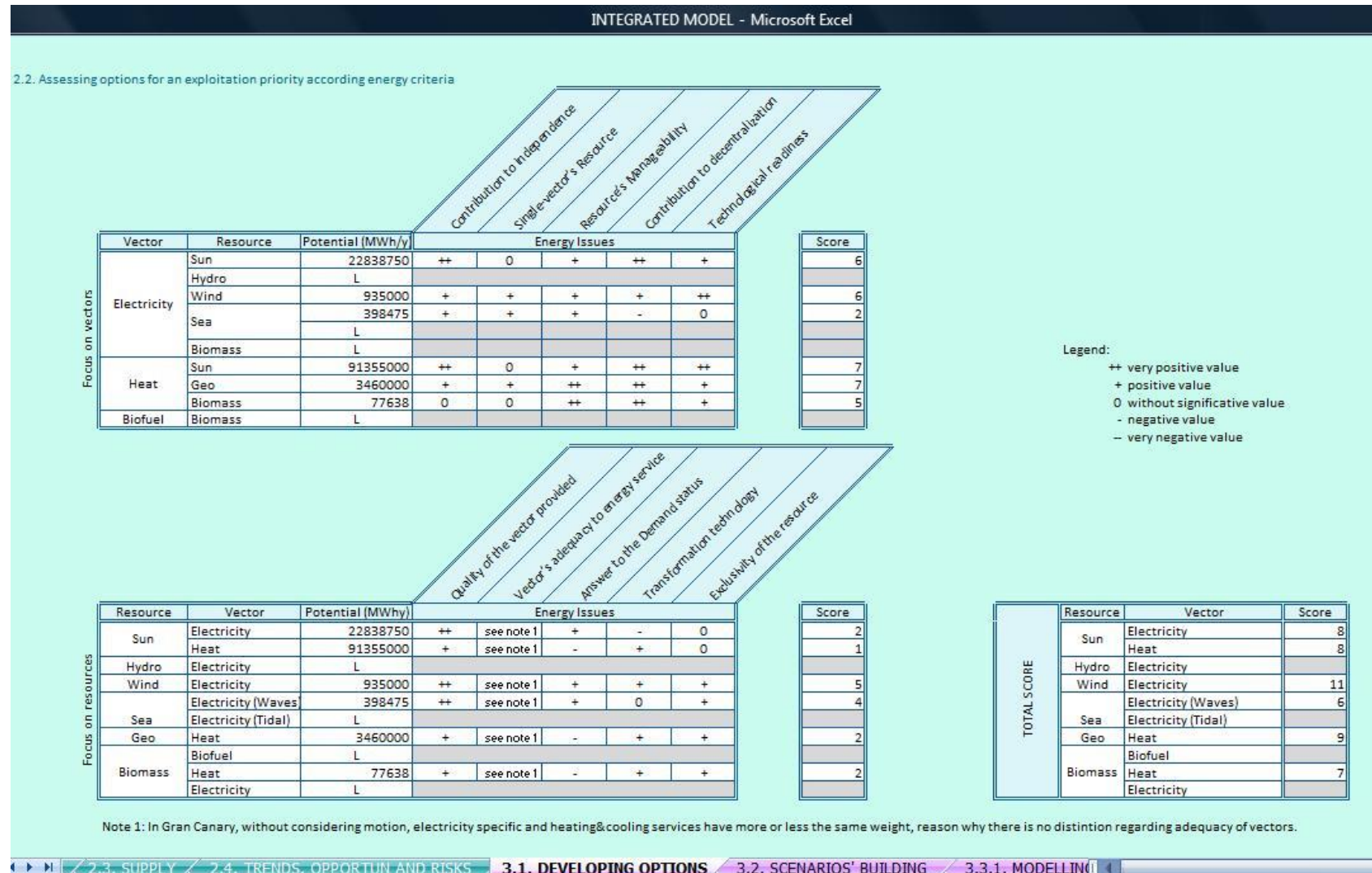
Document	Scope	Energy-related Goals	Environment-related Goals
An Energy Policy for Europe	EU	- Combating climate change; - Limiting the EU's external vulnerability to imported hydrocarbons; - Providing secure and affordable energy to consumers.	-
20 20 by 2020 - Europe's climate change opportunity	EU	- Reduction of at least 20% in greenhouse gases (GHG) by 2020; - 20% share of renewable energies in EU energy consumption by 2020.	-
Energy efficiency: delivering the 20% target	EU	- 20% reduction of primary energy consumption compared to projections for 2020.	-
An EU Energy Security and Solidarity Action Plan	EU	- Infrastructure needs and the diversification of energy supplies; - External energy relations; - Oil and gas stocks and crisis response mechanisms; - Energy efficiency; - Making the best use of the EU's indigenous energy resources.	-
A European Strategic Energy Technology Plan (SET-Plan)	EU	- Accelerating innovation in cutting edge European low carbon technologies.	-
EU Strategy for Sustainable Development	EU	- To limit climate change and its costs and negative effects to society and the environment; - Sustainable transport; - Sustainable consumption and production.	- To improve management and avoid overexploitation of natural resources, recognising the value of ecosystem services.
Spanish Strategy for Climate Change and Clean Energy	National	- To assure the reduction of the emissions of GHG's; - To set the bases for a sustainable development; - To reduce the energy intensity; - To promote energy efficiency and renewable resources, energy-demand management and low carbon technologies.	-

Document	Scope	Energy-related Goals	Environment-related Goals
Spanish Strategy for Sustainable Development	National	- To increase the savings and efficiency in the use of the resources in all sectors; - To optimize the mobility needs (people and goods) in energy and environmental terms; - To increase the weight of renewable energy in the energy mix; - Improving the energy efficiency on transportation and buildings.	- Improving air quality; - To optimize the mobility needs (people and goods) in energy and environmental terms; - Conservation and management of the natural resources and land use.
Plan of Renewable Energy in Spain	National	- Quantification of global and sectorial goals and measures in order to achieve 20% renewables in the year 2020 (reference 2005)	-
Spanish Action Plan 2008-2012	National	- 12.4% total reduction of final energy compared to projections for 2012; - 13.7% total reduction of primary energy compared to projections for 2012; - 14% total reduction of CO2 eq. emissions, compared to projections for 2012. (the plan specifies the reductions by activity sector)	-
Canaria's Energy Plan	Regional	- Diversification of the energy resources and promotion of the endogenous ones; - To maximize the rational use of energy; - To promote the maximum use of renewable energy resources (especially wind and solar)	- To improve environmental protection; - To integrate the environmental dimension in all the energy decisions for a sustainable development of the region.
Canaria's Strategy for Climate Change	Regional	- Reduction of the GHG's emissions; - Rational use of energy; - Promotion of the endogenous and renewable energy.	-
Insular Plan of Land Use - Gran Canaria	Insular	- Promotion of alternative electricity generation in situ	- Definition of a land-use planning model for the island guaranteeing its sustainable development; - Planning of island's natural resources.

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Annex III – Applying Energy issues to define supply strategies



Annex IV - Results from scenarios modelling

Modelling Energy Demand - Results according the strategy followed for the use of energy vectors:

INTEGRATED MODEL - Microsoft Excel					
1. MODELLING DEMAND					
1.1. Energy demand (2030)					
2030					
SCENARIO 1 maintaining structure	Energy Service	Quantity	Proposed distribution		
			Energy Vector	Quantity	
	Electricity Specific	2667001 MWhe	Grid's Electricity	4175620 MWhe	
	Heating/Cooling	2352724 MWht	Solar Heat	26395 MWht	
	Motion	7137429 MWWhm	Fossil Fuels	8377275 MWWh(t+m)	
	n/d	422136 MWh			
SCENARIO 2 adequate structure limited to existing vectors	Energy Service	Quantity	Energy Vector	Quantity	
	Electricity Specific	2667001 MWhe	Grid's Electricity	3025080 MWhe	
	Heating/Cooling	2352724 MWht	Solar Heat	2138875 MWht	
	Motion	7137429 MWWhm	Fossil Fuels	7415334 MWWh(t+m)	
	n/d	422136 MWh			
SCENARIO 3 Adequate structure counting with all potential vectors	Energy Service	Quantity	Energy Vector	Quantity	
	Electricity Specific	2667001 MWhe	Grid's Electricity	3132983 MWhe	
	Heating/Cooling	2352724 MWht	PV Electricity	1225447 MWhe	
	Motion	7137429 MWWhm	Solar Heat	526526 MWht	
	n/d	422136 MWh	Biomass Heat	17936 MWht	
			Geo Heat	1338910 MWht	
			Fossil Fuels	6337489 MWWh(t+m)	
3.3.6. MODELLING OPT OTHERS 4.1. MODELLING SCENARIOS 4.2. SCENARIOS ANALYSIS 4.3. INTEGRATED ASSESSME					

Modelling Energy Supply - Results according the strategy followed for the exploitation of endogenous renewable energy resources.

INTEGRATED MODEL - Microsoft Excel

2. MODELLING SUPPLY

Auxiliary tables »

SCENARIO A1

Resource	Vector	Quantity to supply (MWh)	Installed capacity	Units
Wind	Electricity	4021859	2010.9	MW
Sun	Electricity	656610	261.7	
Hydro	Electricity	13930	4.9	
Sun	Heat	209900	122.0	
Other Renewable	Electricity	117427	29.4	
	Heat			

Vectors Provided	Quantity to supply (MWh)
Grid's Electricity	4751112
Solar Heat	209900
Other R. Heat	58713

SCENARIO B2

Resource	Vector	Quantity to supply (MWh)	Installed capacity	Units
Sun	Heat	1251297	727	MW
Sun	Electricity	1333501	531	MW
Geo	Heat	1023789	117	MW
Wind	Electricity	1200151	600	MW
Sea	Electricity	133350	58	MW
Biomass	Heat	77638	19182	ton

Vectors Provided	Quantity to supply (MWh)
Grid's Electricity	1333501
PV Electricity	1333501
Solar Heat	1251297
Geo Heat	1023789
Biomass Heat	77638

SCENARIO C3

Resource	Vector	Quantity to supply (MWh)	Installed capacity	Units
Wind	Electricity	1333501	667	MW
Geo	Heat	1251297	143	MW
Sun	Heat	1023789	595	MW
Sun	Electricity	1200151	478	MW
Biomass	Heat	77638	19182	ton
Sea	Electricity	133350	58	MW

Vectors Provided	Quantity to supply (MWh)
Grid's Electricity	1466851
PV Electricity	1200151
Solar Heat	1023789
Geo Heat	1251297
Biomass Heat	77638

3.3.6. MODELLING OPT OTHERS

4.1. MODELLING SCENARIOS

4.2. SCENARIOS' ANALYSIS

4.3. INTEGRA

Annex V – Integrated Assessment

Description of indicators used for CDF 1 – Energy Shift

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 1 - ENERGY SHIFT				
1. Diversity				
Accounts for the diversity attained in each planning proposal (based on indicator used for energy performance)				
2. Adequacy to energy services				
Global adequacy calculated by the sum of partial adequacy (absolute value). As the result is closer to zero, more adequate the solution is.				
3. Self-sufficiency				
Accounts for self-sufficiency in each planning proposal (based on indicator used for energy performance)				
4. Decentralization				
Accounts for decentralization in each planning proposal (based on indicator used for energy performance)				
5. Shift on energy vectors in use				
Considers the difference between the traditional demand structure (represented by A1) and the improved demand structures, being the highest the best				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
Shift on energy vectors in use	0	4224961	6844965	6844965
6. Level of matching				
Accounts for the matching achieved in each planning proposal (based on indicator used for energy performance)				
4.3. INTEGRATED ASSESSMENT IA - 1 IA - 2 IA - 3 support_energy resources support_comparativeanaly				

Summary of results under CDF 1 – Energy Shift

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 1 - ENERGY SHIFT				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
C1 - Energy resources towards the vision				
Diversity (%)	50	50	100	100
Adequacy to energy services	1.728	0.264	0.574	0.574
Self-sufficiency (%)	10.5	35.8	31.0	49.6
Decentralization (%)	1.5	45.1	52.9	55.3
C2 - Demand side effort for the shift				
Shift on energy vectors in use	0	4224961	6844965	6844965
Level of matching (%)	13.9	37.7	37.1	49.6

Description of indicators used for CDF 2 – Energy Resources' Allocation

INTEGRATED MODEL - Microsoft Excel

INTEGRATED ASSESSMENT - SUPPORT TO CDF 2 - ENERGY RESOURCES' ALLOCATION

1. Energy exploitation of natural resources

Considers the exploitation of the natural energy resources on each planning proposal, regarding the limits of the natural resources in the island, according the values:

{0} = all the energy resources are explored below their limit of exploitation

]0 ; 0.5[= less that half of the energy resources are explored near their limit of exploitation

[0.5 ; 1]= half or more of the energy resources are explored near their limit of exploitation

	Scenario A1	Scenario B2	Scenario C3	Scenario D
Energy exploitation of natural resources	0.4	0.2	0.2	0.4
	wind and hydro	wind	wind	wind and biomass

2. Total installed capacity for energy purposes

Considers the total installed capacity (of renewable resources) in the island. The lower the value less intensity in the exploitation of the resources for energy purposes

3. Competition among other uses

Applied to the energy resources that can have multiple uses (e. g. water or biomass resources), this indicator considers the affection of those resources according three levels:

0 = low affection on other uses

1 = medium affection on other uses

2 = high affection on other uses

	Scenario A1	Scenario B2	Scenario C3	Scenario D
Competition among other uses	2	0	0	1
	Water		Biomass	

4.3. INTEGRATED ASSESSMENT

IA - 1

IA - 2

IA - 3

support_energy resources

support_comparativeanal

INTEGRATED MODEL - Microsoft Excel

INTEGRATED ASSESSMENT - SUPPORT TO CDF 2 - ENERGY RESOURCES' ALLOCATION

4. Competition for same territorial areas

Considers the territorial expression on the use of the resources assuming that planning proposals with higher land areas occupied for energy purposes represent higher pressure/competition with other uses of land-based resources in the island.

	Scenario A1	Scenario B2	Scenario C3	Scenario D
Competition for same territorial areas (km ²)*	95.41	100.30	97.53	102.18

* accounted for sun and wind

SCENARIO A1

Resource	Vector	Quantity to s	Installed cap	Units	Area	units	Conversion factors
Wind	Electricity	935000	467.5	MW	93500000	m2	Wind - 5 MW/km2
Sun	Electricity	570032.02	227.16095		1893007.9	m2	Sun PV - 0.12 kW/m2
Hydro	Electricity	12093.004	4.2476305				
Sun	Heat	26394.629	15.339345		21913.349	m2	Sun Heat - 0.7 kW/m2
Other Renewables	Electricity	101943.13	25.485783	MW			
Total					95414921 m2		
					95.414921 Km2		

SCENARIO B2

Resource	Vector	Quantity to s	Installed cap	Units	Area	units
Sun	Heat	2138875.3	1243.016	MW	1775737.1	m2
Sun	Electricity	1512540.1	602.75572	MW	5022964.3	m2
Geo	Heat	0	0	MW		
Wind	Electricity	935000	467.5	MW	93500000	m2
Sea	Electricity	151254.01	65.762615	MW		
Biomass	Heat	0	19182.325	ton		
Total					100298701 m2	
					100.2987 Km2	

SCENARIO C3

Resource	Vector	Quantity to s	Installed cap	Units	Area	units
Wind	Electricity	935000	467.5	MW	93500000	m2
Geo	Heat	1650906.8	188.45968	MW		
Sun	Heat	753853.58	438.10503	MW	625864.33	m2
Sun	Electricity	1026180.7	408.93875	MW	3407822.9	m2
Biomass	Heat	17936.072	19182.325	ton		
Sea	Electricity	279292.39	121.43147	MW		
Total					97533687 m2	
					97.533687 Km2	

SCENARIO D

Resource	Vector	Quantity to s	Installed cap	Units	Area	units
Wind	Electricity	935000	467.5	MW	93500000	m2
Geo	Heat	1650906.8	188.45968	MW		
Sun	Heat	671789.65	390.41325	MW	557733.21	m2
Sun dec	Electricity	1026180.7	408.93875	MW	3407822.9	m2
Sun grid**	Electricity	1420768.4	566.18416	MW	4718201.3	m2
Biomass*	Heat	100000				
Sea**	Electricity	437155.54	190.06763	MW		
Total					102183757 m2	
					102.18376 Km2	

Summary of results under CDF 2 – Energy Resources’ Allocation

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 2 - ENERGY RESOURCES' ALLOCATION				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
C3 - Energy intensity in the use of natural resources				
Energy exploitation of natural resources	0.4	0.2	0.2	0.4
Total installed capacity for energy purposes (MW)	739.7	2379.0	1624.4	2211.6
C4 - Global affection of natural resources				
Competition among other uses	2	0	0	1
Competition for same territorial areas (km ²)	95.41	100.30	97.53	102.18

4.3. INTEGRATED ASSESSMENT IA - 1 IA - 2 IA - 3 support_energy resources support_comparativea

Description of indicators used for CDF 3 – Energy System and SD nexus

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 3 - ENERGY SYSTEM AND SUSTAINABLE DEVELOPMENT NEXUS				
1. Adequacy to territorial strategy				
Assesses the contribution of planning proposals to the strategy followed for the development in the island according five levels: -2 = global negative contribution for the development path -1 = partial negative contribution for the development path 0 = without specific contribution for the development path 1 = partial positive contribution for the development path 2 = global positive contribution for the development path				
According the sustainability results of the development alternatives for Gran Canary, the one with best performance is alternative 3 - "Development by renovation and integral requalification". The energy planning were assessed considering this development path:				
Scenario A1 - No changes are considered at demand side and the supply makes use of some resources that already register stress - it is considered a value of -1				
Scenario B2 - No changes are considered at the demand side and the supply makes the effort to use some of the most abundant resources - it is considered the value 0				
Scenario C3 - The demand side registers a change on the use of energy at end use, that can express an effort in renovation and the supply makes use of the existing renewable resources - it is considered the value 1				
Scenario D - The demand side registers a change on the use of energy at end use, that can express an effort in renovation and the supply makes use of the existing renewable resources, allying their use with the improvement of some biophysical aspects - it is considered the value 2				
2. Amelioration of island's sensitiveness				
Accounts for the positive or negative effects that energy planning proposals can have on the global environmental context of the island: + positive effect - negative effect				
- Accounted for the specific actions regarding the use of water resources and biomass				
3. Intra-generational access to energy				
Relates with the effort that current generation has to apply to accomplish the planning proposal. Affected by the shift at the demand side, it is considered that the efforts to attain a higher shift imply the change of end-use equipments, resulting in higher intra-generational inequalities and difficult access to the energy vectors considered in the planning proposals.				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
Intra-generational access to energy (effort % of energy to shift)	0.0	33.6	54.4	54.4
4. Intergenerational access to energy				
Based on the dependency of Gran Canary from external energy resources, it assumes that the intergenerational access to energy is higher when the island reduces its energy dependency.				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
Intergenerational access to energy (% of external energy required)	89.5	64.2	69.0	50.4
4.3. INTEGRATED ASSESSMENT IA - 1 IA - 2 IA - 3 support_energy resources support_comparatives				

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 3 - ENERGY SYSTEM AND SUSTAINABLE DEVELOPMENT NEXUS				
5. Energy affordability (for electricity)				
Electricity costs - based on the open source calculator http://en.openei.org/apps/TCDB/ (reports from 2008 to 2012) annouced at NREL webpage http://www.nrel.gov/analysis/tech_lcoe.html				
levelized cost of energy				
Biomass				
Geothermal				
Small Hydro	0.14	\$/kWh		
Solar PV	0.27	\$/kWh		
Solar thermal				
Wind	0.06	\$/kWh		
Ocean	0.22	\$/kWh		
Concentrate	0.19	\$/kWh		
	Scenario A1	Scenario B2	Scenario C3	Scenario D
Energy affordability (for electricity, at current prices)(\$/kWh)	0.141	0.192	0.176	0.183
6. Jobs creation				
According Wei, 2010				
Biomass	1.61	Jobs/Mw		
Geothermal	1.7	Jobs/Mw		
Small Hydro	2.07	Jobs/Mw		
Solar PV	1.85	Jobs/Mw		
Solar thermal	0.95	Jobs/Mw		
Wind	0.83	Jobs/Mw		
	Scenario A1	Scenario B2	Scenario C3	Scenario D
Jobs creation	852.8	2738.6	1981.9	3041.0
7. CO2 emissions				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
CO ₂ emissions (t CO ₂ eq/inh)	3.8	1.8	2.7	1.5
8. % of renewable electricity				
Electricity from renewables/Total electricity consumed				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
% of renewable electricity	41.2	85.9	58.7	100.0
4.3. INTEGRATED ASSESSMENT IA - 1 IA - 2 IA - 3 support_energy resources support_comparative				

Summary of results under CDF 2 – Energy Resources’ Allocation

INTEGRATED MODEL - Microsoft Excel				
INTEGRATED ASSESSMENT - SUPPORT TO CDF 3 - ENERGY SYSTEM AND SUSTAINABLE DEVELOPMENT NEXUS				
	Scenario A1	Scenario B2	Scenario C3	Scenario D
C5 - Contribution for SD path adopted for Gran Canary				
Adequacy to territorial strategy	-1	0	1	2
Amelioration of island's sensitiveness	-	0	0 +	
C6 - General SD concerns related with the use of energy				
Intra-generational access to energy (effort % of energy to shift)	0.0	33.6	54.4	54.4
Intergenerational access to energy (% of external energy required)	89.5	64.2	69.0	50.4
Energy affordability (for electricity, at current prices)(\$/kWh)	0.141	0.192	0.176	0.183
Jobs creation	852.8	2738.6	1981.9	3041.0
CO ₂ emissions (t CO ₂ eq/inh)	3.8	1.8	2.7	1.5
% of renewable electricity	41.2	85.9	58.7	100.0

4.3. INTEGRATED ASSESSMENT IA - 1 IA - 2 **IA - 3** support_energy resources support_comparativ