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Department of Mechanical Engineering

Decision Support Methodology for Local Sustainable Energy Planning

Ana Rita Fragoso Neves

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Supervisor: Vítor Manuel Silva Leal
Professor at the Faculty of Engineering of the University of Porto
Co-Supervisor: João Carlos da Cruz Lourenço
Professor at the Instituto Superior Técnico, Technical University of Lisbon

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Abstract

First initiatives of energy and climate action at the local level can be tracked back into the 1990s. Although, only in the last decade integrated local energy planning initiatives have gained greater expression. A number of energy or climate action plans have been materialising on the ground, while the topic has not deserved the corresponding attention on the scientific literature so far. The new energy paradigm calls for a need to focus on the energy services for which energy is actually demanded and to identify the appropriate energy carriers and technologies to satisfy those services. Energy has several implications in sustainable development and thus a holistic perspective to local energy systems is deemed necessary. Hence, this thesis builds on the need to improve local energy planning processes by proposing a decision support methodology for local sustainable energy planning. The focus is on providing an energy services-oriented modelling approach and a solid and comprehensive basis for evaluating alternative energy action plans. Since energy planning is a decision process, it involves choices regarding the future of the community. In order to make well-weighted choices it is important to include the values and preferences of the local actors into the energy planning process.

During this research, several methods from different disciplines were reviewed in order to identify the most suited combination to satisfy the methodology's requirements. While methods compatible with the thesis' purpose were identified for problem structuring (cognitive mapping, causal mapping and decision conferencing) and for multi-criteria evaluation (MACBETH), the same did not happen for energy models. It was indeed necessary to build an end-use energy model, in order to accommodate hypothetical future changes at the energy services and technology levels and determine the impact of each alternative scenario on the multiple objectives identified.

The methodology was applied to the practical case of the municipality of Barreiro in order to demonstrate how it can be made operational. With the help of the local energy planning assistant tool developed, a reference scenario for 2020 was modelled, six alternatives were generated and their impacts regarding the attainment of the objectives were quantified. Furthermore, those impacts were transferred as inputs for the multi-criteria evaluation model, which was built by five local actors. Finally, the analysis of the benefits of the alternatives versus their investments allowed exploring the trade-offs that a decision-maker can face when selecting an alternative. The methodology proposed adopts an eclectic and socio-technical approach, intended to support decision in the whole energy planning process - from structuring to the choice of the action plan.

Sumário

As primeiras initiativas na área da energia e clima a nível local remontam aos anos 90. No entanto, apenas na última década as iniciativas de planeamento energético local integrado começaram a ganhar expressão. Vários planos de acção para a energia e clima locais têm vindo a ser elaborados, enquanto o tópico ainda não mereceu a mesma atenção na literatura científica. No contexto de um novo paradigma energético, os serviços energéticos surgem como um ponto central, assim como a identificação dos vectores energéticos e tecnologias apropriadas para satisfazer esses serviços. A energia tem diversas implicações no desenvolvimento sustentável pelo que uma perspectiva holística aos sistemas energéticos locais é fundamental. A presente tese propõe uma metodologia de apoio à decisão para o planeamento energético sustentável a nível local, direccionada para a modelação a nível dos serviços energéticos e para a avaliação de alternativas (i.e. planos de acção). Sendo o planeamento energético um processo de decisão, este requer a realização de escolhas em relação ao futuro da comunidade. De forma a obter escolhas devidamente ponderadas, torna-se importante incluir os valores e as preferências dos actores locais no processo de planeamento energético.

No decorrer desta investigação, métodos de disciplinas diferentes foram analisados de forma a identificar uma combinação apropriada para integrar na metodologia. Tendo sido possível encontrar métodos compatíveis com os requesitos e objectivos da metodologia para as disciplinas de estruturação de problemas (mapas cognitivos, mapas causais e conferências de decisão) bem como para a avaliação multi-critério (MACBETH), o mesmo não aconteceu para a modelação energética. Para esta última, foi necessário desenvolver um modelo de serviços energéticos, de forma a acomodar alterações hipotéticas na procura de serviços energéticos e nas tecnologias utilizadas, assim como para determinar os impactes the cada uma das alternativas nos objectivos múltiplos considerados.

A metodologia foi aplicada ao município do Barreiro com o objectivo de demonstrar a sua operacionalização. Com recurso à ferramenta de planeamento energético local desenvolvida, procedeu-se à modelação de um cenário de referência para 2020, à construção de seis alternativas e à quantificação dos impactes das alternativas que serviram como *inputs* para o modelo multi-critério. A análise dos benefícios das alternativas em relação ao investimento permitiu ainda explorar os *trade-offs* que um decisor pode enfrentar aquando da escolha de uma alternativa. A metodologia proposta adopta uma abordagem eclética e socio-técnica, com o intuito de apoiar a decisão ao longo de todo o processo de planeamento energético, isto é, da fase de estruturação até à escolha de um plano de acção.

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1. Introduction

1.1 The transition to a new energy paradigm

Energy contributes to the satisfaction of human needs and aspirations, the major objective of development. It provides a variety of energy services to which access is fundamental to improve human welfare. Sustainable development has become a goal of our society and it must be the driver of energy planning as energy systems of today are still markedly unsustainable. Current energy systems are largely driven by the combustion of fossil fuels, which causes a number of negative impacts in the environment, in the society and in the economy. Impacts such as the greenhouse gases (GHG) emissions are considered to be the principal cause of climate change (IPCC, 2007); the depletion of natural resources affects the ecosystems and the wellbeing of human population; and, for many countries, the costs and risks on the security of energy supply due to the dependence of imported fossil fuels from other countries affect negatively the economy.

The need to shift to a new energy paradigm first emerged after the oil crisis of the 1970s. The deep concern with the implications of the conventional fossil fuel supply-side paradigm has led several authors to work out a new approach to energy planning. They suggested that the emphasis on energy planning needed to shift from expanding energy supply to improving energy use. Energy is useful as 'it provides such services as cooking, lighting, heating, refrigeration, mechanical work, and personal and freight transport in ways that improve the quality of life' (Goldemberg *et al.*, 1987, p. 36). The important thing is to understand how and by whom different forms of energy are used today and how the energy end-use system might evolve in the future. The use of an end-use approach allows at identifying better ways of meeting future energy demand, by focusing on the level of energy services instead of the magnitude of energy consumption. Energy services can be increased not only by increasing the supply, but also by using energy more efficiently (Reddy, 2002).

Goldemberg *et al.* (1987) has also emphasised that energy is only one global problem, among other such as global economic crisis, poverty, population growth, nuclear risks, environmental degradation and climate change, that must be managed in order to achieve a sustainable world society. However, all these global problems are strongly related to energy use. As so, the solution to the energy problem must contribute to, and be consistent with, the solutions of these other global problems.

The transition to sustainability, and thus to this new energy paradigm, has been referred to as the Sixth Wave of Industrialism (see Figure 1). According to Newman, Beatley & Boyer (2009), the Sixth Wave coincides with the end of cheap oil, which had its peak in the Fourth Wave and was still dominating the Fifth Wave. The cheap oil had consequences in cities such as the domination by automobiles and consequently the sprawling in every direction (automobile city). The Sixth Wave is thus 'the beginning of an era of resource productivity and investment in new series of sustainability technologies related to renewables and distributed, small-scale water, energy, and waste systems […], all of which are more local and require far less fuel to distribute' (Newman, Beatley & Boyer, 2005, p. 53). However, 'it is clear that the changes needed for the resilient city are not just technology substitutions, they are in the business paradigms, the culture of the utilities that will provide the infrastructure, and the organisation that can enable new ways of managing our cities; every householder needs to be part of it' (Newman, Beatley & Boyer 2005, p. 53).

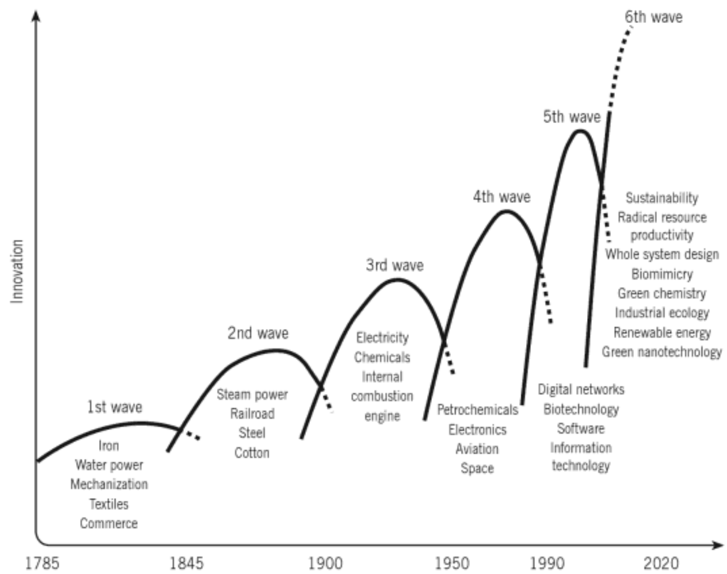


Figure 1 - Waves of industrial innovation. Source: Hargroves & Smith (2005)

1.2 The focus on local action

The 'global' problem of climate change has its roots in the intensive use of energy, which is in turn used 'locally' to sustain local activities. Therefore, local authorities have a significant role to play in the new energy paradigm. Local authorities can take action in several of their roles in what regards community-wide energy management (CEMR, Energie-Cités & Climate Alliance 2006): consumer and service provider, as responsible for many public buildings, street lighting and collective transport, using high amounts of energy; planner, developer and regulator, by taking strategic decisions on land use planning such as avoiding urban sprawl and as a regulator by setting energy performance standards; advisor and motivator, as responsible to inform and motivate citizens on how to use energy more sustainably; and as producer and supplier, by promoting the use of renewable energy.

Local authorities are able to visualise the details that are not seen by higher levels of government and are the 'first responder' to local issues, since local citizens and businesses turn to local leaders in times of emergency (Lerch, 2007). A decentralised design of policies allows for better fit local circumstances and citizens' needs. 'Citizens are also more likely to interact directly with their local government, providing greater opportunities for addressing local social acceptance issues by gaining support for local clean energy programs' (Busche, 2010, p.4).

Agenda 21, the global action plan for Sustainable Development for the 21st Century highlights the need to 'think globally, act locally' (UNSD, 1992). The Aalborg Charter emphasises the capacity of local authorities to solve some of the global environmental problems, as they are close to where environmental problems are perceived and closest to the citizens (Charter of European Cities & Towns Towards Sustainability, 1994).

The European Union (EU) has made the fight against climate change a top priority. The EU Climate Action and Energy Package set a series of targets to be met by 2020 (Commission of the European Communities, 2008). Member States are obliged to curb their GHG emissions by at least 20%. Recognising the importance to act at the local level in the implementation of sustainable energy policies, the European Commission launched the Covenant of Mayors initiative in 2008, as mentioned in the EU Action Plan for Energy Efficiency (Commission of the European Communities, 2006). The initiative consists on the formal commitment of cities which aim to go beyond the objectives of the EU for 2020 in terms of reducing their GHG emissions through the implementation of a Sustainable Energy Action Plan. The initiative stresses the fact that cities must become the leading actors for implementing sustainable energy policies. The European Commission acts as 'the political endorser and provider of moral, technical and visibility support' (Torres & Doubrava, 2010, p. 95).

Since the 1990s that acting on energy and climate at the local level has been gaining expression. Several networks of local authorities in which their members commit to implement sustainable energy policies and actions with the aim of reducing GHG emissions have been emerging worldwide. These networks started in Europe in 1990 with Climate Alliance (Climate Alliance, 2012) and Energy Cities (Energy Cities, 2012). At the international level, the International Council for Local Environmental Initiatives (ICLEI) launched the Cities for Climate Protection Campaign (ICLEI, 2008; ICLEI-Europe, 2012) in 1993 and in 2005 the C40 Cities Climate Leadership Group (network of the 40 world's megacities) was created (C40 Cities, 2011). More recently, the Mexico City Pact (ICLEI, 2010) was launched at the World Mayors Summit on Climate held in 2010. It is expected to build on existing actions, such as the Covenant of Mayors in Europe or the US Conference of Mayors Climate Protection Agreement and the achievements of global advocacy through the Local Government Climate Roadmap.

1.3 What is local sustainable energy planning?

Planning is a decision process which consists on defining objectives and on identifying and choosing strategies to reach those objectives. 'Planning is an iteractive procedure that needs to be reviewed when new problems arise, values of perceptions change, additional aspects have to be considered, new technologies or strategies become available or the institutional framework changes (Graeber & Schlenzig, 1998, p. 13). Planning is not a prediction of the future but is a technique that allows creating a rational basis for decision-making helping in providing policy recommendations (Graeber & Schlenzig, 1998).

The concept of local sustainable energy planning adopted in this thesis is rooted on the new energy paradigm (see section 1.1.), in which the focus of energy systems planning is on the level of services that energy provides to human beings. As the ultimate goal is sustainable development, economic, environmental and social dimensions must be considered in the energy planning process.

The main goal of local sustainable energy planning is thus to plan how future energy services needs could be satisfied in the presence of multiple sustainability objectives. A future energy system which reduces the side effects on the environment to a level within its assimilative capacity, and which raises opportunities for economic and social development, taking a longer-term perspective, is the basis to achieve greater sustainability.

The so-called reference scenario gives the expected evolution for a certain time horizon of the energy demand, based on current trends and compliance with legal requirements and policies foreseen today. The reference scenario is thus the basis to build and compare possible alternative strategies. The alternatives of action at the local level refer to what energy demand side actions can be implemented and/or small-scale energy supply infrastructure (based on endogenous energy resources) can be deployed during the implementation period of the plan.

Since the planning is community-wide, the actions undertaken will have implications at several levels in the community: economic development, environmental protection and social welfare. The effectiveness of the implementation of actions depends on the receptivity by citizens and business, namely in changing their behaviours. Therefore, it is necessary to involve the local actors and consider their points of view in the energy planning, to ensure transparency and legitimacy of the process. The process shall result in the choice of an alternative based on the local actors' values and preferences.

Local sustainable energy planning endeavours to assess and weight the impact of alternatives under well-defined and agreed environmental, economic and social objectives.

1.4 Local energy planning practices

First initiatives of energy and climate action at the local level can be tracked back into the 1990s. Although, it has been during the last decade that pioneer cities started to prepare their local energy and climate action plans in response to acting on climate change and other local motivations in an integrated manner. Particularly at EU level, the Covenant of Mayors initiative was a tipping point in the development of those action plans. By December 2012 more than 2,000 Sustainable Energy Action Plans have been prepared by local authorities and the number is expected to continuously rise (Covenant of Mayors Office, 2012).

Although a number of local energy and climate action plans can be identified, the topic is seldom documented in the scientific literature. As so, it becomes necessary to delve into local energy planning practices taking place on the ground. For this, it was decided to investigate a sample of local energy and climate action plans. An energy planning process typically results in the elaboration of an action plan which specifies the actions to be adopted in order to achieve the objectives.

The sample of action plans was identified in 2008 through a web search using the Google search engine and websites operated by local authorities known from previous research work (Neves, 2007). The selection of 10 municipalities with an energy or climate action plan was performed by ensuring representation of different geographic contexts and municipality sizes. The sample comprises five United States (US) municipalities and five EU municipalities with published plans between 2002 and 2010 (Table 1). Some of the initial plans were updated since the start of this research, and those updates were included in the review as well. Two reasons were found that justify the update of the plans by the local authorities: the time horizon of the planning period was reached or was about to be reached, in the case of US municipalities and Barcelona (ES); EU municipalities engaged in the Covenant of Mayors, and have decided to update their action plan in line with the European Commission's guidelines (EU, 2010). All information collected is based on information publicly available at the local authorities' websites, namely the action plans and associated documents such as monitoring reports.

Table 1 – Action plans reviewed.

Municipality	Country	Title of action plan	Plan year	Update plan year	Population
Cambridge (Ca)	US	City of Cambridge climate protection plan. Local actions to reduce greenhouse gas emissions	2002	-	105,162
Chicago (Ch)	US	Chicago climate action plan. Our City. Our Future.	2008	-	2,695,598
Los Angeles (LA)	US	GREEN LA. An action plan to lead the nation in fighting global warming.	2007	-	3,792,621
San Francisco (SF)	US	Climate Action Plan for San Francisco. Local Actions to Reduce Greenhouse Gas Emissions.	2004	2009	805,235
Seattle (Se)	US	Seattle, a Climate Change: Meeting the Kyoto Challenge. Climate Action Plan.	2006	-	608,660
Almada (Al)	PT	*Estratégia Local para as Alterações Climáticas*	2007	2010	174,030
Stockholm (St)	SE	Stockholm's Action Programme against Greenhouse Gas Emissions.	2002	2010	837,031
Barcelona (Bcn)	ES	Plan for Energy Improvement in Barcelona	2002	2010	1,624,537
Dublin (Du)	IE	Action Plan on Energy for Dublin	2008	2010	505,739
London (Lo)	UK	Action today to Protect Tomorrow. The Mayor's Climate Change Action Plan.	2007	2010	7,825,200

The review of action plans aimed at investigating the steps undertaken and the issues considered by local authorities when drawing up their action plans. Table 2 summarises the main characteristics of interest to this thesis of the 10 action plans selected.

Table 2 – Review of 10 energy and climate action plans (and associated documents).

Items		Ca	Ch	LA	SF	Se	Al	St	Bcn	Du	Lo	Total
Diagnosis of current situation	By sector and energy carrier	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
	By end-use and energy carrier	×	×	×	×	×	×	×	✓*	×	×	1
Definition of objectives	Environmental	✓	✓	✓	×	✓	×	×	✓	✓	✓	7
	Economic	✓	✓	✓	×	✓	×	×	✓	✓	✓	7
	Social	✓	✓	✓	×	✓	×	×	×	✓	✓	6
Target setting	GHG reduction	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
	Other	×	×	×	×	×	×	×	×	✓	×	1
Projections on energy demand or	Reference/ business-as-usual scenario	×	✓	×	✓	×	✓	✓	✓	✓	✓	7

Items		Ca	Ch	LA	SF	Se	Al	St	Bcn	Du	Lo	Total
GHG emissions	1-2 alternative scenarios	×	✓	×	✓	×	✓	✓	✓	✓	✓	7
	3 or more alternative scenarios	×	×	×	×	×	×	×	×	×	×	0
Basis for selecting the actions	Definition of specific criteria for selection/ prioritisation	×	✓	×	×	×	×	✓	×	×	✓	3
	Past actions or actions from other plans of the municipality	✓	×	×	✓	×	×	×	×	×	×	2
	Actions included in other municipalities' action plans (best practices)	×	✓	×	×	×	×	×	✓	×	×	2
	Inputs from stakeholders	×	✓	×	×	×	×	×	×	×	×	1
	No reference in the action plan	×	×	✓	×	✓	✓	×	×	✓	×	4
Estimates of the impact of actions/ alternatives	in GHG emissions reduction	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	9
	in other indicators	×	×	×	×	×	✓	✓	✓	✓	✓	5
Definition of indicators for monitoring **	Overall energy sustainability indicators	×	×	×	×	✓	×	✓	✓	×	✓	4
	Action progress-based indicators	✓	×	×	✓	✓	×	×	✓	×	×	4

* For residential and transport sectors.

** Indicators are normally found in municipalities' monitoring reports.

Although some common features of action plans can be identified in Table 2, such as the diagnosis of current situation in terms of GHG emissions by sector and by energy carrier and the setting of a GHG emissions reduction target, there are great variations in local energy planning practices among municipalities.

A characterisation of energy consumption and GHG emissions by energy end-use categories is not a practice adopted by municipalities. Only the plan of Barcelona (Ajuntament de Barcelona, n.d.) contains such a disaggregated characterisation, but only for the residential and transport sectors.

GHG emissions reduction corresponds to the only target being adopted by the local authorities, with the exception of Dublin which adopts a target on energy use as well. Nevertheless, objectives at other environmental, economic and social levels are mentioned in about 70% of the action plans. This shows that albeit GHG emissions are an ultimate goal of energy planning, local authorities recognise the importance of energy planning in other sustainable development objectives. Chicago action plan states that *'Beyond helping to solve a global problem, cities and their residents can immediately* *benefit from their efforts to reduce emissions. One result will be better air quality, leading to improved health for everyone. Raising the energy efficiency of buildings saves money, lowers housing costs for families and creates jobs, especially for local businesses. Economic development gets a boost. As people are able to live closer to work, schools and services, they enjoy a better quality of life'* (City of Chicago, n.d.). The same is recognised by London's action plan: *'Reducing London's* CO_2 *emissions will not only benefit the environment but also boost London's economy, improve energy security and tackle fuel poverty, making it a better place to live and work'* (Mayor of London, 2010).

A considerable number of plans (7 out of 10) include a reference or business-as-usual scenario to show how current trends are projected into the future. However, the methodology and assumptions behind the construction of such scenario are not explicitly presented in none of the plans. Stockholm included assumptions on 'population growth' and 'improvement of energy efficiency in buildings per year' (City of Stockholm, 2002), while Almada adopted an annual growth-rate approach (based on European projection studies) (CMA & Ageneal, 2010). In addition to the reference scenario, usually one alternative scenario is considered – the one including the actions outlined in the action plan. Exceptions are Dublin (Codema, 2010) and Stockholm (City of Stockholm, 2002) energy action plans which consider two alternative scenarios to the reference scenario.

In what regards the process of selecting the actions included in the action plans, this is barely documented in the action plans reviewed. The basis for including actions on the plans is superficially mentioned in the action plans of Cambridge: *'It builds on past actions and proposes new actions (...)'* (City of Cambridge, n.d., p.3-5); San Francisco: *'To develop this list of action items, we have drawn from several related plans and policies governing transportation, energy and recycling in the City (...)' (*SF Environment & SFPUC, 2004, p.3-1)*;* Barcelona: *'When preparing its energy strategy, rather than acting in isolation from the rest of the world, Barcelona took into account policies carried out by other cities'* (Ajuntament de Barcelona n.d., p.45); London: *'The approach taken in this action plan has been to set out a program that the Mayor is confident can be delivered in London and which prioritises initiatives that will achieve the greatest carbon emissions reductions most quickly and most cost-effectively'* (Mayor of London, 2007, p.27); and Stockholm: *'The City of Stockholm should have a certain control over the measures; measures must not have a negative impact on other environmental objectives, and; measures must be as cost-effective as possible'* (City of Stockholm, 2002, p.11). The action plan of Chicago presents explicitly the criteria used for evaluating each action: '*reduction potential – total achievable greenhouse gas emissions reductions; cost-effectiveness – cost of implementation and the potential savings generated; feasibility – ease of achievement and potential to overcome barriers; benefits* *and burdens – advantages and drawbacks to the action, such as savings to residents, job creation and quality of life improvements; regional impact – level of opportunity for the larger six-county area (Cook, Will, DuPage, Kane, McHenry and Lake); and rapid deployment – opportunity to effect changes quickly'* (City of Chicago, n.d., p. 17), but the description of the procedure is lacking.

Estimates of GHG emissions reduction of actions or alternatives (set of actions) are included in most of the plans reviewed. Five plans presented quantification of the impact of actions in other indicators such as costs. Stockholm action plan quantified the impact of certain actions in terms of job creation while jobs generated by the implementation of Chicago's Climate Action Plan were subjected to a specific study (Schrock & Sundquist, 2009).

The identification of indicators for monitoring in the action plans reviewed was only included in San Francisco and Seattle action plans. The indicators identified in these plans are easily-measurable indicators and specific to follow-up the progress of each particular action (action-based indicators). For instance, for the action on 'Substantially increase the use of biofuels' in Seattle's action plan (City of Seattle, 2006), the indicator chosen is the 'Number of biofuel stations in Seattle'. This indicator does not provide information on how much biofuel is actually being sold and consumed. Rather than focusing on evaluating the impact of the actions, indicators such as the one presented focus on the degree of implementation of the actions.

But the fact that indicators are not addressed in the action plans does not mean that local authorities are not using them at all. Indeed, it was found out that indicators are afterwards included in monitoring or progress reports. These reports aim at monitoring the implementation of the actions stated in the action plan and although essentially based on a qualitative description of the progress made, the reports contain indicators which vary between overall performance indicators (most frequent are GHG emissions by sector and energy consumption) and action or project-based indicators. Table 3 lists examples of indicators being adopted by four municipalities for monitoring purposes. The list excludes the action-based indicators included in the action plans of San Francisco and Seattle for being too action specific and diverse. The examples of indicators presented in Table 3 show that there is a wide variation on the indicators used among municipalities, and besides GHG emissions it is difficult to identify other common metrics.

Table 3 – Example of indicators included in the reporting of the progress of the energy and climate action plans of Cambridge, Seattle, Stockholm and Barcelona. Sources: City of Cambridge (2004); City of Cambridge (2005); City of Cambridge (2006); City of Seattle (2008a); City of Seattle (2008b); City of Seattle (2009); Hedvik (n.d.); Agència d'Energia de Barcelona (2006); Agència d'Energia de Barcelona (2008).

Indicators	**Ca**	**Se**	**St**	**Bcn**
GHG emissions by sector	✓	✓	✓	✓
Per capita GHG emissions per sector	✓	✓	✓	×
Residential emissions per household	✓	×	✓	×
Per capita residential electricity use	×	✓	×	×
Electricity and natural gas consumption by sector	✓	×	×	×
Use of electricity (total & per capita)	×	×	✓	×
Electricity generated by source in the municipality	×	×	×	✓
Renewable energy produced by source in the municipality	×	×	×	✓
Final energy use by energy sources and by sector	×	×	×	✓
Per capita water consumption	×	✓	×	×
Bike to work day participants	×	✓	×	×
Average Weekday Metro and Sound Transit Ridership	×	✓	×	×
Energy consumption per square foot (of specific municipal buildings)	✓	×	×	×
Vehicle miles travelled (or vehicle kilometre)	✓	✓	✓	×
Vehicles registered	✓	×	×	×
Waste and recycling collected by City	✓	×	×	×
Solar Photovoltaic systems power installed	✓	×	×	×
LEED certified and registered projects	✓	×	×	×
Municipal vehicle fuel use	✓	×	×	×
Energy source of district heating	×	×	✓	×
Surface area of solar thermal installed	×	×	×	✓

From the review of action plans, it is possible to identify common practices on energy planning such as: the elaboration of diagnosis of the current situation in terms of energy demand, supply and GHG emissions; the setting of a GHG emissions reduction target; and the estimates of the GHG emissions reduction potential of the actions selected. The elaboration of a reference scenario (without plan) for a certain time horizon has also a considerable expression among the practices of the municipalities selected. Nevertheless, the practices in constructing a reference scenario or estimating the impact of actions or alternative scenarios are different given that the cities develop their own approaches and do not follow a common standard.

The fact that most of the action plans do not provide any background information about the methods adopted for selecting or prioritising actions seems to indicate that cities have not developed or followed a structured method for this particular task. Monitoring the implementation of an action plan appears to remain a challenge as well, namely in finding adequate and if possible common metrics to track progress towards local energy sustainability. The indicators need to provide a comprehensive overview of the behaviour and impacts of the local energy system. There is a need to shift towards measuring things that *should* be measured instead of things that *can* be measured (Bell & Morse, 2008).

1.5 Research scope and methodology

This thesis addresses the methodological challenges of local energy planning identified in the previous section. The focus is on the methodological framework behind energy planning, namely on end-use energy modelling and on the generation and evaluation of alternative scenarios (or strategies) based on multiple sustainability objectives. Energy planning is a decision process and thus involves choices regarding the future of the community. In order to ensure transparency and make well-weighted choices it is important to include the values and preferences of the local actors into the energy planning process.

In this context, the key research question underlying this thesis is: *How to develop a methodology for decision support on local energy planning, which allows selecting a mid-term energy action plan based on local actors' sustainability objectives and preferences?*

In order to address the research question, the methodology intended to be developed in this thesis shall focus on the following features:

1) Include all the relevant energy demand sectors, end-uses, carriers, and end-use conversion technologies;
2) Provide a database of energy management actions to be included in the generation of alternative mid-term action plans and quantify their impacts;
3) Evaluate alternative mid-term action plans based on multiple strategic objectives of sustainable development that arise at the local level as well as local actors' preferences on those objectives.

These features will be the ground upon which the decision support methodology for local sustainable energy planning will be designed (chapter 4). Being the features of multidisciplinary nature, it becomes necessary to explore methods from different disciplines (chapter 3) to support the design of the methodology, namely energy modelling techniques to aid in modelling the local energy system at the end-use level; problem structuring methods to help in defining the objectives of the local sustainable energy planning problem; and multi-criteria evaluation methods to support on the incorporation of multiple objectives and preferences from the local actors into the energy planning process. An eclectic approach will thus be used in the development of the methodology.

The territorial scope of this work is the local level. According to the Eurostat administrative division for EU Member States, the scope refers to municipalities or NUTS III (Nomenclature of Territorial Units for Statistics) levels. The reason for focusing on the local level is that local authorities own a great power and responsibility to promote energy sustainability in their administrative territories (see section 1.2).

Therefore, this thesis aims at developing a technically sound and scientifically based decision support methodology for local sustainable energy planning, which accommodates the multiplicity of objectives and preferences of local actors. It combines technical modelling with involvement of local actors, leading to the creation of a socio-technical approach to local energy planning. By adopting a comprehensive approach, the methodology proposed seeks to pave the way towards sustainable and inclusive local energy planning.

1.6 Thesis roadmap

The current chapter (chapter 1) introduced the issue of local energy planning and provided a review of current local energy planning practices. It also presented the research scope of this thesis, including the main research question and the key features of the decision support methodology for local sustainable energy planning intended to be developed in this thesis.

Based on the outcomes of the review of local energy planning practices (section 1.4), it was considered worth to investigate deeper existing indicators for local sustainable energy. The review has identified a lack of common and comprehensive metrics to evaluate local energy sustainability as well as a lack of methods for selecting appropriate actions to be included in local energy action plans. Thus, the aim of chapter 2 is twofold: to provide local authorities with a comprehensive set of indicators; and at the same time to initiate the first research step towards the development of the methodology with the identification of potential indicators (later called attributes) that may be used in the selection of actions/alternatives.

Chapter 3 provides an extensive review of background methods and theories to support the design of the methodology proposed in this thesis. The review of methods from different disciplines, such as energy systems modelling and multi-criteria decision analysis, aimed at identifying suitable methods to be integrated in the methodology as well as the needs for the development of new methods. The identification of those methods and analysis of their suitability in line with the desired features of the methodology (section 1.5.) is performed in section 3.5.

Chapter 4 describes in detail the proposed decision support methodology for local sustainable energy planning. The methodology is a patchwork of several methods, approaches and theories - energy modelling, cognitive/causal mapping, value-focused thinking, strategy generation table, decision conferencing, multi-attribute value theory and MACBETH. It adopts a socio-technical approach to the whole energy planning process – from structuring to the choice of the action plan, by combining social aspects resulting from the interaction with the local actors with technical aspects deriving from the application of models and tools.

Chapter 5 provides an application of the methodology for the municipality of Barreiro in Portugal. The whole process of application of the methodology is documented in this chapter, namely the application of the local energy planning assistant tool developed and the interaction with the local actors in the construction of the multi-criteria evaluation model.

The conclusions of this work are presented in chapter 6 as well as suggestions for future research.

1.7 Summary

This chapter introduced the issue of local energy planning and provided a review of current local energy planning practices. Throughout this chapter local sustainable energy planning was defined and the key issues that are addressed in this thesis were identified. In particular, this thesis aims at developing a decision support methodology for local sustainable energy planning, focused on modelling energy demand at end-use level and on the evaluation of alternative scenarios based on multiple objectives and local actors' preferences. By adopting a comprehensive approach, the methodology proposed seeks to pave the way towards sustainable and inclusive local energy planning.

2. In-depth study of local energy sustainability indicators

2.1 Introduction

The review on local energy planning practices in the previous chapter (see section 1.4) has shown that although indicators are being adopted by local authorities for monitoring their energy and climate action plans, there is a wide variation on the indicators used across municipalities. Indicators are frequently action-specific, being only developed to assess the progress on the implementation of each action and not the overall impact.

The reasons for having a chapter dedicated to local energy sustainability indicators are twofold: 1) the need for proposing comprehensive and potentially common metrics to evaluate local energy sustainability; and 2) the need for identifying indicators (later called attributes in chapter 4) to help in the choice of actions/alternatives during the energy planning process. The use of indicators in the planning stage has, very likely, the potential to help in the choice of actions to be integrated in energy and climate action plans, and therefore to provide new insights to conventional energy planning processes (Neves & Leal, 2010).

In this context, this chapter contains a review of existing energy-related indicators and proposes a framework of local energy sustainability indicators. The proposed framework of indicators aims at serving several functions within an energy planning process:

- **Diagnosis** – indicators allow providing a characterisation of the current status of the local energy system. The integration of environmental, social and economic indicators helps to see the broader picture of the local energy system – 'Helicopter view'.
- **Monitoring** – indicators allow monitoring the progress towards the vision and objectives set at the beginning of the energy planning process.
- **Benchmarking** – indicators allow a solid basis for comparison with other municipalities. Municipalities are able to measure where they are in relation to other municipalities. For this, it is important to adopt the same calculation method and to take into account certain characteristics of local authorities such as demographic and economic factors when performing comparisons. Further recommendations on the calculation method of indicators are detailed in a methodological guide (appendix I).

- **Planning** – indicators can be used as attributes in a multi-criteria evaluation within the energy planning process, and in this way assist in the identification of the alternative that better suits the objectives identified.

The use of indicators has been considered a fundamental tool to measure sustainable development. Agenda 21, the United Nations' action plan for sustainable development, which resulted from the United Nations Conference on Environment and Development in 1992, calls countries to develop indicators of sustainable development. These indicators need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems (UNSD, 1992). The Aalborg Charter, approved in 1994 by the European Conference on Sustainable Cities and Towns, commits the signatory local authorities to the use of different types of indicators, including those of urban environmental quality, urban flows, urban patterns, and indicators of urban systems sustainability. The indicators are considered to be a supporting tool for policy-making towards sustainability, useful to describe and monitor current status and progress (Charter of European Cities & Towns towards Sustainability, 2004).

2.2 Methodology

The development of the framework of local energy sustainability indicators encompassed several methodological steps as shown in Figure 2.

The first step consisted in performing a literature review of sets of energy and sustainable development indicators, namely the Energy Indicators for Sustainable Development (IAEA, 2005); the United Nations Commission of Sustainable Development (CSD) Indicators of Sustainable Development (United Nations, 2007); Sustainable Development Indicators proposed by Eurostat Task-Force (Eurostat, 2005); European Environment Agency core set of indicators (EEA, 2005); European Common Indicators (AIRI, 2003), and; Study on Indicators for Sustainable Development at the local level (JRC, 2004). Publications on sustainable development sets of indicators in Portugal (APA, 2007) and in Switzerland (Montmollin & Altwegg, 2000) were also included in the literature review. Starting by performing this literature review aimed at ensuring that this work would not 'reinvent the wheel', but instead 'adapt the wheel' to the context of local energy sustainability.

The European Common Indicators (AIRI, 2003) report and the Study on Indicators for Sustainable Development at the local level (JRC, 2004) were designed only for the local level. In the case of the European Common Indicators, the indicators have been developed according to a bottom-up approach, involving an extensive consultation with local authorities (AIRI, 2003). A bottom-up approach was also adopted in the development of the framework of local energy sustainability indicators herein proposed.

The choice of reviewing publications on indicators oriented to both national and local levels as well as of reviewing publications with a broader scope than only energy was due to the lack of sufficient works on energy-related indicators oriented to the local level. This has called attention to the newness of the topic and again to the need of developing the framework of indicators.

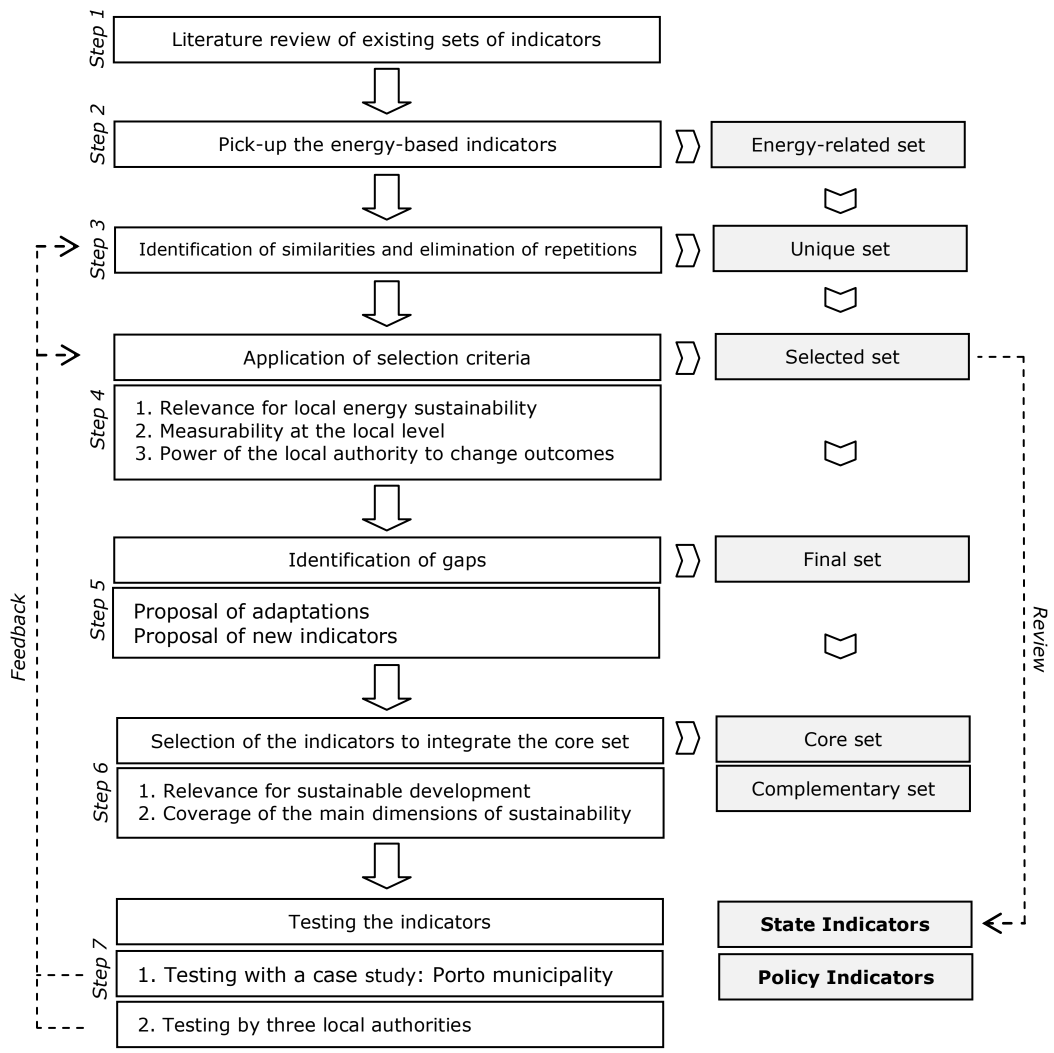
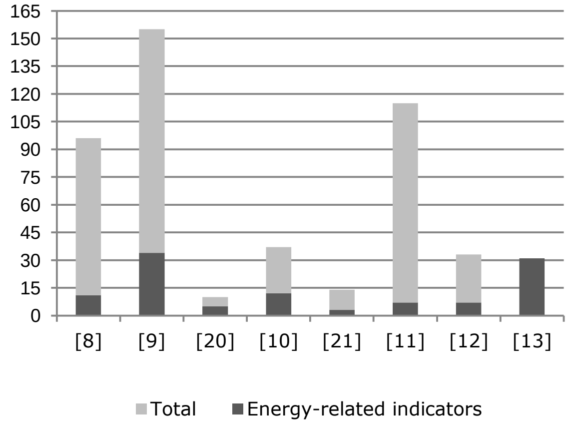


Figure 2 - Methodology adopted for the development of the framework of local energy sustainability indicators.

Step 2 in Figure 2 consisted in identifying the energy-related indicators included in the eight publications reviewed. This resulted in the identification of 110 indicators. Figure 3 shows the number of energy-related indicators in the overall number of indicators in each publication.



1 UN Indicators of Sustainable Development
2 Eurostat Sustainable Development Indicators
3 European Common Indicators
4 EEA Core Set of Indicators
5 JRC Indicators of Sustainable Development at the Local Level
6 Sustainable Development Indicators for Portugal
7 Sustainable Development Indicators for Switzerland
8 IAEA Energy Indicators for Sustainable Development

Figure 3 – Representativeness of energy-related indicators in each set of indicators.

In step 3 (Figure 2), similar indicators were removed from the set. This resulted in 59 indicators. Step 4 consisted in the application of three selection criteria:

1) Relevance of the indicator for local energy sustainability;
2) Potential measurability at the local level;
3) Power of the local authority to change the outcomes measured by the indicator.

The indicators that fulfilled simultaneously the three criteria were eligible for the following step. The selection process is documented in Table 4.

Table 4 – Application of selection criteria to the indicators.

Indicator	**Criteria**		
	Relevance for local energy sustainability	**Measurability at the local level**	**Roles of Local authorities**
Share of households (or population) without electricity or commercial energy	✓	✓	×
Share of household income spent on fuel and electricity	✓	✓	✓
Household energy use for each income group and corresponding fuel mix	×	✓	×
Accident fatalities per energy produced by fuel chain	×	×	×
Energy use per capita	✓	✓	✓
Energy use per unit of GDP	×	✓	✓
Efficiency of energy conversion and distribution	×	×	×
Reserves-to-production ratio	×	×	×
Resources-to-production ratio	×	×	×
Industrial energy intensities	✓	✓	✓
Agricultural energy intensities	✓	✓	✓
Service/commercial energy intensities	✓	✓	✓
Household energy intensities	✓	✓	✓
Transport energy intensities	✓	✓	✓
Fuel shares in energy and electricity	✓	✓	✓
Non-carbon energy share in energy and electricity	✓	✓	×
Renewable energy share in energy and electricity	✓	✓	✓
End-use energy prices by fuel and by sector	✓	✓	×
Net energy import dependency	×	×	×
Stocks of critical fuels per corresponding fuel consumption	×	×	×
GHG emissions from energy production and use, per capita and per unit of GDP	✓	✓	✓

Indicator	Criteria		
	Relevance for local energy sustainability	**Measurability at the local level**	**Roles of Local authorities**
Ambient concentrations of air pollutants in urban areas	✓	✓	✓
Air pollutant emissions from energy systems	✓	✓	×
Contaminant discharges in liquid effluents from energy systems	✓	✓	×
Oil discharges into coastal waters	✓	✓	×
Soil area where acidification exceeds critical load	×	×	×
Rate of deforestation attributed to energy use	✓	×	✓
Ratio of solid waste generation to units of energy produced	×	×	×
Ratio of solid waste properly disposed of to total generated solid waste	×	×	×
Ratio of solid radioactive waste to units of energy produced	×	×	×
Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste	×	×	×
Average satisfaction with the local community	×	✓	✓
Business demography	✓	✓	✓
Attendance at community group meetings	✓	✓	✓
GHG emissions by sector	✓	✓	✓
Combined heat and power generation	✓	✓	×
Energy consumption by transport mode	✓	✓	✓
Access to public transport	✓	✓	✓
External costs of transport activities	×	×	×
Emissions of air pollutants from transport activities	✓	✓	✓
Share of major proposals with an impact assessment	✓	✓	×
Responses to EC internet public consultations	✓	✓	✓
E-government on-line availability	✓	✓	✓
E-government usage by individuals: total	×	✓	✓
CO_2 removed by sinks	×	×	✓
External costs of energy use	×	×	×
Energy tax revenue	×	✓	×
Road share of inland freight transport	×	×	×
Modal split of freight transport	×	✓	×
Freight transport prices by mode	×	×	×
Investment in transport infrastructure by mode	×	✓	✓
Annual energy consumption, total and by main user category	✓	✓	✓
Modal split of passenger transport	✓	✓	✓
Percentage of population using solid fuels for cooking	✓	✓	×
Eco-efficiency of economic activities	×	×	×
Use of cleaner and alternative fuels	✓	×	✓
Projections of GHG emissions and removals and policies and measures	×	×	✓
Global and European temperature	×	×	×
Atmospheric GHG concentrations	×	×	×

Step 5 consisted in a critical analysis with the aim of identifying possible remaining gaps. This has led to the identification of new indicators as well as to the adaption of existing ones.

The set of indicators reached was still considered too large. The Bellagio Principles (Hardi & Zdan, 1997) and the United Nations Commission of Sustainable Development (United Nations, 2007) recommend that indicators should be limited in number, but remain open-ended and adaptable to future needs. It was then decided to divide the set in two subsets: a smaller and manageable set called the core set and a larger set named the complementary set. The indicators that integrate the core set were chosen by their relevance for sustainable development and coverage of the three dimensions of sustainability.

Subsequently, it was conducted the testing of the indicators which was divided into two components:

1) Calculation of the indicators for a case study: the municipality of Porto, Portugal by the author – The objective was to develop methods to compute the indicators and to identify the availability of data.
2) Participation of three local authorities in the calculation of the indicators for their municipalities – They were invited to calculate the indicators by using their human resources with the help of the methodological guide developed (appendix I). Participating local authorities were asked to provide feedback regarding data gathering and calculation difficulties as well as perceived relevance of the indicators to local energy sustainability through a survey.

The inputs resulting from both components of the testing stage were then used to review the set of indicators, as indicated in Figure 2.

The review process resulting from the first component of the testing stage led to the removal of one indicator – Ambient concentration of air pollutants in the atmosphere. Discussions with experts in air quality have highlighted the difficulty of measuring this indicator at the scale of the municipality. In the case of the European Union, Directive 96/62/CE on ambient air quality assessment and management (European Council, 1996) obliges Member-States to the delimitation of their territory into Zones and Agglomerations that are subjected to mandatory air quality assessment. Thus, the measurement of the indicator does not coincide with the boundaries of the municipality, due to the dispersion of pollutants. Also, its relevance regarding the causal relationship energy-environment can be questionable due to the influence of natural events.

2.3 Preliminary framework of indicators

Step 6 in Figure 2 identified a core set composed by eight indicators (Table 5) and a complementary set of 18 indicators (Table 6). These sets of indicators were then subjected to the field testing stage in step 7.

Table 5 - Core set of local energy sustainability indicators resulting from step 6 in Figure 2.

Theme	Core Indicators	Units
Climate Change	GHG emissions from energy use, per capita and per unit of GDP	tonnes CO_2 eq. per capita and per Euro
Use and production patterns	Primary Energy use per capita	toe (p.e.) per capita
	Annual energy consumption per capita by main use category	toe (f.e.) per capita
	Ratio of local renewables production to local consumption of energy and electricity	%
Employment	Ratio of energy-related jobs to population	%
Financial resources	Locally available finance schemes for energy efficiency and renewable energy	% or qualitative
Air quality	Emissions of air pollutants from road transport activities	$\mu g/m^3$ or mg/m^3
Governance and Public engagement	Active public participation in energy-related policy-making	% or qualitative

p.e. – primary energy | f.e. – final energy

Table 6 - Complementary set of local energy sustainability indicators resulting from step 6 in Figure 2.

Theme	Complementary Indicators	Units
Climate Change	GHG emissions by sector	tonnes CO_2 eq. per capita and per Euro
Use and production patterns	Industrial energy intensity	toe (f.e.) per Euro
	Agricultural energy intensity	toe (f.e.) per Euro
	Service/commercial energy intensity	toe (f.e.) per Euro
	Household energy intensity	toe (f.e.) per capita
	Transport energy intensity	toe (f.e.) per pkm or tkm
	Energy consumption by transport mode	toe
	Modal split of passenger transport	% of pkm
	Travel distance by mode of transport	pkm/year
	Access to public transport	%
	Fuel shares in energy and electricity	%
	Renewable energy share in energy and electricity	%
	Energy production from micro-generation projects	%
Affordability	Share of household income spent on fuel and electricity	%
Governance and Public engagement	Responses to public consultations of energy-related projects	%
	E-government on-line energy-related information availability	qualitative
	Awareness raising campaigns on energy issues	%
	Local Authority advice and assistance to the citizens on energy issues	qualitative

p.e. – primary energy | f.e. – final energy

2.4 Field testing of the preliminary framework of indicators

2.4.1 Calculation of the indicators for the municipality of Porto

The first component of the testing stage consisted in the calculation of the indicators presented in Table 5 and Table 6 to the municipality of Porto in Portugal. This task was performed in 2009 by the author. The data used to compute the indicators was relative to the year 2006, being the most recent year for which data was found available.

The testing stage with the municipality of Porto revealed several difficulties in collecting data to compute the indicators. Table 7 summarises these difficulties and indicates the current data demands to compute the indicators for the case of Portuguese municipalities. Available statistics hardly have the data required for the indicators at municipal level. Most of the data is available for the national and regional levels. Sometimes it is possible to find at the level of NUTS III (Nomenclature of Territorial Units for Statistics). In the absence of data for the municipal level, estimates need to be performed based on the closest upper level of administrative division. However, this reduces the accuracy of the indicator.

There were eight indicators for which data was not available. In order to calculate these indicators it would be necessary to collect the data through a survey. These indicators were not calculated during the testing stage.

Table 7 – Difficulties found in local data collection for computing the indicators for the municipality of Porto.

Indicator	Difficulties in local data collection
GHG emissions from energy use, per capita and per unit of GDP	Consumption of oil products by the transport sector was not available. Instead, data on the sales of oil products in the municipality had to be used, with the possibility of not reflecting exactly the consumption of oil products. Municipal GDP was not available. The closest level of data available was by NUTS III (Grande Porto). Two studies were found on GDP for Portuguese municipalities for the year 2000. Thus, estimates were performed based on the value of Porto GDP for 2000 and then using the growth rate of the NUTS III.
Primary Energy use per capita	The conversion factor to express electricity (final energy) in terms of primary energy was not available for every year. This factor depends on the electricity national mix which varies every year and had to be calculated.
Annual energy consumption per capita by main use category	The consumption of petroleum products and natural gas by activity sector was not available at the municipal level at the time the indicators were computed. So, estimates had to be performed based on the district level. At present, the Portuguese Directorate-General for Energy and Geology provides the consumption of petroleum products by activity sector at the municipal level available for the year 2008. However, data on natural gas is still not available.
Ratio of local renewables production to local consumption of energy and electricity	Data on local renewables production requires a survey in order to collect the installed capacity and energy produced by small, medium and large-scale renewable energy projects in the territory of the municipality.

Indicator	Difficulties in local data collection
Ratio of energy-related jobs to population	Working age population was not available at the National Statistics Office at the level of the municipality, only at the level of NUTS II (Norte region). It was assumed the activity level (working age population divided by total population) of the NUTS II to the municipality of Porto. The number of employed population in energy-related jobs has to be collected through a survey. Energy-related jobs can be found in the following areas: municipal energy department or energy agency; energy auditing; renewable energy installation; building retrofitting; green building construction; building maintenance; or transit operators and construction and maintenance workers.
Locally available finance schemes for energy efficiency and renewable energy	Data on the finance schemes requires a survey to the local authority and Energy Service Companies.
Emissions of air pollutants from road transport activities	This indicator requires data on the fuel use by type of vehicle so that the emission factors developed by the European Environmental Agency could be applied. Final energy use by mode of transport was not available on the statistics. In alternative, this could be determined by knowing the total final energy use and the disaggregation of the vehicle fleet. However, data on the vehicle fleet by type of vehicle and by type of fuel were not available at the municipal level, only at the national level. Estimates had to be performed based on the population.
Active public participation in energy-related policy-making	Number of participants and number of public participation initiatives need to be collected through a survey.
GHG emissions by sector	The same situation as reported for the indicator annual energy consumption per capita by main user category. The GHG emissions were calculated from the final energy use per sector.
Industrial energy intensity	Value added by sector was not available at the municipal level. The closest level was for NUTS III. Estimates had to be performed based on the value added of the NUTS III and the indicator 'Number of workers according to the activity sector in the municipality' for the Grande Porto and for Porto.
Agricultural energy intensity	Value added by sector was not available at the municipal level. The closest level was for NUTS III.
Service/commercial energy intensity	Value added by sector was not available at the municipal level. The closest level was for NUTS III.
Household energy intensity	Value added by sector was not available at the municipal level. The closest level was for NUTS III.
Transport energy intensity	Number of passengers per km (pkm) by mode of transport and number of tonnes per km (tkm) was not completely available at the municipal level. Data exists at the national level. However, at the municipal level it is only possible to find the pkm for public transport (metro, tram, buses) from the transport companies' reports. There is a need to develop transport studies as a way to gather data on the use of transport in the municipalities and understand the movements of people in and out the municipality.
Energy consumption by transport mode	The same situation as reported for the indicator Emissions of air pollutants from road transport activities.
Modal split of passenger transport	The same situation as reported for the indicator Transport energy intensity in what regards pkm data by mode of transport.
Travel distance by mode of transport	The same situation as reported for the indicator Transport energy intensity in what regards pkm data by mode of transport.
Access to public transport	This indicator requires the collection of data through a survey or through the use of Geographical Information Systems to measure the distribution of the population against the walking distance to public transport nodes.
Fuel shares in energy and electricity	Consumption of oil products was not available. Instead, data on the sales of oil products in the municipality was used.
Renewable energy share in energy and electricity	-
Energy production from micro-generation projects	Energy produced by micro-generation requires a survey to collect the data.
Share of household income spent on fuel and electricity	Average income and average expenditure on fuel and electricity per household were not available at the municipal level, only by NUTS II. It was assumed the same value as for the NUTS II.
Responses to public consultations of energy-related projects	Requires gathering data on the number of citizens which participate in public consultation initiatives through a survey.
E-government on-line energy-related information availability	Requires an investigation of the information available online.
Awareness raising campaigns on energy issues	Requires a survey to know the number of citizens targeted by the campaigns.
Local Authority advice and assistance to the citizens on energy issues	Requires a survey to know the number of citizens to whom the local authority has provided advice and assistance.

Following the calculation of the indicators to the municipality of Porto, it was elaborated a methodological guide (see appendix I) that was distributed to the local authorities that participated in the second component of the testing stage. The guide was composed by detailed methodological sheets for each indicator, specifying the data requirements and sources, the calculation method and an exemplification of calculation of the indicators for the case of Porto, so that the method could be easily understood and replicated.

2.4.2 Calculation of the indicators by the participating local authorities

The second component consisted in the calculation of the indicators by three participants. Eight Portuguese local and regional energy agencies were invited to participate in the testing stage, from which two accepted: AdEPorto and AREANATejo. In the United States (US), the City of Boston was contacted and a meeting was arranged with two representatives from the City Council, who accepted to participate. Details on the participants can be found in Table 8.

Table 8 – Characteristics of the participants involved in the testing stage.

Name	Type	Municipalities	Location	Population in 2007 (INE, 2009; City of Boston, 2009)	Testing period	
					sent	received
AdE Porto	Local Energy agency	Porto	Second largest city in Portugal and the centre of Porto Metropolitan Area.	221 800	Jun. 2009	Nov. 2009
AREANA Tejo	Regional Energy agency	Alter do Chão, Arrinches, Avis, Campo Maior, Castelo de Vide, Crato, Elvas, Fronteira, Gavião, Marvão, Monforte, Mora, Nisa, Portalegre, Sousel	14 municipalities located in North Alentejo in Portugal.	Total of 106 233 (varies from 3 129 in Monforte to 24 028 in Portalegre)	Jun. 2009	Sep. 2009
City of Boston	City Council	Boston	Capital and largest city of the Commonwealth of Massachusetts in the US.	608 352	Oct. 2009	Jan. 2010

The attempt of calculation of the indicators by the participants revealed some major difficulties. The first one was at the level of gathering participants who were willing to calculate the indicators. Eight energy agencies were contacted in Portugal. First, an invitation letter together with the methodological guide was sent by post to the directors of the energy agencies, and then phone calls were made to encourage them to participate. Three of the energy agencies did not reply back. One agency replied negatively, being the justification related to the fact of not having enough human resources to assign to this voluntary work. Two other energy agencies have initially replied affirmatively to the invitation but ended up not complying with the task that was asked. From this attempt of involving Portuguese energy agencies, only two agencies accepted to participate: AdEPorto and AREANATejo.

Common difficulties mentioned by both participants and non-participants invited were the lack of staff capacity and other priority projects. As a result, the participants calculated only a few indicators. Table 9 presents the indicators that were calculated by the participants. The energy agency AREANATejo calculated the indicators for the 14 municipalities that make part of the area of intervention of the energy agency.

Table 9 – Local energy sustainability indicators calculated by the participants during the testing stage.

Indicators	AdEPorto	AREANATejo	City of Boston
GHG emissions from energy use, per capita and per unit of GDP	✓	✓	✓
Primary Energy use per capita	✓	✓	✓
Annual energy consumption per capita by main use category	✓	✓	✓
Ratio of local renewables production to local consumption of energy and electricity	-	-	✓
Ratio of energy-related jobs to population	-	-	-
Locally available finance schemes for energy efficiency and renewable energy	-	-	-
Emissions of air pollutants from road transport activities	-	-	✓
Active public participation in energy-related policy-making	-	-	-
GHG emissions by sector	✓	✓	-
Industrial energy intensity	-	✓	-
Agricultural energy intensity	-	✓	-
Service/commercial energy intensity	-	✓	-
Household energy intensity	✓	✓	-
Transport energy intensity	-	-	-
Energy consumption by transport mode	✓	-	-
Modal split of passenger transport	-	-	-
Travel distance by mode of transport	-	-	-
Access to public transport	-	-	-
Fuel shares in energy and electricity	-	✓	-
Renewable energy share in energy and electricity	-	-	-
Energy production from microgeneration projects	-	-	-
Share of household income spent on fuel and electricity	-	-	-
Responses to public consultations of energy-related projects	-	-	-
E-government on-line energy-related information availability	-	-	-
Awareness raising campaigns on energy issues	-	-	-
Local Authority advice and assistance to the citizens on energy issues	-	-	-

In the case of the Portuguese energy agencies, the data used for the calculation of the indicators had been previously collected for the elaboration of the energy matrixes. An energy matrix is a report that contains a characterisation of the energy demand and supply of the municipality. Both energy agencies have hired external consulting companies to make their energy matrixes reports.

The participants were asked to answer a survey in which they commented on the relevance of each indicator as well as the measurement difficulties experienced. The indicators that were not considered as very relevant by the local authorities are presented in Table 10. AREANATejo, which has municipalities with low population density reported that the assessment of transport-based indicators was not very relevant in their context. The City of Boston stated that the indicator that assesses active public participation in energy-related policy-making was not very relevant, since the State and Federal are the policy levels responsible for energy policy-making. For them, this indicator would only show how active the citizens are in State and Federal policy-making. The ratio of energy-related jobs to population was pointed out by the City of Boston and AdEPorto as not very relevant. They believe that the share of energy-related jobs will be minimal and they consider difficult to define what energy-related jobs are.

Table 10 – Indicators not considered as very relevant by the participating local authorities.

Indicators	AdEPorto	AREANATejo	City of Boston
Ratio of energy-related jobs to population	✓	-	✓
Active public participation in energy-related policy-making	-	✓	✓
Modal split of passenger transport	-	✓	-
Travel distance by mode of transport	-	✓	-
Access to public transport	-	✓	-
Responses to public consultations of energy-related projects	-	✓	-

In what regards the difficulties to compute the indicators, the participants confirmed that the data was not readily available for more than half of the indicators asked. There was a need to perform estimates as well as surveys to collect the data required. This difficulty has shown the need to improve regular statistical data monitoring procedures at the level of municipalities – a meaningful indicator cannot be dropped just because the data required to its calculation is not yet available. Having a data-driven approach to select the indicators is not recommended. Choosing an easily measured indicator might fail to provide the information that is actually important for the local authority. The objective is to measure what *should* be measured and not what *can* be measured (Bell & Morse, 2008). Not only European and national statistics bodies have an important role to play in collecting data at the level of municipalities, but also local authorities could organise surveys and studies to gather data. This would help them to compute the indicators and to understand better how the energy is used in the municipality and its impacts.

AdEPorto recognised that computing most of the indicators would require external expertise, while AREANATejo only recognised this for one indicator. The City of Boston also recognised the need for external expertise.

2.5 Revision of the preliminary framework of indicators

The results of both components of the testing stage constituted valuable inputs in the review process of the set of indicators. This experience has validated that it is important to have a limited number of indicators, albeit comprehensive in terms of the aspects covered. Both participating and non-participating local authorities have mentioned time and staff constraints to perform the task of calculating the indicators. Large sets tend to be complex and time-consuming in computing all the indicators and this might discourage local authorities. The review of the set was performed by having in mind the practical experience gained during the testing with the municipality of Porto and the feedback given by the local authorities. Table 11 presents the review process, including observation notes. There were an extensive number of indicators to assess transport and public participation. These indicators were found to be strongly correlated, so it was decided to reduce their number by identifying a comprehensive yet non-redundant set of indicators to translate local sustainable mobility and public participation in energy issues.

Table 11 – Review of the framework of indicators after the testing stage.

Indicators	Decision on continuity	Observations
GHG emissions from energy use, per capita and per unit of GDP	✓	Named 'GHG emissions from energy use, per capita and per unit of GDP, and by sector' (Households, Services, Industry, Transport).
Primary Energy use per capita	✓	-
Annual energy consumption per capita by main use category	✓	-
Ratio of local renewables production to local consumption of energy and electricity	✓	-
Ratio of energy-related jobs to population	✓	Although there were two local authorities not considering as a very relevant indicator, it was decided to keep it based on references such as the report on the Potential Workforce Impacts of the Chicago Action Plan which estimates a generation of '2 500 energy efficiency related jobs on annual basis, plus hundreds of jobs in areas such as renewable energy ...' (Schrock & Sundquist, 2009). Energy-related jobs are here defined as jobs generated in renewable energy and energy efficiency sectors in the municipality. To clarify the concept it was decided to change the name of the indicator to 'Ratio of green energy jobs to population'.
Locally available finance schemes for energy efficiency and renewable energy	✓	The indicator depends on the political context, but there is plenty of room for local authorities to introduce finance schemes, such as energy performance contracting and third party financing as Bristol, Graz and Heidelberg have done (Neves, 2007).
Emissions of air pollutants from road transport activities	✓	-
Active public participation in energy-related policy-making	✓	Changed to Public participation in energy-related policy-making, including now active participation, consultation and information.

Indicators	Decision on continuity	Observations
GHG emissions by sector	×	Included in indicator GHG emissions from energy use, per capita and per unit of GDP.
Industrial energy intensity	✓	-
Agricultural energy intensity	✓	-
Service/commercial energy intensity	✓	-
Household energy intensity	✓	-
Transport energy intensity	✓	-
Energy consumption by transport mode	×	The calculation of the transport energy intensity requires knowing the energy consumption by transport mode. No new information will be added by keeping this indicator.
Modal split of passenger transport	×	Derived from the data used to compute the transport energy intensity.
Travel distance by mode of transport	×	Derived from the data used to compute the transport energy intensity.
Access to public transport	✓	Adapted to 'Public Transit Ridership'. Access to public transport requires a more complex computing method using geographic information systems.
Fuel shares in energy and electricity	×	Derived from the data used to compute the renewable energy share in energy and electricity, and both indicators would be very similar.
Renewable energy share in energy and electricity	✓	-
Energy production from microgeneration projects	×	Derived from the data used to compute the ratio of local renewables production to local consumption of energy and electricity
Share of household income spent on fuel and electricity	✓	-
Responses to public consultations of energy-related projects	×	Can be assessed in the indicator public participation in energy-related policy-making, now including information, consultation and active participation.
E-government on-line energy-related information availability	×	Can be assessed in the indicator public participation in energy-related policy-making, now including information, consultation and active participation.
Awareness raising campaigns on energy issues	✓	-
Local Authority advice and assistance to the citizens on energy issues	✓	-

2.6 Final proposed framework of local energy sustainability indicators

The final proposed framework of local energy sustainability indicators consists of 18 indicators, after the revision performed in section 2.5. In the context of using the indicators in energy planning processes, it was considered a new organisation of the indicators, dividing them in two types: state indicators and policy indicators. State indicators focus in assessing the physical state of the local energy system. Policy indicators aim to assess the mechanisms promoted by the local authority that may lead to the achievement of a more sustainable state of the local energy system. For instance, if the local authority provides financial incentives for renewable energy, this might lead to the deployment of more renewables in the municipality, the reduction of fossil fuels consumption and consequently the reduction of GHG emissions. The previous division into core (Table 5) and complementary (Table 6) sets had the disadvantage of mixing these indicators. Table 12 and Table 13 present the proposed state and policy indicators, respectively.

Table 12 – State indicators.

	State Indicators	Units
S1	GHG emissions from energy use, per capita and per unit of GDP, and by sector	tons CO_2 eq. per capita and per Euro
S2	Primary energy use per capita	toe (p.e.) per capita
S3	Final energy use per sector	toe (f.e.)
S4	Ratio of local renewables production to local consumption of energy and electricity	%
S5	Industrial energy intensity	toe (f.e.) per Euro
S6	Agricultural energy intensity	toe (f.e.) per Euro
S7	Service/commercial energy intensity	toe (f.e.) per Euro
S8	Household energy intensity	toe (f.e.) per capita
S9	Transport energy intensity	toe (f.e.) per pkm or tkm
S10	Public transit ridership	pkm per capita
S11	Emissions of air pollutants from road transport activities	tons
S12	Renewable energy share in energy and electricity	%
S13	Share of household income spent on fuel and electricity	%
S14	Ratio of green energy jobs to population	%

p.e. – primary energy | f.e. – final energy

Table 13 – Policy indicators.

	Policy Indicators	Units
P1	Locally available finance schemes for energy efficiency and renewable energy	qualitative
P2	Awareness raising campaigns on energy issues	%
P3	Public participation in energy-related policy-making	% or qualitative
P4	Local Authority advice and assistance to the citizens on energy issues	qualitative

In order to assist in providing a clear understanding of what the set of indicators aims to measure, Figure 4 provides an illustrative representation of the energy chain within the Earth ecosystem and the indicators. Primary energy refers to the energy that is gathered directly from natural resources. Final energy refers to the delivered energy that is made available to the consumer, not taking transformation losses into account. Useful energy is the part of energy that is used to provide the energy service (work, heat). The Earth ecosystem's physical limits represented in Figure 4 are limits of the ability of Earth sources to provide materials and energy needed to keep people, factories and transport functioning, and to the ability of Earth sinks to absorb the pollution and waste (Meadows, Randers & Meadows, 2004).

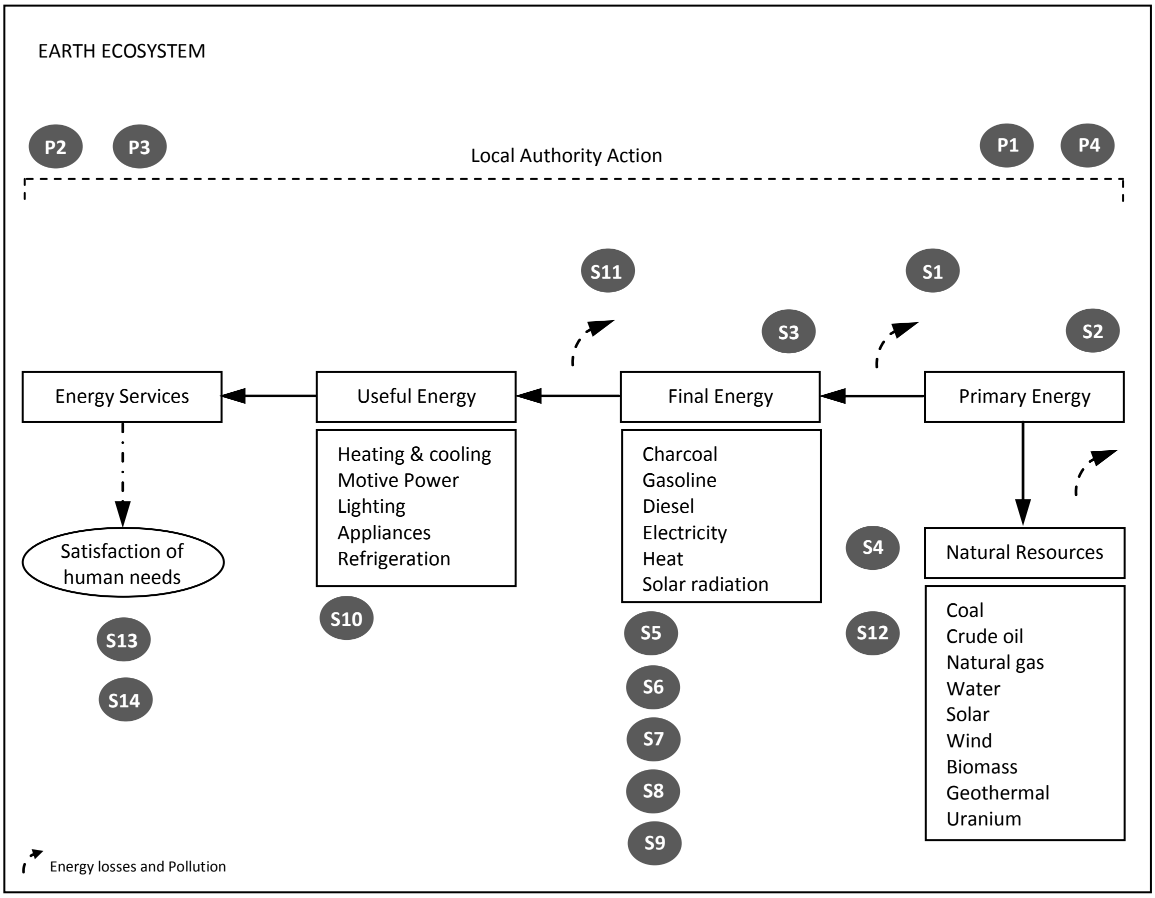


Figure 4 – The energy chain within the Earth ecosystem and the related state and policy indicators (presented respectively in Table 12 and Table 13).

2.7 Summary

Driven by the wide variety and limitations of indicators being adopted in local energy planning practices across Europe and US, this chapter presented a deep review of indicators and proposed a comprehensive framework of local energy sustainability indicators. A methodology based on literature review and bottom-up consultation with local actors was adopted for the development of the framework composed by 14 state indicators and four policy indicators. This work was also driven by the potential to use indicators (attributes) to help in the choice of alternatives in energy planning processes, which will be addressed in the decision support methodology for local sustainable energy planning in chapter 4.

3. Review of methods for supporting the design of the methodology for local sustainable energy planning

3.1 Introduction

The intent of this chapter is to perform a review of existing methods which can be of particular relevance to the design of the methodology. The literature shows the existence of an array of methods in the research fields of interest to this thesis: energy systems modelling and multi-criteria decision analysis. The purpose of this chapter is thus to explore these methods and to search for the 'fitness for purpose', i.e. the methods that are suitable to be used in the methodology to be further developed in chapter 4. The evaluation of the suitability of the methods reviewed relates to their ability in fulfilling the characteristics specified in section 1.5., in particular:

- model energy demand at the end-use level so that the model accommodates (and quantifies) changes in the local energy system induced by energy management actions;
- evaluate alternative scenarios by considering the multiplicity of sustainable development objectives that arise at the local level as well as the local actors' preferences on those objectives.

At this time, it is worth to clarify the terminology adopted in this thesis in what regards *methodology*, *method/technique* and *tool*, once these terms are open to different interpretations. Herein, the terminology proposed by Mingers & Brocklesby (1997, p. 490-491) is adopted:

- *methodology* refers to 'a structured set of guidelines or activities to assist people in undertaking research or intervention'.
- *method or technique* is 'a specific activity that has a clear and well-defined purpose within the context of a methodology'. Methods or techniques are complementary and combined together within the methodology.
- *tool* is 'an artefact, often computer software, that can be used in performing a particular technique or a whole methodology'.

According to Mingers & Brocklesby (1997, p. 490): 'We can see the relation between methodology and technique as that between a *what* and a *how*. The methodology specifies *what* type of activities should be undertaken, and the techniques are particular ways of performing these activities. Generally each *what* has a number of possible *hows*.'

3.2 Energy models

A model is a representation of the reality in which only the aspects of a system which are relevant to the analysis are captured (Wolfram, 2002). Energy models provide a representation of energy systems. They have been developed with the aim of supporting energy planning and conducting policy analysis.

Energy models have been designed for different purposes: generate forecasts, explore alternative scenarios, analyse impacts of different options and policies on the economic/environment/social situation and/or compare and appraise several options based on one or more criteria. Although some models focus only on one aspect, there are models which combine several purposes. In fact, some models are constructed as a modular package enabling the user to select the module (sub-model) which is relevant for the analysis. Another aspect concerning the purpose refers to the energy carriers addressed. There are models including only electricity, models including 'energy' as a whole where it is not possible to differentiate between energy carriers, and models where all the relevant energy carriers are distinguished (Van Beeck, 1999).

At the level of the underlying methodology employed for the development of energy models, a distinction can be made between models of (Van Beeck, 1999):

1. **Optimisation** - Optimisation models are typically used to find the 'best possible solution' for the given variables, under a certain criterion and while meeting the given constraints. The outcomes can be the determination of an optimal mix of technologies for the energy system, subject to emission limits, cost, etc. (Cormio *et al.*, 2003), the maximisation of revenues or minimisation of costs for the energy system (Hiremath, Shikha & Ravindranath, 2007). Optimisation is also used in national energy planning for analysing the expansion of energy infrastructure (Van Beeck, 1999).
2. **Simulation** - Simulation models are descriptive models based on a logical representation of a system, and reproduce a simplified operation of this system (World Energy Conference, 1986 *fide* Van Beeck, 1999). Simulation models allow exploring the effects of different hypotheses via scenarios. The impacts of different assumptions and policies can be evaluated by creating different scenarios.
3. **Econometric** – Econometric methodologies are defined as methodologies that apply statistical techniques to extrapolate market behaviour into the future. They

focus on measuring aggregated data in the past to predict the short - or medium - term future in terms of labour, capital, or other inputs. Econometric models are thus used to predict the future as accurately as possible using measured parameters.

4. **Macro-economic** – Macro-economic models address the entire economy and the interaction among sectors. The Input-Output approach is used to describe transactions among economic sectors and assist in analysis of energy-economy interactions. As macro-economic models do not concentrate on energy specifically but on the economy as a whole, some authors do not see macro-economic models as energy models.
5. **Economic equilibrium** – Economic equilibrium models focus on the medium to long-term and are used to study the energy sector as part of the overall economy. These models focus on simulating very long-term growth paths and do not systematically rely on econometric relationships but are instead benchmarked on a given year in order to guaranteed consistency of parameters.
6. **Spreadsheet/Tool boxes** – Spreadsheet models refer to a highly flexible model which often includes a reference model that can be modified by the user according to individual needs. For instance, the user can specify the penetration of the technology in some future year.
7. **Backcasting** – Backcasting models allow at constructing visions of desired futures by interviewing experts and by looking at which trends are required or need to be broken to achieve the desired futures.
8. **Multi-criteria** – Multi-criteria models aim at considering multiple criteria in the analysis. These criteria can be either quantitative or qualitative.

Energy models can either use a single methodology or a combination of methodologies. For instance, many econometrics or macro-economic models also use optimisation techniques, while spreadsheet models also usually use optimisation or simulation methodology (Van Beeck, 1999).

Table 14 provides an overview of existing energy models.

Table 14 – Overview of existing energy models. Sources: Van Beeck (1999); SEI (2012); Aalborg University (n.d.); IAEA (n.d.); Spitz (2009); IIASA (2006); Loulou, Goldstein & Noble (2004); Graeber & Schlenzig (1998).

Model	Developer	Purpose	Methodology	Level	Sectoral coverage	End-use level coverage	Time horizon
EFOM-ENV Energy Flow Optimization Model - Environment	European Commission	Scenario development and modelling possibilities of environmental regulation through restrictions in the optimisation.	Optimisation	National	Energy producing and consuming sectors	No	Medium to long-term
ENPEP Energy and Power Evaluation Program	International Atomic Energy Agency (IAEA)/Argonne National Laboratory	Evaluates energy system development strategies, it includes several models on assessing energy demand, optimizing expansion of the electric sector, evaluate environmental consequences of different energy strategies, and computing market clearing prices and balance energy demand and supply under market conditions.	Macro-Economic / Economic equilibrium	National Local	All sectors	No	Short, medium and long-term
MESSAGE Model for Energy Supply System Alternatives and their General Environmental Impact	International Institute for Applied Systems Analysis (IIASA)	Scenario development through minimizing the total systems costs under the constraints imposed on the energy system. Given this information and other scenario features such as the demand for energy services, the model configures the evolution of the energy system from the base year to the end of the time horizon.	Optimisation	National Local	Energy sector	No	Short, medium and long-term
EnergyPLAN Advanced energy system analysis computer model	Aalborg University	Simulates and optimizes the operation of an energy system; the consequences are analysed hour by hour for one year - technically as well as economically - of different national energy systems and investments.	Optimisation / Simulation	National	Energy sector	No	n.a.
LEAP Long-range Energy Alternatives Planning	Stockholm Environmental Institute	Integrated energy planning, scenario development and greenhouse gas mitigation analysis.	Simulation / Spreadsheet	National Regional Local	All sectors, including non-energy sector	Yes	Medium to long-term
MARKAL MARket ALlocation	International Energy Agency	Provides a technology-rich basis for estimating energy dynamics over a multi-period horizon. The model aims at supply energy services at minimum global cost.	Optimisation	National Regional	Energy sector	Yes	Medium to long-term
MESAP Modular Energy Systems Analysis and Planning	IER, University of Stuttgart	Integrated energy and environmental planning through a set of tools for demand analysis, integrated resource planning, demand-side management and the simulation or optimisation of supply system.	Econometric (demand), simulation or linear programming (supply)	National Local	All sectors	Yes	Medium to long-term
MEDEE Modèle d'Evaluation de la Demande En Energie	Institut Économique et Juridique de l'Énergie (IEJE)	Explores the impacts of socio-economic changes in long-term energy demand by disaggregating total energy demand into relevant homogenous end-use categories.	Simulation /Spreadsheet	National regional	All sectors	Yes	Long-term

From the analysis of the energy models presented in Table 14 it is possible to identify three models of particular interest for this thesis: LEAP, MESAP and MEDEE, due to their focus on a disaggregated analysis of energy demand by end-use related to the energy carriers and energy conversion technologies, and the use of a scenario technique.

LEAP (Long-range Energy Alternatives Planning) was designed to help policy makers in evaluating energy policies and developing sustainable energy plans. It can be used to project the energy supply and demand in order to glimpse future patterns, identify potential problems and assess the impacts of policies. LEAP is a scenario-based energy-environment modelling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given energy system under a range of alternative assumptions on population, economic development, technology, price, etc. Energy demand projections in each sector can be either created based on macroeconomic indicators (e.g. Gross Domestic Product) or through a detailed bottom-up forecast based on an end-use analysis (SEI, 2006).

MESAP (Modular Energy Systems Analysis and Planning Software) was designed as a decision support system for energy and environmental management on a local, regional or global scale. MESAP supports every phase of the structured analysis procedure for energy planning. It has a modular design and includes the following modules: *PlaNet* – for demand analysis, demand side management, supply simulation and integrated resource planning; *INCA* – for investment calculation; *E3-Net* – energy system optimisation; and *PROFAKO* – for electricity and district heating operation and expansion planning. The MESAP module *PlaNet* was created for strategic planning and uses the scenario technique to explore the future impact of different strategies. This module was designed to analyse energy demand and to simulate energy systems including their environmental impacts. The end-use approach is used to calculate the demand for energy services. The MESAP philosophy is based on the 'Reference Energy System' which consists of a representation of real energy systems as a network of commodities that are converted in a chain of processes (Graeber & Schlenzig, 1998).

MEDEE (Modèle d'Evaluation de la Demande En Energie) aims at relating the evolution of long-term energy demand to evolution of society. The philosophy behind the model is that energy demand is induced by socio-economic determinants such as economic activities and satisfaction of social needs. These determinants lead to a demand for useful energy whose intensity depends on the conversion technologies used. Final energy is thus determined from the level of useful energy demand and the efficiency of technologies used to convert final energy into useful energy. Therefore the final energy demand is related to the social, economic and technological pattern of development of a society. The MEDEE model involves the disaggregation of the total energy demand into end-use categories, so that the impacts of changes in socio-economic development on long-term energy demand can be taken into account. Examples of such changes are government policies (e.g. transportation and energy conservation polities); technology (e.g. replacement with more energy efficient equipment); social needs (e.g. saturation); etc. (Lapillone & Chateau, 1981).

3.3 Problem structuring

3.3.1 What is problem structuring?

Structuring the problem is considered of crucial importance for the analysis and characterisation of a decision situation. Indeed, the way in which a problem is stated influences the decision itself: 'Get it wrong and you'll march out in the wrong direction. Get it right and you'll be well on your way to where you really want to go. A good solution to a well-posed decision problem is almost always a smarter choice than an excellent solution to a poorly posed one' (Hammond, Keeney & Raiffa, 1999, p. 16).

Problem structuring methods consider that the most demanding and troubling task in decision situations is to decide what the problem is (Rosenhead & Mingers, 2001). Therefore, diagnosing, exploring and structuring problems can be the most time-consuming phase of the whole decision process (Thomas & Samson, 1986).

Problem structuring methods were born out of a crisis of dissatisfaction with the ability of traditional operation research to give modellers access to more strategic problems (Mingers & Rosenhead, 2011). The traditional operational research approach was seen as 'restricted to well-structured problems – that is, problems for which a consensual formulation can be stated in terms of performance measure or measures, constraints, and the relations through which action produces consequences' (Mingers & Rosenhead, 2004, p. 531). The clear and unambiguous specification of well-structured problem means that in general have one 'best' solution (Rosenhead & Mingers, 2001). The limitation of traditional operational research to well-structured problems excluded the so-called ill-structured problems.

Strategic problems have some of the characteristics of ill-structured problems in their makeup (Mingers & Rosenhead, 2011). Ill-structured problems are characterised by the existence of (Rosenhead & Mingers, 2001):

- Multiple actors;
- Multiple perspectives;
- Incommensurable/conflicting interests;
- Important intangibles;
- Key uncertainties.

Local energy planning falls under the characteristics of ill-structured problems. It is a complex problem where multiple actors are involved and different interests are at stake. Some of the interests are conflicting and/or incommensurable (i.e. absence of a common unit of measure across values) due to its multidimensional nature (environment, economic and social). Structuring helps to frame the problem and recognise the existence of different points of view. Structuring also allows a detailed study of the values and objectives of the actors involved, the identification of evaluation criteria and preferences among those criteria, and the identification of alternatives. Although time consuming, it is worth spending the time in structuring the problem as this will influence the course of action chosen.

3.3.2 Problem structuring methods

There are several problem structuring methods in the context of soft operational research. According to Mingers & Rosenhead (2011) the most widely used are:

1. **Strategic Options Development and Analysis (SODA)** - is a general problem identification method that uses cognitive mapping as a modelling device for eliciting and recording individuals' views of a problem situation. The merged individual cognitive maps (or a joint map developed within a workshop session) provide the framework for group discussions, and a facilitator guides participants towards commitment to a portfolio of actions.
2. **Soft Systems Methodology (SSM)** - is a general method for system redesign. Participants build ideal-type conceptual models, one for each relevant world view. They compare them with perceptions of the existing system in order to generate debate about what changes are culturally feasible and systemically desirable.
3. **Strategic Choice Approach (SCA)** - is a planning approach centred on managing uncertainty in strategic situations. Facilitators assist participants to model the interconnectedness of decision areas. Interactive comparison of

alternative decision schemes helps them to bring key uncertainties to the surface. On this basis the group identifies priority areas for partial commitment, and designs explorations and contingency plans.

Other problem structuring methods include Robustness Analysis - an approach that focuses on maintaining useful flexibility under uncertainty - and Drama Theory - which draws on two approaches, metagames and hypergames, and focuses on the need to manage the tension between conflict and cooperation (Rosenhead & Mingers, 2001).

Causal mapping technique is another example of a problem structuring method. This technique makes possible to articulate a large number of ideas and their interconnections in such a way that an area of concern can be better understood. A causal map is a word-and-arrow diagram in which ideas and actions are causally linked with one another through the use of arrows. The arrows indicate how one idea or action leads to another, i.e. indicate the causes and consequences of an idea or action. Causal mapping is therefore a technique that helps making sense of complex problems. When an individual uses causal mapping to help clarify his or her thinking it is called cognitive mapping, because it relates to the individual own cognition (Bryson *et al.*, 2004). Eden (2004) describes cognitive mapping as a representation of thinking about a problem that follows from the process of mapping. 'Maps are not just a graphical description of what is said, rather they are interpretations of what is meant by the interviewee' (Eden, 2004, p. 675).

In addition, particularly close to the philosophy of problem structuring methods is the decision conferencing process. 'It builds models to support choice between decision alternatives in cases where the consequences may be multidimensional' (Mingers & Rosenhead, 2004, p. 532). Decision conferences are conducted in the form of a workshop and are characterised by: attendance by key actors, impartial facilitation, on-the-spot modelling with continuous display of the developing model, and an interactive and iterative group process. The key actors are chosen to represent all the main perspectives on the issue of concern (Phillips, 2007). 'In decision conferences the output is a group product shaped by participants, so individual attributions are inappropriate' (Phillips, 2007, p.377). The aim is the achievement of a shared understanding, the development of a sense of common purpose, and the generation of a commitment to action (Watson & Buede, 1987).

3.3.3 Value-focused thinking

Value-focused thinking is a philosophy to help in decision-making. It starts by identifying the actors' values and uses values to create alternatives and evaluate them (Keeney, 1992).

Keeney (1992) argues that values should be the driving force for decision-making. He proposes value-focused thinking as an alternative to the more usual approach of alternative-focused thinking. The former consists in first deciding what is wanted and then figuring out how to get it. The latter consists in first identifying what are the alternatives and then choosing the best from the lot. In fact, the reason for interest behind a decision situation is the desire to avoid undesirable consequences and to achieve the desirable ones. The desirability of consequences is a concept based on values and this should be the focus of decision-making whether alternatives are the means to achieve the fundamental values (Keeney, 1992).

Keeney (1992) identifies nine benefits of value-focused thinking (Figure 5). In particular, guiding strategic thinking through a clear identification of strategic objectives is of utmost importance since it gives a stable point of reference to guide decision-making for the long-term. The evaluation of alternatives is based on explicit values, which improves the process of building a sound value model. The value model integrates value judgements with the consequences of the alternatives. Also, value-focused thinking contributes to facilitate the interactions among multiple actors.

Figure 5 – Overview of value-focused thinking benefits. Source: Keeney (1992).

3.3.4 Problem structuring and energy planning

A survey of applications of problem structuring methods can be found in Mingers & Rosenhead (2004) where it is notable the wide range of application areas. Approximately 50 examples were identified in this review, but none of them covers the area of energy planning. Also, it was found out that combining problem structuring methods is a common occurrence (Mingers & Rosenhead, 2004).

Some examples of application to areas close to local energy planning were found in the literature not covered by the survey of Mingers & Rosenhead (2004): the use of Soft Systems Methodology by Neves (2004) to identify the objectives for each potential evaluator of energy efficiency initiatives; and the use of Soft Systems Methodology to structure a problem of urban energy planning (Coelho, Antunes & Martins, 2009). The use of cognitive mapping to identify the fundamental and means objectives in the context of strategic town planning was also found in the literature (Bana e Costa *et al.*, 2002a). In these three examples, problem structuring methods have been used as a first step of a multi-criteria evaluation process.

An example of structuring energy objectives for Germany using the value tree methodology was found in Keeney, Renn & von Winterfeldt (1987). This methodology aims at identifying and structuring a hierarchy of values with general values and concerns at the top and specific criteria at the bottom. ‘The purpose is to create a value tree where the relationship between the lower-level criteria and higher-level categories is hierarchical and one of inclusion; avoids interdependencies between higher-level value categories; and creates and exhaustive and non-redundant list of criteria’ (Keeney, Renn & von Winterfeldt, 1987, p. 354). The outcome was a value tree representing a ‘snapshot’ of the values and concerns of important social groups in Germany. The process of constructing the value tree was based on inputs from many different perspectives providing in this way some legitimacy to the process. The value tree offers a good basis for evaluating alternative energy options (Keeney, Renn & von Winterfeldt, 1987). Value tree is also called objectives hierarchy (Keeney, 1992).

3.4 Multi-Criteria Evaluation

3.4.1 What is multi-criteria evaluation?

The principal aim of multi-criteria evaluation is 'to help decision-makers learn about the problem situation, about their own and others values and judgements and through organisation, synthesis and appropriate presentation of information to guide them in identifying, often through extensive discussion, a preferred course of action' (Belton & Stewart, 2002, p. 5). The focus of multi-criteria evaluation is on supporting or aiding decision-making instead of prescribing how decisions 'should' be made (Belton & Stewart, 2002).

Multi-criteria evaluation is particularly useful to give sequence to the problem structuring phase when the complexity arises from multiple and conflictive objectives (Montibeller, 2005). It is designed to help people making choices that are in line with their values in cases characterised by multiple, incommensurate and conflicting criteria. These values receive expression as objectives that are then operationalised by the definition of appropriate attributes (Bogetoft & Pruzan, 1997). An attribute measures the degree to which an objective is achieved. It is also known in the literature as *value dimension* (von Winterfeldt & Edwards, 1986), *evaluation measure* (Kirkwood, 1997) and *descriptor of performance* (Bana e Costa *et al.*, 2002b; Bana e Costa *et al.,* 2008). Others have used terms such as *measure of effectiveness, measure of performance* and *criterion* (Keeney, 1992).

In general, there is no alternative that is the best in all objectives. Therefore, trade-offs between objectives must be made. The preferred alternative can be called the compromise solution since it is determined based on trade-offs between the values of different objectives (Bogetoft & Pruzan, 1997).

Figure 6 presents the common stages in a multi-criteria evaluation process, since the identification of the problem, through problem structuring, model building and using the model built to inform and challenge thinking, and to determine an action plan.

Figure 6 – The multi-criteria evaluation process. Source: based on Belton & Stewart (2002).

Problem structuring is the first phase of a multi-criteria evaluation process. As described in section 3.3, it allows understanding the problem at hands by identifying the values for which the decision is to be judged and evaluated. Model building consists in the development of formal models of decision-maker preferences, objectives, value trade-offs, etc., so that alternatives can be compared to each other and evaluated in a systematic and transparent manner. It is on this phase that different multi-criteria evaluation methods are distinguished, namely in the nature of the model, in the information required and in how the model is used. Common to all methods is the need to define somehow, the objectives to guide the evaluation, the alternatives to be considered, and some measure of the relative significance of the different objectives. It is in the detail of how this information is elicited and synthesised that the methods differ. The multi-criteria evaluation process is expected to end with the selection of an action plan or alternative (Belton & Stewart, 2002).

3.4.2 Types of multi-criteria decision aiding problems

When analysing a decision problem, typically using multiple criteria, the first step is to identify the type of problem (or its problematic from the French word '*problématique*') (Roy, 2005). The word problematic refers to the way in which decision aiding is envisaged. Roy (1996) has introduced four different problematics where multi-criteria decision aiding may be useful:

1. **Choice** – Choosing one alternative from a set of alternatives.
2. **Sorting** – Sorting alternatives into predefined homogenous categories which are given in a preference order.
3. **Ranking** – Placing alternatives in a preference ordering from best to worst.
4. **Description** – Describing alternatives and their consequences in a formalised and systematic manner so that decision-makers can evaluate them. This is identified as learning problematic by Belton & Stewart (2002) in which the decision-maker seeks simply to gain a greater understanding of what may or may not be achievable.

Figure 7 illustrates the above-mentioned problematics in multi-criteria decision aiding.

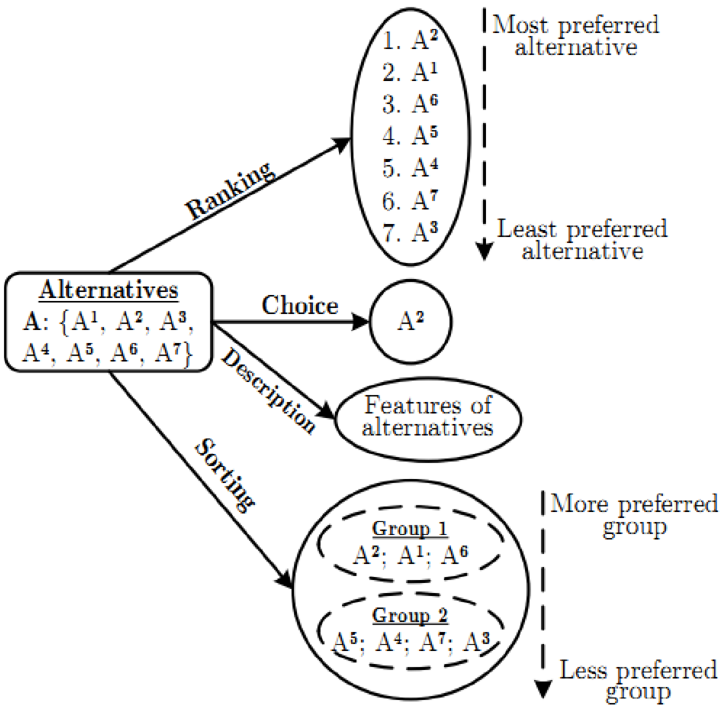


Figure 7 – Problematics in multi-criteria decision aiding. Source: Chen (2006).

The local energy planning problem addressed in this thesis falls into the choice problematic. The decision-maker has to choose one alternative from a set of alternatives, which correspond to different possible energy action plans.

3.4.3 Multi-criteria evaluation methods

A diversity of multi-criteria evaluation methods can be found in the literature as well as many different ways of classifying them. The classification of such methods has been pointed out by Bogetoft & Pruzan (1997) as a multiple criteria problem in itself.

Two broad families of multi-criteria evaluation methods can be identified: discrete and continuous methods. This relates to the number of alternatives to be appraised, which can be explicitly defined and discrete, or implicitly defined by a set of constraints and continuous.

Multi-criteria evaluation methods may be classified in three broad categories (Montibeller, 2005; Belton & Stewart, 2002) as presented and described below.

Figueira, Greco & Ehrgott (2005) present a collection of state of the art surveys of multi-criteria decision aiding, in which a more detailed description of different methods can be found in addition to this section.

3.4.3.1 Multi-attribute value and utility theories

Multi-attribute Value (Utility) Theory

These methods are designed for problems with discrete alternatives. The main objective is to evaluate performances of alternatives on each objective via a value (or utility) function that maps the attributes according to the decision-makers' preferences (Montibeller, 2005). In multi-attribute value theory (MAVT), the decision-maker's overall preference is synthesized from individual building blocks, where each building block describes preferences with respect to one of the objectives that have been identified. This means that instead of directly assessing the overall value score $V(X)$ of alternative X, the decision-maker first focuses on assessing the partial value function $v_i(x_i)$ describing preferences with respect to the performances x_i on attribute i, for all attributes (Belton, 1999). Thus, value functions are used to transform the performances of alternatives (that consist in direct or indirect factual data) into value scores, since they measure the preferences expressed by the decision-makers upon differences of performances, which are of subjective nature.

Weights (w_i) are assigned to the various objectives i as a way of transforming partial value scores into overall value scores. Weights represent trade-offs between different objectives that the decision-makers accept to make (i.e. how much they are willing to give up on a given aspect to gain on another one). The weights should be always elicited anchoring the decision-makers judgements on two (reference) levels of each attribute, which may be, for example, the *worst* and the *best* levels (see, e.g., Montibeller, 2005) or the *neutral* and the *good* levels (see, e.g., Bana e Costa *et al.,* 2008). Note that this differ from the popular belief that weights are direct indicators of the importance of the objectives, which Kenney (1992, p. 147) considers to be the 'most common critical mistake' when using an additive model.

The overall value score attributable to each alternative is derived by aggregating partial values (Diakoulaki, Antunes & Martins, 2005). This is performed via the application of an additive model (Eq. 1). The alternative with the highest value score is chosen.

$$V(X) = \sum_{i=1}^{n} w_i \, v_i \, (x_i) \qquad \text{Eq. 1}$$

$$\text{with} \quad \sum_{i=1}^{n} w_i = 1, w_i > 0 \, , i = 1, \dots, n$$

where:
V is the overall value function
x_i is the performance level of alternative X on attribute i
v_i , $i = 1, \dots, n$ are single-attribute (or partial) value functions
w_i , $i = 1, \dots, n$ are the weights of the objectives

This form of value function is only possible if the decision maker's preferences satisfy a condition known as mutual preferential independence (Dyer & Sarin, 1979). 'Given a set of attributes, X, then a subset Y of X, is preferentially independent of its complement, Z, if preferences relating to the attributes contained in the subset Y, do not depend on the level of attributes in the complementary set, Z. Mutual preference independence requires that every subset of attributes is preferentially independent of its complement' (Belton, 1999, p. 12-5).

If there is uncertainty about the outcomes, then multi-attribute utility theory (MAUT) (Keeney & Raiffa, 1993) should be employed and utility functions must be established instead of value functions. However, utility functions, which model both value and risk attitude, require a more complex elicitation process. Due to the cognitive burden that utility functions impose, value functions have been utilised frequently as a proxy of utility functions (Montibeller, 2005).

Note that the additive model is a compensatory value function model, i.e. a low performance in one criterion can be compensated by a high performance on another criterion. However, before the evaluation takes place an alternative that does not meet a non-compensatory aspect (e.g. if it produces an unbearable environmental impact) can be screened out from posterior analysis.

The Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) developed by Saaty (1980) is considered by Belton & Stewart (2002) to have many similarities to the multi-attribute value function approach. AHP also develops a linear additive model and present its results in cardinal rankings, which mean that each alternative is given a numerical desirability score. Although, the two methods rely on different assumptions for value measurements, the methods used to elicit preference judgements from decision-makers, and the manner of transforming these into quantitative scores (Belton & Stewart, 2002). AHP operates by using pairwise comparisons between attributes and between alternatives (using a ratio scale). AHP assumes that the decision-maker is always able to provide precise answers to the preference elicitation questions.

AHP has been subject of substantial debate among practitioners. The method is appealing because the pairwise comparison form of data input is straightforward and convenient. On the other hand, the rank reversal problems have caused some concerns (Department for Communities and Local Government, 2009). Rank reversal refers to the fact that by adding a new alternative which does not change the range of outcomes of any attribute may lead to a change in the ranking of the other alternatives (Belton & Stewart, 2002). Another criticism to AHP is that the scales it generates do not always respect the preference judgements expressed by evaluators (Bana e Costa & Vansnick, 2008).

The MACBETH approach

MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) approach is a decision-aid approach to multi-attribute value measurement (Bana e Costa, De Corte & Vansnick, 2012). MACBETH requires only qualitative judgements about differences of value to help an individual or a group to quantify the relative attractiveness of different options. The development of the MACBETH was inspired by difficulties that individuals or groups have in producing numerical representations of their strengths of preference, which is not a natural cognitive task. MACBETH was developed with the following question in mind: How can a value scale be built on alternative *X*, both in a qualitatively and quantitatively meaningful way, without forcing group *J* to produce direct numerical representations of preferences and involving only two elements of alternative

X for each judgement required from group *J*? (Bana e Costa, De Corte & Vansnick, 2005a).

MACBETH is operated by asking an individual or a group to provide preferential information, for the determination of the value scales at the level of each objective and for weighting the objectives. It allows measuring 'the attractiveness or value of options through a non-numerical pairwise comparison questioning model, which is based on seven qualitative categories of difference in attractiveness: is there no difference (indifference), or is the difference very weak, weak, moderate, strong, very strong, or extreme?' (Bana e Costa, De Corte & Vansnick, 2012, p. 359). The numerical (cardinal) scales proposed by MACBETH are obtained by linear programming (Bana e Costa, De Corte & Vansnick, 2012).

M-MACBETH decision support system software (Bana e Costa, De Corte & Vansnick, 2005b) was designed to combine the technical elements of the MACBETH approach with the social aspects of decision conferencing (see section 3.3.2). It supports on-the-spot creation of a computer-based additive value model based on qualitative value judgements of difference in attractiveness as well as sensitivity and robustness analysis of the model outputs (Bana e Costa, De Corte & Vansnick, 2012, p. 359).

3.4.3.2 Multi-objective programming

Multi-objective programming has its roots on mathematical programming dealing with decision problems characterised by multiple and conflicting objective functions that are to be optimised over a feasible set of decisions. Such problems are referred to as multi-objective programs (MOPs). Multi-objective programming methods have been developed for situations where feasible alternatives are available implicitly through constraints in the form of mathematical functions. The primary goal of multi-objective is to seek solutions of MOPs (Ehrgott & Wiecek, 2005). Often this approach is used as a first phase of the multi-criteria evaluation process where there are many alternatives (Belton & Stewart, 2002).

A multi-objective problem can be formulated as following (Stewart, 1992; Keefer, Kirkwood & Corner, 2004 *fide* Catrinu, 2006):

$$\begin{aligned} &\max \mathrm{F}(\mathrm{x}) \\ \text{subject to:}\quad &G(x) = 0 \\ &H(x) \leq 0 \\ &x \ \geq 0 \end{aligned} \qquad \text{Eq. 2}$$

where:

x = vector of decision variables

$F(x)$ = vector of objective functions

$G(x)$ = set of equality constraints

$H(x)$ = set of inequality constraints

The aim of multi-objective programming is to select the efficient solutions (non-dominated) situated on the Pareto curve, from the set of feasible solutions.

Examples of traditional methods within multi-objective programming are the weighted-sum and goal programming. Weighted-sum is one of the simplest methods, where weights have the role of scaling different units and also of representing trade-offs between objectives. In goal programming, the decision-maker sets a target for each outcome and the algorithm searches for solutions that minimise the solution-to-target weighted deviations. Both methods elicit preferences *a priori* from the decision-maker. There are other methods that elicit interactively preferences during the optimisation and others that elicit preferences *a posteriori*, once the whole feasible region is found (Montibeller, 2005).

3.4.3.3 Outranking

Unlike the methods presented above, the outcome of an outranking analysis is not a value for each alternative, but an outranking relation on the set of alternatives. These methods are generally applied to discrete choice problems, in which alternatives are compared pairwise to determine which of the two is preferred for each criterion. An alternative *a* is said to outrank (*S*) an alternative *b* if there is enough evidence to conclude that *a* is at least as good as *b,* whereas there is no strong argument to prove the contrary. The comparisons are made in terms of indifference, weak preference and veto thresholds and incomparability (Belton & Stewart, 2002).

The validation of the outranking relation *aSb* is subject to the fulfilment of two conditions: 1) concordance – which ensures that a sufficient majority of criteria is in favour of the assertion *aSb*; 2) non-discordance – which ensures that none of the criteria in the minority should oppose too strongly to the assertion *aSb* (Figueira, Mousseau & Roy, 2005).

Outranking methods belong to the French (or Continental European) school of multi-criteria decision aiding. There are two families of methods: ELECTRE (Elimination Et Choix Traduisant la REalité) (Roy, 1968; Roy, 1996) and PROMETHEE (Preference Ranking Organization METhod for Enrichment Evaluations) (Brans, Vincke & Mareschal, 1986).

ELECTRE methods (ELECTRE I, IS, II, II; IV, TRI) were designed to help decision-makers in choosing and ranking actions, and more recently for sorting actions into predefined and ordered categories with the ELECTRE TRI. ELECTRE methods are appropriate when more than five criteria (up to twelve or thirteen) are included in the aggregation procedure. Also the use of ELECTRE methods is relevant when compensation of the loss on a given criterion by a gain on another one is not acceptable for the decision-maker, and therefore non-compensatory aggregation procedures should be used (Figueira, Mousseau & Roy, 2005). In outranking methods, the weights do not represent trade-offs or scaling factors introduced to ensure commensurability between attributes, but are rather coefficients of importance (Belton & Stewart, 2002).

It has also been suggested that ELECTRE might be used to produce a shortlist of alternatives for more detailed evaluation. Those alternatives can then be further analysed through a different method (Belton & Stewart, 2002).

In the PROMETHEE approach, a pairwise comparison of alternatives is conducted to determine a preference function for each criterion. The preference index determined is used to make a valued outranking relation, which then determines a ranking of the alternatives (Belton & Stewart, 2002).

Outranking methods are appealing in the sense that they are based on less restrictive assumptions than multi-attribute value theory. However, the major drawbacks arise from the non-intuitive inputs that are required, such as concordance and discordance threshold levels; indifference, preference and veto thresholds; and the preference functions of PROMETHEE (Belton & Stewart, 2002). Also, outranking methods are considered to be in general complex, particularly the procedures for aggregating information, what might become more complicated if they are used in decision conferencing (see section 3.3.2) (Montibeller, 2005).

3.4.4 Portfolio decision analysis

In portfolio decision analysis problems the aim is to select a subset (or portfolio) from a large set of alternatives. In these problems, an individual decision-maker or a group are faced with alternative courses of action that consume resources, which are limited and generate benefits, which are typically evaluated against multiple objectives (Salo, Keisler & Morton, 2011a).

Several portfolio decision analysis approaches can be adopted to solve resource allocation problems (Salo, Keisler & Morton, 2011b). In the case of problems where the alternatives cannot be partially funded (i.e. where an alternative must be totally funded or not funded at all) two of the most applied approaches are the benefit-to-cost ratio approach and the optimisation approach (Kirkwood, 1997; Kleinmuntz, 2007; Lourenço, Morton & Bana e Costa, 2012). The benefit-to-cost ratio approach consists in the following steps (Phillips & Bana e Costa, 2007): first, determine the benefit value (v_j) of each alternative j; second, associate a cost (c_j) to each alternative j; third, compute the benefit-to-cost ratio (v_j/c_j) of each alternative; forth, list the alternatives for most to least benefit–to-cost ratio; finally, fifth, go down the list, choosing alternatives until the budget is exhausted. The optimisation approach consists in finding the combination of alternatives that maximises the cumulative benefit without exceeding the budget, by solving a mathematical programming problem known as the 'knapsack problem' (Kellerer, Pferschy & Pisinger, 2004).

Selecting alternatives based on their benefit-to-cost ratios is considered to be a useful technique in the presence of a single resource constraint. However, the optimisation approach is considered to be more flexible than the benefit-to-cost ratio approach, since it can consider more constraints in addition to a budget constraint (Kleinmuntz, 2007). Optimisation can also be used in decisions where alternatives are specified by continuous decision variables (Kirkwood, 1997).

3.4.5 Multi-criteria evaluation and energy planning

Diakoulaki, Antunes & Martins (2005) provide an extensive review of applications of multi-criteria evaluation methods to energy planning problems. The authors point out the extremely high number of existing papers and reports devoted to problems and applications in the energy sector, being therefore impossible to make an exhaustive review of all the literature.

The first applications of multi-criteria evaluation to energy planning date back to the late 1970's – early 1980's. These first applications were dedicated to power systems planning problems. The interest in multi-criteria evaluation has been gaining popularity since then, in particular due to the trend for market deregulation and the growing need for incorporating economic, environmental and social goals in energy planning (Diakoulaki, Antunes & Martins, 2005).

Multi-objective programming models have been widely applied in power systems, namely capacity expansion planning, transmission and distribution network expansion, reactive power compensation planning, load dispatch, load management, among others (Diakoulaki, Antunes & Martins, 2005).

Similarly to multi-objective programming models, the application of models dealing with discrete alternative options also focuses greatly in the electricity sector. However, there is also a diversity of decision contexts at either the supply or the demand side of the whole energy sector for the application of models dealing with discrete alternative options. Figure 8 synthesizes the results of the review of publications concerning the application of discrete methods to energy planning performed by Diakoulaki, Antunes & Martins (2005). For each main group of application it is possible to visualise the methods employed.

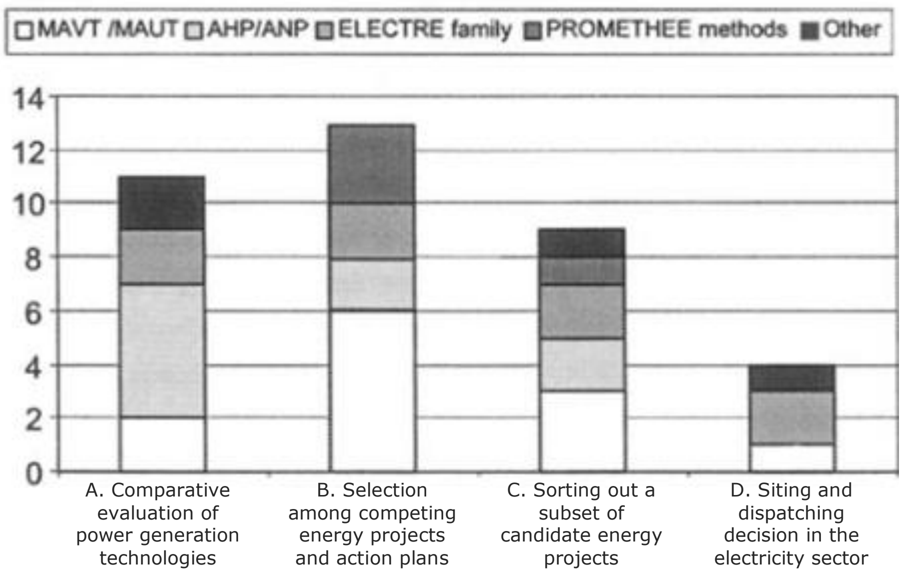


Figure 8 – Multi-criteria evaluation methods in energy planning applications. Source: Diakoulaki, Antunes & Martins (2005).

Of particular interest to this thesis is the use of multi-criteria evaluation methods for choice dilemmas seeking to identify the most desired alternative among alternative scenarios or alternative energy plans (corresponding to group B in Figure 8). From the review carried out by Diakoulaki, Antunes & Martins (2005) it is possible to conclude that energy planning applications are oriented to the electricity sector; energy policy planning at the national level; and single energy resource or single energy carrier planning. The scope of this thesis is energy planning with multiple energy carriers, taking place at the local level, with a special focus, although not exclusively, on demand-side interventions. Examples of such application were not found in the extensive literature review carried out by Diakoulaki, Antunes & Martins (2005).

Pohekar & Ramachandran (2004) present a review of more than 90 published papers using multi-criteria evaluation techniques applied to energy planning, namely renewable energy planning, energy resource allocation, building energy management, transportation energy management, planning for energy projects and electric utility planning. The applications observed to be most popular were in renewable energy planning followed by energy resource allocation. These two application areas refer to compilation of feasible energy plan and dissemination of various renewable energy options, having into account investment planning, energy capacity expansion and evaluation of alternative energies. Once more, applications to local sustainable energy planning (as defined in section 1.3) are missing from the identified applications.

Løken (2007) presents a review of multi-criteria evaluation methods in energy planning. He concludes that most of the applications are for only one energy carrier and are at high planning level, such as national and regional levels. Oriented to the local level, Løken (2007) applies a multi-criteria approach to discrete investment planning in local energy systems with multiple energy carriers.

3.5 'Fitness for purpose' evaluation of methods

This section aims at identifying, from the set of methods reviewed in the previous sections, the suitable methods (herein called 'fitness for purpose') to be integrated in the methodology (chapter 4) or the needs for the development of new methods. The suitability of a certain method is evaluated in relation to the desired features of the methodology depicted in section 1.5. The pre-specified features of the methodology can only be satisfied by combining methods from different disciplines, namely energy modelling techniques to aid in modelling the local energy system at the end-use level; problem structuring methods to help in defining the objectives of the local sustainable energy planning problem; and multi-criteria evaluation methods to support the incorporation of multiple objectives and preferences from the local actors into the energy planning process.

Energy models

Although the review of energy models identified three models (LEAP, MESAP and MEDEE) that present characteristics close to the features outlined in section 1.5, they are still not able to guarantee the fulfilment of all the desired features. These models offer an analysis of energy demand at the end-use level and have structured processes for developing energy demand scenarios. However, for the purpose of local sustainable energy planning – the scope of the methodology proposed in this thesis – it is important to provide the user with a database of energy management actions that they can select and combine in order to explore different alternative scenarios. Furthermore and foremost, the evaluation of such alternative scenarios should not be based in one single objective but should include other sustainability objectives that reflect the values and preferences of the local actors. The selected attributes need to be integrated into the energy model in order to quantify how well each alternative strategy performs in each objective. This is not possible to be performed in existing energy models.

Therefore, for this work it will be required to develop a comprehensive end-use energy model for local sustainable energy planning that allows taking into consideration changes at energy services and technology levels and determine the impact of each alternative scenario on multiple sustainability objectives. The development of such model shall take into consideration features of existing energy models and complement with new features as above described.

Problem structuring

Contrarily to what happened in the review of energy models where a new end-use model was deemed necessary, the review of problem structuring methods led to the identification of 'fitness for purpose' methods that can thus be replicated into the research area of local energy planning.

Causal mapping (Bryson *et al.*, 2004) and cognitive mapping (Eden, 2004) are the selected problem structuring methods. These methods are able to comply with the purpose of helping individuals and groups to have a better understanding of a complex issue such as local sustainable energy planning by mapping their thinking about the problem. On the other hand, they are rather simple to apply and do not require considerable experience or training. Thus, these methods are considered useful for identifying the objectives of local sustainable energy planning from different local actors (see section 4.4).

Value-focused thinking is also selected as the philosophy to guide the decision support methodology for local sustainable energy planning. Starting the process by identifying and structuring the values is expected to help to understand the problem at hand and enhance the quality of the decision. The method described by Keeney (1992) for the identification of fundamental objectives is considered appropriate to be included together with causal mapping and cognitive mapping techniques in the problem structuring phase of the methodology. It provides a solid procedure to distinguish the fundamental or strategic objectives, over which attributes should be defined and the value model developed, from the means objectives.

Decision conferencing (Phillips, 2007) was also found suitable to be used, particularly in the model building phase (see section 4.8). It allows a shared understanding of the problem by the participants in the decision conference and also to consider their perspectives in the multi-criteria evaluation model.

As shown in the literature review (section 3.3), the application of problem structuring methods to local energy planning is not a common practice. In this way, this thesis contributes to the application of problem structuring methods to a new research area: local energy planning.

Multi-criteria evaluation

Multi-criteria evaluation methods are well-established methods and their application areas are wide ranging. Nevertheless, their application to the area of local sustainable energy planning, as defined in this thesis (see section 1.3), is still missing (see section 3.4.5).

From the range of potential multi-criteria methods, the aim is to search for a suitable method for the local energy planning problem addressed in this thesis. The method should be easy to use and easy to understand, since its application will not focus only on backroom analysis but essentially in interacting with the local actors for model building. It is thus important to avoid a ‘black-box’ approach (data in, energy action plan out) to local energy planning. If the local actors perceive the methodology as a black box, i.e. not understanding the logic behind, they might not trust in the outcomes of the methodology (Løken, 2007).

Of particular interest to this thesis is the use of multi-criteria evaluation methods for choice dilemmas (section 3.4.2) seeking to identify the most desired alternative among alternative scenarios or alternative energy plans.

The family of discrete methods is considered appropriate to the decision problem at hand, in which alternatives are discrete. Within this family, the multi-attribute value theory approach emerges as suitable to deal with local energy planning problems in a context where greater interaction with local actors is foreseen. According to Montibeller (2005) this approach is appropriate for interacting with decision-makers in a decision conferencing mode, while outranking methods are in general more complex to be used in decision conferencing. Moreover, multi-attribute value theory has been also widely employed in practice and has been well researched and tested (Montibeller, 2005).

Multi-attribute value theory does not model the decision-maker's attitude to risk and in this way it is not designed to incorporate uncertainties in the model as in multi-attribute utility theory (MAUT). The choice for multi-attribute value theory instead of utility theory was based in the need to keep the approach simple when interacting with the local actors. It was considered that employing utility theory in the decision situation addressed in this thesis would increase the complexity to understand and interpret the results by the local actors. Moreover, sensitivity and robustness analyses can be used to test the effects of uncertainty of weights, imprecision of data estimates and personal disagreements on the model results. The experience of Løken (2007) in applying multi-attribute utility theory to a local energy planning problem with the involvement of actors have shown that 'many of the participants had problems understanding and answering the type of questions used in the MAUT preference-elicitation interviews'.

In multi-attribute value theory the use of the additive function model to aggregate value scores derived from multiple attributes requires the acceptance of compensation between performances in different attributes, thus it is considered as a working hypothesis for the local energy planning problem. Trade-offs shall occur among attributes that measure the performance of alternatives in strategic sustainable development objectives. Nevertheless, this working hypothesis must be validated by the local actors.

The choice to incorporate the MACBETH method within the decision support methodology for local sustainable energy planning was essentially based on its suitability to build a multi-criteria evaluation model in direct interaction with local actors. The fact that actors only need to provide qualitative judgements about differences of attractiveness between two performance levels instead of a numerical representation of their strengths of preferences is expected to ease this task. The use of M-MACBETH software tool allows a visual interactive interface that can be used during decision conferences and promote the debate among local actors. Moreover, this thesis seeks for a socio-technical approach to local energy planning, for which MACBETH is an appropriate method. MACBETH is a well-researched method with a wide range of application areas (see Bana e Costa, De Corte & Vansnick, 2012, Table 4), but as for all the multi-criteria evaluation methods reviewed, its application to local sustainable energy planning is still a novelty.

The use of a portfolio decision analysis approach (section 3.4.4) was also considered to be employed, because it would allow combining all the possible actions to find efficient alternatives (i.e. efficient portfolios of actions) for several investments (Lourenço, Morton & Bana e Costa, 2012). However, this option was abandoned because it was not possible to consider the combined effects of actions, which occur frequently, as further referred in section 4.6.3.

3.6 Summary

In this chapter, energy models, problem structuring methods and multi-criteria evaluation methods were reviewed. The review of energy models made evident the need for developing a new end-use energy model for local energy systems, since none of the existing models was able to fulfil simultaneously the desired features of the methodology. With respect to problem structuring, the 'fitness for purpose' methods identified were cognitive/causal mapping and decision conferencing. For the multi-criteria evaluation it was chosen to adopt the multi-attribute value theory approach and to apply the MACBETH method, since it was considered to be particularly suited for interacting with local actors, in this case through decision conferences. These methods will be patched together in order to develop the decision support methodology for local energy planning in the following chapter.

4. Decision Support Methodology for Local Sustainable Energy Planning

4.1 Outline of the methodology

The proposed methodology consists of nine methodological steps, in which different methods and/or tools are applied (Figure 9). The methodology results in a patchwork of an array of methods offering support to the different stages of an energy planning process. In order to design a methodology supporting the whole energy planning process, an eclectic approach was deemed necessary.

The first step (modelling the local energy system) consists in making a diagnosis of the current situation and estimating future energy demand. For this, it was necessary to design an end-use energy model (section 4.2), which includes the disaggregation of energy demand into end-use categories and allows the projection (estimate of future trends) of energy demand under a reference scenario. The model was implemented in a Microsoft Excel spreadsheet, which became the Local Energy Planning Assistant (LEPA) tool. To be noted that the design of the model employed in this step relates to the attributes chosen in step IV (section 4.5) and to the actions identified in step V (section 4.6). The model is further used in step VI (section 4.7) for assessing the impact of alternatives in each objective. In case additional actions and different objectives would be identified, it would be necessary to carry out adjustments to the model.

The second step consists in identifying the relevant local actors (section 4.3) who will further be involved in other methodological steps (as represented in Figure 9). Next, objectives of local sustainable energy planning are identified and structured (section 4.4). This step makes use of cognitive and causal mapping techniques (Bryson *et al.*, 2004; Eden, 2004) to involve the local actors in the identification and structuring of the objectives following a value-focused thinking approach (Keeney, 1992). Afterwards, appropriate attributes (section 4.5) for the objectives are proposed, which after being validated by the local actors will be used to measure the extent to which alternatives satisfy the objectives.

Thereafter, alternatives need to be generated. This is what step V (section 4.6) focuses: first on identifying a catalogue of actions and after on generating alternatives by adopting a 'strategy generation table' procedure (Howard, 1988; Kirkwood, 1997; Matheson & Matheson, 1998). An alternative is herein considered as a combination of individual actions that achieve a pre-specified GHG emissions reduction target. For the evaluation process to take place, it becomes necessary to assess the impacts of the alternatives in step VI (section 4.7). The assessment of the impact of each alternative on the objectives is included in the end-use energy model developed.

Step VII consists in building a value function for each objective (section 4.8.1) and in weighting the objectives (section 4.8.2) in a decision conferencing process (Phillips, 2007) with the local actors. The Multi-Attribute Value Theory (Belton & Stewart, 2002) and the MACBETH approach (Bana e Costa & Vansnick, 1999; Bana e Costa *et al.*, 2011; Bana e Costa *et al.* 2012) are here adopted as well as the M-MACBETH software tool (Bana e Costa, De Corte & Vansnick, 2005a). This step results in an overall benefit score obtained for each alternative (section 4.8.3). In order to verify the stability of the results obtained, a robustness analysis is carried out in step VIII (section 4.9). Finally, it is considered useful to balance the overall benefit of each alternative with its investment needs (section 4.10), in order to provide better insight to the decision-makers' choice.

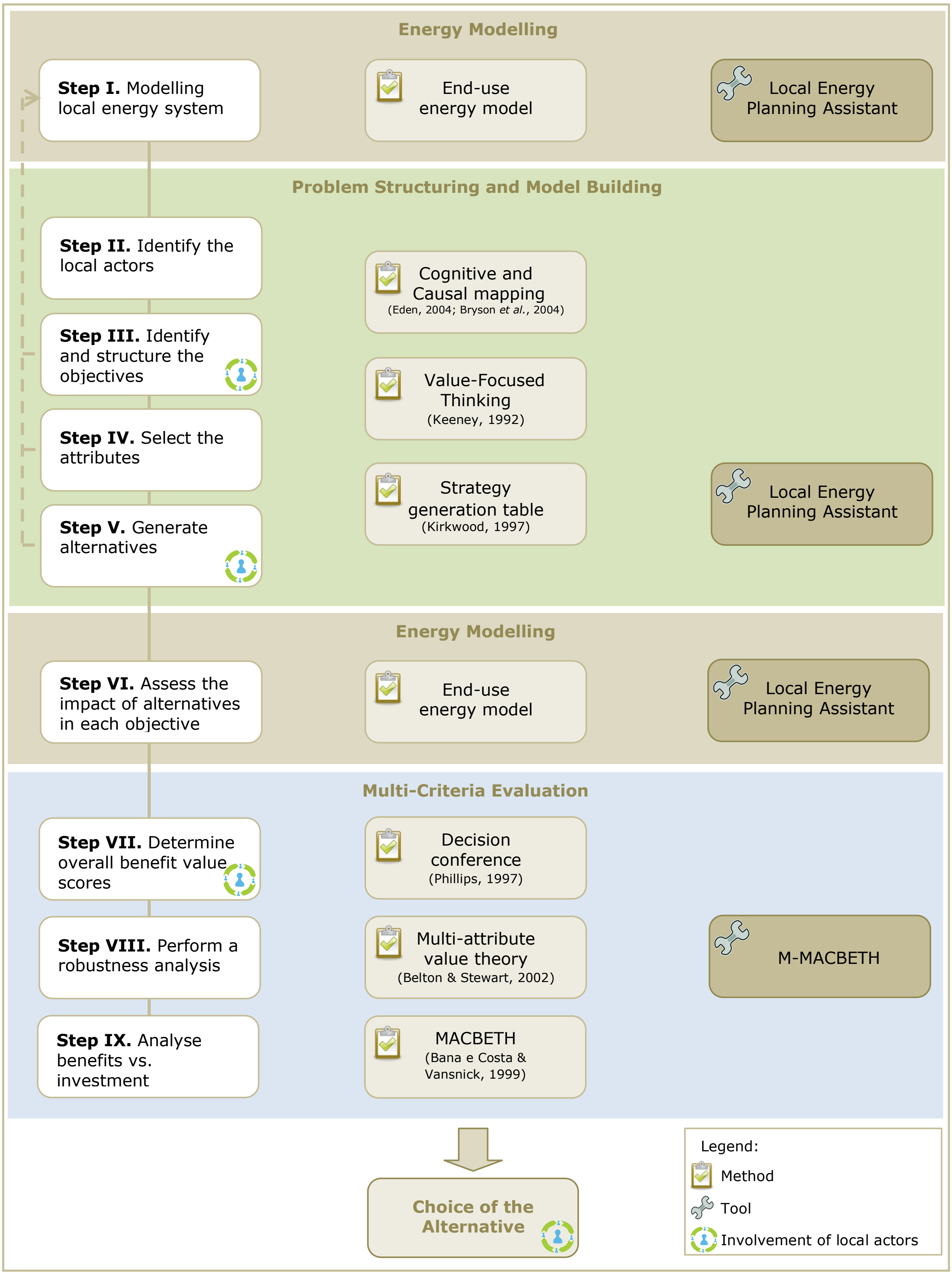


Figure 9 – Scheme of the methodology illustrating the methodological steps and the patching together of several methods and tools.

4.2 Step I – Modelling the local energy system

4.2.1 Structure of energy demand

In order to analyse current energy demand and estimate future demand with reasonable precision and flexibility of management, it is necessary to know the energy services for which energy is demanded and in which form.

Energy service refers to the service that is provided by using energy (e.g. lighting, hot water, space heating). The forms of energy inputs that the end-users can use to fulfil the desired energy service are called *energy carriers* (e.g. electricity, gasoline, natural gas). In order to obtain the services that energy provides, *end-use conversion technologies* are used. Those technologies convert *final energy*, i.e. the delivered energy that is made available to the consumer, not taking transformation losses into account, into *useful energy*, i.e. the part of energy that is used to provide the energy service. For instance, using electricity at home to switch on a lamp (*conversion technology)* converts the delivered energy (*final energy*) into radiant energy (*useful energy*) and then finally into lighting (*energy service*) which is the desired end.

The structure of energy demand adopted in the end-use energy model is organised into the following layers:

1) Sectors of economy;
2) Energy services or end-uses (hereafter referred with index *j*);
3) Energy carriers (hereafter referred with index *i*);
4) End-uses' conversion technologies (hereafter referred with index *t*).

The sectors considered are households; services; transport; industry (including construction); agriculture and fisheries; and street lighting. To be noted that the inclusion of street lighting as an additional sector resulted from the review of local energy and climate action plans (performed in section 4.6.2 for the identification of actions), which showed the preference of local authorities to analyse separately this sector.

The structure of energy demand developed for the energy end-use model is illustrated in Figure 10 for the households sector, Figure 11 for the services sector, Figure 12 for the transport sector, Figure 13 for the industry sector, Figure 14 for agriculture and fisheries sector, and Figure 15 for street lighting.

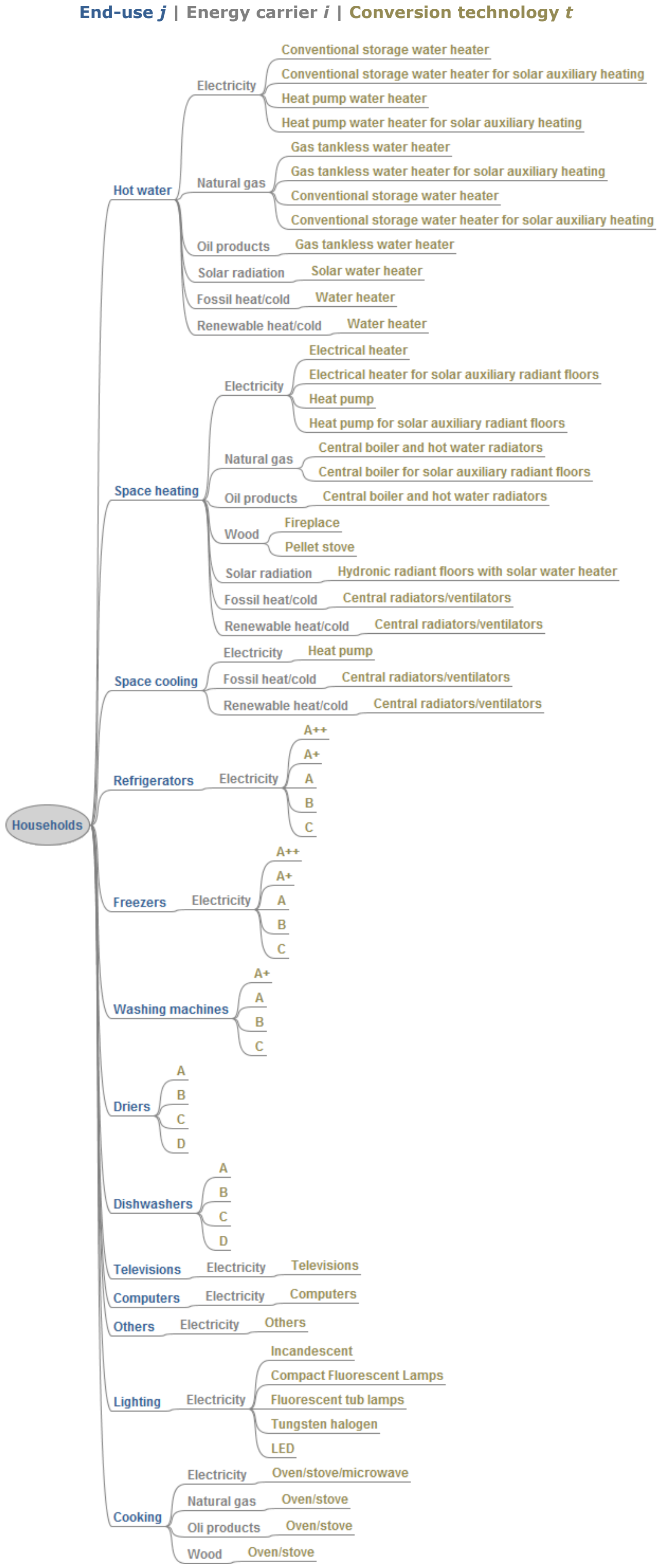


Figure 10 – Structure of the households sector: end-uses, energy carriers and conversion technologies.

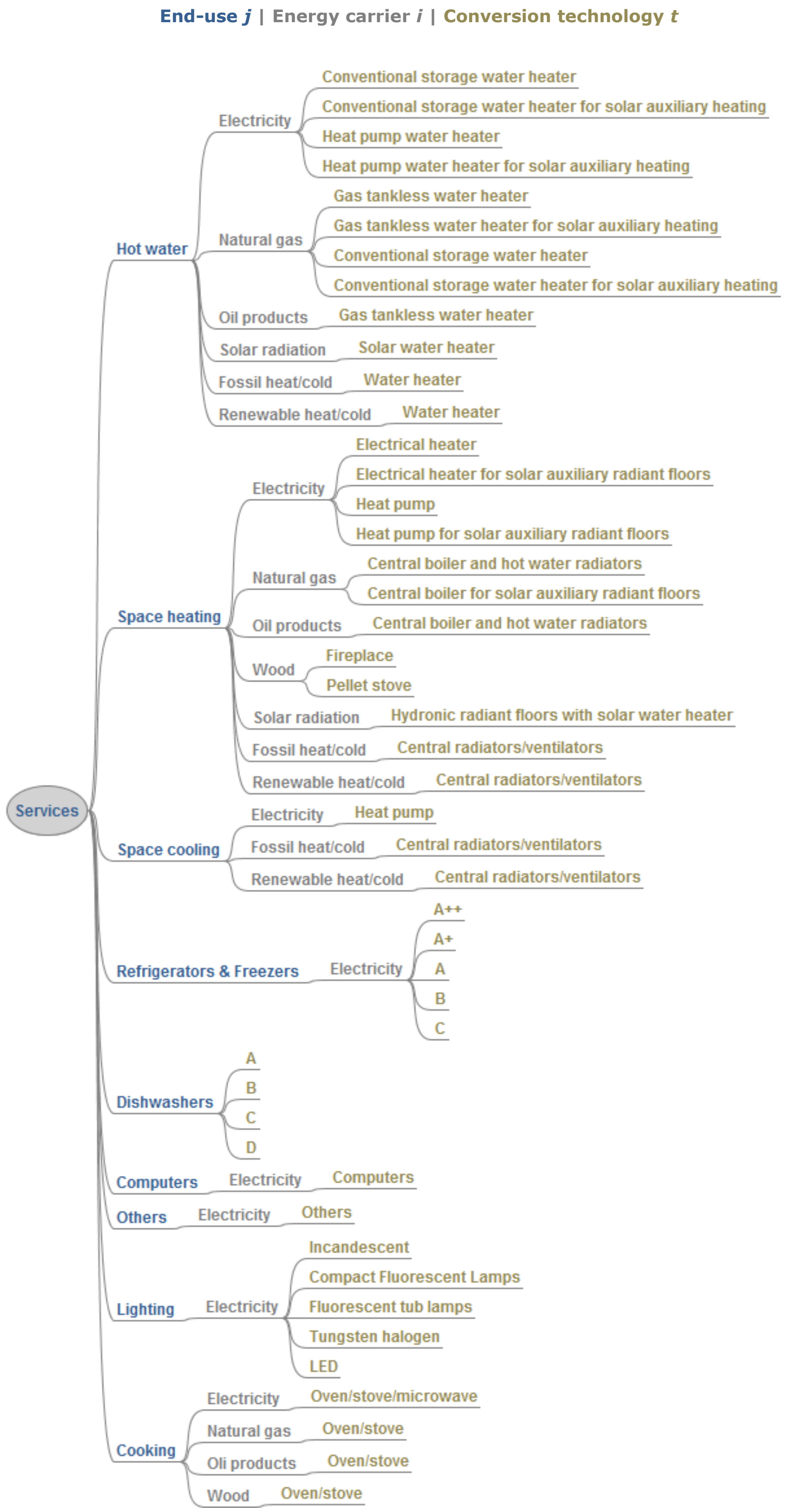


Figure 11 – Structure of the services sector: end-uses, energy carriers and conversion technologies.

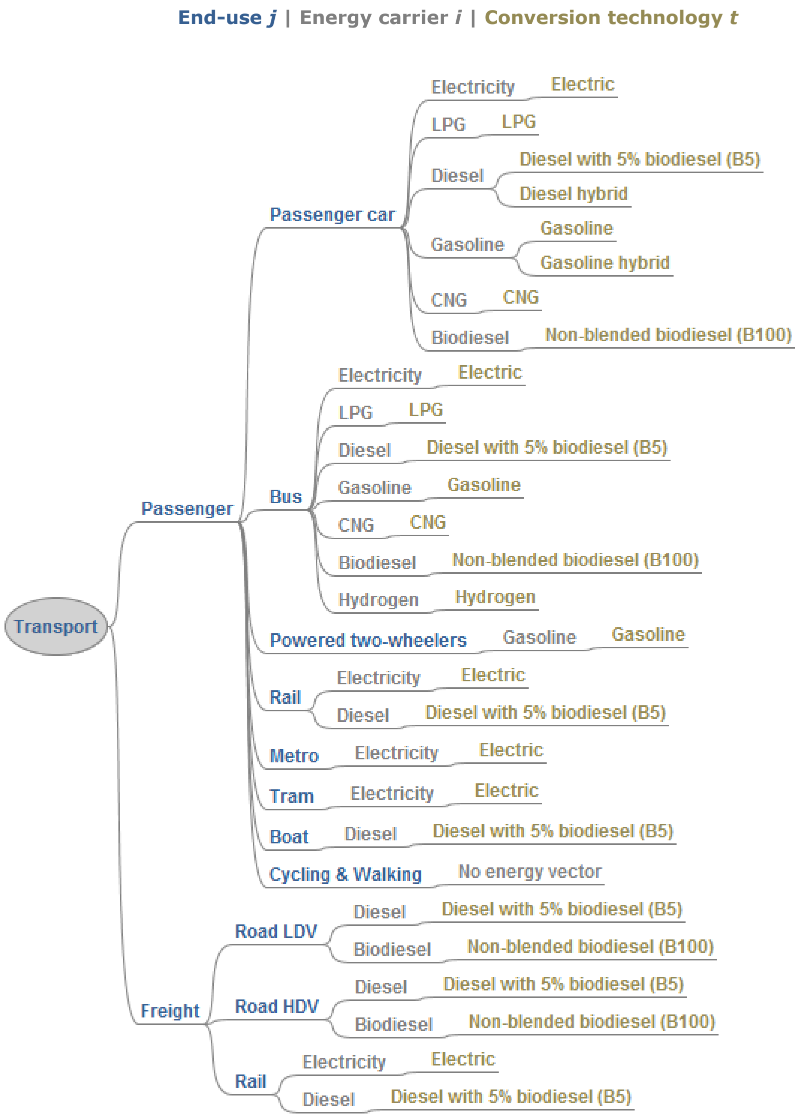


Figure 12 – Structure of the transport sector: end-uses, energy carriers and conversion technologies.

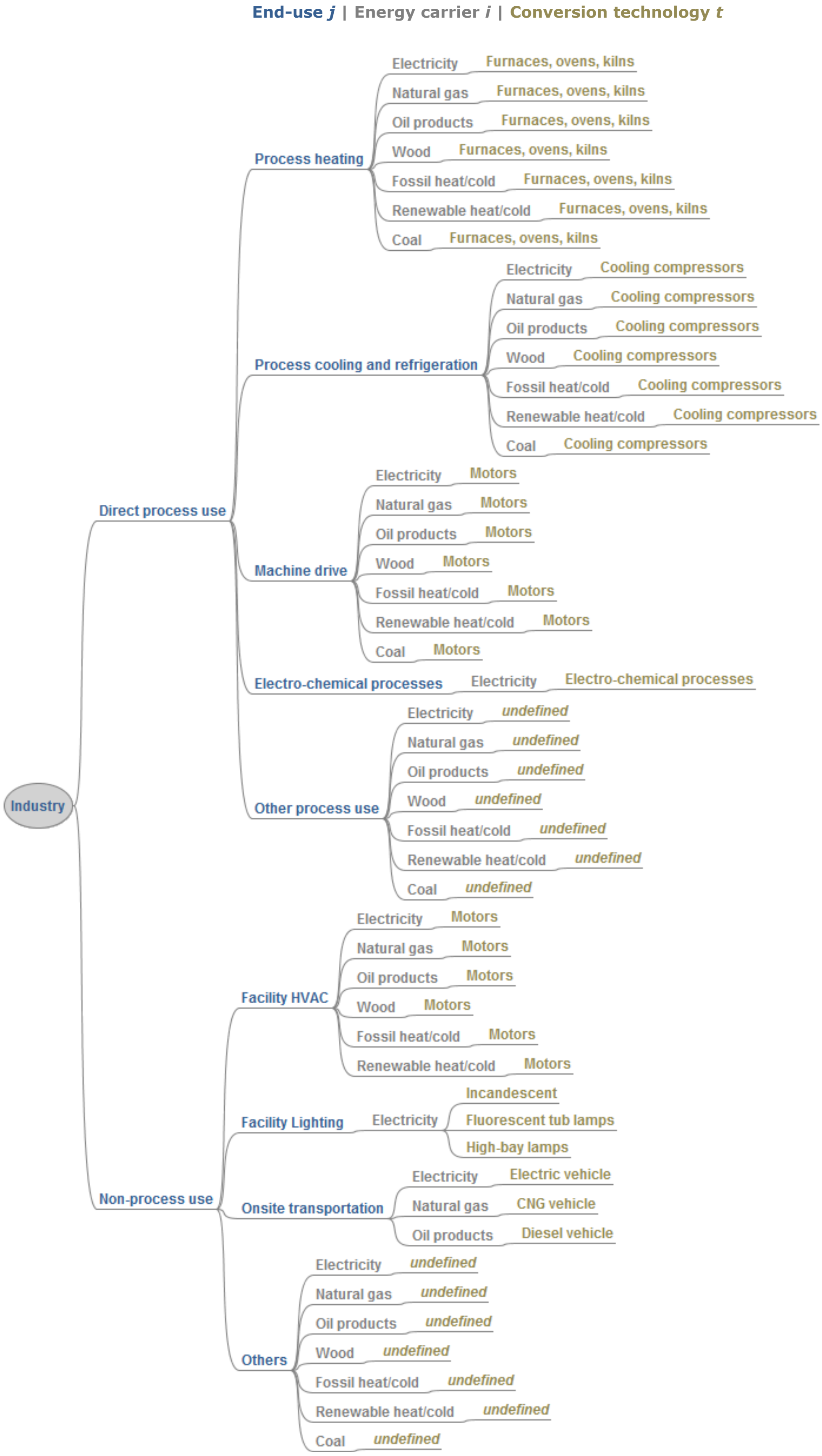


Figure 13 – Structure of the industry sector: end-uses, energy carriers and conversion technologies.

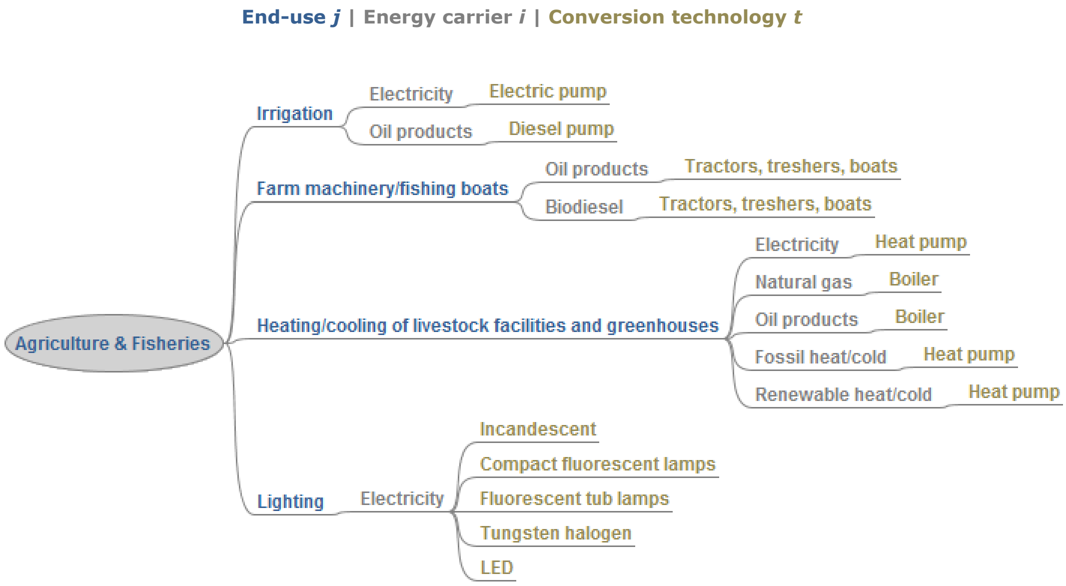


Figure 14 – Structure of the agricultures and fisheries sector: end-uses, energy carriers and conversion technologies.

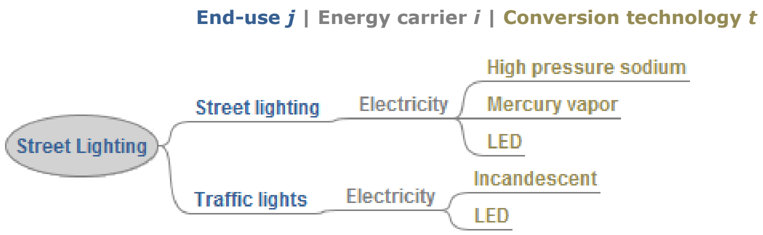


Figure 15 – Structure of the street lighting sector: end-uses, energy carriers and conversion technologies.

4.2.2 Breakdown of energy demand in the base year

This step starts by identifying for the chosen base year the amount of each energy carrier (i) required by end-use (j) in each sector. Next, for each energy carrier inside each end-use, the distribution of the energy carrier by end-use energy conversion technologies (t) is performed. Also, the efficiency of each end-use energy conversion technology is collected.

The collection of information relative to the breakdown of final energy demand can be made through bottom-up surveys or can be based on existing studies and national surveys on energy demand in the different sectors of economy. Efficiencies of technology can be found in national level studies and literature studies (see Table 24 in chapter 5).

The next step is thus to determine useful energy demand which will be further used for the projection of future energy demand for all sectors, except transport, in which a specific approach was adopted (see section 4.2.3).

Useful energy demand in the base year (*b*) is estimated by multiplying final energy demand by end-use conversion technology efficiency (i.e. conversion of final to useful energy) for each end-use (*j*), respective energy carriers (*i*) and conversion technologies (*t*), as follows:

$$UE_{\,i,j,t\;b} = FE_{i,j,t\;b} \times \eta_{\,i,j,t\;b} \qquad \text{Eq. 3}$$

where:
$UE_{i,j,t\;b}$ = amount of useful energy from energy carrier *i* for end-use *j* by conversion technology *t* in the base year *b* [toe]
$FE_{i,j,t\;b}$ = amount of final energy of energy carrier *i* for end-use *j* by conversion technology *t* in the base year *b* [toe]
$\eta_{i,j,t\;b}$ = efficiency of conversion technology *t* for end-use *j* supplied by energy carrier *i* in the base year *b* [%]

In the case of transport, an approach based on the transport energy intensity expressed in final energy use per unit of passenger-km travelled or per unit of tonnes-km hauled by mode (*j*) and engine fuel type (*t*) is adopted. Transport energy intensity is collected for the base year for each transport mode (*j*) and engine fuel type (*t*). This data can be found available at the national level, or default values can be collected from literature studies (see Table 24 in chapter 4).

4.2.3 Projection of energy demand – reference scenario

After having the breakdown of energy demand (as presented in the previous section) for the base year, energy demand is estimated for a certain time horizon by adopting a reference projection. This reference scenario depicts a future state of energy demand and supply based on the local energy system's structure, socio-economic trends and compliance with legal requirements and policies foreseen today. The reference scenario is the projected energy system over which alternatives will be assessed (see section 4.7).

The projection of energy demand is based on the evolution of key socio-economic variables, responsible for inducing energy demand (Table 15). Each socio-economic variable is estimated for the time horizon based on historical data or existing socio-economic projection studies.

Table 15 – Identification of key socio-economic variables which influence energy demand for each sector.

Sector	Key socio-economic variable
Households	Number of dwellings
Services	Gross-Value Added (GVA)
Transport	Transport energy intensity (toe/pkm and toe/tkm) Transport activity (pkm and tkm)
Industry	Gross-Value Added (GVA)
Agriculture and Fisheries	Gross-Value Added (GVA)
Street Lighting	Number of dwellings

The number of dwellings is responsible for inducing energy demand in the sector of households. This variable is also used for street lighting based on the assumption that construction of new dwellings will increase the deployment of street lighting in new urbanized areas. Energy demand is induced by economic activities. As so, sectoral Gross Value Added (GVA) is used for services, industry and agriculture and fisheries sectors. In the transport sector, the needs for personal travel expressed in passenger-km and the needs for distribution of goods expressed in tonnes-km are the determinants of energy demand.

For all sectors (with slight differences on the transport sector), the projection of energy demand is based on the influence of the respective key socio-economic variable in useful energy demand for each end-use, as presented in Eq. 4.

As so, for a certain time horizon (*y*), useful energy demand is estimated based on the expected evolution of the key socio-economic variable (*X*) for each sector, as follows:

$$UE_{i,j,t\ Ry} = UE_{i,j,t\ b} \times \frac{X_y}{X_b} \qquad \text{Eq. 4}$$

where:

$UE_{i,j,t\ Ry}$ = amount of useful energy of energy carrier *i* for end-use *j* by conversion technology *t* in the Reference Scenario *R* relative to time horizon *y* [toe]

$UE_{i,j,t\ b}$ = amount of useful energy of energy carrier *i* for end-use *j* by conversion technology *t* in the base year *b* [toe]

X_y = value of key socio-economic variable in the time horizon *y* for each sector [number of dwellings or euros (GVA)]

X_b = value of key socio-economic variable in the base year *b* for each sector [number of dwellings or euros (GVA)]

The following schemes (Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20) illustrate the key socio-economic variable responsible for inducing useful energy demand in each sector and the respective end-uses.

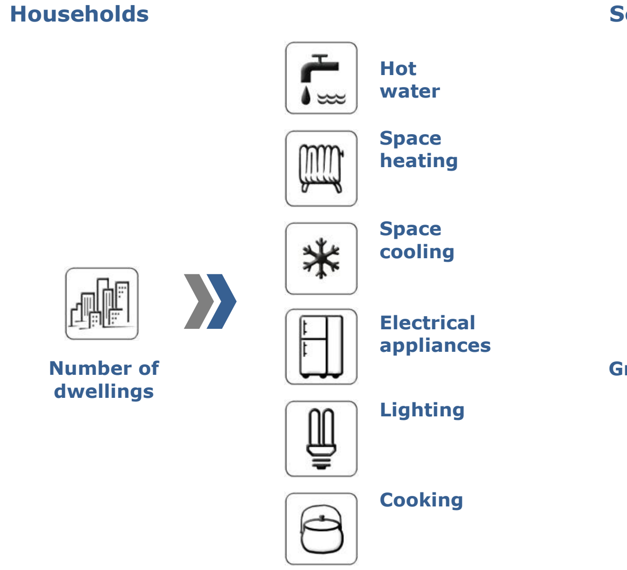


Figure 16 – Simplified methodological scheme for the estimates of future energy demand in the households sector.

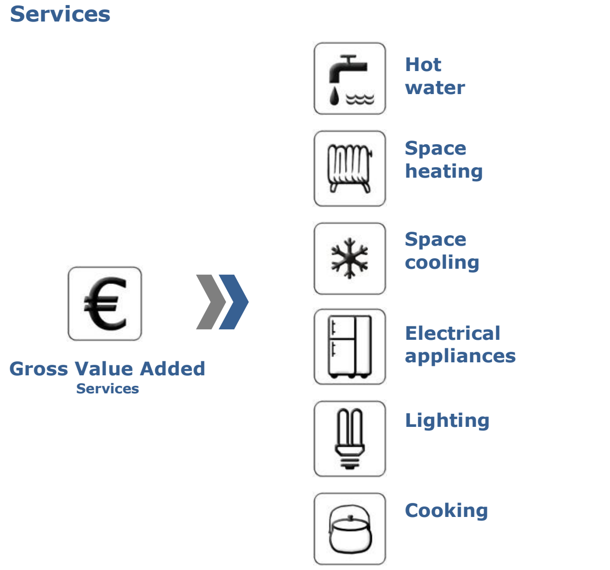


Figure 17 – Simplified methodological scheme for the estimates of future energy demand in the services sector.

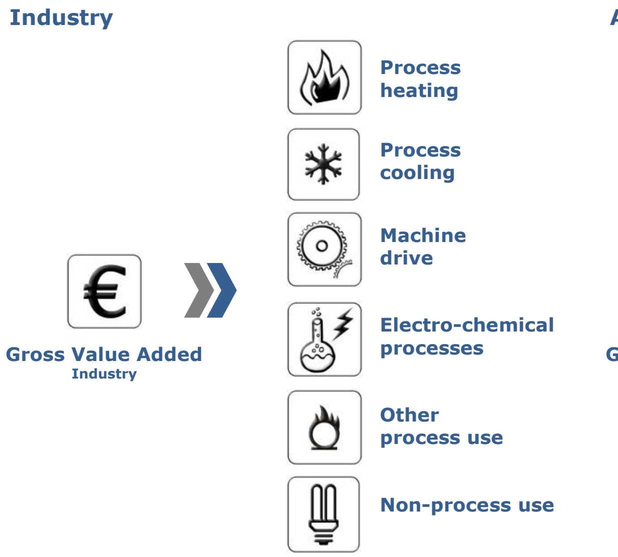


Figure 18 – Simplified methodological scheme for the estimates of future energy demand in the industry sector.

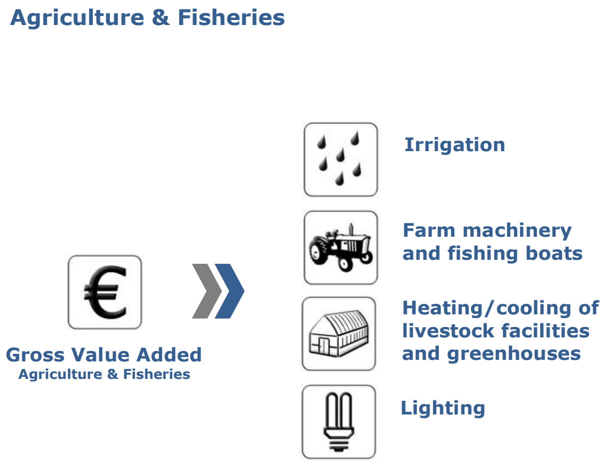


Figure 19 – Simplified methodological scheme for the estimates of future energy demand in the agriculture & fisheries sectors.

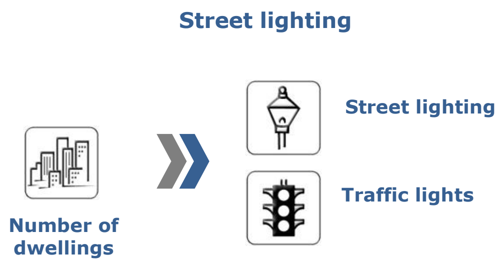


Figure 20 – Simplified methodological scheme for the estimates of future energy demand for street lighting.

As some energy service needs can increase or decrease depending on a number of factors such as social, technological or climate factors, it becomes necessary to apply an evolution factor to the useful energy estimated (Eq. 5). The evolution factor is by default 1, which means that the needs of an energy service are only function of the key socio-economic variable. However, there are cases where energy services needs are expected to increase. For instance in countries where thermal comfort conditions of dwellings are not yet totally satisfied, it is expected that there will be an increase in space heating, space cooling and/or hot water end-uses categories. Also, an increase in the ownership of electrical appliances (e.g. computers) per dwelling is also expected to occur in the future. The energy service needs evaluation factor accounts for these behavioural/cultural changes. The determination of evolution factors can be based on experts' consultation.

Total useful energy demand by end-use (*j)* in each sector is thus estimated by applying an evolution factor of energy services needs as follows:

$$UE_{j\ Ry} = \sum_{i=1}^{n} \left(UE_{i,j,t\ Ry}\right) \times EvF_{j\ Ry} \qquad \text{Eq. 5}$$

where:

$UE_{i\ Ry}$ = amount of useful energy for end-use *j* in Reference Scenario *R* relative to time horizon *y* [toe]

$UE_{i,j,t\ Ry}$ = amount of useful energy of energy carrier *i* for end-use *j* by conversion technology *t* in the Reference Scenario *R* relative to time horizon *y* [toe]

$EvF_{j\ Ry}$ = evolution factor of energy services needs for end-use *j* in the Reference Scenario *R* relative to time horizon *y* [-]

Afterwards, assumptions are made in terms of shifting of end-use conversion technologies within an end-use (*S*) according to trends and legislation foreseen and efficiency (η) of those technologies (Eq. 6). Thus, total useful energy demand by end-use is disaggregated according to the share of end-use supplied by each conversion technology (*S*). Final energy demand by end-use, including respective energy carriers and conversion technologies, is estimated according to the following equation:

$$FE_{i,j,t\ Ry} = \frac{UE_{i,j\ Ry} \times S_{i,j,t\ Ry}}{\eta_{\ i,j,t\ Ry}} \qquad \text{Eq. 6}$$

where:

$FE_{i,j,\ t\ Ry}$ = amount of final energy of energy carrier *i* for end-use *j* by conversion technology *t* in the Reference Scenario *R* relative to time horizon *y* [toe]

$UE_{i,j\ Ry}$ = amount of useful energy of energy carrier *i* in end-use *j* in the Reference Scenario *R* relative to time horizon *y* [toe]

$S_{j,t\ Ry}$ = share of end-use *j* that is supplied with energy carrier *i* by conversion technology *t* in the Reference Scenario *R* relative to time horizon *y* [%]

$\eta_{i,j,t,\ Ry}$ = efficiency of conversion technology *t* for end-use *j* supplied by energy carrier *i* in the Reference Scenario *R* relative to time horizon *y* [%]

In the case of transport, the estimates of future final energy demand are based on:

1) Efficiency change factors (*ECF*) of future transport energy intensity by each mode of transport, as represented in Eq. 7. Efficiency change factors can be found in projection studies (e.g. EC, 2007).
2) Evolution (Δ) of transport activity (*pkm* and *tkm*) in each mode, according to past trends or projection studies;
3) Assumptions in terms of shifting of passengers-km and tonnes-km inside each mode (*S*) according to trends and legislation foreseen;
4) Efficiency of fuel engine types (η).

Figure 21 shows a simplified scheme of the method adopted for projecting final energy demand in transport based on key socio-economic variables and end-uses (or modes of transport).

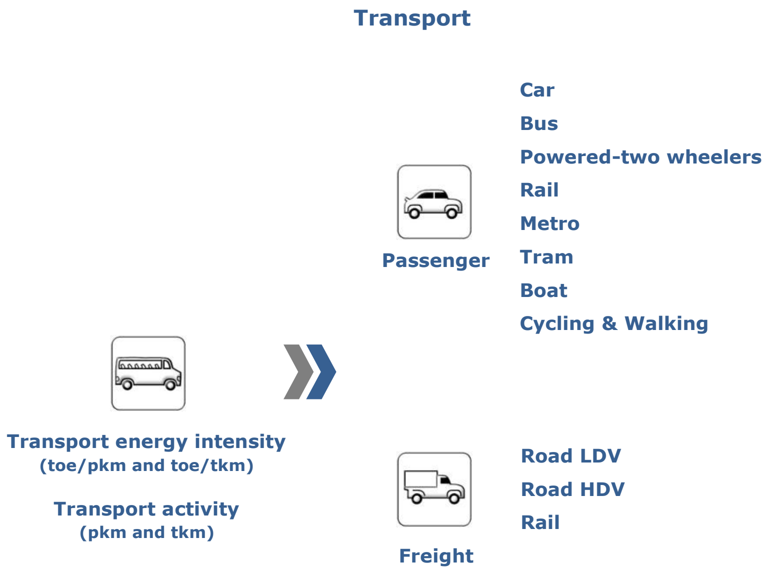


Figure 21 – Simplified methodological scheme for estimates of future energy demand in the transport sector.

Future final energy demand by mode (*j*) and by energy carrier (*i*) and engine fuel type (*t*) is thus estimated by considering the variation in transport energy intensity and transport activity.

Transport energy intensity in the time horizon (*y*) is estimated by means of an efficiency change factor (*ECF*) as follows:

$$TEI_{\ i,j,t\ Ry} = TEI_{i,j,t\ b} \times (1 + ECF_{j\ Ry}) \qquad \text{Eq. 7}$$

where:

$TEI_{i,j,t\ Ry}$ = transport energy intensity of mode *j* with engine fuel type *t* using energy carrier *i* in the Reference Scenario *R* relative to time horizon *y* [toe/pkm and toe/tkm]

$TEI_{i,j,t\ b}$= transport energy intensity of mode *j* with engine fuel type *t* using energy carrier *i* in the base year *b* [toe/pkm and toe/tkm]

$ECF_{j\ Ry}$ = efficiency change factor in transport energy intensity of mode *j* in the Reference Scenario *R* relative to time horizon *y* [%]. An efficiency improvement corresponds to a negative value.

Transport activity in the time horizon is estimated by applying a projected change (Δ) in passenger-km (*pkm*) and tonnes-km (*tkm*) as follows:

$$pkm_{j\ Ry} = pkm_{j\ b} + pkm_{j\ b} \times \Delta_{j\ b \rightarrow Ry} \qquad \text{Eq. 8}$$

where:

$pkm_{j\ Ry}$ = passenger-km (or tonnes-km) in mode *j* in the Reference Scenario *R* relative to time horizon *y* [pkm or tkm]

$pkm_{j\ b}$ = passenger-km (or tonnes-km) in mode *j* in the base year *b* [pkm or tkm]

$\Delta_{j\ b \rightarrow Ry}$ = change in passenger-km (or tonnes-km) in mode *j* between the base year *b* and the Reference Scenario *R* relative to time horizon *y* [%]

Afterwards, passenger-km travelled by mode (*j*) and tonnes-km hauled by mode (*j*) are disaggregated according to the fuel engine type used for travelling and hauling. Final energy demand by mode, including respective energy carriers and fuel engine types, is estimated according to the following equation:

$$FE_{i,j,t\ Ry} = TEI_{i,j,t\ Ry} \times pkm_{j\ Ry} \times S_{pkm\ i,j,t\ Ry} \qquad \text{Eq. 9}$$

where:

$FE_{i,j,t\ Ry}$ = amount of final energy for mode *j* with engine fuel type *t* using energy carrier *i* in the Reference Scenario *R* relative to time horizon *y* [toe]

$TEI_{i,j,t\ Ry}$ = transport energy intensity of mode *j* with engine fuel type *t* using energy carrier *i* in Reference Scenario *R* relative to time horizon *y* [toe/pkm and toe/tkm]

$pkm_{j\ Ry}$ = passenger-km (or tonnes-km) by mode *j* in Reference Scenario *R* relative to time horizon *y* [pkm and tkm]

$S_{pkm\ i,j,t\ Ry}$ = Share of passenger-km (or tonnes-km) in mode *j* with engine fuel type *t* using energy carrier *i* Reference Scenario *R* relative to time horizon *y* [%]

4.2.4 Quantification of GHG emissions

After determining the estimated future energy demand, the calculation of GHG emissions for both base year and reference scenario takes place. GHG emissions are associated to the use of energy that takes places within the territory of the local authority. Emissions occur either directly due to fuel combustion in the territory, for instance in transport, or indirectly via fuel combustion associated to electricity/heat/cold produced outside the territory but consumed within the territory. Thus, GHG emissions are estimated based on a 'consumer-approach', in which the impacts of GHG emissions from energy production are allocated to the municipalities based on the amount of energy they use.

GHG emissions are calculated for each sector and for each energy carrier by multiplying final energy use by the corresponding emission factor (IPCC, 2006), as follows:

$$GHG_i = FE_i \times EF_i \qquad \text{Eq. 10}$$

where:
GHG_i = emissions of a given GHG by type of energy carrier *i* [t]
FE_i = amount of final energy used [toe]
EF_i = emission factor of a given GHG by type of energy carrier *i* [t GHG/toe]

GHG emissions attributable to electricity need to be tracked back to the GHG emissions taking place at the power plants that produce electricity into the national grid. In this way, GHG emissions are determined based on the national electricity mix emission factor which is calculated as follows:

$$NEEF = \frac{\sum_r GHG_r}{EP - OL} \qquad \text{Eq. 11}$$

where:
NEEF = national emission factor for electricity [t CO_2 eq./toe]
GHG_r = amount of GHG emissions by energy resource *r* [t CO_2 eq.]
EP = amount of electricity produced [toe]
OL = amount of electricity used by electricity industry own use, transport and distribution losses [toe]

Second, the local electricity emission factor concerning small-scale electricity production (electricity is consumed close to where it is produced) is calculated as follows:

$$LEF = \frac{\sum_r GHG_r}{EP} \qquad \text{Eq. 12}$$

where:

LEF = local emission factor for electricity [t CO_2 eq./toe]

GHG_r = amount of GHG emissions by energy resource *r* [t CO_2 eq.]

EP = amount of electricity locally produced [toe]

The emission factor is then multiplied by electricity consumption in order to determine total GHG emissions attributable to electricity consumption:

$$GHG_e = (EC - LEP - GEP) \times NEEF + LEP \times LEF + GEP \times PEF \qquad \text{Eq. 13}$$

where:

GHG_e = amount of GHG emissions attributable to electricity consumption [t CO_2 eq.]

EC = electricity consumption [toe]

LEP = local electricity production [toe]

GEP = green electricity purchases by the local authority [toe]

NEEF = national emission factor for electricity [t CO_2 eq./toe]

LEP = local emission factor for electricity [t CO_2 eq./toe]

PEF = green electricity purchases emission factor (is equal to zero in IPCC approach) [t CO_2 eq./toe]

The national electricity emission factor is kept constant for the quantification of GHG emissions in the time horizon. This is due to the fact that changes in the national electricity emission factor are related to national policies and local authorities have no influence on that. This methodology focuses on actions that are within the power of the local authority to change and aims to measure the effects of those actions.

GHG emissions attributable to heat/cold production within the territory of the local authority are calculated as follows:

$$HEF = \frac{\sum_r GHG_r}{HP} \qquad \text{Eq. 14}$$

where:

HEF = emission factor for heat/cold [t CO_2 eq./toe]

GHG_r = amount of GHG emissions by energy resource *r* [t CO_2 eq.]

HP = amount of heat/cold locally produced [toe]

In order to calculate the amount of GHG emissions by energy resource (GHG_r) it becomes necessary to determine the amounts of fuel used for the production of heat/cold and electricity from combined heat and power (CHP) plants. This requires a method of dividing the total fuel use between the two energy outputs. The method adopted

(OECD/IEA, 2004) divides the amount of fuel use in proportion to the amount of the two energy outputs produced. Electricity is usually feed into the grid, and thus is accounted in the national electricity emission factor.

The imputed fuel used for heat/cold and electricity is determined as follows:

$$F_h = F \times \frac{H}{H+E} \quad \text{Eq. 15} \qquad F_e = F \times \frac{E}{H+E} \quad \text{Eq. 16}$$

where:
F_h = fuel used for heat/cold production [toe]
F_e = fuel used for electricity production [toe]
F = total amount of fuel consumed in the transformation process [toe]
H = amount of heat produced [toe]
E = amount of electricity produced [toe]

In the case of transport sector, Kennedy *et al.* (2010) present and compare three approaches to quantify GHG emissions: i) based on quantity of fuel sold; ii) use fuel consumption values estimated from vehicles kilometres travels (VKT); iii) estimate fuel consumption by scaling from wider regions using a scaling factor such as population. The analysis has shown that in the cases analysed in the study, the differences between the three approaches were less than 5%. According to IPCC guidelines (2006), the first approach (fuel sold) is appropriate for CO_2 while the second (VKT) is appropriate for CH_4 (methane) and N_2O (nitrous oxide), which are more dependent on the age and technology of vehicles.

The methodology of this work can either adopt local fuel sales or estimated fuel use values. Fuel sales data is usually available. Nevertheless, it should be paid particular attention if the municipality is located in border regions, due to the effect of 'fuel tourism'. The use of fuel sales is based on the assumption that the fuel purchased within the local authorities' boundaries is representative of the activity within the territory. For the transport sector, GHG emissions are determined by multiplying fuel sold (or estimated fuel use) by the corresponding emission factor (IPCC, 2006):

$$GHG_i = FS_i \times EF_i \quad \text{Eq. 17}$$

where:
GHG_i = emissions of a given GHG by type of energy carrier *i* [t]
FS_i = amount of fuel sold or estimated fuel use by type *i* [toe]
EF_i = emission factor of a given GHG by type of energy carrier *i* [t GHG/toe]

To calculate the total CO_2 emissions, the emissions are summed over all energy carriers:

$$GHG_g = \sum GHG_i \qquad \text{Eq. 18}$$

where:
GHG_g = total emissions of a given GHG *g* [t]
GHG_i = emissions of a given GHG by type of energy carrier *i* [t]

GHG emissions are herein expressed in tonnes of CO_2 equivalent. To include other greenhouse gases, the amount of CH_4 and N_2O needs to be converted into CO_2 equivalent by multiplying the emission of a GHG by its Global Warming Potential (GWP) (UNFCC, 2011) according to the following equation:

$$GHG = \sum GHG_g \times GWP_g \qquad \text{Eq. 19}$$

where:
GHG = total GHG emissions [t]
GHG_g = emissions of greenhouse gas *g* [t]
GWP_g = global warming potential of greenhouse gas *g* for 100-year time horizon, corresponding to CO_2: 1, CH_4: 21 and N_20: 310 [-]

Emissions of CO_2 usually dominate the local GHG inventory. CH_4 is of significance for landfills and waste water treatment plants, and other gases are of significance for industry.

4.3 Step II – Identify the local actors

'A problem being a social construction, it cannot be defined without due consideration for the persons who will be affected or who will somehow be brought to participate in the various phases of its definition or solution' (Banville *et al.,* 1998).

Actors are those that may affect or are affected by governance issues. This includes not only those that have a stake or interest, and those that play a role, but also those that are concerned or affected by a situation (Guimarães Pereira *et al.,* 2005). A participatory decision-making process has the potential to be more transparent, improve the legitimacy of the energy action plan and reduce conflict situations, given that the actors' views are considered during the process.

Local actors play an essential role in the energy planning process. In particular, their participation is of utmost importance at the following stages: identification of strategic objectives (section 4.4); generation of alternatives to be analysed under a multi-criteria evaluation framework (section 4.6); and building of a value model that reflects the views and preferences of the local actors in respect to the objectives (section 4.8).

In this step, the identification of the local actors to be involved in the process of energy planning takes place. Banville *et al.* (1998) identifies several methods and strategies for identifying, classifying and managing actors. Nevertheless, this source points out that those methods or strategies are simple heuristics that can help the selection.

A typology of local actors is identified in Table 16. This list, aimed at be as comprehensive as possible, outlines potential actors grouped into Standard Stakeholders – 'those that are both affected and affecting the problem, and are, at the same time, participating in the process of formulating and solving it' (Banville *et al.,* 1998, p.18) and into Interest Groups. For each context, it becomes important to identify the relevant actors, by knowing how each actor affects, is affected or is interested by the problem (Banville *et al.,* 1998). The selection of the local actors needs to ensure that all important points of view are represented, while keeping the participation process manageable.

Table 16 – Identification of local actors in local sustainable energy planning (based in Lahdelma, Salminem & Hokkanen, 2000; Coelho, Antunes & Martins, 2009; EU, 2010).

Standard stakeholders	**Interest groups**
Decision-makers (e.g. the Mayor)	Social and Environmental non-governmental organisations
Technicians/experts from the local energy agency/Department of Environment or Energy	Local technicians (installers and maintenance)
Planners from the Department of Planning	Building constructors
Analysts responsible for the process	Transportation companies
	Energy utilities
	Energy Service Companies (ESCOs)
	Residents
	Universities

4.4 Step III – Identify and structure the objectives

4.4.1 Guidelines on identifying and structuring objectives

'The achievement of objectives is the sole reason for being interested in any decision. And yet, unfortunately, objectives are not adequately articulated for many important decisions' (Keeney, 1992, p. 55). In order to avoid the situation previously mentioned, this section provides guidelines on how to promote a structured approach and deep thinking about the objectives regarding the decision situation of local sustainable energy planning. 'If you really care about a decision, objectives are worth deep and serious thoughts' (Keeney, 1992, p. 55).

In this step, the involvement of the local actors is of particular importance. Therefore, the realisation of interviews with the local actors in order to identify objectives should be carried out. The interviews should be conducted individually in order to promote thinking from every individual. In group meetings, it might happen that members anchor on the ideas presented by the first speakers (Keeney, 1992).

The interview should begin by first giving an explanation about the purpose of the work and the importance of the interviewee's participation. Then, the interviewee is asked to express objectives for local sustainable energy planning without performing any ranking or priorities. The cognitive mapping technique (Eden, 2004) is here used to map the interviewee's thinking about the problem of local sustainable energy planning. The cognitive map is drawn in the form of a means-ends graph trying to identify fundamental objectives at the top of the hierarchy. The procedure for separating the fundamental objectives from the means objectives is described by Keeney (1992). It consists of an iterative process by asking for each objective 'Why is it important?' If the response to the question identifies that the objective is important because of its implications for some other objective, this is a means objective. If the response is that the objective is one of the essential reasons for interest in the situation, this is a candidate for a fundamental objective.

After each interview, the cognitive map should be revised in order to clarify meanings, and eliminate redundancies, and returned to the interviewee for comments.

The next step consists in merging the individual cognitive maps into a joint causal map in order to identify the fundamental objectives. The merging of individual cognitive maps is made through merging similar concepts (objectives) and linking related concepts.

Afterwards, a means-ends objectives network is built. The primary aim is to clearly distinguish between means and ends (or fundamental) objectives and the linkages among them. This network will provide understanding of the fundamental objectives and assist the development of the fundamental objectives hierarchy. Keeney (1992) points out nine important properties of the set of fundamental objectives: essential, controllable, complete, measurable, operational, decomposable, non-redundant, concise, and understandable. One of the benefits of the means-objectives network is to avoid duplication in the fundamental objectives hierarchy caused by the inclusion of means objectives. ‘Fundamental objectives should be as useful as possible for creating and evaluating alternatives, identifying decision opportunities, and guiding the entire decision-making process’ (Keeney, 1992, p. 82).

The group causal map together with the means-ends objectives network and the fundamental objectives hierarchy is sent to the interviewees for validation.

Note that it is possible to use only a causal map or a means-ends objective network to structure the objectives with the interviewees. However, in situations where is not possible to gather them to discuss, in group, the issues of the problem at hands it is believed that by presenting them with these two graphs enables more deep thinking and thus a better validation of the fundamental issues to be taken into account.

4.4.2 Literature review and involvement of local actors for the identification and structuring of objectives

In order to include objectives of local sustainable energy planning in the proposed methodology it was conducted an extensive research involving literature review and interviews. The research aimed at ensuring a broad coverage of the objectives so that many local authorities would be able to use the framework of objectives herein proposed (see section 4.4.3). However, it is possible that local authorities can perceive other objectives as relevant attending to their local circumstances. In this case, local authorities should follow the guidelines presented in section 4.4.1 in order to identify and structure the objectives for their specific contexts.

4.4.2.1 Literature review

A literature review of a sample of energy and climate action plans was carried out. The objectives contained in these plans were collected and maps were constructed from the written text by adopting a causal mapping technique (see appendix II). This technique made possible to articulate the objectives and their interconnections. The reviewed action plans were: in Europe: Barcelona; Copenhagen; Dublin; Delft; Falkenberg; Gotland; Hilleroed; London; Malmö; Stavanger; Suupohja; Swansea; Trysil; and Venice; and in the US: Berkeley; Los Angeles; Pleasanton; and Seattle. The review also encompassed three energy planning guidebooks: Covenant of Mayors (EU, 2010), enova (2008), and MODEL (EnEffect, 2004). Figure 22 illustrates the causal map drawn from the information contained in Gotland energy plan (Municipality of Gotland, 2006).

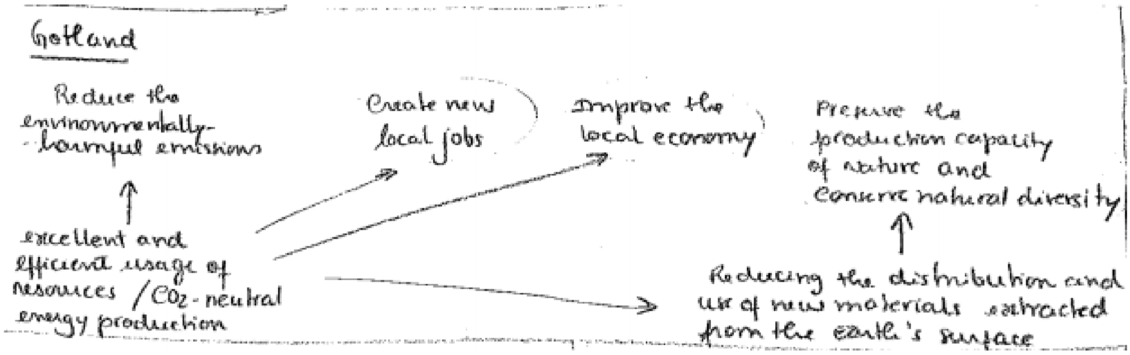


Figure 22 – Causal map of the objectives stated in Gotland energy plan (Municipality of Gotland, 2006).

The identification and structuring of the objectives stated in the action plans was based on the author’s perception of the problem from the written text of the action plans and no interviews were performed. The individual casual maps were thus merged into a joint causal map in order to identify the fundamental objectives. The joint causal map illustrated in Figure 23 represents a network of objectives linked by arrows. The direction of arrows is such that an option always leads to a desired outcome, with the most important outcome hierarchically superior to others (Eden & Ackermann, 2001). For instance, ‘improve the comfort of homes and offices’ leads to ‘improve citizens’ wellbeing’.

The literature review has shown that the objective of reducing the GHG emissions is common to most of the action plans. From the analysis of the written text it was possible to identify a set of means objectives to reach the reduction of GHG emissions. For the merging of these objectives it was adopted the concept of ‘trias energetica’ adopted by Delft climate plan (Municipality of Delft, 2003). Most of the means objectives presented in the energy and climate action plans analysed fall under the umbrella of the ‘trias energetica’ which is decomposed into: reduce demand by energy savings among end-users, applying sustainable and renewable energy sources and optimising in the application of fossil fuel sources regarding its energy efficiency and reliability. However, it is notable that it is possible to find objectives that attend more to the particularities of each municipality. For instance, there are municipalities expressing their concerns related to discontinue fossil fuels/electricity for heating and hot water purposes (Stavanger and Falkenberg) while others aim to promote bioenergy resources (Trysil), focus on land use patterns to reduce automobile dependence (Los Angeles) or develop a city so that it is ready for weather patterns expected from climate change (Copenhagen).

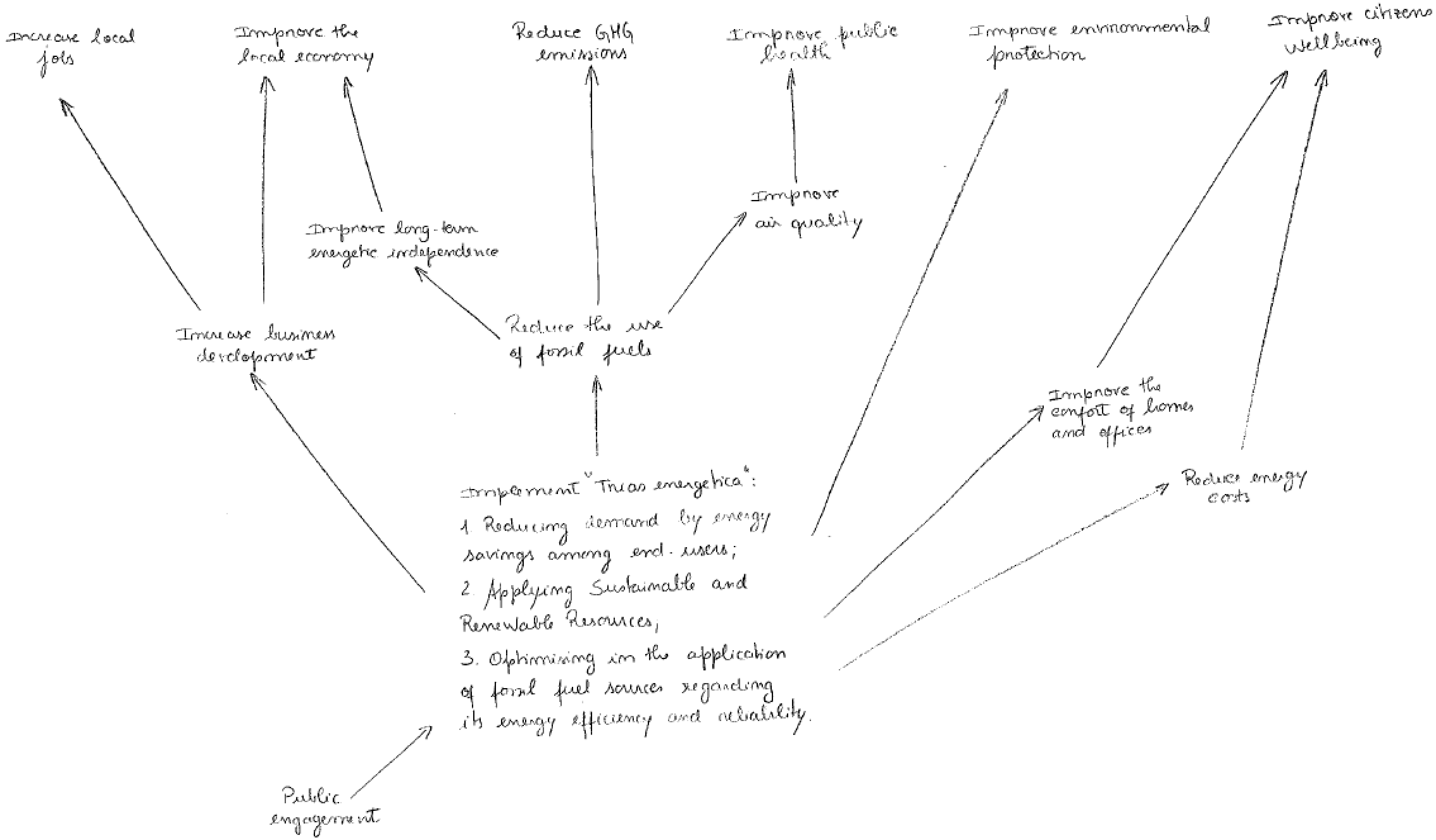


Figure 23 – Aggregated map of the objectives stated in the local energy and climate action plans reviewed.

4.4.2.2 Involvement of local actors

The literature review of local energy and climate action plans has led to the identification of objectives of local sustainable energy planning common to several municipalities. However, this work was performed through the analysis of the written text of the plans and this lacks the engagement of the local actors which is crucial for the identification of their points of view and to explore the implications of the model. Working from written text despoils the meaning that derives from intonation, body movement, and from interaction (Rosenhead & Mingers, 2001). Thus, as performed next, it is of particular importance that the objectives are identified together with the local actors.

The local actors involved in the identification and structuring of objectives were representatives of Portuguese local/regional energy agencies and local authorities which correspond to the group of standard stakeholders identified in Table 16. There was a need to balance the outcomes resulting from the involvement of an extensive variety of stakeholders with time and cost constraints, as well as physical proximity. It was decided not to rely exclusively upon the actors from the case study (Chapter 5), so that the objectives would not be highly dependent on the context. Nevertheless, it was later observed a general agreement by the interviewees representing different geographic and demographic contexts on the objectives. This was the main reason why interviewing five actors was considered sufficient, as a data saturation point was reached – when new information is not obtained or new information is negligible (Kunmar, 1999).

The choice of energy agencies was due to their important role in promoting sustainable energy communities as well as by the provision of technical expertise. According to the Matrix Insight and Ecologic Institute (2010), the added value from energy agencies to the local communities consists in the provision of information and advice to local energy users; provision of technical assistance and advice on EU energy policy and legislation to public authorities; implementation and monitoring of policies and defining rules and standards; and in market facilitation by providing a platform for exchanging experiences, disseminating innovative ideas and new technology.

The actors interviewed as well as their respective function and municipality are presented in Table 17. The interviews were conducted individually and lasted between one and two hours.

Table 17 – The local actors interviewed.

Name	Position	Institution	Type	Municipality	Population (INE, 2011)	Interview date (2011)
Eduardo de Oliveira Fernandes	President	AdEPorto	Local Energy Agency	Porto	237,584	31 Jan.
Philippe Bollinger	Director	AMESeixal	Local Energy Agency	Seixal	158,269	25 Jan.
Cristina Garrett	Technical officer at Municipal Development Office	Oeiras City Council	City Council	Oeiras	172,120	18 Jan.
Susana Camacho	Director	S.Energia	Regional Energy agency	Alcochete, Barreiro, Moita, Montijo	213,584	14 Jan.
Nuno Banza	City Councilman for the Environment	Barreiro City Council	City Council	Barreiro	78,767	14 Jan.

The process of identifying and structuring the objectives together with the local actors adopted the guidelines proposed in section 4.4.1.: from each interview resulted a cognitive map (see appendix III); the five cognitive maps were subsequently merged into a group causal map (Figure 24); the group causal map was transformed in the means-ends objectives network (Figure 25); the fundamental objectives hierarchy was developed (Figure 26); and finally all the information was sent to the interviewees for validation. The interviewees agreed in general with the objectives. One of the interviewees made one suggestion of modification that was taken into account when reviewing the fundamental objectives hierarchy.

The group causal map was transformed into a means-ends objectives network (Figure 25). The relationship between the levels of objectives in the network is causal. The lower-level objective is a means to the higher-level objective. Means objectives contribute to achieve ends or fundamental objectives. For example, 'reduce the consumption of fossil energy' is a means to 'reduce GHG emissions', but also to other objectives such as 'improve long-term energy independence'. Indeed, each means objective can contribute to multiple fundamental objectives and multiple means objectives can contribute to one fundamental objective (Keeney, 1992).

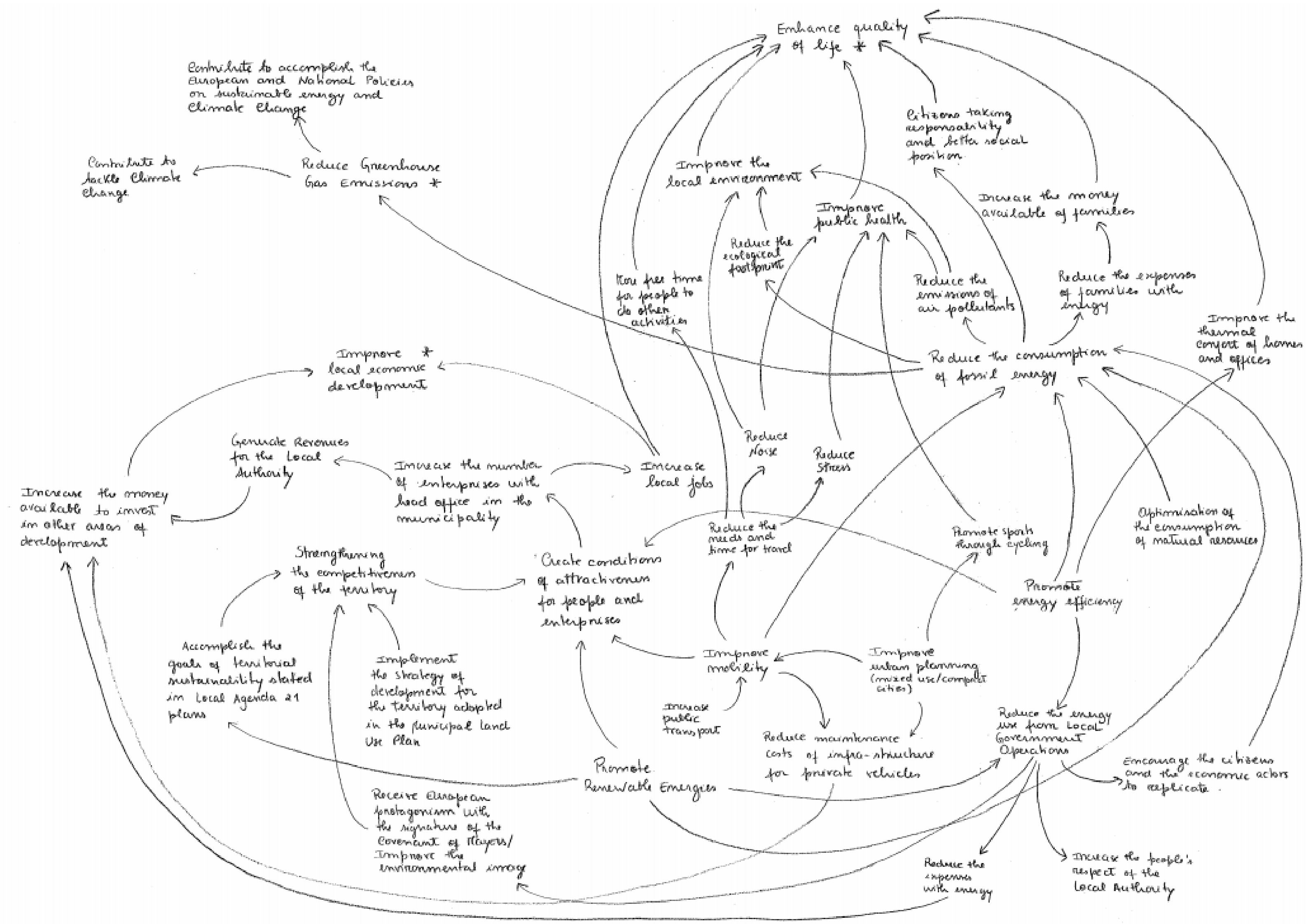


Figure 24 – Group causal map resulting from the aggregation of the individual cognitive maps.

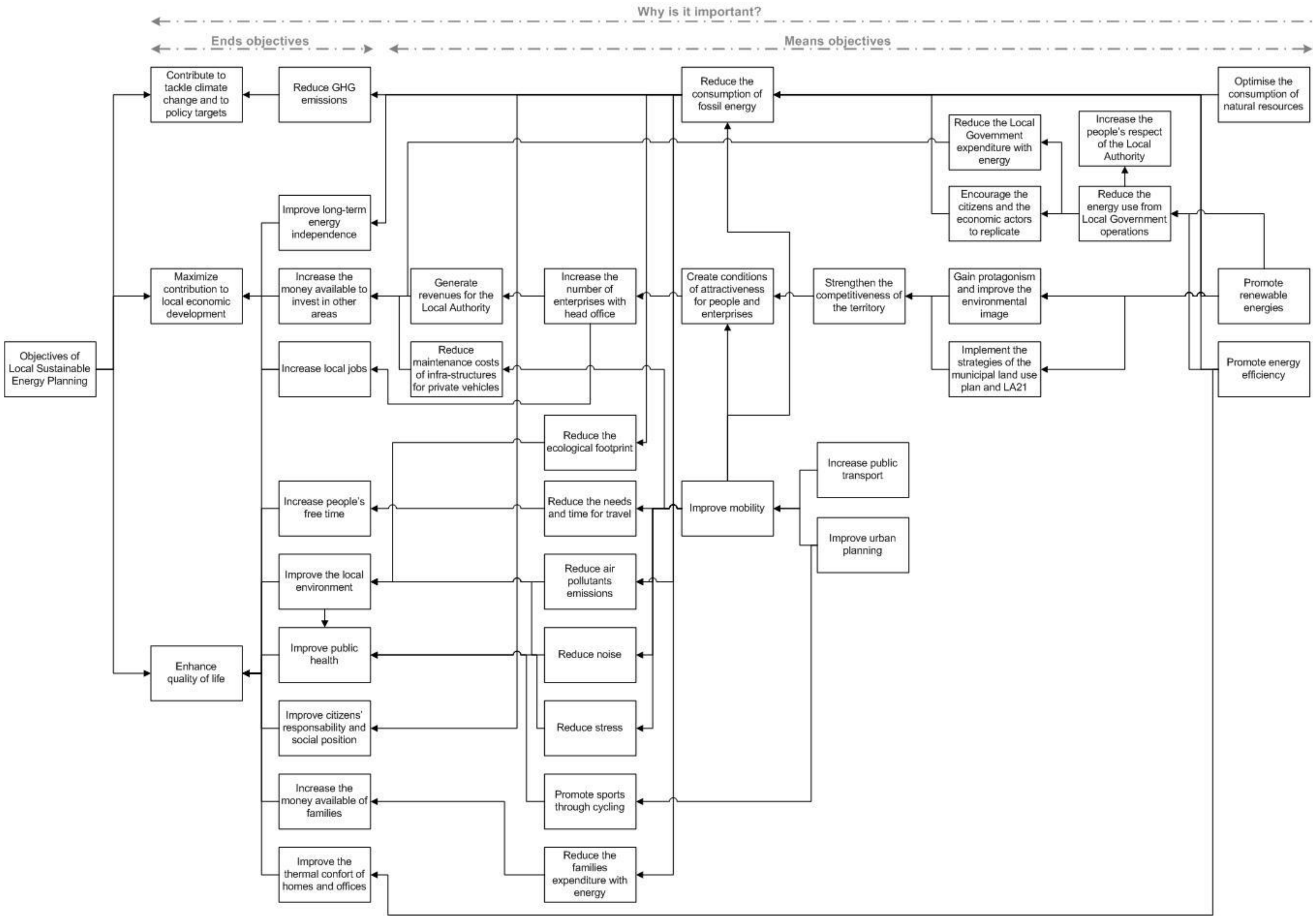


Figure 25 – Means-ends objectives network.

4.4.3 Proposal of fundamental objectives

The previous section provided an extensive research on identification and structuring of local sustainable energy planning objectives. The literature review of local energy and climate action plans (section 4.4.2.1) and the means-ends objectives network resulting from the interviews with local actors (section 4.4.2.2) were the basis for the development of the fundamental objectives hierarchy (Figure 26). The fundamental objectives identified from literature review were fine-tuned with the inputs from the local actors' approach.

For the development of the fundamental objectives hierarchy for local sustainable energy planning, it was considered useful to distinguish the three dimensions of sustainability: environment, economic development and social (quality of life). For each of these categories, more specific fundamental objectives specifying their meaning were identified.

Note that the relationships between the levels of the fundamental objectives hierarchy are not causal as in the means-ends objectives network. The links relate to what is meant by the objective.

The fundamental objectives hierarchy presented in Figure 26 identifies the levels of objectives that will be used to evaluate alternatives within the multi-criteria evaluation framework. The grey boxes indicate the objectives over which attributes will be defined (see section 4.5.3).

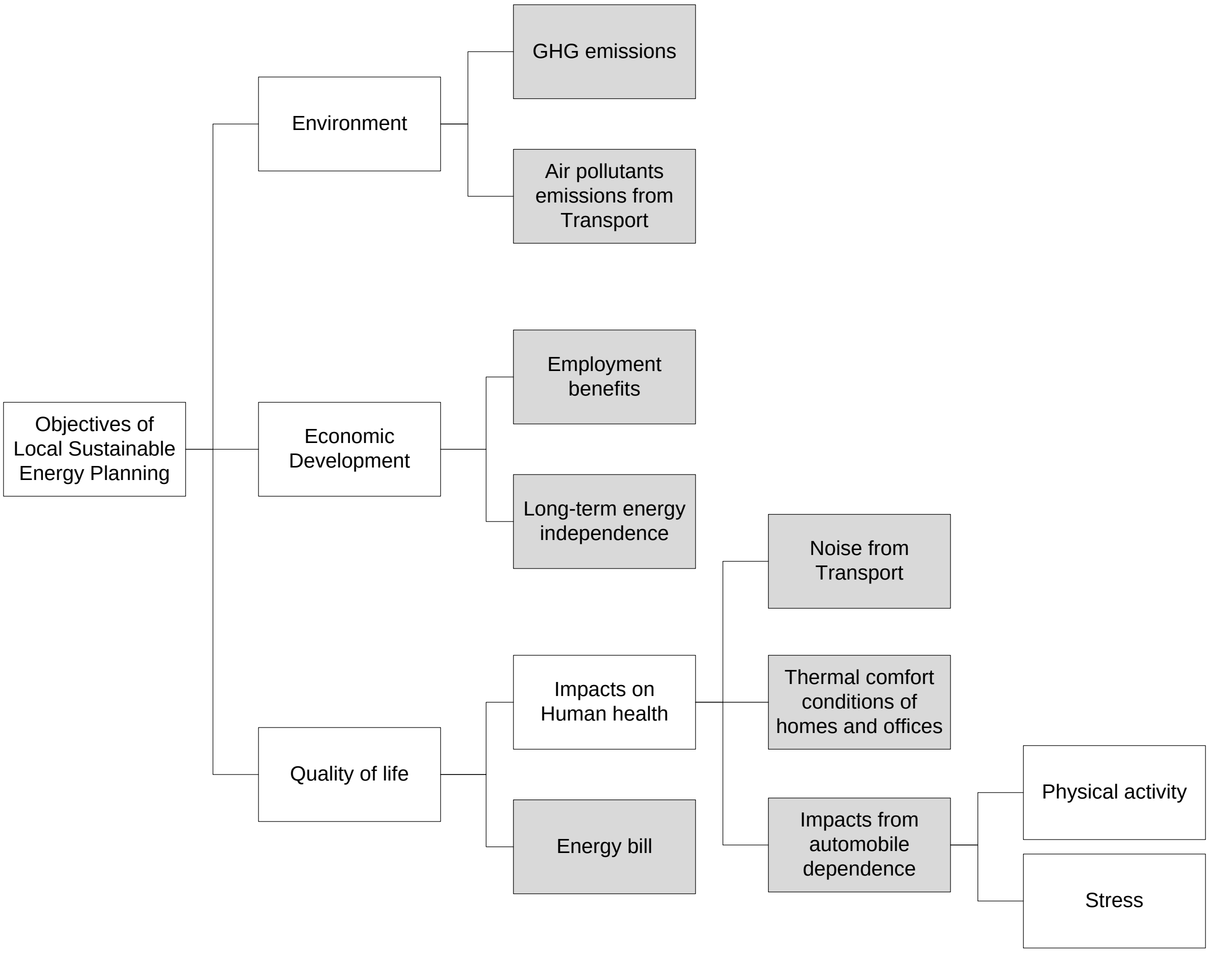


Figure 26 – Fundamental objectives hierarchy.

* The grey boxes indicate the set of objectives over which attributes are defined.

Each fundamental objective was clearly written to avoid ambiguous interpretations of its meaning in Table 18. The methodology herein proposed adopts the objectives listed and develops the following sections under this set of objectives.

Table 18 – Local sustainable energy planning objectives.

	Local Sustainable Energy Planning Objectives
O1	Reduce GHG emissions
O2	Reduce air pollution from road transport
O3	Maximise employment benefits
O4	Improve long-term energy independence
O5	Minimise the negative impacts on human health caused by noise from transport
O6	Minimise the negative impacts on human health by improving thermal comfort conditions of homes and offices
O7	Minimise the negative impacts on human health caused by automobile dependence
O8	Reduce energy bill

It is common to find in other energy planning-related works (see for instance Keeney, Renn & von Winterfeldt (1987); Neves (2004); Coelho, Antunes & Martins (2009); Souza (2011)) the identification of 'minimise costs' as a fundamental objective. Nevertheless, being this work oriented to strategic objectives of sustainable energy planning, the minimisation of cost was not identified as a fundamental objective. It is envisaged that the scope of the methodology is to provide decision-makers with an understanding of the benefits of alternatives upon strategic objectives without limiting the analysis of an alternative *a priori* because of its possible high investment needs. On the other hand, the issue of cost is addressed in the proposed methodology at a later stage allowing the decision-maker to compare the overall benefit of each alternative with its investment needs (see section 4.10). The fact that the decision-makers often experience difficulties in making judgments about the trade-off between costs and benefits when cost is treated as an attribute (Goodwin & Wright, 2004) also supported this decision.

4.5 Step IV – Select the attributes

4.5.1 Guidelines on choosing attributes

An attribute measures the degree to which an objective is achieved (Keeney, 2007). Since the identification of appropriate attributes for the objectives typically needs to take into account technical knowledge, this task should be done with the aid of experts and not come directly from the involvement of the local actors (MCDA-RES, 2003).

Keeney & Gregory (2005) specify five desirable properties of good attributes:

- **Unambiguous** – a clear relationship exists between consequences and descriptions of consequences using the attribute;
- **Comprehensive** – the attribute levels cover the range of possible consequences for the corresponding objective, and value judgements implicit in the attribute are reasonable;
- **Direct** – the attribute levels directly describe the consequences of interest;
- **Operational** – the information necessary to describe consequences can be obtained and value tradeoffs can reasonably be made;
- **Understandable** – consequences and value trade-offs made using the attribute can readily be understood and clearly communicated.

In order to meet all the desired characteristics, it is common that the definition of some attributes need to be reconsidered as well as the introduction of new ones or aggregation of some of them, for instance. The choice of a set of attributes can interact with the construction of each of them (Bouyssou, 1990).

According to Keeney (1992), there are three types of attributes: natural attributes, constructed attributes, and proxy attributes. Natural attributes are those that have a common interpretation to everyone. For example, if the objective is to 'minimise cost', the attribute 'cost measured in euros' is a natural attribute. Basically, most natural attributes can be counted or physically measured. The natural attributes directly measure the degree to which an objective is met. If a natural attribute cannot be found there are two possibilities: to construct an attribute to measure the associated objective directly or to measure the achievement of the objective indirectly using a proxy attribute (Keeney, 1992).

Constructed attributes are developed specifically for a given decision context, unlike natural attributes which are relevant in numerous decision contexts. Constructed attributes involve the description of several distinct levels of impact that directly indicate the degree to which the associated objective is achieved. The descriptions of those impact levels should be unambiguous to all individuals involved in a given decision situation (Keeney, 1992).

Proxy attributes do not directly measure the fundamental objective. As an example, for the fundamental objective 'to minimise the damage to stone statues and historic buildings caused by the acid rain formed by water and sulphur dioxide', one proxy attribute is 'the sulphur dioxide concentration measured by parts per million in the vicinity of those statues and buildings'. This indirectly indicates the impacts on statue and building disfiguration. It also directly measures the achievement of a means objective: 'minimise sulphur dioxide concentrations'. This objective is a means to building disfiguration as well as to health effects and environmental impacts. A proxy (indirect) attribute for a fundamental objective may also be a natural (direct) attribute for a means objective (Keeney, 1992).

The attributes are important to describe how well each of the alternatives under consideration satisfies the objectives of concern and to make reasoned value tradeoffs between those objectives (Keeney & Gregory, 2005).

4.5.2 Literature review on attributes

Using attributes to select actions to be included in energy action plans is not yet a common practice. The use of attributes for the choice of actions was investigated in 30 local energy and climate action plans as well as in seven guidance reports for local energy action plans (ASPIRE (2007), Covenant of Mayors (EU, 2010), ICLEI's CAPPA

(ICLEI-USA, 2010), PEPESEC (Norling, 2010), MUSEC (2009), enova (2008) and MODEL (EnEffect, 2004)). Only in seven action plans and four guides it was found out a reference or recommendation to the use of some kind of criteria to help in the choice of actions to be included in the action plan. Table 19 lists the items found which could directly or indirectly be identified with attributes.

Table 19 – Items found from the review of energy and climate action plans and guides that can be potentially identified with attributes.

	Attributes	[1]	[2]	[3]*	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Cost	Cost-effectiveness of GHG reduction	✓	✓	-	✓	✓	✓	✓	-	-	-	✓
	Investment cost	-	-	-	-	-	-	-	-	✓	✓	-
	Operation and maintenance costs	-	-	-	-	-	-	-	-	-	✓	-
	Financial return on investment	-	-	-	-	-	-	-	-	-	✓	-
Environ.	GHG reduction potential	✓	-	✓	-	-	✓	✓	✓	-	-	✓
	Energy saving	-	-	-	-	-	✓	✓	✓	✓	-	-
	Improved air quality	-	-	-	-	-	-	-	-	✓	-	-
Social	Job creation	✓	-	-	-	-	-	-	-	✓	-	-
	Commitment of local actors	-	✓	-	-	✓	-	✓	✓	-	-	-
	Political and social acceptability	-	-	-	-	-	-	-	-	✓	-	-
Others	Feasibility/existence of proven technologies	✓	✓	-	-	✓	-	✓	✓	-	-	✓
	Implementation timeframe/rapid deployment	✓	-	-	-	-	-	-	-	-	✓	-
	Consistency and complementarities with ongoing local local programmes	-	-	-	-	✓	✓	✓	✓	-	-	-
	Level of effort required by Local Government staff	-	-	-	-	-	-	-	-	-	✓	-
	Regional impact: level of opportunity for the region/country	✓	-	-	-	-	-	-	-	-	-	-
	Relevance to the overall objectives of the local authority	-	-	-	-	-	-	-	-	✓	-	-
	Control of the Local Authority over the measures	✓	-	-	-	-	-	-	-	-	✓	-
	Contribution to boosting the economy	-	-	✓	-	-	-	-	-	-	-	-

* Attributes are defined for allocation of funding and not for the choice of the measures of the action plan.
Plans: [1] Chicago; [2] Delft; [3] Hamburg; [4] Stockholm; [6] Roznovsko; [7] Scalve; [8] Suupohja
Guides: [5] ASPIRE; [9] Covenant of Mayors; [10] ICLEI CAPPA; [11] PEPESEC

From the analysis of Table 19, it is possible to conclude that the attributes stated in the energy and climate action plans and local energy planning guides, are not appropriate to assess all the fundamental objectives identified. It is expected that the attributes are able to evaluate the extent to which the alternatives satisfy strategic objectives of local sustainable energy planning (i.e. objectives that should be stable over years). For instance, the attribute related to the costs of the measure, the feasibility, the rapid deployment and commitment cannot be used to measure the performance of alternatives on strategic objectives. However, attributes such as GHG emissions reduction potential or job creation are considered to be suitable to evaluate strategic objectives of a municipality.

On a complementary exercise, Table 20 intends to explore the appropriateness of the indicators developed in chapter 2 in evaluating the objectives of local sustainable energy planning identified in Table 18 (section 4.4.3). Crossing the indicators with those objectives, it is possible to verify that some indicators can be considered as appropriate to be used as attributes to measure the performance of the alternatives upon the fundamental objectives. Indicators such as the energy intensities by sector revealed to be too specific to be used for assessing the impact of alternatives upon more strategic objectives like the fundamental objectives.

Table 20 – Analysis of the indicators developed in chapter 2 in relation to the fundamental objectives.

		O1	O2	O3	O4	O5, O6, O7	O8
S1	GHG emissions from energy use, per capita and per unit of GDP, and by sector	✓	-	-	-	-	-
S2	Primary energy use per capita	-	-	-	✓	-	-
S3	Final energy use per sector	-	-	-	-	-	-
S4	Ratio of local renewables production to local consumption of energy and electricity	-	-	-	✓	-	-
S5	Industrial energy intensity	-	-	-	-	-	-
S6	Agricultural energy intensity	-	-	-	-	-	-
S7	Service/commercial energy intensity	-	-	-	-	-	-
S8	Household energy intensity	-	-	-	-	-	-
S9	Transport energy intensity	-	-	-	-	✓	-
S10	Public transit ridership	-	-	-	-	✓	-
S11	Emissions of air pollutants from road transport activities	-	✓	-	-	✓	-
S12	Renewable energy share in energy and electricity	-	-	-	✓	-	-
S13	Share of household income spent on fuel and electricity	-	-	-	-	-	✓
S14	Ratio of green energy jobs to population	-	-	✓	-	-	-

O1: Reduce GHG emissions; O2: Reduce air pollution from road transport; O3: Maximise employment benefits; O4: Improve long-term energy independence; O5: Minimise the negative impacts on human health caused by noise from transport; O6: Minimise the negative impacts on human health by improving thermal comfort conditions of homes and offices; O7: Minimise the negative impacts on human health caused by automobile dependence; O8: Reduce energy bill.

4.5.3 Proposal of attributes

This section concludes the process of selecting attributes to measure the performance of alternatives on the fundamental objectives identified in section 4.4.3. The fundamental objectives shown in grey boxes in Figure 26 indicate the set of objectives over which attributes should be defined. The proposal of attributes results from an analysis of the literature review (section 4.5.2) and from the application of the guidelines outlined in section 4.5.1. If different fundamental objectives are identified for other contexts, the process of selection of the attributes should follow the guidelines provided in section 4.5.1.

Table 21 summarises the fundamental objectives and the respective attributes proposed.

Table 21 – Fundamental objectives and respective attributes.

	Fundamental Objectives	Attributes
O1	Reduce GHG emissions	Tonnes of CO_2 equivalent emissions reduced
O2	Reduce air pollution from road transport	Tonnes of NO_x emissions reduced
O3	Maximise employment benefits	Number of net jobs gained
O4	Improve long-term energy independence	Tonnes of oil equivalent (primary energy) of imported fossil fuels reduced
O5	Minimise the negative impacts on human health caused by noise from transport	Number of people who benefit from noise levels reduction to below 55 dB
O6	Minimise the negative impacts on human health by improving thermal comfort conditions of homes and offices	Tonnes of oil equivalent (final energy) reduced for space heating and cooling of homes and offices
O7	Minimise the negative impacts on human health caused by automobile dependence	Number of passenger-km shifting from passenger cars to public transit, walking and cycling
O8	Reduce energy bill	Euros saved per household per year

The explanations regarding each attribute are presented in sequence below.

Tonnes of CO_2 equivalent emissions reduced

Purpose: Measures the achievement of objective O1 – i.e. the extent to which each alternative contributes to reduce GHG emissions, and consequently contribute to the improvement of the global environment.

Rationale: The reduction of GHG emissions is measured in tonnes of CO_2 equivalent emissions. Anthropogenic GHG emissions are associated to the energy consumption of the different sectors of economy.

Tonnes of NO_x emissions reduced

Purpose: Measures the achievement of objective O2 – i.e. the extent to which each alternative contributes to the reduction of air pollution from transport, and consequently to improve the quality of the local environment.

Rationale: The emission of air pollutants is caused by energy-related activities, such as power generation and transport, as well as by natural events such as forest fires and volcanic eruptions. Emissions from power generation plants located in the municipality, if existing, are not directly considered because they are influenced by national legislation and are usually out of the scope of control of the local authority. Emissions caused by natural events are also not assessed because the scope of the evaluation is to assess the impact of human energy-related activities on the environment. The choice of nitrogen oxides (NO_x) as a proxy attribute to represent the objective of reduction of air pollution is related to its serious damage in the environment. Ecosystems are damaged by the deposition of acidifying substances like NO_x which lead to loss of flora and fauna; excess nutrient nitrogen (eutrophication) in the form of NO_x can disrupt plant communities and lead to a loss of biodiversity; ground level ozone is formed through the reaction of volatile organic compounds (VOCs) and NO_x in the presence of sunlight, and results in physical damage and reduced growth of agricultural crops, forests and plants. In relation to public health, ozone and particulate matter are the pollutants of most concern. However, it is intended to assess the impact of air pollution in the environment and not strictly in a human well-being perspective.

Number of net jobs gained

Purpose: Measures the achievement of objective O3 – i.e. the extent to which each alternative contributes to the overall employment in the municipality from implementation of energy efficiency and renewable energy measures.

Rationale: Jobs created can be direct and indirect. Direct jobs are jobs created directly from the implementation of the measures, the so-called green energy jobs. Green energy jobs are defined as employment opportunities in energy efficiency and renewable energy that contribute to the improvement of environmental quality in what regards reducing the negative impacts from energy generation and use. Green energy jobs can be found in three main areas (UNEP, 2008):

- Renewable energy supply – installation, operation and maintenance of renewable energy systems technicians (from Small and Medium Enterprises (SMEs) and Energy Service Companies (ESCOs));
- Green buildings and retrofitting – green designers, architects, energy auditors, engineers, project managers and various jobs in construction;
- Energy efficiency of individual components of buildings (e.g. water heaters, cooking equipment, electrical appliances, heating, ventilation and air conditioning systems, lighting)– equipment and installation technicians, electricians and energy auditors;
- Transport – public transit operators.

Indirect jobs are created in other sectors of economy due to the impacts of the measures in terms of reduced energy bills paid by consumers and businesses which enable them to greater purchase of non-energy goods, equipment and services. According to Geller, DeCicco & Laitner (1992), 'less than 10% of the net jobs created are associated with direct investment in efficiency measures while more than 90% are associated with energy bill savings and respending of those savings'. Gold & Navel (2011) also estimate the jobs created due to energy efficiency in appliances and conclude that 'job creation is driven in large part, by the energy saved when less efficient appliances are replaced with more efficient appliances, proving energy and dollar savings for consumers. Consumers and businesses then have additional money to spend in more labor-intensive but equally productive sectors of the economy, creating a net increase in jobs and wages'.

Tonnes of oil equivalent (primary energy) of imported fossil fuels reduced

Purpose: Measures the achievement of objective O4 – i.e. the extent to which each alternative contributes to increase long-term energy independence, and consequently energy security.

Rationale: The dependence on imported fossil fuels from foreign countries makes municipalities (particularly in the EU) more economically vulnerable as it increases in cost. Thus, the importance of energy security is vital for economic and social sustainability. The municipalities should be able to adapt to change, namely to energy supply disruptions. This can be achieved through policies to diversify energy sources, use endogenous energy resources and enhance energy efficiency. Since most EU municipalities are dependent on imports of fossil fuels, the primary energy consumption of imported fossil fuels reduced was the attribute chosen. This attribute is applicable for municipalities located in countries which rely greatly on imports of fossil fuels.

Number of people who benefit from noise levels reduction to below 55 dB

Purpose: Measures the achievement of objective O5 – i.e. the extent to which each alternative contributes to reduce noise impacts, and consequently reduce negative impacts on human health.

Rationale: Noise is an important environmental problem in urban areas and endangers health and the quality of life. The main source is road traffic, but there is also aircraft, neighbourhood, industry and rail noise. This evaluation work deals only with the road traffic, because it is an energy-related activity which can be managed by the local authority. Measures on land use planning, public transport, walking and cycling can be implemented by the local authority. Also, EEA (2010) shows that a large number of people are affected by noise from road traffic (Figure 27) many as 56 million people in the largest cities in the EU-27 are exposed to average road traffic noise levels above 55 dB L_{den} (day evening night level which is an indicator for annoyance), approximately 50% of the population living in agglomerations with a population of more than 250 000.

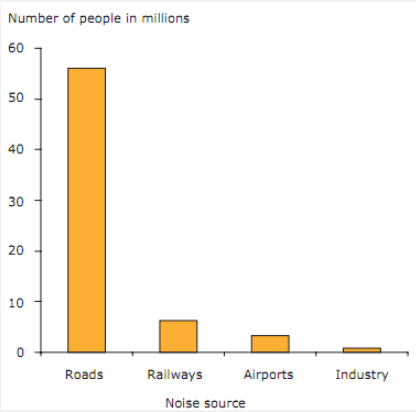


Figure 27 – Reported noise exposure of more than 55 dB L_{den} in European agglomerations with more than 250 000 inhabitants. Source: NOISE, 2010 *fide* EEA, 2010.

Tonnes of oil equivalent (final energy) reduced for space heating and cooling of homes and offices

Purpose: Measures the achievement of objective O6 – i.e. the extent to which each alternative contributes to positive impacts on human health resulting from improving the comfort conditions of residential and services buildings.

Rationale: Human thermal comfort is defined by ASHRAE (2004) as the state of mind that expresses satisfaction with the surrounding environment. According to Bluyssen, Aires & van Dommelen (2011) the indoor environment can be defined as healthy when the combination of its physical, chemical and biological properties are such that they do not cause illnesses in the building occupants and that they secure a high level of comfort to the building occupants in the performance of the designated activities for which the building has been intended and designed. Thermal comfort can be increased through the installation of insulation and energy efficient heating and cooling systems in buildings. The insulation of buildings (external walls, roofs and installation of double glazing) leads to a reduction of useful energy needs for heating and cooling and consequent reduction in final energy needs. The installation of energy efficient heating and cooling systems has impacts in the reduction of final energy for heating and cooling. When both measures are undertaken together in the same building, the overall benefit in terms of energy savings will be less than the sum of the benefits of the two measures together. For instance, Hong *et al.* (2009) studied the impact of insulation and central heating on mean indoor temperatures of a sample of dwellings in England. The combination of insulation and central heating resulted in an increase in the indoor temperature by 2.83 °C, while central heating alone resulted in an increase by 1.89 °C and insulation alone by 1.19 °C. The selection of a proxy attribute as final energy reduced in space heating and cooling indirectly measures the increase in thermal comfort conditions.

Number of passenger-km shifting from passenger cars to public transit, walking and cycling

Purpose: Measures the achievement of objective O7 – i.e. the extent to which each alternative contributes to reduce the negative impacts on human health from stress and lack of transport-related physical activity caused by automobile dependence.

Rationale: A proxy attribute to indirectly measure the impact on human health is the number of passenger-km shifting from passenger cars to other means of transport like public transit, walking or cycling. In order to combat growing traffic congestion (the principal cause of stress in urban areas), passengers can shift from passenger cars to public transit. Public transit provided should be sufficiently available and not affected by traffic congestion. Transport-related physical activity can be encouraged by promoting walking and cycling to work or to school. This requires improving the quality of walking and cycling infrastructure in the municipality. In the EU, half of all car trips are for less than 6 km, for which cycling is considered often faster than driving (in urban areas); 10 % are for less than 1 km, an ideal walking distance (European Commission, 2001 *fide* EEA, 2002).

Euros saved per household per year

Purpose: Measures the achievement of objective O8 – i.e. the contribution of each alternative to lower households' energy bills and make energy services in households more affordable to families.

Rationale: Households financial savings with energy can be achieved through improved energy conservation and energy efficiency. The expenditure on energy can be obtained by the energy consumed for the energy services multiplied by the corresponding unit price.

4.6 Step V – Generate alternatives

4.6.1 Definition of Alternatives

Alternatives represent means of achieving (or trying to achieve) the stated objectives and pre-specified targets. To be allowed not to choose (i.e. do nothing) is also considered an alternative (Zeleny, 1982). In the case of local energy planning, alternatives are a combination of individual actions that together achieve a pre-specified target. The target is herein defined as achieving a minimum level of GHG emissions reduction by a time horizon in relation to a base year, in accordance with EU energy and climate policies (Commission of the European Communities, 2008; Torres & Doubrava, 2010). Each alternative is basically considered as an energy action plan that the local authority, after the evaluation process, may choose to implement. The following section identifies a catalogue of local energy management actions, which are the ground upon which the alternatives will be generated.

4.6.2 Proposal of a catalogue of actions

The process of identification of a catalogue of actions was divided into two stages. First, it was performed a literature review of journal articles, and afterwards it was investigated to what point the actions identified from the literature review of journal articles are actually being addressed in local energy and climate action plans (appendix IV).

A literature review was performed in order to ensure the coverage of a broad range of actions to be implemented at the local level. In the review of journal articles (Gaglia *et al*., 2007; Iqbal & Al-Houmound 2009; Wong *et al.*, 2003; Dascalaki & Santamouris, 2002; Papadoulos *et al.,* 2002; Doukas *et al.* 2009; Balaras, 2007; Balaras *et al.,* 1999; Akbari et al., 1997; Verbeeck & Hens, 2005; Dorer & Weber, 2009; Stanley *et al.,* 2009; McCollum & Yang, 2009; Hankey & Marshall, 2009; Michaelis & Davidson, 1996; Kenworthy & Laube, 1996) three criteria were applied in order to identify a first list of actions:

1) **Technical actions** – The aim of this work is to provide decision support in the choice of technical actions. The issue of finding appropriate policy actions/promotion mechanisms to implement each of the technical actions, e.g. financial incentives, regulations, awareness/education, is a subsequent phase of the planning process but is not within the scope of this work;

2) **Local authority's control actions** – This work addresses actions that are directly or indirectly (through local policies) within the influence of the local authority. These actions focus mostly on the demand side. Typically, the supply side is dealt at regional and national levels. The areas where the local authority usually has no control of intervention were excluded of consideration, namely industry and large-scale renewable energy supply.
3) **Community-scale actions** – The focus of this work is community-wide and not only Government operations actions. It is understandable that local authorities should lead by example and implement actions on their municipal buildings, facilities and vehicle fleet, but the scope of energy planning should be the whole community (subjected to criterion 2). Therefore, the scope of actions considered is not limited to the infrastructure owned by the local authorities but includes also that owned by individuals and private companies.

Afterwards, it was investigated to what point the actions identified from the literature review of journal articles were being addressed in the local energy and climate action plans (appendix IV). For this, 18 action plans in the EU (Almada; Barcelona; Camborn, Pool and Redruth; Copenhagen; Dublin; Gotland; London; Milan; Stockholm; Swansea; Terrasa; and Venice) and in the US (Cambridge; Berkeley; Chicago; Los Angeles; San Francisco; and Seattle) were analysed. From this analysis, it was observed a great diversity of actions among the plans, as well as a mix of technical actions and policy actions. There were also found other technical actions that had not been identified from the literature review of journal articles. These were mainly related to sectors such as street lighting, land use and green areas, waste, water, industry and large-scale renewable plants. It is possible to note that in some cases, the actions stated in the plans are very dependent on the context. For instance, renewables power plants are not common to be within the scope of control of the local authority, but they are stated as actions in the plans of Gotland and Swansea. The thermal valorisation of waste for district heating could only be a possible action in municipalities with waste treatment infrastructure in their territory.

The next step consisted in merging the information on actions collected from both sources – the journal articles and the local energy and climate action plans. There was also the need to perform a critical analysis in order to identify if the list of actions was sufficiently comprehensive of the whole space of decision options. Actions covering the industrial sector are not addressed in this work. One reason for this is the fact that the local authority itself usually lacks the power to impose improvement actions to the private industrial sector. Another reason is that industry is usually subjected to specific regulations, such as the European CO2 Emission Trading Scheme (ETS). This is in line with the Covenant of Mayors (EU, 2010), where the industrial sector is not a key target of the initiative due to the reasons mentioned above.

The process of literature review of journal articles, local energy and climate action plans and critical analysis of the actions identified, resulted in the identification of 47 actions in the sectors of households, services and transport, which are presented in Table 22. Nevertheless, this set of technical actions can never be considered closed and should be open to revision at any time, in order to adapt to technology changes along time.

Table 22 – Catalogue of technical actions.

	HOUSEHOLDS
	Thermal insulation
1	Decrease building's heating needs
2	Decrease building's cooling needs
	Water heating fuel shift
3	Switch electric conventional storage water heaters to natural gas water heaters
4	Switch other fossil fuel water heaters to natural gas water heaters
5	Switch fossil fuel water heaters to solar water heater
6	Switch fossil fuel water heaters to renewable heat water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
	Space heating equipment fuel shift and efficiency shift
7	Switch fossil fuel boilers to natural gas central boilers
8	Switch electric heaters to natural gas central boilers
9	Switch electric heaters to heat pumps
10	Switch fossil fuel central boilers to hot water or steam radiators (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
11	Switch fossil fuel central boilers to solar radiant heating
12	Switch fireplaces to pellet stoves
	Space cooling equipment fuel shift
13	Switch electric heat pumps to chilled water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
	Electrical appliances' efficiency
14	Replace refrigerators and freezers with A+ and A++ refrigerators
15	Replace washing machines with A+ washing machines
16	Replace driers with A driers
17	Replace dishwashers with A dishwashers
	Lighting efficiency
18	Replace incandescent lamps by more efficient lamps
	Cooking fuel shift
19	Switch other fossil fuels stoves to natural gas stoves
	Renewable electricity generation
20	Use of small-scale renewable electricity
	SERVICES
	Thermal insulation
21	Decrease building's heating needs
22	Decrease building's cooling needs
	Water heating fuel shift
23	Switch conventional electric water heaters to natural gas water heaters
24	Switch fossil fuel water heaters to natural gas water heaters
25	Switch fossil fuel water heaters to solar water heaters
26	Switch fossil fuel water heaters to renewable heat water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
	Space heating equipment fuel shift and efficiency shift
27	Switch fossil fuel central boilers to natural gas central boilers
28	Switch electric heaters to natural gas central boilers
29	Switch electric heaters to heat pumps

30	Switch fossil fuel central boilers to hot water or steam radiators (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
31	Switch fossil fuel central boilers to solar radiant heating
32	Switch fireplaces to pellet stoves
	Space cooling equipment fuel shift
33	Switch electric heat pumps to chilled water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)
	Electrical appliances' efficiency
34	Replace refrigerators and freezers with A+ and A++ refrigerators
35	Replace dishwashers with A dishwashers
	Lighting efficiency
36	Replace incandescent lamps by more efficient lamps
	Cooking fuel shift
37	Switch other fossil fuels stoves to natural gas stoves
	Renewable electricity generation
38	Use of small-scale renewable electricity
	TRANSPORT
	Modal shift
39	Modal shift from individual passenger cars to collective transport buses
40	Modal shift from individual passenger cars to collective transport metro
41	Modal shift from individual passenger cars to walking and cycling for short distances
	Fuel shift
42	Switch passenger-km travelling in petroleum fuels passenger cars to electric passenger cars
43	Switch passenger-km transported in diesel collective transport buses to electric buses
44	Switch passenger-km transported in diesel collective transport buses to CNG buses
45	Switch passenger-km transported in diesel collective transport buses to biodiesel buses
46	Switch passenger-km transported in diesel collective transport buses to hydrogen buses
47	Switch passenger-km transported in diesel collective transport trains to electric trains

4.6.3 Guidelines on generating alternatives

It is important to have a good set of alternatives to analyse. This means to have 'a reasonable number of sufficiently different alternatives providing the best possible information about attainable limits of all relevant dimensions, criteria, or objectives' (Zeleny, 1982).

Having already a catalogue of individual actions (Table 22) it now becomes necessary to develop a rationale and a procedure on how these actions can be combined with the ultimate goal of generating alternatives.

The rationale adopted is based on a tailor-made approach. This means that the actions included in the process of generating alternatives should be tailored to the local circumstances. While in some local contexts a specific action can have a strong impact, in other context the effect of the same action can be minimal or even null. The methodology proposes to first perform an individual analysis of actions in order to identify the actions that deal with significant energy consumption end-uses and consequently may contribute considerably to the pre-specified GHG emissions reduction target that each alternative must fulfil. This aims to avoid increasing the complexity of the model by integrating actions that will not produce important effects. Indeed, 'the main challenge in constructing models is precisely to identify which effects are important enough that they have to be kept, and which are not' (Wolfram, 2002, p. 366).

Each action presented in Table 22 can be implemented in several degrees of implementation. In this methodology, five degrees of implementation were proposed for each action plus the possibility of not implementing each of them. Considering all the possible combinations between the 47 actions and the possible degrees of implementation would result in a very large number of alternatives (precisely, 6^{47}). Although this would be possible to generate with the help of a computer-based decision support system, it was considered to be impractical due to the combined effects of actions that need to be considered. When multiple actions are applied in one particular end-use, the reduction in energy use does not always correspond to the sum of the impact of individual actions. For instance, for space heating in buildings it is possible to introduce more energy efficient equipment and improve thermal insulation of buildings. When these two measures are implemented together in the same building, their effectiveness does not correspond to the sum of their individual impacts, it is actually less. Chidiac *et al.* (2011) studied the effectiveness of individual and multiple energy retrofitting measures (ERM) and concluded that 'comparing the linear addition of multiple ERMs with simulated combination results, the trend found was that the majority of results were less than the sum of single ERM modelling'. The end-use energy model developed in this work accommodates the generation of alternatives in such a way that considers the combined effects in energy savings and GHG emissions reduction of implementing joint actions. However, to consider all the combinations of actions would require a specific accounting of each combination and not simply combining the results of each action taken individually.

In view of the limitations exposed in the previous paragraph, the process of generating alternatives implemented in this work is based upon the so-called 'strategy generation table' procedure (Howard, 1988; Kirkwood, 1997; Matheson & Matheson, 1998). The adoption of the strategy generation table (hereafter called alternative generation table) approach is able to provide a structured and visual procedure to the user in sorting out its desired alternatives to evaluate. Figure 28 shows a screenshot of the alternative generation table used in the application of the methodology to the case study (see chapter 5).

Figure 28 – Screenshot of the alternative generation table.

CUSTOMIZE MEASURES FOR BUILDING ALTERNATIVE 1

	Households									
Name Alternative 1	Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Diversified policies	Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain
	Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	**Shift 10%**	Shift 10% to A+ and A++	**Increase 10%**
	Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	**Shift 20%**	Shift 20%	Shift 20%	**Shift 20% to A+ and A++**	Increase 20%
	Decrease 30%	**Shift 45%**	Shift 30%	Shift 30%	**Shift 30%**	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
	Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%
Limit of application	50%	79%		38%		39%		10%	59%	50%

Services								
Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	**Shift 20%**	**Shift 20%**	**Shift 20%**	**Shift 20% to A+ and A++**	Increase 20%
Decrease 30%	**Decrease 30%**	**Shift 45%**	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%
50%	50%	84%		47%		50%	59%	50%

Transport							Target
Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	**GHG emissions reduction**
Maintain	**Maintain**	Maintain	**Maintain**	Maintain	Maintain	**Maintain**	**-20%**
Shift 10%	Shift 10%	**Shift 10%**	Shift 20%	Shift 20%	Shift 20%	Shift 20%	
Shift 20%	Shift 20%	Shift 20%	Shift 40%	**Shift 40%**	Shift 40%	Shift 40%	
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	**Shift 60%**	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	Shift 80%	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	
78%		50%	100%				

The rows of the alternative generation table represent the possible degrees of implementation for the different actions that are presented in the columns (Figure 28). The only exception is the first row (named 'Maintain') that means 'no implementation of the action'. The user builds an alternative by selecting one cell from each of the columns. At the end, the user can visualise if the selected combination of actions/degrees of implementation respects the constraint of GHG emissions reduction. If not, the user should redefine the selection of actions/degrees of implementation in order to accomplish the target reductions in GHG emissions. The recommended number of alternatives is five and they should be reasonably different among them.

Once a degree of implementation is selected for each action, this change is computed in the end-use energy model in the respective end-use and conversion technology category. For instance, if a shift of 45% in the action 'water heating fossil fuel shift to solar' is chosen, this means that the share of hot water (end-use) supplied by solar water heater (conversion technology) increases by 45% and the share of hot water supplied by fossil fuel water heaters reduces by 45% in relation to the reference scenario constructed in the end-use energy model. To note that in this particular case, a change to solar technology needs to consider at the same time a transfer share for the backup systems running on electricity or natural gas to satisfy the useful energy needs for hot water.

The five different levels of implementation visible on the alternative generation table presented in Figure 28 vary according to each action. It was assumed that the maximum theoretical potential of each action (100%) was not realistic to be achieved in mid-term energy planning, with the exception for the actions on fuel shift in buses. However, this might change in the perspective of long-term planning, in which case a modification to the degrees of implementation integrated in the end-use energy model could be easily done. The degrees of implementation were thus limited by a maximum achievable potential. The assumed limit of application for each action is shown in the last row of the alternative generation table and it is determined based on the potential to change the reference scenario, namely the shift in conversion technologies.

4.6.4 GHG emissions condition

As mentioned in section 4.6.1 the alternatives (k) to be evaluated have to comply with a minimum requirement – a GHG emissions reduction target. In this way alternatives are only eligible if they fulfil the pre-specified target according to the following condition:

$$\left(1-\frac{GHG_{ky}}{GHG_b}\right)\times 100\% \ \geq T \qquad \text{Eq. 20}$$

where:
GHG_{ky} = amount of GHG emissions of alternative k in the time horizon y [t CO_2 eq.]
GHG_b = amount of GHG emissions in the base year b [t CO_2 eq.]
T = GHG emissions reduction target by time horizon y in relation to base year b [%]

The GHG emissions reduction target is set on the emissions of sectors where actions are planned. This means that emissions resulting from Industry and Agriculture &

Fisheries sectors, for which actions are not foreseen in this methodology (see section 4.6.2), are not taken into account for target setting.

4.7 Step VI – Assess the impacts of the alternatives on the attributes

The attributes identified in section 4.5 are here used to evaluate the accomplishment of objectives (section 4.4.3) by each alternative (section 4.6). Each attribute refers to the difference between the result of an alternative and the result of the reference scenario (section 4.2.3), both for the plan horizon year. Determining the impact of each alternative in comparison to the reference scenario allows evaluating the impact resulting from the implementation of different sets of actions against a future trend 'without plan'.

The calculation method for each attribute is presented below.

- **Tonnes of CO_2 equivalent emissions reduced**

The quantification of GHG emissions of each alternative is calculated as described in step I (see section 4.2.4) for the base year and reference scenario. The attribute is then simply calculated as the difference in GHG emissions between an alternative (*k*) and the reference scenario (*R*).

- **Tonnes of NO_x emissions reduced**

The estimation of NO_x emissions adopts the simplified method proposed by EEA (2007). The method is based on fuel consumption data, which then is multiplied by appropriate bulk emission factors. It is recommended to use the country-specific emission factors (EEA, 2007). NO_x emissions are estimated for the reference scenario and each alternative (*k*) using the equation:

$$E = \sum_j FE_j \times EF_j \qquad \text{Eq. 21}$$

where:

E = total emissions of NO_x [g NO_x]

F_j = final energy consumption of vehicle category j [kg fuel]

EF_j = final energy consumption specific emission factor of NO_x for vehicle category j [g NO_x/kg fuel]

Vehicle category j = Gasoline PC (passenger cars); Diesel PC; Power two-wheeles; Diesel buses; Diesel LDV; Diesel HDV; Biodiesel buses and PC; CNG buses; CNG PC.

The attribute for each alternative (k) is then the result of the difference in NO_x emissions from the alternative and the reference scenario.

- **Number of net jobs gained**

The estimation of the number of net jobs gained due to the implementation of energy efficiency and small-scale renewable energy actions is performed based on employment multipliers for energy efficiency (jobs-year/toe of final energy savings) and for renewable energy (job-years/toe of renewable energy generated). Therefore, the number of jobs is calculated by using the following equations:

$$J_{EE} = (FE_n - FE_R) \times M_{EE} \quad \text{Eq. 22}$$

where:
J_{EE} = number of jobs attributable to energy efficiency actions [-]
FE_n = Total final energy use in households, services and transport sectors in alternative k [toe]
FE_R = Total final energy in households, services and transport sectors in reference scenario R [toe]
M_{EE} = employment multiplier for energy efficiency [jobs/toe of final energy savings]

$$J_{RE} = (RE_n - RE_R) \times M_{RE} \quad \text{Eq. 23}$$

where:
J_{RE} = number of jobs attributable to small-scale renewable energy actions [-]
RE_n = final energy converted from small-scale renewable energy sources in alternative k [toe]
RE_R = final energy converted from small-scale renewable energy sources in reference scenario R [toe]
M_{RE} = employment multiplier for renewable energy [jobs/toe of renewable energy generated]

The total number of jobs gained due to energy efficiency and renewable energy actions is calculated for each alternative (k) as follows:

$$J_k = J_{EE} + J_{RE} - JL_s \quad \text{Eq. 24}$$

where:
J_k = number of net jobs gained in alternative k [-]
J_{EE} = number of jobs attributable to energy efficiency actions [-]
J_{RE} = number of jobs attributable to small-scale renewable energy actions [-]
JL_s = job losses in conventional energy supply industry (assumed to be equal to zero once local actions are essentially at the demand side) [-]

Estimates of employment multipliers can be found in the study presented by Wei, Patadia & Kammen (2010), which reports an energy efficiency employment multiplier of 0.38 jobs-year/GWh of energy savings. The study assumes that the majority of jobs are induced jobs (90%) and only 10% are direct jobs associated with energy efficiency products or installation based on another study (Geller, 1992 *fide* Wei, Patadia & Kammen, 2010). Table 23 shows the estimated employment multipliers per unit of energy for different energy technologies. They should be replaced by more context-specific values if and when available.

Table 23 – Employment multipliers for different energy technologies.
Source: Wei, Patadia & Kammen, 2010.

Energy technology	Total jobs-year/GWh	Total jobs-year/toe
Solar Thermal	0.23	0.003
Solar PV	0.87	0.010
Biomass	0.21	0.002
Geothermal	0.25	0.003
Landfill Gas	0.72	0.008
Small Hydro	0.32	0.004
Wind	0.17	0.002

- **Tonnes of oil equivalent of imported fossil fuels reduced**

The determination of the amount of imported fossil fuels for the reference scenario and each alternative *(k)* is based on primary fossil energy consumption according to the following equation:

$$TPFE = [(FE_e - RE_e) \times FPF_e] + [FE_i \times FPF_I] \quad \text{Eq. 25}$$

where:
TPFE = Total primary fossil energy consumption [toe]
FE_e = Final energy consumption concerning electricity [toe]
RE_e = Renewable electricity consumption [toe]
FPF_e = Fossil primary energy conversion factor associated to centralised production of electricity [-]
FE_i = Final energy consumption of fossil fuels *i* [toe]
FPF_i = Fossil primary energy conversion factor associated to fossil fuels *i* (approximately 1) [toe]

The primary energy conversion factor for centralised production of electricity is calculated as follows:

$$PEF = \frac{\sum PER_{Electricity\ Plants} + \sum\left(PER_{CHP\ plants} \times \frac{E_{CHP\ plants}}{E_{CHP\ plants} + H_{CHP\ plants}}\right) + I}{TE - L + I} \quad \text{Eq. 26}$$

where:
PEF = Primary energy conversion factor [-]
$PER_{Electricity\ plants}$ = Primary energy resources consumed by electricity plants [toe]
$PER_{CHP\ plants}$ = Primary energy resources consumed by CHP plants [toe]
$E_{CHP\ plants}$ = Electricity produced by CHP plants [toe]
$H_{CHP\ plants}$ = Heat produced by CHP plants [toe]
I = Electricity imported [toe]
TE = Total electricity produced [toe]
L = Electricity consumed by the energy industry for own use and electricity losses [toe]

In the case of fossil primary energy conversion factor it is only considered the electricity produced through the combustion of fossil fuels. It accounts how much primary fossil fuel resources are used for each unit of electricity (final energy).

The attribute refers to the difference in primary fossil energy consumption between each alternative (k) and the reference scenario.

- **Number of people who benefit from noise levels reduction to below 55 dB**

The quantification of this attribute requires *in situ* noise measurements in order to develop road traffic noise maps. The number of people affected by noise can be calculated by measuring the noise level at the most exposed façade of a building (4 m above the ground) and then assign a level to each dwelling of the building (Arana *et al.,* 2008). The determination of the expected reduction in noise levels and the number of people who benefits from noise levels reduction is associated to the expected reduction of road traffic that will derive from each alternative in relation to the reference scenario. As this attribute requires inputs from another scientific field – Acoustics – and this is out of the scope of the current research work, it was decided to remove this attribute from the methodology proposed herein. However, this does not mean that the objective of integrating it at some point in local energy planning processes should be dropped. On the other hand, it is recognised that the issue of noise is reasonably addressed at the urban planning level via EU directives, so the risk of it being actually ignored in local management is typically small.

- **Tonnes of oil equivalent reduced for space heating and cooling of homes and offices**

The amount of final energy consumed for space heating and cooling end-uses (j) in the households and services sector in the reference scenario and in each alternative (k) is determined as follows:

$$TFE = \sum FE_{i,j} \quad \text{Eq. 27}$$

where:
TFE = total final energy consumption for space heating and cooling end-uses [toe]
$FE_{i,j}$ = amount of final energy of energy carrier i for end-use j [toe]

The attribute is then calculated via the difference in final energy consumption between each alternative (*k*) and the reference scenario.

- **Number of passenger-km shifting from passenger cars to public transit, walking and cycling**

The shift of passenger-km from passenger cars to public transit, walking and cycling in each alternative (*k*) is determined via the difference in the number of passenger-km in passenger cars in the reference scenario and the number in each alternative.

- **Euros saved per household per year**

The annual energy cost per household in the reference scenario and in each alternative (*k*) is accounted as follows:

$$S = \frac{\sum_i (FE_i \times C_i) + \sum_j (PKM_j \times C_j)}{\left(\frac{P}{N}\right)} \qquad \text{Eq. 28}$$

where:
S = euros saved per household per year [€]
FE_i = amount of final energy of energy carrier *i* [toe]
C_i = end-use cost of energy carrier *i* [€/toe]
PKM_j = number of passenger-km by mode of transport *j [pkm]*
C_j = cost per passenger-km of mode of transport *j* [€/pkm]
P = number of inhabitants [-]
N = average number of persons per household [-]

Reference values for the transport costs, in €/pkm, can be found in the study of Fiorello *et al.* (2009), if context-specific values are not available.

The annual energy cost savings per household is given by the difference between the annual energy cost in the reference scenario and the annual energy cost in each alternative (*k*).

At this point, it has already been selected an attribute for each objective, as intended. It has been also decided to drop the noise reduction objective from the model due to the reasons explained above. However, an attribute only defines a preferential ordinal scale (Stevens, 1946) with respect to its associated objective. In order to choose the best alternative among several alternatives taking into account multiple objectives, it becomes necessary to integrate more preferential information. It is thus needed to build a measurable value function (Dyer & Sarin, 1979; Belton, 1999) for each objective and to weight the objectives to assess the overall value scores of the alternatives (see section 4.8). The preferred alternative is then selected based on the highest overall value score.

4.8 Step VII – Determine overall benefit value score

4.8.1 Build a value function for each objective

In this step, the value functions describing the local actors' preferences in respect to each objective are constructed during a decision conferencing process. The MACBETH approach and software is used to support this task. Value functions define an interval scale of measurement (Stevens, 1946), that is, a scale that focuses on the difference of value between performance levels (Belton, 1999).

The local actors are first invited to define the two reference levels on the attribute scale: 'neutral' – a performance that is neither positive nor negative – and 'good' – a performance that is considerably attractive. The visualisation of the outcomes of step VI – the assessment of the impacts of each alternative under consideration (section 4.7) – may help to define the reference levels, though not strictly required by the method. Other performance levels, if possible, should also be defined in the attribute scale. In case of cardinal attribute scales, equally spaced performances levels should be used. The 'neutral' and 'good' reference levels must have assigned (anchor) scores, being the highest score assigned to the 'good' level; for example, 0 and 100 value units, respectively, may be used. The value scores for the other performance levels need also to be assessed, for which the MACBETH method is a good fit.

The MACBETH procedure consists in asking the group of local actors to judge the differences in attractiveness between each two levels of performance, choosing one (or more) of the MACBETH semantic categories: *very weak, weak, moderate, strong,* or *extreme.* MACBETH only requires qualitative judgements to the local actors to generate value scales. The process can start by asking the difference of attractiveness between the 'neutral' and the 'good' reference levels, and is followed by asking the difference between each two of the other performance levels, though not all combinations are required (Bana e Costa *et al*., 2008).

The qualitative judgements expressed by the group are inserted into the M-MACBETH decision support system (Bana e Costa, De Corte & Vansnick, 2005a), which subsequently proposes a numerical value scale by solving a linear programming problem that reconciles those judgements (Bana e Costa, De Corte & Vansnick, 2005b). The proposed MACBETH scale should then be subjected to group analysis and discussion in terms of proportions of the resulting scale intervals. If the group wishes to make adjustments to the proposed scale, M-MACBETH can apply them if the proposed changes stay within the limits defined by the relationships among the qualitative judgements given.

4.8.2 Weight the objectives

This step consists in weighting the objectives in order to allow the calculation of an overall value score for each alternative by applying the additive model (see section 4.8.3). It is important to note that weights do not indicate the importance of the objectives, despite that is the 'most common critical mistake' made when prioritising objectives (Keeney, 1992, p. 147). In fact, the weights are scaling factors that define acceptable trade-offs between objectives (Belton, 1999).

The weighting procedure is initiated by inviting the group of local actors during the decision conference to first rank the 'neutral-good' swings by their overall attractiveness. The facilitator asks the following to the group: '*If you could choose only one objective to change from 'neutral' to 'good' which one would you choose?*' The answer to this question identifies the most preferred 'neutral-to-good' swing. The questioning procedure continues in the same way until the final ranking of swings is achieved.

Afterwards, the facilitator asks the group to qualitatively judge the overall attractiveness of each 'neutral-good' swing using the MACBETH semantic categories (last column in MACBETH weighting matrix – see Figure 66 in chapter 5). The next step is to elicit qualitative judgements regarding the difference of attractiveness between swings. It begins by asking the group '*What is the difference in attractiveness between the most attractive neutral-to-good swing and the second most attractive neutral-to-good swing?*' The pairwise comparison continues between the most attractive swing and each of the other remaining swings until the first row (see Figure 66 in chapter 5) of the MACBETH weighting matrix is complete. Then the difference of attractiveness between each two consecutive neutral-to-good swings is asked (starting by comparing the second-most and the third-most attractive swings). If wanted, the process can stop without completing the MACBETH weighting matrix of judgements, since MACBETH is able to create the weighting scale with the information already present in the matrix of judgements

Note that the questions posed to the group focus on the importance or attractiveness of the improvements from neutral to good on the objectives, and not simply in terms of importance of the objectives (Bana e Costa, De Corte & Vansnick, 2012).

Based on the weighting qualitative judgements expressed, M-MACBETH proposes a weighting scale by solving the linear programming problem (Bana e Costa, De Corte & Vansnick, 2005b). The local actors are then invited to analyse the proposed scale to validate the weights.

4.8.3 Aggregate partial value functions

The overall score *V* of an alternative *k* with a performance profile $(X_1, \ldots, X_n)$ in the *n* objectives is given by an additive value function model of the form:

$$V(X_1, \ldots, X_n) = \sum_{i=1}^{n} w_i \, v_i \, (X_i) \qquad \text{Eq. 29}$$

With $\sum_{i=1}^{n} w_i = 1, w_i > 0$ and $\begin{cases} v_i(good) = 100 \\ v_i\,(neutral) = 0 \end{cases}, i = 1, \ldots, n$

Where $v_i\,,\ i = 1, \ldots, n$ are single-attribute value functions

$w_i\,, i = 1, \ldots, n$ are the weights of the objectives

This form of value function can only be applied if and only if the local actors' preferences satisfy the mutual preferential independence condition among objectives.

4.9 Step VIII – Perform a robustness analysis

This step aims at exploring the robustness of the results obtained. Robustness analysis in multi-criteria evaluation is recommended due to possible difficulties that may be experienced by the actors when eliciting preferences. In order to validate the model in the face of uncertainty, it is necessary to know if the stability of the outputs of the additive value model is ensured. In particular, robustness analysis allows verifying if the preferred alternative would change when there are small variations in the weight of a given objective (Bana e Costa, De Corte & Vansnick, 2012).

The robustness analysis of the model outputs can be made with M-MACBETH. The software considers variations on the weights of all objectives and on the value scores of the alternatives in order to verify if the ranking of the alternatives is stable.

4.10 Step IX – Analyse benefits vs. investment

This final step intends to analyse the relation between the benefits of each alternative and the overall investment required. The generation of a benefit-investment graph allows plotting each alternative's overall benefit value score determined in section 4.8 with its investment needs.

The M-MACBETH decision support system allows including a cost to each alternative, without entering a cost node into the value tree, and in this way making possible a separate analysis of the benefits versus investment. As discussed in section 4.4.3, the methodology proposed in this thesis opts to include the investment in the analysis *a posteriori.* Thus, the intention of this step is to allow decision-makers to have a better understanding of the balance between benefits and expected investment for the alternatives, without limiting the analysis of an alternative *a priori* because of high investment needs. The alternatives are first evaluated based on the strategic objectives of local sustainable energy planning.

Using the benefit-investment graph generated by M-MACBETH it is possible to identify the efficient alternatives, i.e. when there is no other alternative that provides more benefit than it without costing more, or that costs less than it without having less benefit. Afterwards, the procedure suggested by Edwards and Newman (1986 *fide* Goodwin & Wright, 2004) for choosing one alternative from the efficient frontier could be adopted (as exemplified in section 5.12).

4.11 Summary

This chapter has detailed the decision support methodology for local sustainable energy planning step by step. The methodology patches together several methods and theories – energy modelling, cognitive and causal mapping, value-focused thinking, strategy generation table, decision conferencing, multi-attribute value theory and MACBETH – resulting in a new socio-technical approach to energy planning which allows the generation and evaluation of several alternative paths in terms of strategic objectives of local sustainable energy planning. To be eligible for the decision process each alternative has to comply with a GHG emissions reduction target, making in this way the process of energy planning in line with international policies on energy sustainability and climate change. The next chapter demonstrates the application of the proposed methodology to a concrete example.

5. Application of the methodology to the municipality of Barreiro

5.1 Introduction

This chapter provides an example of application of the proposed decision support methodology for local sustainable energy planning (chapter 4). The design of the methodology and the application to a real case were made alongside in order to incorporate adjustments deriving from insights coming from the ground. The purpose of applying the methodology to a concrete example is threefold:

- to demonstrate how the steps of the methodology can be applied to a practical case;
- to identify bottlenecks and make adjustments to the methodology, if necessary;
- to explore the outcomes.

The municipality chosen for applying the methodology was Barreiro in Portugal. When this work started, Barreiro was initiating its energy planning process. At the time, the local energy agency (S.Energia) had elaborated the diagnosis of the current situation in terms of energy use and GHG emissions which was considered useful for the data collection phase of this work. The availability of technical staff to participate in regular meetings and in the multi-criteria evaluation process itself was a major requisite for selecting the participating municipality. The main reason was the fact that the methodology relies on the principle of involving the local actors in the energy planning process and it was necessary to explore if the method was indeed fit when involving them.

Section 5.3 addresses the first step of the methodology – Modelling Barreiro's energy system. Issues on data collection are discussed and the modelling results deriving from the application of the local energy planning assistant tool are presented. This tool was constructed for the operationalization of the methodological steps related to the modelling of the energy system (steps I, V and VI in chapter 4). Section 5.4 describes the process of involving the local actors. The following section (5.5) presents the objectives and attributes identified during the design of the methodology (see sections 4.4 and 4.5) that were applied to the municipality of Barreiro. The process of generating alternatives was implemented using the local energy planning assistant tool and is described in section 5.6. The outputs generated by the tool, namely the quantitative impacts of the alternatives on the attributes presented in section 5.7, are inputs for the next methodological steps concerning the building of the multi-criteria evaluation model described in sections 5.8, 5.9 and 5.10. Section 5.11 presents the results of the robustness analysis, which is followed in section 5.12 by the results of a benefit-investment analysis. Finally, in section 5.13, the conclusions that can be drawn from the application of the methodology to the case of Barreiro are presented.

5.2 Description of Barreiro

The municipality of Barreiro is located in Portugal, in the Setúbal Peninsula, facing North the Tagus river and the city of Lisbon (Figure 29). Barreiro belongs to the Metropolitan Area of Lisbon. Its privileged location near the capital and the river and the installation of the railway in the XIX century, contributed to the creation of large industrial complexes, such as the *Companhia da União Fabril* (CUF) and many cork industries. The proliferation of industrial activity, responsible to attract many people from other parts of the country to live and work in the municipality of Barreiro, lasted until the 1980s, when most of the industries settled came to an end. The ending of industrial activity has lead to a shift to the tertiary sector, where most of the population of Barreiro works nowadays. The agriculture sector has a very low expression and is mainly for self-consumption (Moreira, 2007).

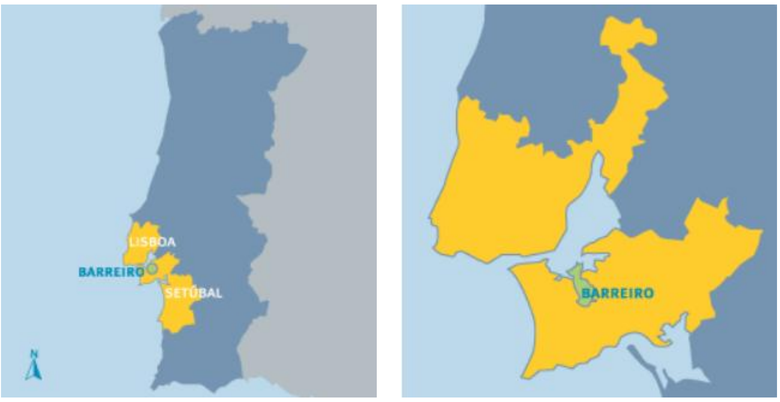


Figure 29 – The location of the municipality of Barreiro in Portugal and zoom into the Metropolitan Area of Lisbon. Source: Moreira (2007).

In what regards the population, the Census of 2011 revealed a number of 79,042 inhabitants. Contrarily to what happened between the Census of 1991 and 2001, when the population decreased from 87,006 to 78,995 inhabitants, the population is now considerably stable (INE, 2011). Since the 1980s that Barreiro had been experiencing a reduction of its population associated to the loss of many industries.

The municipality has an area of 33.80 km^2 and is divided in eight parishes: Alto do Seixalinho; Barreiro; Coina; Verderena; Lavradio; Palhais; Santo André and Santo António da Charneca.

5.3 Modelling Barreiro's energy system

5.3.1 Overview of the Local Energy Planning Assistant (LEPA) tool

The tool constructed is divided into two main parts: 1) the energy modelling of the base year and reference scenario and 2) the generation and assessment of alternative scenarios. The tool was developed for this example in particular, but it can be used for other municipalities as well.

The tool consists of an MS Excel spreadsheet including several sheets. The 'Start' sheet (screenshot in Figure 30) is used to specify the GHG emissions reduction target as well as the base year and the time horizon for which the target was set, and provides the links to all the other sheets.

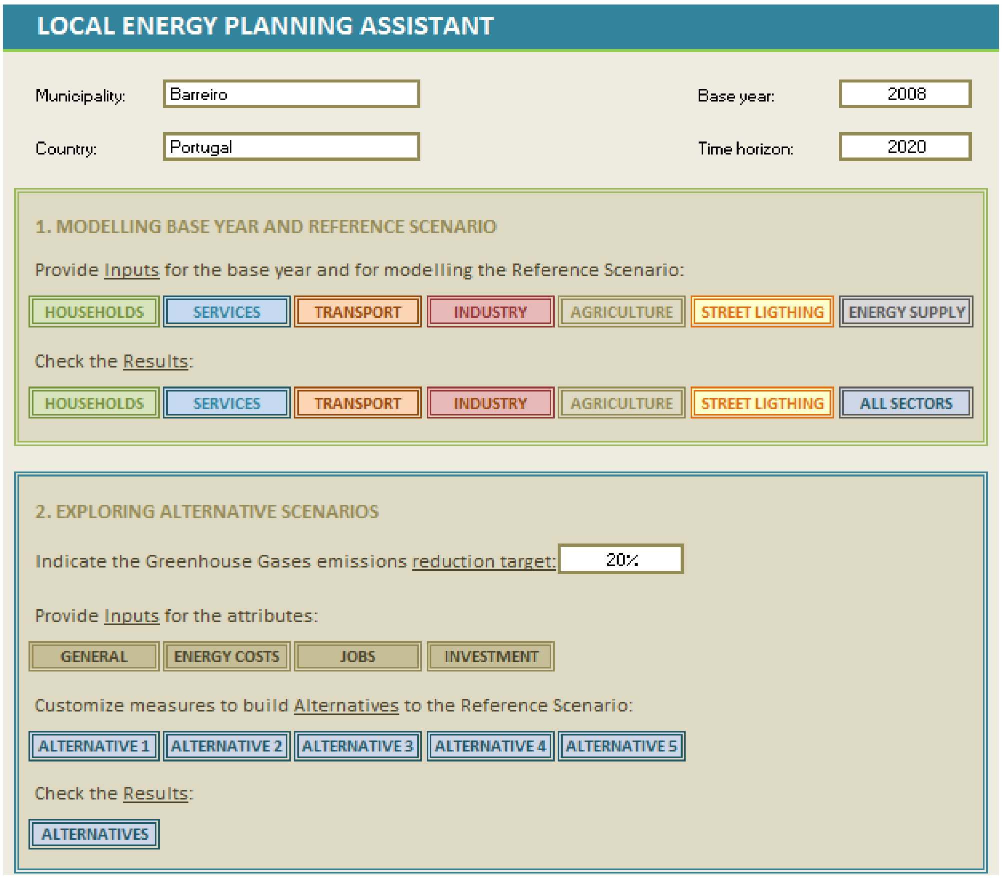


Figure 30 – Screenshot of the 'Start' sheet of the local energy planning assistant tool.

The first part of the tool is dedicated to modelling the base year and the reference scenario, and contains the following sheets:

1) Input sheets concerning the demand sectors (HH_input; SE_input; TR_input; IN_input; AG_input; SL_input). They are used to insert data on energy use and on the key socio-economic variables for each sector: households, services, transport, industry, agriculture & fisheries, street lighting;
2) Input sheet concerning the supply sector (SU_input), which is used to provide detailed characterisation in terms of use of primary energy resources and electricity and heat/cold production from the national electricity mix; local Combined Heat and Power (CHP) plants; small-scale local electricity production and green electricity purchases;
3) Input sheet used for the calculation of indicators per capita or per unit of GDP (Ge_Input);
4) Output sheets concerning the results of the modelling exercise, which is used to display results in the form of tables and graphs for each sector (HH_result; SE_result; TR_result; IN_result; AG_result; SL_result) as well as aggregated results (All_result) for the base year and reference scenario.

The second part of the tool is dedicated to explore alternatives to the reference scenario and includes the following sheets:

1) Input sheets related to the attributes (Ge_Input; Cost_input; Job_input; Invest_input) containing default values which can be modified when more accurate and context-specific data is available;
2) Dynamic sheets concerning the alternatives (Customise_A1; Customise_A2; Customise_A3; Customise_A4; Customise_A5), which are used for the generation of alternatives via the selection of individual actions;
3) Output sheets concerning the results of the alternatives, which display the results of each alternative (A_Result) and the performance of the alternatives on the attributes (Alternatives) that will further be used as inputs for multi-criteria evaluation.

5.3.2 GHG emissions reduction target

The GHG emissions reduction target adopted for Barreiro is to reduce by 2020 at least 20% below 2008 levels. The choice of this target was based on the interest shown by Barreiro in becoming a signatory of the Covenant of Mayors initiative at the time of this work. Covenant signatories commit to curb GHG emissions by at least 20% by 2020 through the implementation of a Sustainable Energy Action Plan. Barreiro has effectively joined the Covenant of Mayors on the 20th April 2011.

5.3.3 Overview of input data

The first step when applying the end-use energy model is to collect the input data. This is certainly one of the most demanding tasks in the application of the methodology for energy planning due to the fact that not all the required data is readily available at the municipal level. As a result of data availability limitations and lack of bottom-up municipal data, many assumptions and scaling-down from other administrative levels such as regional or national have been made for the case of Barreiro. The preference was always given to the closest level of administrative division for which data was available.

Table 24 lists the input data required for the base year and specifies the typical data sources in Portugal as well as estimation methods when local data is missing. The input data necessary to build the reference scenario for the time horizon year is listed in Table 25 as well as the typical data sources in Portugal and the projection method applied. All the input data used for Barreiro energy modelling can be found in Appendix V.

Table 24 – Input data for the base year and identification of potential sources, assumptions or estimates.

	Data	Municipal level data sources	Other sources and estimates in the absence of municipal data
Energy demand	**Final energy use by energy carrier**		
	Electricity	Directorate-General of Energy and Geology (DGEG, 2008a).	-
	Natural Gas	Natural gas provider (Setgás, S.A., 2008)	-
	Oil products	Directorate-General of Energy and Geology (DGEG, 2008b).	-
	Wood	n.a.	Estimates based on national wood consumption by sector (DGEG, 2008c), number of dwellings with fireplace for households (INE, 2002), number of enterprises for industry (INE, 2009), and use of a climatic correction factor.
	Solar radiation	n.a.	Estimates based on national solar thermal energy consumption by sector (DGEG, 2008c), number of dwellings (Households) (INE, 2010a) and number of enterprises (Services) (INE, 2009).
	Heat/cold	n.a.	Specification of Barreiro cogeneration plant was found in DGEG (2008c).
	Coal	n.a.	Estimates based on national coal consumption (DGEG, 2008c) and number of enterprises in industry (INE, 2009).
	Key socio-economic variables		
	Number of occupied dwellings	National Statistics Institute (INE, 2010a; INE, 2010b)	-
	Sectoral Gross Value Added (GVA)	n.a.	Estimates based on GVA for NUTSIII level (INE, 2010c) and number of employees (INE, 2009).
	Passenger transport activity	n.a. for passenger car and powered-two wheelers; for bus, rail and boat from collective transport companies' annual activity reports (TCB, 2011; Transtejo, 2010a; Transtejo,	Estimates based on national passenger transport intensity (E.Value Lda., 2006) and fuel sales (for diesel, gasoline, LPG) (DGEG, 2008b). Estimates for rail based on specific fuel consumption (E.Value Lda., 2006).

	Data	Municipal level data sources	Other sources and estimates in the absence of municipal data
		2010b)	
	Freight transport activity	n.a.	Estimates for road LDV and road HDV based on national passenger transport intensity (E.Value, Lda., 2006) and fuel sales (diesel) (DGEG, 2008b; DGEG, 2007). Estimates for train based on national freight transport intensity (CP, n.d.) and fuel sales (diesel and electricity) (DGEG, 2008b; DGEG, 2007).
	Breakout of each energy carrier by end-use	n.a.	Assumptions based on expert consultation and based on several national level statistics and studies: DPP (2009), Agência para a Energia *et al.* (2004), EDP Distribuição (2006), except for Industry which used an US source: DOE (2006).
	Share of conversion technology in each energy carrier and end-use	n.a.	Assumptions based on expert consultation and on Presidência do Conselho de Ministros (2008) for electrical appliances and lighting.
	Conversion technology efficiency	n.a.	Agência para a Energia (2009), MOPTC (2006), DPP (2009), Hinrichs (1996), Kobayashi *et al.* (2009), Almeida *et al.* (2003), CIBO (1997).
Energy supply	**National energy production mix**	-	Directorate-General of Energy and Geology (DGEG, 2008c).
	Small-scale local energy production	not applicable	-
	Green electricity purchases	not applicable	-

n.a. – not available

Table 25 – Input data for the time horizon and identification of potential sources and projection method.

	Data	Source	Projection method
Energy demand	**Key socio-economic variables**		
	Number of occupied dwellings	National Statistics Institute (INE, 2010b)	Historical past data trend.
	Sectoral Gross Value Added (GVA)	DPP (2008)	Application of national annual % change in sectoral GVA to the estimated GVA of Barreiro.
	Passenger transport activity	EC (2007)	Application of national annual % change in pkm to the pkm in Barreiro by mode of transport.
	Freight transport activity	EC (2007)	Application of national annual % change in tkm to the tkm in Barreiro by mode of transport.
	Breakout of each energy carrier by end-use	-	Assumptions based on expert consultation.
	Evolution factors of energy service needs	-	Assumptions based on expert consultation and on EC (2007) for transport.
	Share of conversion technology in each energy carrier and end-use	-	Assumptions based on expert consultation and on DPP (2009); Presidência do Conselho de Ministros (2008).
	Conversion technology efficiency	-	Assumptions based on DPP (2009).
Energy supply	**National energy production mix**	-	Use of constant factors, once it is not related to the local authority action.
	Small-scale local energy production	Tecninvest (2009)	CHP plant running on natural gas.
	Green electricity purchases	-	-

5.3.4 Households energy demand

The first set of inputs to the energy model consists in the final energy demand in the households sector by energy carrier in Barreiro for the year 2008, which was chosen as the base year. This data was directly collected from the national statistics body or energy suppliers for the main energy carriers: electricity, oil products and natural gas. For the remaining energy carriers it was necessary to perform estimations as indicated in Table 24.

The second set of inputs is related to the key socio-economic variable and its reference projection until 2020. Energy demand in the households sector is driven by the number of dwellings. Past data on the number of dwellings in the municipality of Barreiro from 2001 until 2009 (INE, 2010a and INE, 2010b) was used to build a projection (linear regression) until 2020 (see Figure 31). The projection has revealed that the number of dwellings is expected to increase by 12% in 2020 in relation to existing dwellings in 2008.

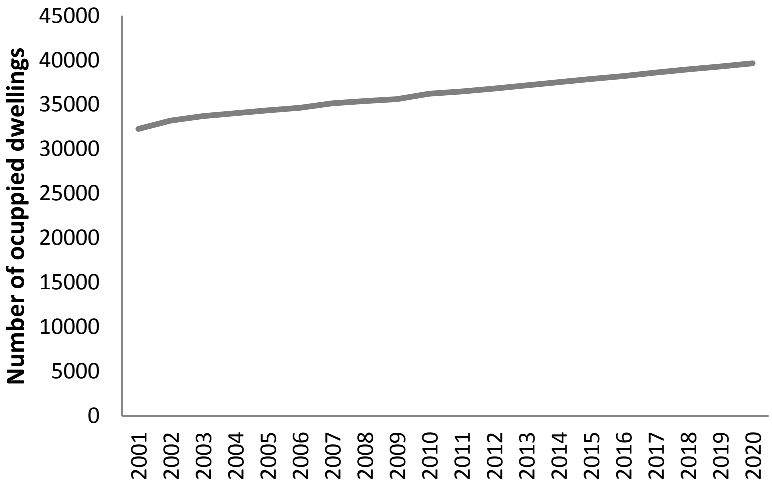


Figure 31 – Projection of the number of occupied dwellings in Barreiro. Sources: INE, 2010a; INE, 2010b.

Afterwards, another set of inputs is given to the energy model, which consists in the breakdown of each energy carrier by end-use in 2008. Those inputs are collected from several sources and when data is limited are based on assumptions (see Table 24). Figure 32 shows the inputs provided for Barreiro in 2008.

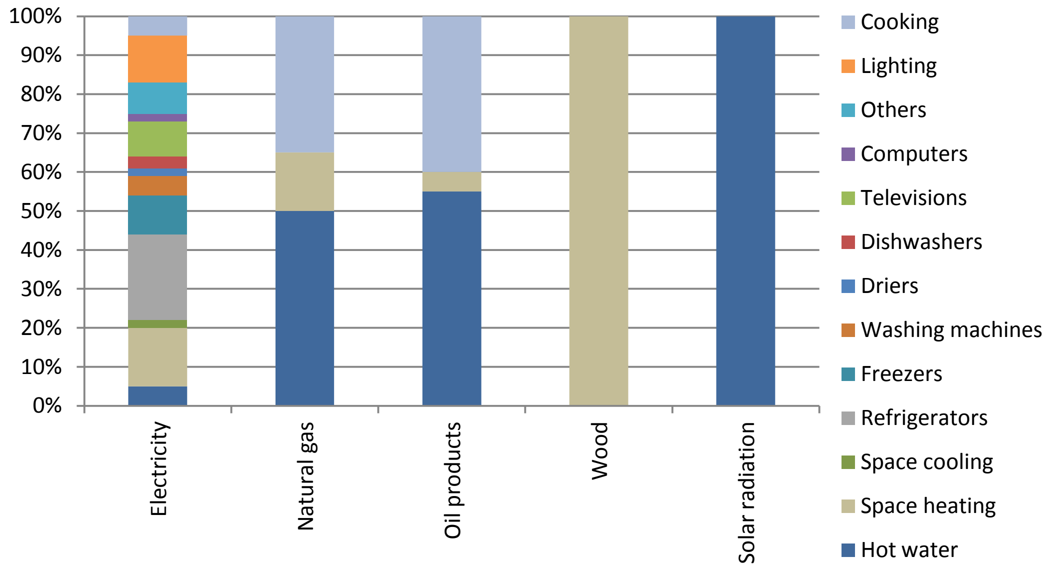


Figure 32 – Assumed breakdown of energy carriers by end-use for households in 2008.

Next, end-use related inputs are provided for building the 2020 reference scenario. The share of end-use supplied by energy carrier and respective end-use conversion technology in the 2020 reference scenario was assumed based in several sources (see Table 25), while the evolution factor of energy services needs was based on expert consultation. All the input data can be found in appendix V. The main assumptions were:

- Higher penetration of natural gas in replacement of electricity and oil products for hot water;
- Shift from oil products to natural gas for space heating;
- Shift to electrical appliances with higher efficiency classes;
- Phase-out of incandescent lamps due to national regulation in place;
- Higher penetration of natural gas in replacement of oil products for cooking, while electricity penetration to continue approximately constant.

Figure 33 shows the estimated breakdown of households final energy demand by end-use in 2008 and in 2020 reference scenario. In 2008, electrical appliances and hot water represented the bulk of the final energy use in Barreiro's households, accounting for 30% and 28%, respectively. Cooking represented 20% and space heating 15% of total final energy use. In 2020 reference scenario, the bulk of final energy demand is still used for electrical appliances and hot water, but there is a slight increase in energy used for space heating and a decrease in energy used for lighting. These small changes can be explained by 1) the demand for increasing comfort in homes which is reflected in a higher usage of space heating equipments, although more efficient 2) the phase-out of incandescent lamps as defined in the National Energy Efficiency Action Plan (Presidência do Conselho de Ministros, 2008) which strongly contributes to increase the efficiency of this particular end-use.

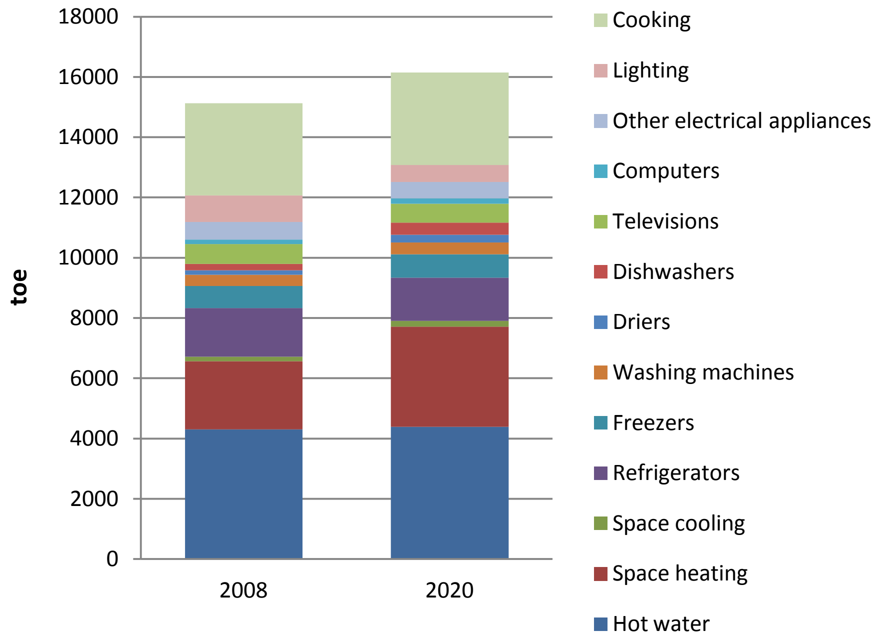


Figure 33 – Estimated breakdown of final energy use by end-use in households for 2008 and 2020 reference scenario.

5.3.5 Services energy demand

Similarly to the households energy demand modelling, the first set of inputs concerning the energy modelling of the services sector consists in the final energy demand per energy carrier in the year 2008 (see Table 24 for more detailed information on the data sources).

The second set of inputs concerns the key socio-economic variable. The projection of energy demand in the services sector is built based on the projection of the services' Gross Value Added. The estimate of Barreiro's Gross Value Added was based on scaling-down the Gross Value Added of NUTSIII – Península de Setúbal (INE, 2010c) using the indicator of the number of employees in the services sector available at both NUTSIII and municipal levels (INE, 2009). Data for the projection of Gross Value Added was collected from the DPP (2008) projection study for Portugal and applied to the municipality of Barreiro, based on the assumption that the annual growth rate in services' Gross Value Added in the municipality is the same than in the country. The projection (see Figure 34) shows that the services' Gross Value Added is expected to increase by 27% in 2020 in relation to existing dwellings in 2008. Note that the projection study was made prior to the financial and economic crisis of 2008 which means that a possible loss in Gross Value Added might have occurred during 2008-2012. However, this could only be confirmed via an update of figures relative to this period in the existing projection studies.

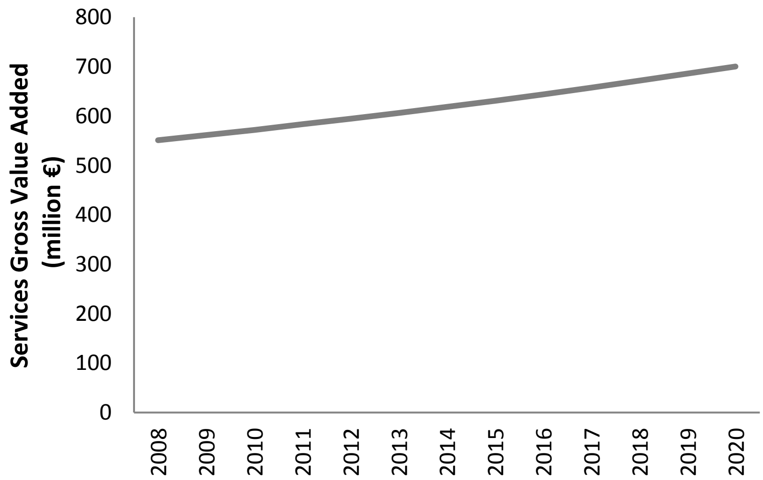


Figure 34 – Projection of services' Gross Value Added in Barreiro. Source: based on DPP (2008) projections.

Next, inputs concerning the repartition of each energy carrier by end-use in 2008 are provided to the energy model. Those inputs are collected from several sources and when data is limited are based on assumptions (see Table 24). Figure 35 presents the assumed breakdown of each energy carrier by end-use in 2008.

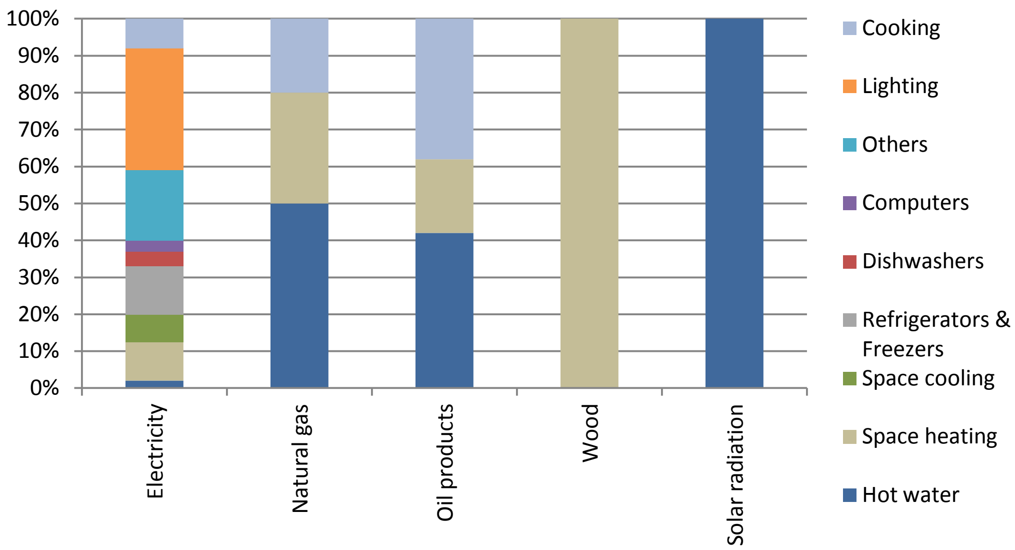


Figure 35 – Assumed breakdown of energy carriers by end-use for services in 2008.

The last set of inputs to be provided in the energy model refers to the construction of the reference scenario. The share of end-use supplied by energy carrier and respective end-use conversion technology in the 2020 reference scenario was assumed based in several sources (see Table 25), while the evolution factor of energy services need was based on expert consultation. All the input data can be found in appendix V. The main assumptions were:

- Higher penetration of solar thermal for hot water and maintenance of natural gas as the major energy carrier for satisfaction of hot water needs in services;

- Increase in the use of natural gas for space heating;
- Space cooling continues to be satisfied only by electricity;
- Shift to electrical appliances with higher efficiency classes;
- Phase-out of incandescent lamps due to national regulation in place;
- Higher penetration of natural gas in replacement of electricity for cooking.

The breakdown of final energy demand by end-use in 2008 and in 2020 reference scenario is presented in Figure 36. The demand for space heating is expected to increase significantly in relation to the base year. This relates to the fact that space heating is an energy service still not fully satisfied in Portugal, and consequently in Barreiro. Similarly, the needs for space cooling in services' buildings are also considered not to be completely satisfied and will grow up to 2020. Lighting is expected to continue to represent more than one quarter of total final energy demand in the services sector.

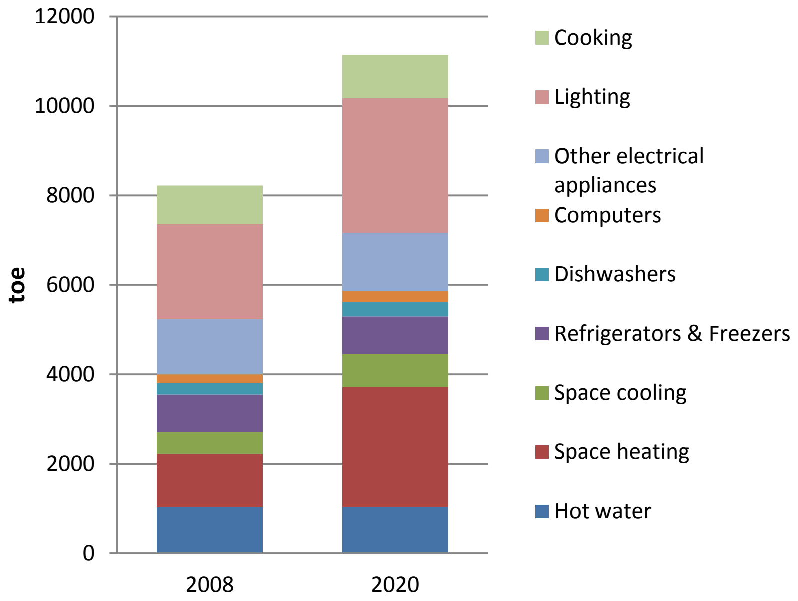


Figure 36 – Estimated breakdown of final energy use by end-use in services for 2008 and 2020 reference scenario.

5.3.6 Transport energy demand

The first set of inputs consists in providing the final energy demand for transport in 2008 by energy carrier (see Table 24 for more detailed information on the data sources).

The second set of inputs refers to the key socio-economic variables and their reference projection until 2020. The needs for travel of persons and goods lead to transport energy demand. The projection of passenger transport energy demand is thus based on the projection of passenger-km (Figure 37). In Barreiro, the number of passenger-km travelling in passenger cars is expected to increase 27% by 2020 in relation to 2008 based on a projection for Portugal (EC, 2007). According to the same source, the passenger-km travelling by other modes of transport are expected to remain stable over time, with only a slightly increase in bus and train ridership. Although an extension of a metro line from neighbouring municipalities to Barreiro is foreseen, the National Government has not provided any indication of when the construction should start (Chorão, 2010). On the careful side, for the projection it was assumed that the metro line will not become operational before 2020 and therefore it was not considered into the reference scenario.

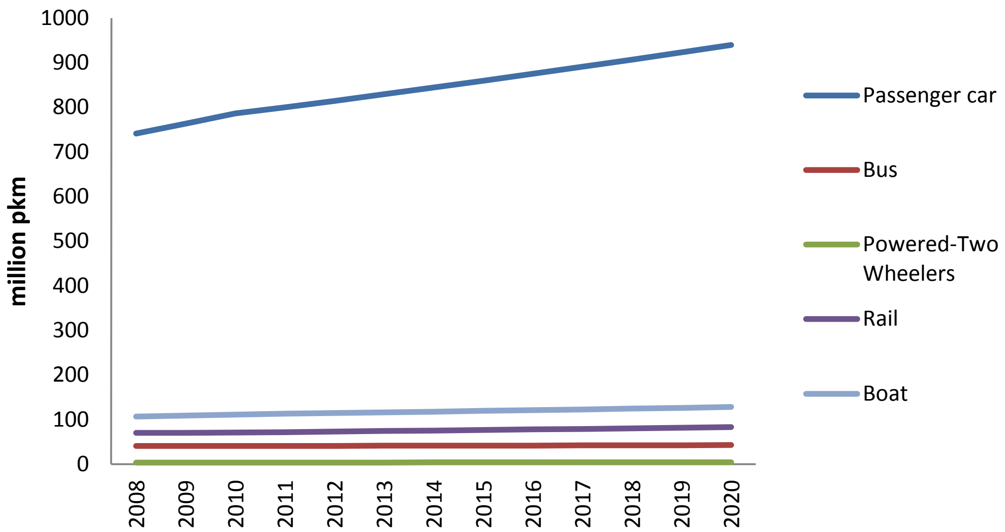


Figure 37 – Assumed evolution of passenger-km by mode of transport in Barreiro.

The projection of tonnes-km for freight transport is presented in Figure 38 and is based on a projection for Portugal (EC, 2007). Estimates of tonnes-km for the base year were based on fuel sales by mode of transport (DGEG, 2007) and on national freight transport energy intensity (E.Value Lda., 2006). Data on fuel sales revealed that road freight transport in the District of Setúbal (the lower level of administrative division for which fuel sales data distinguishes freight from passenger transport) represents only 2% of overall transport diesel consumption. The same share was applied to the municipality of Barreiro.

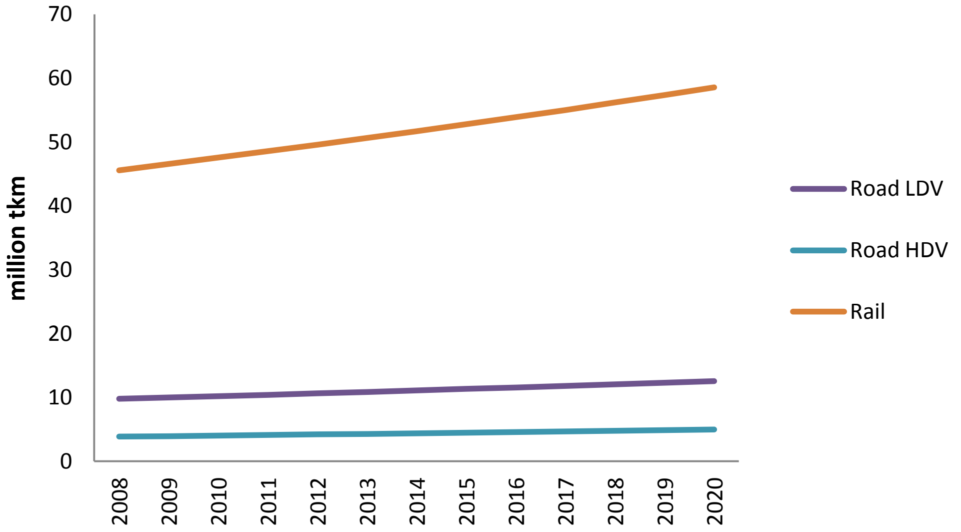


Figure 38 – Assumed evolution of tonnes-km by mode of transport in Barreiro.

Afterwards, inputs are provided regarding the distribution of each energy carrier by mode of transport in 2008. Those inputs and associated assumptions were based on different sources as presented in Table 24. Figure 39 displays the assumed breakdown of each energy carrier by mode of transport.

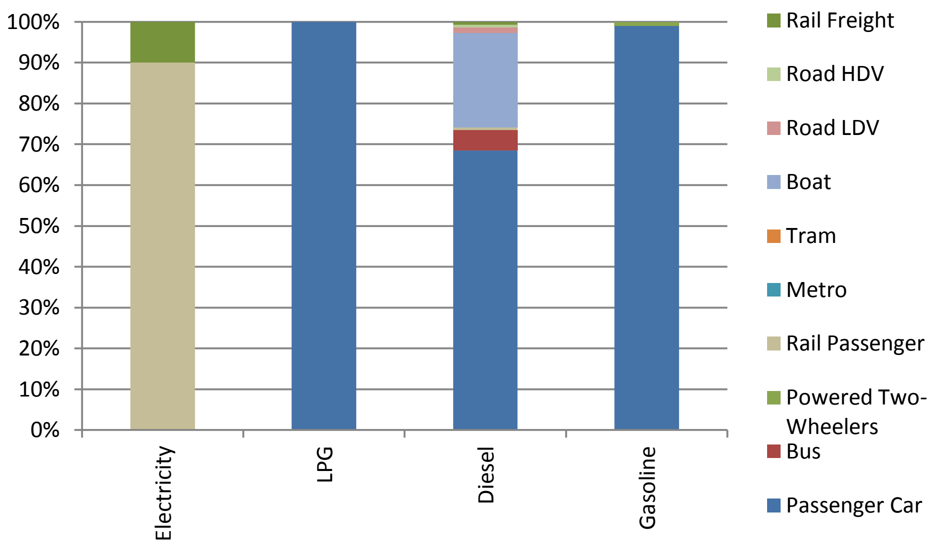


Figure 39 – Assumed breakdown of energy carriers by mode for transport in 2008.

In what regards the construction of the 2020 reference scenario, the assumed evolution of transport energy intensity and transport activity by mode of transport was based in several sources (see Table 25). All the input data can be found in appendix V. The main assumptions were:

- An efficiency change factor in transport energy intensity of 10% for passenger transport and 5% for freight transport between 2008 and 2020, according to projections to Portugal (EC, 2007);

- A great increase in passenger-km according to EC (2007) projection for Portugal, in which the distribution by mode of transport remains constant with passenger cars leading the mode of transport in Barreiro;
- An increase in tonnes-km according to EC (2007) projection for Portugal, in which the distribution by mode of transport remains constant;
- Total shift to trains running on electricity in replacement of diesel following the national trend of electrification of railways.

Figure 40 and Figure 41 present the estimated breakdown of passenger and freight transport final energy use by mode of transport, respectively. In Figure 40, it is possible to observe that passenger car is responsible for more than 70% of final energy used for passenger transport in 2008 and the reference projection reveals that this is expected to continue to be the predominant means of transport in Barreiro. Transport by boat, frequently used by the inhabitants of Barreiro who work in Lisbon, represent almost 20% of overall final energy use for passenger transport. The reference scenario assumes that no major changes in the breakdown of final energy use by mode are expected to occur. Shifts in energy carriers and technologies for transport are only expected to occur in trains with the shift from diesel to electric trains and in passenger cars via the introduction of hybrid gasoline and diesel passenger cars, but with less expression.

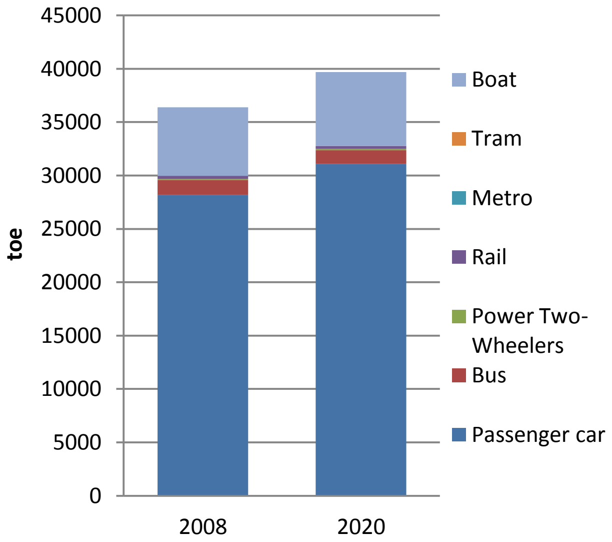


Figure 40 – Estimated breakdown of final energy use by end-use in passenger transport for 2008 and 2020 reference scenario.

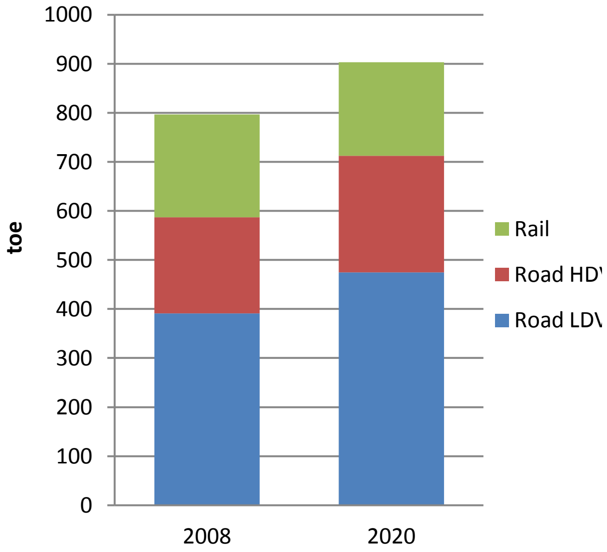


Figure 41 – Estimated breakdown of final energy use by end-use in freight transport for 2008 and 2020 reference scenario.

5.3.7 Industry energy demand

The first set of inputs regarding the energy modelling of the industry sector consists in the final energy demand per energy carrier in the year 2008 (see Table 24 for more detailed information on the data sources).

The second type of inputs to gather is related to the key socio-economic variable and its projection until 2020. The projection of energy demand in industry is built based on the projection of the industry's Gross Value Added. The estimate of Barreiro's Gross Value Added was based on scaling-down the Gross Value Added of NUTSIII – Península de Setúbal (INE, 2010c) using the indicator of the number of employees in industry at both NUTSIII and municipal levels (INE, 2009). Data for the projection of Gross Value Added was collected from the DPP (2008) projection study for Portugal and applied to the municipality of Barreiro, based on the assumption that the annual growth rate in industry's Gross Value Added in the municipality is the same than in the country. The projection (see Figure 42) shows that the industry's Gross Value Added is expected to increase by 21% in 2020 in relation to existing dwellings in 2008.

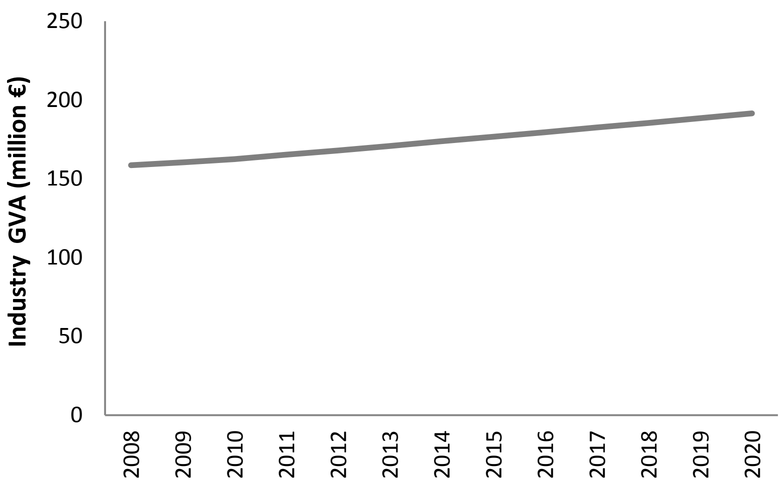


Figure 42 – Projection of industry's Gross Value Added in Barreiro. Source: based on DPP (2008) projections.

Afterwards, inputs concerning the breakdown of each energy carrier by industrial end-use in 2008 are provided. Those inputs are collected from several sources and when data is limited are based on assumptions (see Table 24). Figure 43 presents the assumed breakdown of each energy carrier by end-use.

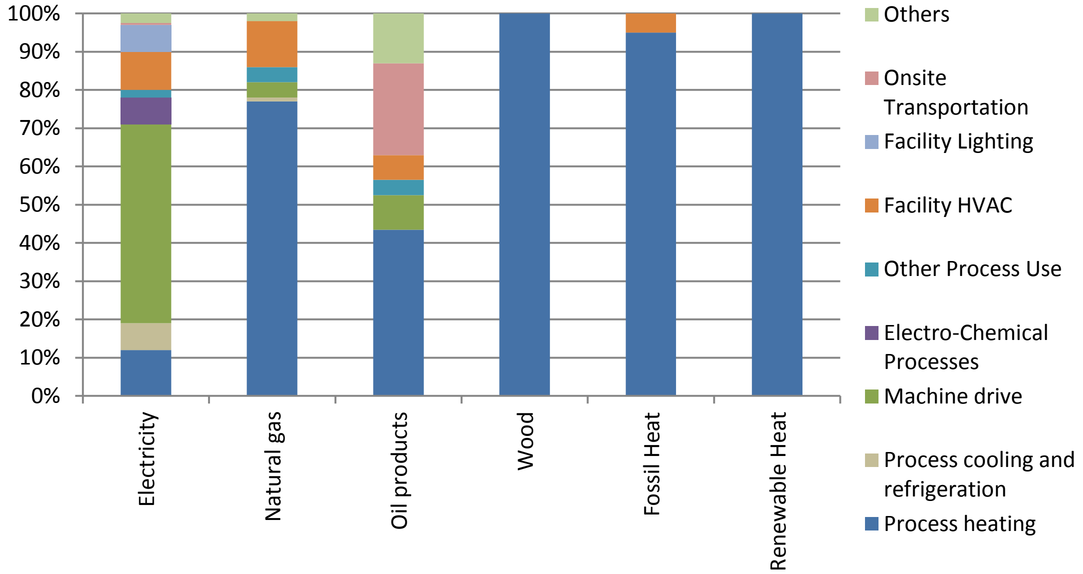


Figure 43 – Assumed breakdown of energy carriers by mode for transport in 2008.

Finally, the end-use related inputs regarding the 2020 reference scenario are provided. The share of end-use supplied by energy carrier and respective end-use conversion technology in the 2020 reference scenario was assumed based in several sources (see Table 25), while the evolution factor of energy services need was based on expert consultation. All the input data can be found in appendix V. The main assumptions behind the reference scenario in terms of changes in the share of end-use supplied by energy carrier and respective end-use conversion technology were:

- Increase in the use of fossil heat for process heating and facility HVAC due to the foreseen cogeneration plant (Tecninvest, 2008) in replacement of oil products;
- Shift from oil products to natural gas and electricity for process heating and to electricity for facility HVAC.

The breakdown of final energy demand by end-use in 2008 and in 2020 reference scenario is presented in Figure 44. For the reference scenario it was assumed that the distribution of end-uses remains the same, but shifts in energy carriers used to satisfy the end-uses change as mentioned above. Process heating is the main end-use accounting for more than 50% of total final energy use in 2008 and in the 2020 reference scenario.

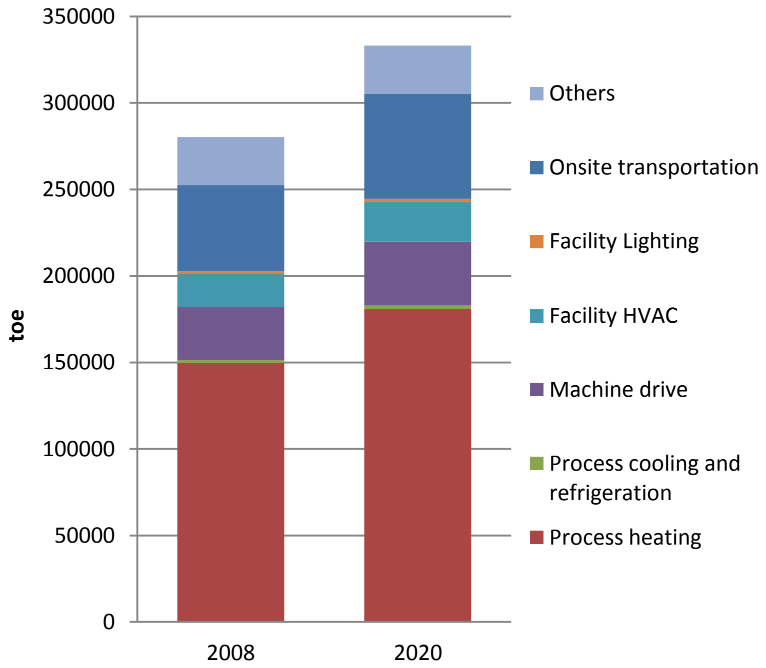


Figure 44 – Estimated breakdown of final energy use by end-use in industry for 2008 and 2020 reference scenario.

5.3.8 Agriculture & Fisheries energy demand

The first set of inputs consists in the final energy demand of this sector by energy carrier in 2008 (see Table 24 for more detailed information on the data sources).

The second set of inputs is related to the key socio-economic variable. Unlike the sectors of services and industry in which the projection of energy demand is based on the projection of sectoral Gross Value Added, the same was not possible for the agriculture & fisheries sector in Barreiro. As described in section 5.3.5, the municipal Gross Value Added of each sector of activity needs to be estimated based on scaling-down from NUTSIII and on the variable of number of employees according to the sector of activity available at both scales. However, according to the available existing official data, the number of employees in agriculture & fisheries sector in Barreiro is zero (INE, 2009). This means that the Gross Value Added of agriculture & fisheries sector in Barreiro is zero, according to the scaling-down methodology adopted to estimate sectoral Gross Value Added. Indeed, agriculture in Barreiro is mainly of subsistence as referred by Moreira (2007). The reference evolution for 2020 has considered the final energy demand as constant due to the lack of orientations regarding the future evolution of this sector in Barreiro.

With respect to the characterisation of agriculture & fisheries end-uses in Barreiro, Figure 45 presents the assumed breakdown of each energy carrier by end-use in 2008. The energy used in the agriculture sector is residual. Fisheries activities do not take place in Barreiro.

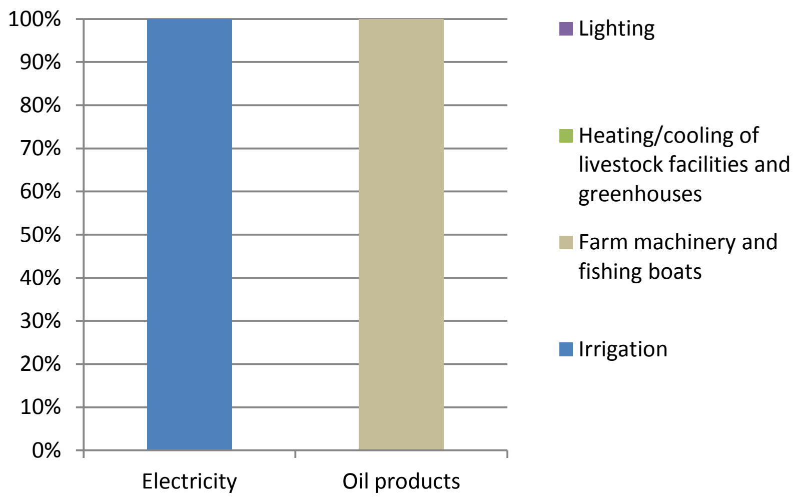


Figure 45 – Assumed breakdown of energy carriers by end-use in agriculture & fisheries in 2008.

5.3.9 Street lighting energy demand

The first set of inputs consists in the final energy demand of street lighting by energy carrier in 2008 (see Table 24 for more detailed information on the data sources).

The second set of inputs concerns the key socio-economic variable and its projection until 2020. Energy demand for street lighting is considered to be induced by the number of dwellings. The projection of the number of dwellings can be found in Figure 31 in section 5.3.4.

The third set of inputs regarding the base year of 2008 refers to the breakdown of electricity demand (the only energy carrier accounted for street lighting) by the two main end-uses: traffic lights and street lighting. Figure 46 shows those inputs.

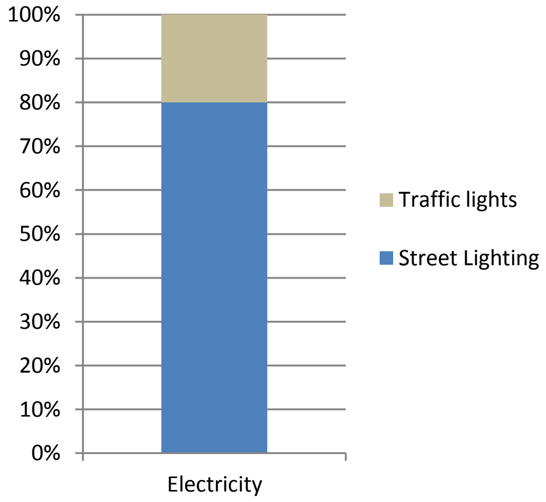


Figure 46 – Assumed breakdown of energy carriers by end-use in street lighting in 2008.

Finally, the end-use related inputs regarding the 2020 reference scenario are provided. The share of end-use supplied by energy carrier and respective end-use conversion technology in the 2020 reference scenario was assumed based in several sources (see Table 25), while the evolution factor of energy services need was based on expert consultation. All the input data can be found in appendix V. The main assumptions behind the reference scenario in terms of changes in the share of end-use supplied by electricity and end-use conversion technology are according to the regulation in place (Presidência do Conselho de Ministros, 2008):

- Phase-out of mercury vapour lamps in street lighting;
- Shift from incandescent to LED (light-emitting diode) traffic lights.

Street lighting is responsible for 560 toe of final energy use in Barreiro in 2008 and this amount is expected to increase 4% by 2020. Figure 47 represents the breakdown of final energy demand in street lighting by street lighting itself and traffic lights in 2008 and in the 2020 reference scenario.

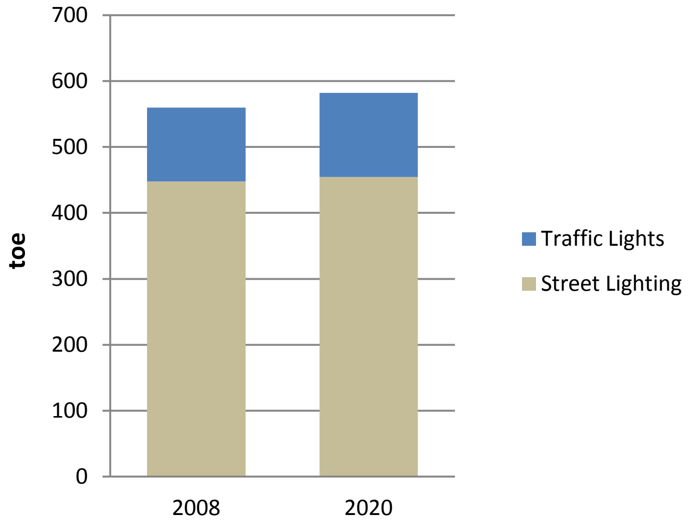


Figure 47 – Estimated breakdown of final energy use by end-use in street lighting for 2008 and 2020 reference scenario.

5.3.10 Overall energy demand and greenhouse gases emissions results

In 2008, the total final energy demand in Barreiro accounted to 352 ktoe (based on the sources and estimates presented in Table 24). However, more than 80% was consumed by the industry sector, in particular the chemical industry. When compared to the national average in terms of energy consumption per capita, Barreiro turns out to be a very atypical municipality. In 2008, the national average was about 1.8 toe/capita of final energy use while in Barreiro was 4.5 toe/capita. Without considering the industry sector, the municipality of Barreiro (0.8 toe/capita) still differs considerably from the national average (1.2 toe/capita) (DGGE, 2008c).

Figure 48 presents side by side the final energy demand by sector in 2008 and the expected final energy demand in the reference scenario for 2020, as estimated by the end-use energy model. The greatest percentual increase in final energy demand (36%) is expected in the services sector, followed by the industry sector (18%). Figure 49 presents final energy demand in per capita terms in 2008 and estimated by 2020.

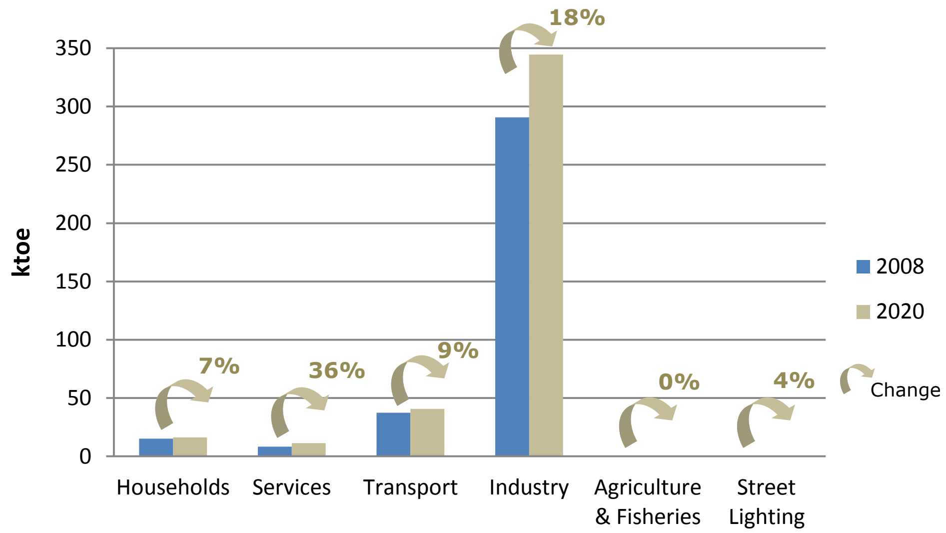


Figure 48 – Final energy demand by sector in Barreiro in 2008 and in 2020 reference scenario.

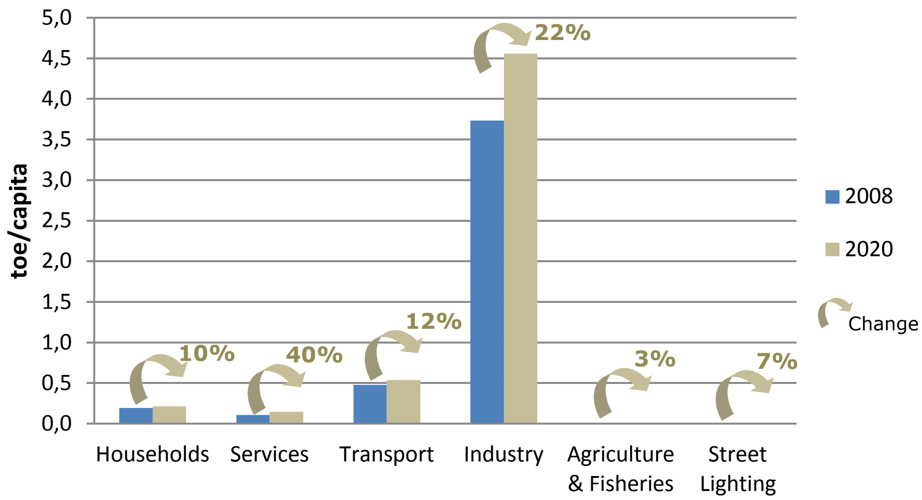


Figure 49 – Final energy demand per capita per sector in Barreiro in 2008 and in 2020 reference scenario.

The projection of the population in Barreiro (via the application of the arithmetic and geometric methods) has shown that the population is expected to decrease by 3% in 2020 in relation to 2008. The projected increase in final energy demand is thus explained by the influence of other factors than population. For instance, in the households sector the number of dwellings is expected to increase (see Figure 31) while the trend in the average number of persons per household is expected to decrease (Eurostat, 2011). Also, the need for energy services is expected to increase in order to fulfil comfort conditions which are currently not completely satisfied. Energy demand in the services and industry sectors is induced by the respective sectoral Gross Value Added (useful energy needs) (see Figure 34) and influenced by changes in energy efficiency (conversion technology of final to useful energy). DPP (2008) projects an increase in both services and industry Gross Value Added, although industry (see Figure 42) is expected to increase at a lower annual growth rate than services gross value added. The greater increase in energy demand in the services sector is explained by a trend (Boyle, Everett & Ramage, 2003; Goldemberg, 1987) to shift to less energy-intensity mix of economic activity: from industrial to commercial activities, which is reflected in Portugal and in the municipality of Barreiro. This trend is observed in the number of employees in establishments in Barreiro according to sector from 2002 to 2009 (Figure 50).

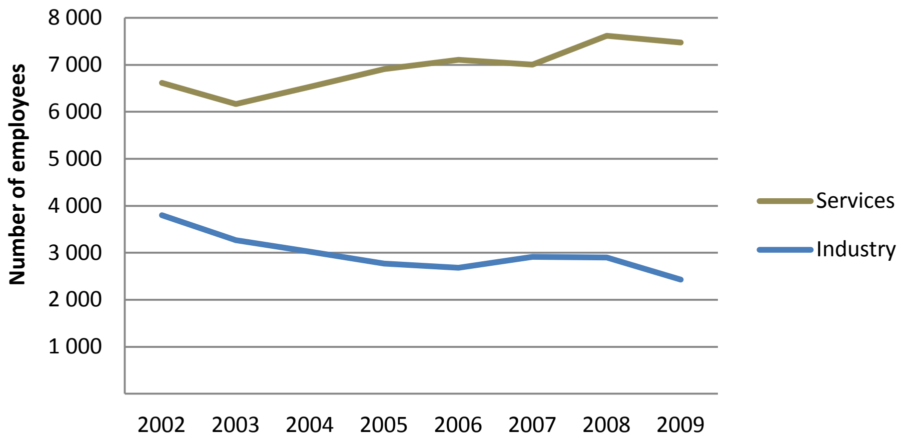


Figure 50 – Number of employees in establishments in Barreiro according to sector of economy. Source: INE, 2004; 2005; 2006; 2007; 2008; 2009; 2010d.

According to the reference projection, overall final energy demand in Barreiro is expected to increase by 17% which corresponds to 413 ktoe of final energy demand in 2020. Figure 51 presents the projected variation in terms of primary, final and useful energy demand (see section 4.2.1). Useful energy demand is expected to increase by 23% which is directly linked to the increased need for energy services. On the other hand, an increase of 17% is expected in final energy demand which translates a greater efficiency in end-use conversion technologies from final to useful energy. Finally, primary energy demand is expected to increase by 19%. It is worth to recall here that since the methodology focuses on local actions and on evaluating the impacts of those actions in the local energy system, the evolution of the national electricity system was not addressed since it is out of the influence of the local authority.

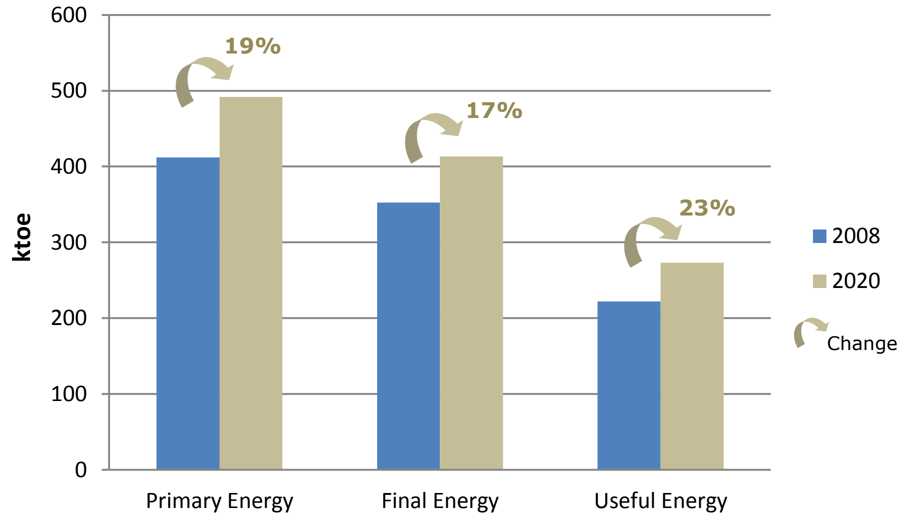


Figure 51 – Energy use in Barreiro in 2008 and in 2020 reference scenario expressed in primary energy, final energy and useful energy.

In what regards the breakdown of energy demand by energy carrier in Barreiro, Figure 52 shows that there is a large consumption of oil products and fossil heat. However, this is mainly attributable to the industry sector. Figure 53 presents the consumption of energy carriers in Barreiro without accounting for industry. This shows that electricity is the most used energy carrier, followed by natural gas. In the reference projection (both in Figure 52 and Figure 53) it is possible to visualise that the consumption of oil products is expected to decrease, due to a shift to other energy carriers such as natural gas to satisfy specific end-uses (e.g. space heating and hot water).

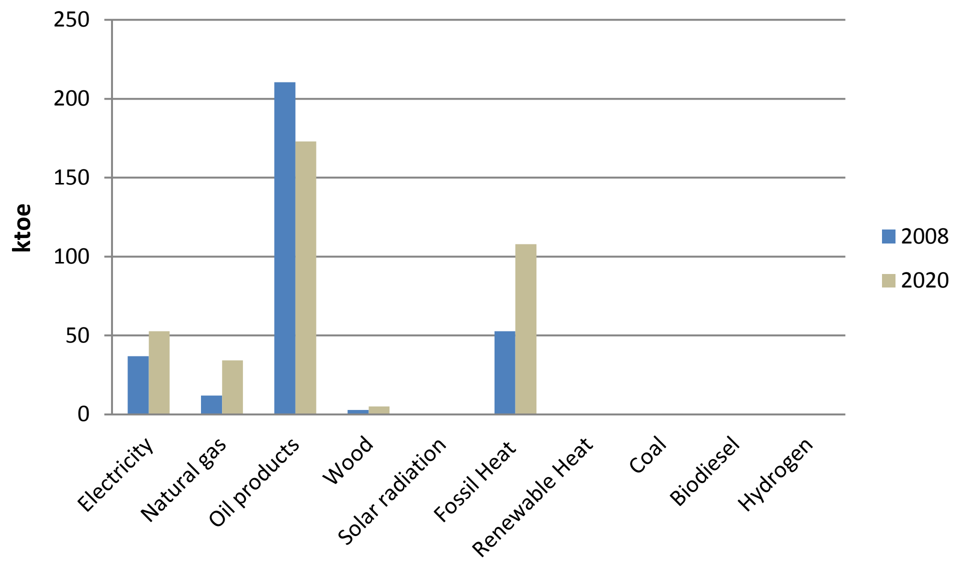


Figure 52 – Final energy demand by energy carrier in Barreiro in 2008 and in 2020 reference scenario.

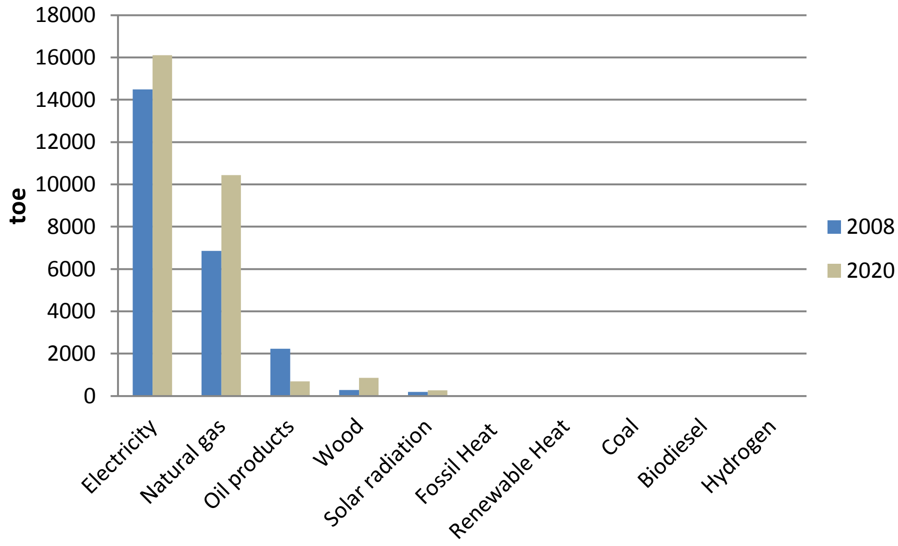


Figure 53 – Final energy demand by energy carrier in Households, Services, Transport and Street Lighting in Barreiro in 2008 and in 2020 reference scenario.

The end-use energy model implemented in the local energy planning assistant tool allows a comprehensive modelling of energy demand in all sectors of economy. However, for the second purpose of the tool – exploring alternatives to the reference scenario – the local energy planning assistant tool concentrates in actions targeting the households, services and transport sectors, for which local authority has the greater control to promote improvements. Actions on industry and agriculture & fisheries were not included in the tool. The former was due to the fact that industry is covered by specific regulations (see section 4.6.2.) and the latter was due to the residual energy demand usually verified in this sector. Nevertheless, as the energy demand structure is implemented for all sectors, the tool can be extended to industry and agriculture & fisheries actions. This would be appropriate for specific cases in which industry and agriculture & fisheries are within the scope of action of local authorities, such as large cities owning industrial facilities and rural municipalities.

Figure 54 presents the overall GHG emissions in Barreiro municipality, as estimated for 2008 and as forecasted for the 2020 reference scenario for 2020, according to the methodology described in section 4.2.4. It is possible to observe the implications in terms of GHG emissions caused by the industry sector ('Total' columns in Figure 54 refers to all sectors while the 'Total H_S_T_ST' columns exclude the industry and agriculture & fisheries sectors). GHG emissions per capita in Barreiro in 2008 were 14.5 tonnes CO_2 eq./capita if all sectors were accounted. However, without the industry sector, emissions per capita correspond to 2.5 tonnes CO_2 eq./capita.

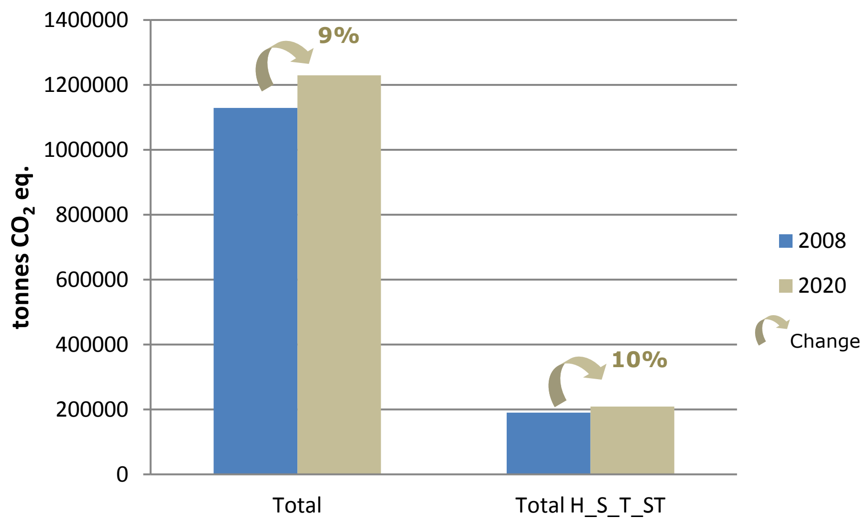


Figure 54 – Overall greenhouse gases emissions (Total) and greenhouse gases emissions without Industry and Agriculture sectors (Total H_S_T_ST) in Barreiro in 2008 and in 2020 BAU evolution.

According to the end-use energy model, it is estimated that under a reference scenario, in 2020 the municipality of Barreiro will increase its greenhouse gases emissions by about 10% in relation to 2008. This means, that the energy action plan to be implemented in the municipality will have to tackle the expected increase and further produce efforts to reduce the GHG emissions 20% below the 2008 levels.

5.4 Involving the local actors

The involvement of local actors took place first with the participation of the City Councilman for Environment of Barreiro City Council and the director of the energy agency (S.Energia) in the identification of the objectives of local sustainable energy planning. The identification of the objectives was part of the process of problem structuring which also involved representatives of other municipalities (see section 4.4.2).

The multi-criteria evaluation model was built during a decision conference (Phillips, 2007). The main purposes of this decision conference were to build a value function for each objective and to weight the objectives. The choice of the participants was made by the energy agency and the City Council. Recommendations for the choice were made so that they would choose the actors considered as relevant in the process of elaboration and implementation of the sustainable energy action plan (see section 4.4.2). The one-day decision conference took place with the participation of technical staff, namely two persons from the Environmental Sustainability Division of Barreiro City Council, three persons from the energy agency (S. Energia) (Table 26).

Table 26 – List of participants in the decision conference.

Name	Position	Institution
Susana Camacho	Director	S.Energia
João Braga	Technician	S.Energia
João Figueiredo	Technician	S.Energia
Andreia Pereira	Head of Environmental Sustainability Office	Barreiro City Council
Cátia Correia	Technician at Environmental Sustainability Office	Barreiro City Council

During the decision conference, a facilitator (the thesis author) guided the decision process helped by an analyst (the thesis co-supervisor). The facilitator started by summarising the model structure created until then, namely by presenting the objectives of the model and their attributes. The facilitator also had the task of stimulating the group discussion concerning the development of the multi-criteria value model, but without contributing to the content of discussion (Phillips, 2007). The analyst used the decision support system M-MACBETH to display on-the spot the model being developed. The interactive environment allowed the group to discuss the implications and sometimes perform slight adjustments (for instance, in the value scale generated by M-MACBETH presented in section 5.8). The steps of this process are described in detail in the following sections.

5.5 Identifying the objectives and attributes

The objectives and attributes identified through the process described in section 4.4.2 were presented to the local actors in order to have their agreement. As mentioned in section 4.7 the objective 'Reduce noise impacts from transport' (objective O5 in Table 21) had to be dropped from the model due to operational reasons. Table 27 lists the objectives and attributes included in the multi-criteria evaluation model developed for Barreiro municipality acknowledged by the local actors.

Table 27 – Objectives and attributes included in the multi-criteria evaluation model developed for Barreiro municipality.

	Objectives	Attributes
O1	Reduce GHG emissions	Tonnes of CO_2 equivalent emissions reduced
O2	Reduce air pollution from road transport	Tonnes of NO_x emissions reduced
O3	Maximise employment benefits	Number of net jobs gained
O4	Improve long-term energy independence	Tonnes of oil equivalent (primary energy) of imported fossil fuels reduced
O5	Minimise the negative impacts on human health by improving the thermal comfort of homes and offices	Tonnes of oil equivalent (final energy) reduced for space heating and cooling of homes and offices
O6	Minimise the negative impacts on human health caused by automobile dependence	Number of passenger-km shifting from passenger cars to public transit, walking and cycling
O7	Reduce energy bill	Euros saved per household per year

5.6 Generating alternatives

As described in the guidelines for generating alternatives (see section 4.6.3), the first step of this stage was to analyse independently each action included in the catalogue of technical actions in relation to the energy context of Barreiro. The local energy planning assistant tool allowed visualising for each action the energy demand of the end-use (in the reference scenario) to be tackled by the action as shown in Table 28. In this way, actions oriented to end-uses with significant final energy use (considered to be greater than 500 toe) were selected to be included in the alternative generation table. The most energy demanding end-uses in Barreiro were space heating, hot water, refrigerators and freezers in households and services and space cooling in services' buildings. In transport, passenger cars were by far the most energy demanding means of transport. Actions targeting passenger cars and buses were selected. Finally, the final energy use of electricity-related end-uses in households and services also highlighted the potential to use renewable electricity locally generated to satisfy those end-uses.

An example of how actions can be selected can be observed in the households sector. In this sector, space heating is expected to account for 3 320 toe by 2020, becoming in this way a priority end-use to act. As so, action 1: 'Decrease building's heating needs' if implemented is expected to deliver significant effects in reducing the overall final energy use. On the contrary, as space cooling is only expected to consume 197 toe in 2020, and if action 2: 'Decrease building's cooling needs' would be implemented this would potentially produce only minor effects in terms of final energy and GHG emissions reduced.

An example of an action with null effect in terms of final energy reduced, as accounted in the model, is action 18: 'Replace incandescent lamps by more efficient lamps'. The implementation of this action is already foreseen in the reference scenario due to existing national energy policies which promote the phase-out of incandescent lamps. Therefore, it does not create any difference between the 'alternative' and the 'reference' scenarios. Also actions like action 40: 'Modal shift from individual passenger cars to collective transport metro' often imply a huge investment in building metro lines (coming from non-municipal funding sources and national-oriented policies). As discussed with the local actors, this action was not foreseen for Barreiro during the planning period.

A total of 26 actions highlighted on bold in Table 28 were selected for the process of generating alternatives. As mentioned in section 4.6.3, this decision aims at avoiding complexity of the model by integrating actions that cannot produce important effects.

Table 28 – Analysis of the final energy use of end-uses (in the reference scenario) to be tackled by each of the actions included in the catalogue of technical actions.

	Action	End-use final energy use in 2020 reference scenario (toe)
	HOUSEHOLDS	
	Thermal insulation	
1	**Decrease building's heating needs**	3320
2	Decrease building's cooling needs	197
	Water heating fuel shift	
3	Switch electric conventional storage water heaters to natural gas water heaters	311
4	Switch other fossil fuel water heaters to natural gas water heaters	352
5	**Switch fossil fuel water heaters to solar water heater**	4136
6	**Switch fossil fuel water heaters to renewable heat water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)**	
	Space heating equipment fuel shift and efficiency shift	
7	Switch fossil fuel boilers to natural gas central boilers	0
8	**Switch electric heaters to natural gas central boilers**	1179
9	**Switch electric heaters to heat pumps**	
10	**Switch fossil fuel central boilers to hot water or steam radiators (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)**	3320
11	**Switch fossil fuel central boilers to solar radiant heating**	
12	**Switch fireplaces to pellet stoves**	739
	Space cooling equipment fuel shift	
13	Switch electric heat pumps to chilled water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)	197
	Electrical appliances' efficiency	
14	**Replace refrigerators and freezers with A+ and A++ refrigerators**	1378
15	Replace washing machines with A+ washing machines	378
16	Replace driers with A driers	238
17	Replace dishwashers with A dishwashers	89
	Lighting efficiency	
18	Replace incandescent lamps by more efficient lamps	0
	Cooking fuel shift	
19	Switch other fossil fuels stoves to natural gas stoves	345
	Renewable electricity generation	
20	**Use of small-scale renewable electricity**	7382
	SERVICES	
	Thermal insulation	
21	**Decrease building's heating needs**	2685
22	**Decrease building's cooling needs**	738
	Water heating fuel shift	
23	Switch conventional electric water heaters to natural gas water heaters	31
24	Switch fossil fuel water heaters to natural gas water heaters	0
25	**Switch fossil fuel water heaters to solar water heaters**	900
26	**Switch fossil fuel water heaters to renewable heat water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)**	
	Space heating equipment fuel shift and efficiency shift	
27	Switch fossil fuel central boilers to natural gas central boilers	0
28	Switch electric heaters to natural gas central boilers	210
29	Switch electric heaters to heat pumps	
30	**Switch fossil fuel central boilers to hot water or steam radiators (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)**	2685
31	**Switch fossil fuel central boilers to solar radiant heating**	
32	Switch fireplaces to pellet stoves	0
	Space cooling equipment fuel shift	
33	**Switch electric heat pumps to chilled water systems (district heating (DHC)/small-scale Combined Heat and Power (CHP) units)systems systems**	738
	Electrical appliances' efficiency	
34	**Replace refrigerators and freezers with A+ and A++ refrigerators**	528
35	Replace dishwashers with A dishwashers	71
	Lighting efficiency	

	Action	End-use final energy use in 2020 reference scenario (toe)
36	Replace incandescent lamps by more efficient lamps	0
	Cooking fuel shift	
37	Switch other fossil fuels stoves to natural gas stoves	0
	Renewable electricity generation	
38	**Use of small-scale renewable electricity**	7662
	TRANSPORT	
	Modal shift	
39	**Modal shift from individual passenger cars to collective transport buses**	31078
40	Modal shift from individual passenger cars to collective transport metro	
41	**Modal shift from individual passenger cars to walking and cycling for short**	
	Fuel shift	
42	**Switch passenger-km travelling in petroleum fuels passenger cars to**	31078
43	**Switch passenger-km transported in diesel collective transport buses to**	1302
44	**Switch passenger-km transported in diesel collective transport buses to**	
45	**Switch passenger-km transported in diesel collective transport buses to**	
46	**Switch passenger-km transported in diesel collective transport buses to**	
47	Switch passenger-km transported in diesel collective transport trains to electric	0

The next step was thus to generate alternatives by combining actions from the set of 26 with the respective degree of implementation using the alternative generation table implemented in the local energy planning assistant tool. Five alternatives were constructed by the author, having in mind the rationale of building considerably different alternatives (Zeleny, 1982; Matheson & Matheson, 1998):

- **A1 – Diversified policies** – includes diversified actions among the sectors of households, services and transport with low to medium ambitious degrees of implementation.
- **A2 – High diversified policies** – includes diversified actions among the sectors of households, services and transport as in alternative A1, but assumes a greater degree of implementation of solar thermal for hot water, introduces the use of solar for space heating, and considers a greater shift to more energy efficient refrigerators and freezers in both households and services. In transport, assumes the introduction of electric buses.
- **A3 – Lifestyles changes** – includes actions arising from changes in citizens' lifestyles, it is assumed a greater penetration of renewable energies in households for hot water, space heating and electricity generation, greater shift to more energy efficient refrigerators and freezers, modal shift to cycling and walking and greater introduction of electric vehicles. Actions on the services sector remain quite similar to alternative A1.
- **A4 – Great resilience** – comprises actions aimed at reducing oil dependence and increasing the diversity of energy carriers via greater introduction of renewable energies in both households and services sectors. In transport, it assumes the introduction of a minor share of buses powered by hydrogen, and the remaining

running in electricity and biodiesel. Modal shift to cycling and walking is assumed the same degree as in alternative A3.

- **A5 – Business changes** – focuses mainly on actions on the services sector, assumes a larger penetration of renewable heat/cold for space heating and cooling, greater shift to more energy efficient refrigerators and freezers, and considerable deployment of renewable energies for hot water and local electricity generation. In transport, it is assumed a penetration of electric vehicles in services' fleets.

The alternatives created range from diversified actions among the sectors of households, services and transport to sectoral-focused alternatives addressing greater lifestyle changes in the households sector or in the business sector.

The process of constructing alternatives is iterative in the sense that alternatives eligible for evaluation have to comply with a GHG emissions condition (see section 4.6.4), which for the case of Barreiro was 20% GHG emission reduction target by 2020 in relation to 2008. The fulfilment of the target is visualised in the last column of the alternative generation table named 'GHG emission reduction'. Figure 55 presents a screenshot of this column.

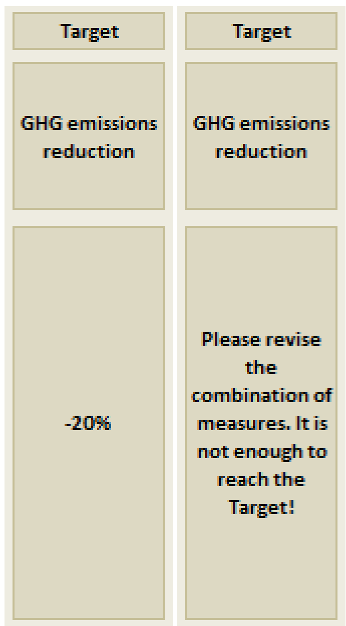


Figure 55 – Display of the fulfilment of GHG emissions condition to the user in the alternative generation table.

The alternative generation tables showing the elements of each alternative are illustrated in the following figures (Figure 56, Figure 57, Figure 58, Figure 59 and Figure 60).

During the decision conference, the five alternatives created were presented to the local actors. The local actors were also invited to build an additional alternative. They engaged in a deep thinking and discussion about the future of Barreiro, exchanging knowledge of the local context among their different areas of expertise (environment, energy, economics). At the end, they were able to visualise that the GHG emissions reduction achieved by the constructed alternative was 21% by 2020 in relation to 2008. All the participating actors considered this reduction to be satisfactory, since this allowed Barreiro to comply with the commitments as Covenant of Mayors signatory.

The new alternative created was named ‘Sustainable Barreiro’ by the actors and is presented in Figure 61. This alternative was also considered into the multi-criteria evaluation process, together with the five alternatives previously created by the author.

A1 – Diversified policies

It includes diversified actions on the sectors of households, services and transport.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain
Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	**Shift 10%**	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	**Shift 20%**	Shift 20%	Shift 20%	**Shift 20% to A+ and A++**	Increase 20%
Decrease 30%	**Shift 45%**	Shift 30%	Shift 30%	**Shift 30%**	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	**Shift 20%**	**Shift 20%**	**Shift 20%**	**Shift 20% to A+ and A++**	Increase 20%
Decrease 30%	**Decrease 30%**	**Shift 45%**	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Transport

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses
Maintain	**Maintain**	Maintain	**Maintain**	Maintain	Maintain	**Maintain**
Shift 10%	Shift 10%	**Shift 10%**	Shift 20%	Shift 20%	Shift 20%	Shift 20%
Shift 20%	Shift 20%	Shift 20%	Shift 40%	**Shift 40%**	Shift 40%	Shift 40%
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	**Shift 60%**	Shift 60%
Shift 40%	Shift 40%	Shift 40%	Shift 80%	Shift 80%	Shift 80%	Shift 80%
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%

Target

GHG emissions reduction
-20%

Figure 56 – Screenshot of the alternative generation table for the alternative A1 – Diversified policies.

A2 – High diversified policies

It follows a similar approach to the alternative A1 – Diversified policies but includes further implementation of renewables for heating purposes, energy efficiency of appliances and alternative means of transport.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	**Shift 10%**	**Shift 10%**	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	**Shift 20%**	Shift 20%	Shift 20%	Shift 20% to A+ and A++	Increase 20%
Decrease 30%	Shift 45%	Shift 30%	Shift 30%	**Shift 30%**	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	**Shift 40% to A+ and A++**	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	**Shift 10%**	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	**Shift 20%**	**Shift 20%**	**Shift 20%**	Shift 20% to A+ and A++	Increase 20%
Decrease 30%	**Decrease 30%**	Shift 45%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	**Shift 40% to A+ and A++**	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Transport / **Target**

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	**GHG emissions reduction**
Maintain	Maintain	Maintain	Maintain	Maintain	**Maintain**	**Maintain**	**-23%**
Shift 10%	**Shift 10%**	**Shift 10%**	**Shift 20%**	Shift 20%	Shift 20%	Shift 20%	
Shift 20%	Shift 20%	Shift 20%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	Shift 60%	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	**Shift 80%**	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	

Figure 57 – Screenshot of the alternative generation table for alternative A2 – High diversified policies.

A3 – Lifestyles changes

It displays actions arising from less energy intensive lifestyles, such as higher penetration of energy efficient equipment, renewable energies and modal shift to low-carbon modes of transport.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain
Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	**Shift 10%**	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20% to A+ and A++	**Increase 20%**
Decrease 30%	Shift 45%	Shift 30%	Shift 30%	**Shift 30%**	**Shift 30%**	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	**Shift 50% to A+ and A++**	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	**Shift 10%**	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	**Decrease 20%**	Shift 30%	Shift 20%	**Shift 20%**	**Shift 20%**	**Shift 20%**	**Shift 20% to A+ and A++**	Increase 20%
Decrease 30%	Decrease 30%	**Shift 45%**	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Transport / **Target**

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	**GHG emissions reduction**
Maintain	Maintain	Maintain	Maintain	Maintain	**Maintain**	**Maintain**	**-30%**
Shift 10%	Shift 10%	Shift 10%	**Shift 20%**	Shift 20%	Shift 20%	Shift 20%	
Shift 20%	**Shift 20%**	**Shift 20%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	Shift 60%	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	**Shift 80%**	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	

Figure 58 – Screenshot of the alternative generation table for alternative A3 – Lifestyles changes.

A4 – Great Resilience

It comprises actions to reduce the oil dependence, increase the diversity of transport modes and promote Transit-Oriented Development. Reducing oil dependence contributes to a less vulnerable city in cases of shortages in fossil fuel supplies.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Shift 15%	**Shift 10%**	Shift 10%	Shift 10%	Shift 10%	**Shift 10%**	**Shift 10%**	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	**Shift 20%**	Shift 20%	Shift 20%	Shift 20% to A+ and A++	**Increase 20%**
Decrease 30%	Shift 45%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	**Shift 40% to A+ and A++**	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	**Shift 10%**	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	**Shift 20%**	**Shift 20%**	**Shift 20%**	Shift 20% to A+ and A++	**Increase 20%**
Decrease 30%	**Decrease 30%**	Shift 45%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	**Shift 40% to A+ and A++**	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Transport / **Target**

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	GHG emissions reduction
Maintain	Maintain	Maintain	Maintain	**Maintain**	Maintain	Maintain	-39%
Shift 10%	Shift 10%	**Shift 10%**	Shift 20%	Shift 20%	Shift 20%	**Shift 20%**	
Shift 20%	**Shift 20%**	Shift 20%	**Shift 40%**	Shift 40%	**Shift 40%**	Shift 40%	
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	Shift 60%	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	Shift 80%	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	

Figure 59 – Screenshot of the alternative generation table for the alternative A4 – Great Resilience.

A5 – Business changes

It aims at achieving greater energy efficiency and deployment of renewable energies, mainly acting on the Services sector.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20% to A+ and A++	Increase 20%
Decrease 30%	Shift 45%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	Shift 10%	Shift 10%	Shift 10%	Shift 10%	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20% to A+ and A++	Increase 20%
Decrease 30%	Decrease 30%	Shift 45%	Shift 30%	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Transport / **Target**

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	GHG emissions reduction
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	-20%
Shift 10%	Shift 10%	Shift 10%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	
Shift 20%	Shift 20%	Shift 20%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	Shift 60%	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	Shift 80%	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	

Figure 60 – Screenshot of the alternative generation table for alternative A5 – Business changes.

A6 – Sustainable Barreiro

It includes diversified actions which the local actors perceive as feasible and that could drive to a sustainable city by 2020.

Households

Building's heating needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of electric heaters to natural gas central boilers	Space heating shift of electric heaters to heat pumps	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating shift of fireplaces to pellet stoves	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	**Maintain**	Maintain	Maintain	Maintain	**Maintain**	**Maintain**	Maintain	Maintain
Decrease 10%	**Shift 15%**	Shift 10%	**Shift 10%**	Shift 10%	**Shift 10%**	Shift 10%	Shift 10%	Shift 10% to A+ and A++	**Increase 10%**
Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20% to A+ and A++	Increase 20%
Decrease 30%	Shift 45%	Shift 30%	Shift 30%	**Shift 30%**	Shift 30%	Shift 30%	Shift 30%	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Shift 60%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40%	**Shift 40% to A+ and A++**	Increase 40%
Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	Shift 50% to A+ and A++	Increase 50%

Services

Building's heating needs	Building's cooling needs	Water heating fossil fuel shift to solar	Water heating fossil fuel shift to renewable heat (DHC/CHP)	Space heating fossil fuel shift to solar radiant heating	Space heating fossil fuel shift to renewable heat (DHC/CHP)	Space cooling electric heat pump shift to renewable heat (DHC/CHP)	Refrigerators and freezers' efficiency	Small-scale renewable electricity generation
Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain	Maintain
Decrease 10%	Decrease 10%	Shift 15%	**Shift 10%**	**Shift 10%**	Shift 10%	Shift 10%	Shift 10% to A+ and A++	Increase 10%
Decrease 20%	Decrease 20%	Shift 30%	Shift 20%	Shift 20%	Shift 20%	Shift 20%	Shift 20% to A+ and A++	**Increase 20%**
Decrease 30%	**Decrease 30%**	Shift 45%	Shift 30%	Shift 30%	**Shift 30%**	**Shift 30%**	Shift 30% to A+ and A++	Increase 30%
Decrease 40%	Decrease 40%	**Shift 60%**	Shift 40%	Shift 40%	Shift 40%	Shift 40%	Shift 40% to A+ and A++	Increase 40%
Decrease 50%	Decrease 50%	Shift 75%	Shift 50%	Shift 50%	Shift 50%	Shift 50%	**Shift 50% to A+ and A++**	Increase 50%

Transport / **Target**

Modal shift of individual passenger cars to collective transport	Modal shift of individual passenger cars to cycling and walking	Fuel shift to electric cars	Fuel shift to electric buses	Fuel shift to CNG buses	Fuel shift to biodiesel buses	Fuel shift to hydrogen buses	GHG emissions reduction
Maintain	Maintain	Maintain	**Maintain**	Maintain	Maintain	**Maintain**	
Shift 10%	Shift 10%	**Shift 10%**	Shift 20%	Shift 20%	Shift 20%	Shift 20%	
Shift 20%	**Shift 20%**	Shift 20%	Shift 40%	**Shift 40%**	**Shift 40%**	Shift 40%	-21%
Shift 30%	Shift 30%	Shift 30%	Shift 60%	Shift 60%	Shift 60%	Shift 60%	
Shift 40%	Shift 40%	Shift 40%	Shift 80%	Shift 80%	Shift 80%	Shift 80%	
Shift 50%	Shift 50%	Shift 50%	Shift 100%	Shift 100%	Shift 100%	Shift 100%	

Figure 61 – Screenshot of the alternative generation table for the alternative A6- Sustainable Barreiro.

5.7 Assessing the impacts of the alternatives

The impacts of each alternative in comparison to the reference scenario were quantified by using the end-use energy model developed. The calculation of each attribute followed the method described in section 4.7. Each attribute refers to the difference between the results of an alternative and the results of the reference scenario. In what regards the reference scenario, its results were calculated for the indicators presented in Table 29. Those indicators served as basis for the calculation of the attributes. Table 29 also shows the results of the indicators for the base year. Table 30 presents the impact matrix constructed for the six alternatives. This matrix synthesises all attributes measured in cardinal numbers for each alternative.

Table 29 – Results for the base year and for the 2020 reference scenario.

	Tonnes CO_2 eq.	Tonnes NO_x	Number of jobs	Toe of imported fossil fuels	Toe for space heating and cooling	Number of pkm (million) in passenger cars	Energy service cost per household per year
Base year	189713	358	n.a.	69546	4089	741	2183
Reference scenario	208385	392	n.a.	77002	6940	940	3374

n.a. – not available

Table 30 – Impact matrix for the six alternatives.

Alternative \ Attribute		Tonnes CO_2 eq. reduced	Tonnes NO_x reduced	Number of net jobs gained	Toe of imported fossil fuels reduced	Toe reduced for space heating and cooling	Number of pkm (million) shifting from passenger cars to public transit, walking and cycling	Euros saved per household per year
A1	Diversified policies	55975	87	52	20726	2786	360	331
A2	High diversified policies	61511	210	86	22311	3086	480	670
A3	Lifestyles changes	76356	259	112	27550	2836	600	958
A4	Great resilience	92546	205	112	34541	2607	600	887
A5	Business changes	55852	106	63	20982	2869	240	303
A6	Sustainable Barreiro	58658	111	76	21464	2095	480	777

In order to get a better sense of how much the impact of each alternative according to each attribute was in relation to the reference scenario, an impact matrix expressed in relative values (Table 31) was provided to the local actors. This matrix shows the percentage of reduction or increase in each attribute in relation to the reference scenario.

Table 31 – Impact matrix for the six alternatives with relative values in relation to reference evolution.

Attribute / Alternative		Tonnes CO_2 eq. reduced		Tonnes NO_x reduced	Number of net jobs gained	Toe of imported fossil fuels reduced	Toe reduced for space heating and cooling of homes and offices	Number of pkm (million) shifting from passenger cars to public transit, walking and cycling	Euros saved per household per year
		% reduction	% target*	% reduction	% increase	% reduction	% reduction	% reduction	% reduction
A1	Diversified policies	27%	20%	22%	n.a.	27%	40%	38%	10%
A2	High diversified policies	30%	23%	53%	n.a.	29%	44%	51%	20%
A3	Lifestyles changes	37%	30%	66%	n.a.	36%	41%	64%	28%
A4	Great resilience	55%	39%	52%	n.a.	45%	38%	64%	26%
A5	Business changes	27%	20%	27%	n.a.	27%	41%	26%	9%
A6	Sustainabl e Barreiro	28%	21%	28%	n.a.	28%	30%	51%	23%

* reduction in relation to the base year, according to the GHG emission reduction target set of 20% by 2020 in relation to 2008.

5.8 Building value functions for each objective

Having the impact matrix (Table 30) as a reference, the local actors who participated in the decision conference process were asked to define a 'neutral' reference level (with the nuance that for the attribute 'Tonnes CO_2 eq. Reduced' the group preferred to analyse using the percentages of reduction presented in Table 31); this means to define a performance that would be neither positive nor negative in the linked objective. The group was also asked to define a 'good' reference level for each attribute, i.e. an impact level considered significantly attractive in the light of the objective. Figure 62 shows the performance reference levels defined for each attribute having as basis the impacts of the alternatives (presented in Table 30 and Table 31).

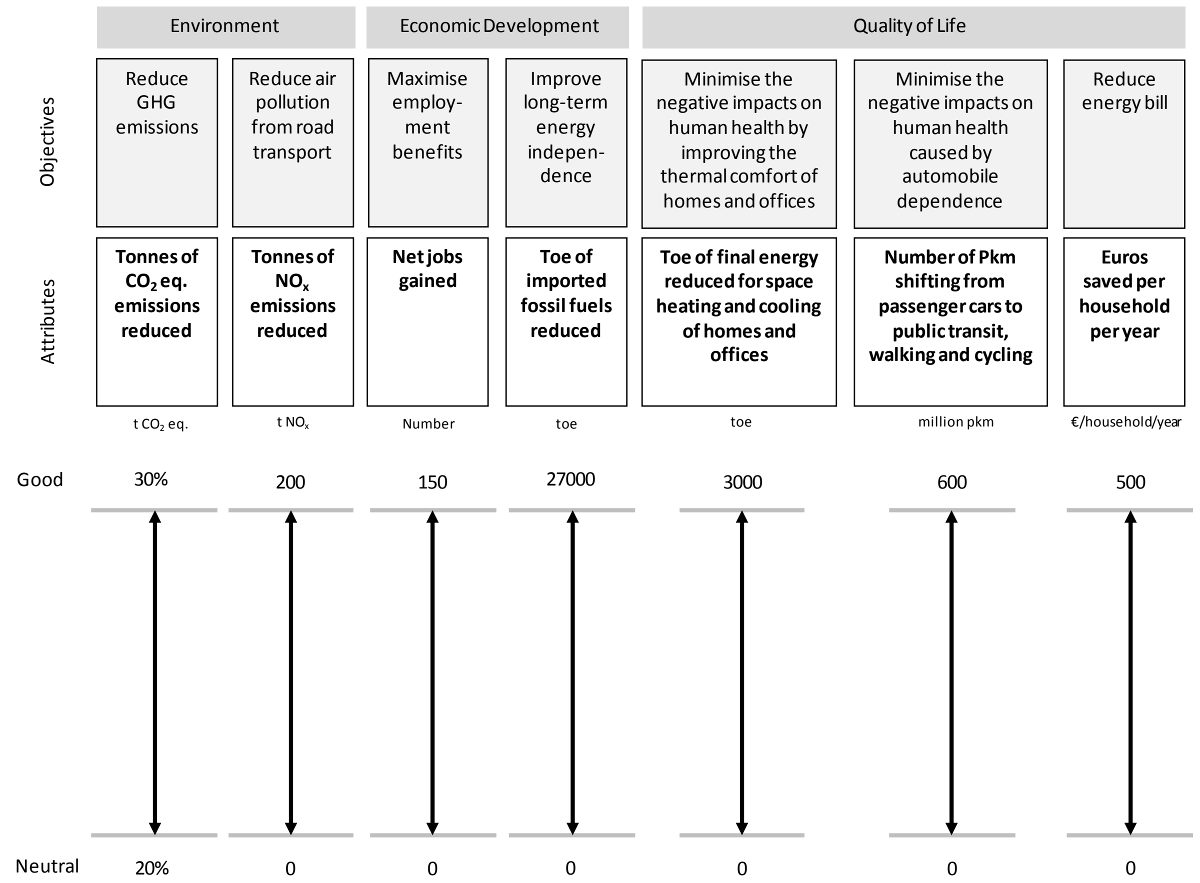


Figure 62 – References 'Good' and 'Neutral' for each attribute.

Afterwards, two more preference levels were added to each attribute (one intermediate performance between neutral and good, and one performance better than good) such that each attribute had four plausible performance levels equally spaced in the attribute scale. The group was then asked to judge the differences in attractiveness between each two levels of performance, choosing one of the MACBETH semantic categories: *very weak, weak, moderate, strong, or extreme*. For each objective, the process was initiated by asking the difference in attractiveness between the 'neutral' performance level and the 'good' performance level. For instance, the group was questioned about the difference of attractiveness between 0 tonnes of NO_x emissions reduced (neutral) and 200 tonnes of NO_x emissions reduced (good), which the group classified as very strongly attractive (see the 'v. strong' in the second row and last column of Figure 63 (b)). The process was followed by asking the difference in attractiveness between each two of the other combinations of performance levels (e.g. 300 and 100 tonnes of NO_x emissions reduced). Figure 63 presents the group judgements matrix for each objective.

(a) Tonnes of CO_2 eq. emissions reduced (in %)

	35	30	25	20
35	no	v. strong	v. strong	extreme
30		no	strong	v. strong
25			no	strong
20				no

(b) Tonnes of NO_x emissions reduced

	300	200	100	0
300	no	v. strong	extreme	extreme
200		no	strong	v. strong
100			no	strong
0				no

(c) Number of net jobs gained

	225	150	75	0
225	no	moderate	strong	v. strong
150		no	moderate	strong
75			no	moderate
0				no

(d) Toe of imported fossil fuels reduced

	40500	27000	13500	0
40500	no	v. strong	v. strong	extreme
27000		no	strong	v. strong
13500			no	moderate
0				no

(e) Toe reduced for space heating and cooling of homes and offices

	4500	3000	1500	0
4500	no	v. strong	extreme	extreme
3000		no	strong	v. strong
1500			no	strong
0				no

(f) Number of pkm (million) shifting from passenger cars to public transit, walking and cycling

	900	600	300	0
900	no	strong	v. strong	extreme
600		no	strong	v. strong
300			no	strong
0				no

(g) Euros saved per household per year

	750	500	250	0
750	no	v. strong	extreme	extreme
500		no	v. strong	v. strong
250			no	strong
0				no

Figure 63 – M-MACBETH judgements matrix for each objective.

The qualitative judgements inputted in the matrixes presented in Figure 63 were then transformed in a numerical value scale by M-MACBETH decision support system using linear programming (Bana e Costa, De Corte & Vansnick, 2012). According to that method, the numerical scale was anchored on the two predefined reference levels, 'neutral' and 'good', to which were assigned the scores 0 and 100, respectively. The proposed MACBETH scale was then subjected to group analysis and discussion in terms of proportions of the resulting scale intervals. M-MACBETH displays an interval around a value score of a performance level (except for the fixed neutral and good reference performances) within which it can be adjusted without violating the relationships between the qualitative judgements inputted in the matrix of judgements. In the case of Barreiro, the group decided to make minor adjustments on the value scales of some objectives. The value functions obtained for each objective after the group discussion are shown in Figure 64.

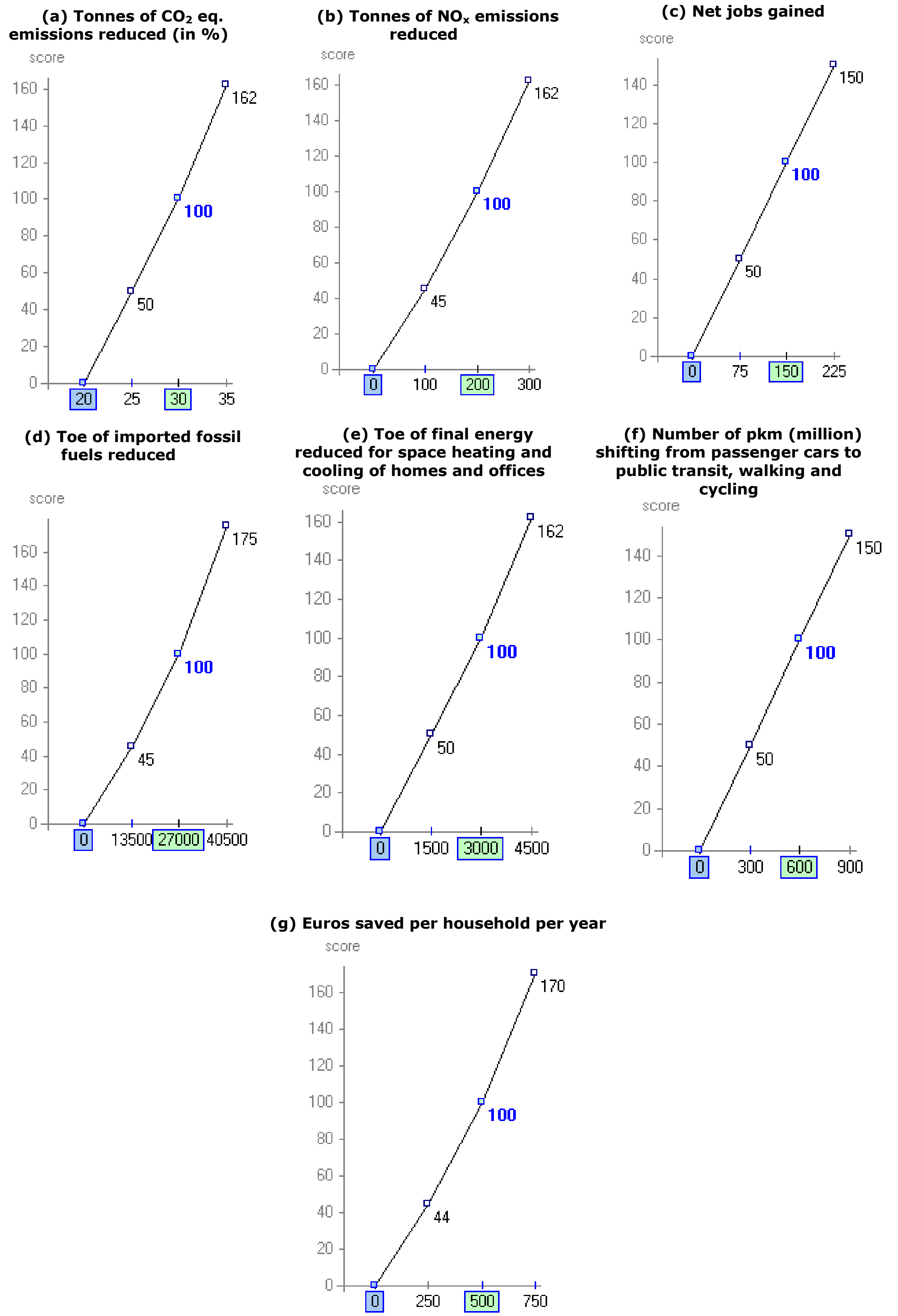


Figure 64 – Value functions for each objective.

5.9 Weighting the objectives

The relative weights for the seven objectives were defined using the MACBETH weighting procedure. The group was first asked to rank the 'neutral-good' swings by their overall attractiveness. The facilitator started by asking the question: 'From the seven objectives, if you could choose just one objective to change from a neutral performance to a good performance which objective would you choose?' The questioning procedure continued until the final ranking of 'neutral-good' swings was achieved.

During the MACBETH questioning procedure to fill in the weighting judgements matrix (Figure 66), the group engaged in a deeper thinking and discussion about the relative importance of the 'neutral-good' swings and decided to change the ranking of the second, third and fourth most attractive swings (initially set as 'Reduce GHG emissions' (2nd), 'Reduce energy bill' (3rd) and 'Reduce air pollution from road transport' (4th)). The final ranking of the 'neutral-good' swings is presented in Figure 65.

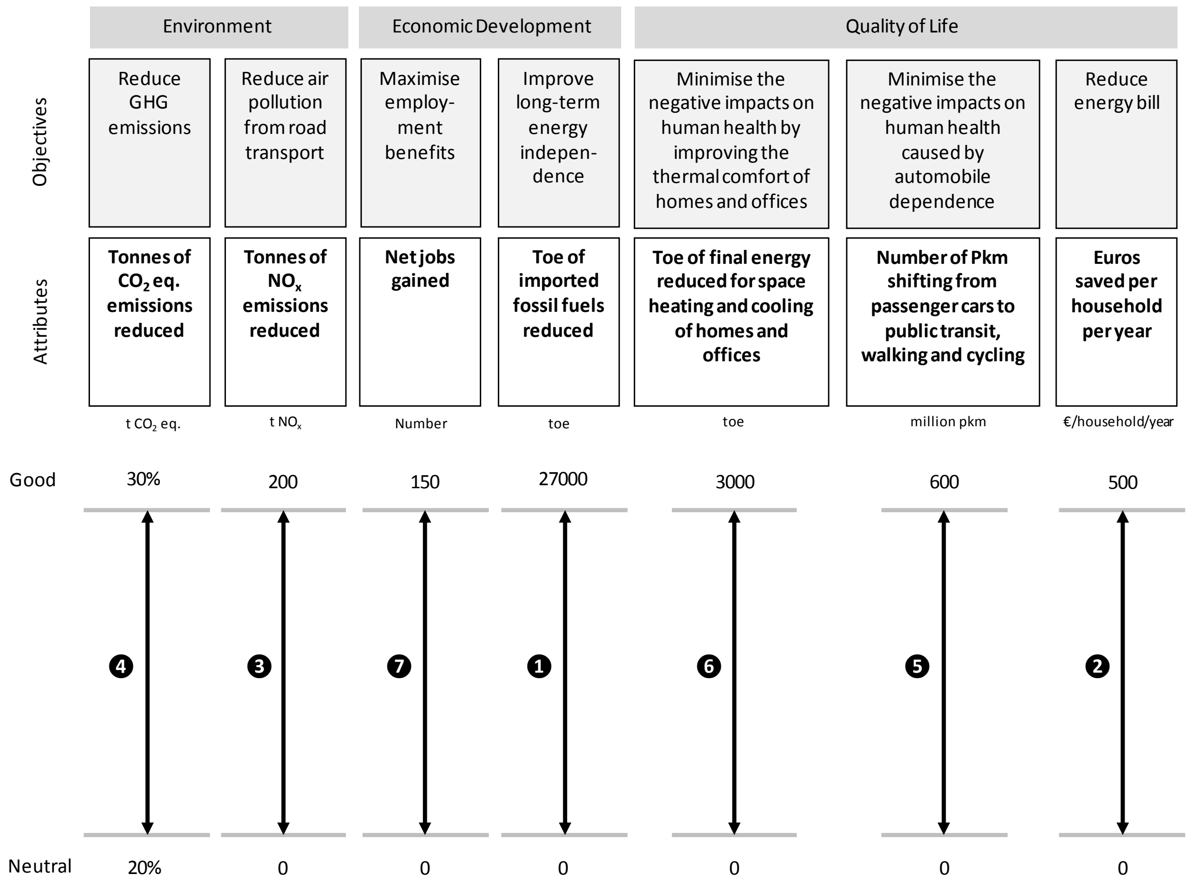


Figure 65 – Final ranking of the swings.

For completing the weighting matrix of judgements (Figure 66), the group was asked to judge the overall attractiveness of each 'neutral-good' swing, which allowed filling in the last column of the MACBETH matrix in Figure 66. For example, the 'neutral-good' swing on the objective 'Improve long-term energy independence' [Imp energy indep] was considered to be of *extreme* overall attractiveness (see the rightmost cell in the first row of the weighting matrix in Figure 66).

Subsequently, the group was asked to pairwise compare the most attractive swing to the second most attractive. For example, 'How much more attractive would be the improvement from neutral to good on 'Improve long-term energy independence' [Imp energy indep] than the improvement of neutral to good on 'Reduce energy bill' [Red energy bill]? The group considered it to be of *very weak* attractiveness (see the second cell in the first row of the weighting matrix in Figure 66). The pairwise comparison continued between the most attractive swing and each of the other swings until filling in the first row of the MACBETH matrix (Figure 66).

Afterwards, judgements concerning the comparison of each two consecutive swings were also made. For example, the group was asked: 'How much more attractive would be the improvement from neutral to good on 'Reduce energy bill' [Red energy bill] than the improvement on 'Reduce air pollution from road transport' [Red air pollution]? The group considered it to be of *very weak* attractiveness. When asked about 'How much more attractive would be the improvement from neutral to good on 'Minimise the negative impacts on human health by improving the thermal comfort of homes and offices' [Health Imp comfort] than the improvement from neutral to good on 'Maximise employment benefits' [Max employment], the group considered that the improvements on health impacts would be *strongly* more attractive than the improvements on employment.

Knowing that the judgements already included in the matrix of judgements (Figure 66) were enough for the M-MACBETH software (Bana e Costa, De Corte & Vansnick, 2005b) to create a weighting scale and since the group did not wish to provide additional judgements the facilitator stopped the questioning procedure.

	[Imp energy indep]	[Red energy bill]	[Red air pollution]	[Red GHG]	[Health Red auto dep]	[Health Imp comfort]	[Max employment]	[all Neutral]
[Imp energy indep]	no	very weak	very weak	vweak-weak	weak-mod	mod-strg	v. strong	extreme
[Red energy bill]		no	very weak	positive	positive	positive	positive	extreme
[Red air pollution]			no	weak	positive	positive	positive	extreme
[Red GHG]				no	weak	positive	positive	extreme
[Health Red auto dep]					no	moderate	positive	v. strong
[Health Imp comfort]						no	strong	strong
[Max employment]							no	moderate
[all Neutral]								no

Legend:
[Imp energy indep] – Improve long-term energy independence (O4)
[Red energy bill] – Reduce energy bill (O7)
[Red air pollution] – Reduce air pollution from road transport (O2)
[Red GHG] – Reduce GHG emissions (O1)
[Health Red auto dep] – Minimise the negative impacts on human health caused by automobile dependence (O5)
[Health Imp comfort] – Minimise the negative impacts on human health by improving the thermal comfort of homes and offices (O5)
[Max employment] – Maximise employment benefits (O3)

Figure 66 – Weighting matrix of judgements.

Figure 67 presents the weighting scale suggested by the M-MACBETH software. The facilitator asked the group to check the resulting weights in order to validate them. For example, the facilitator asked if the 'neutral-good' swing on objective 'Reduce GHG emissions' [Red GHG] is worth four times the 'neutral-good' swing on objective 'Maximise employment benefits' [Max employment] (note that the weights of these objectives are 16% and 4%, respectively), and also if the 'neutral-good' swing on objective 'Improve long-term energy independence' [Imp energy indep] is worth 1.9 times the 'neutral-good' swing on objective 'Minimise the negative impacts on human health by improving the thermal comfort conditions of homes and offices' [Health Imp comfort], which the group agreed.

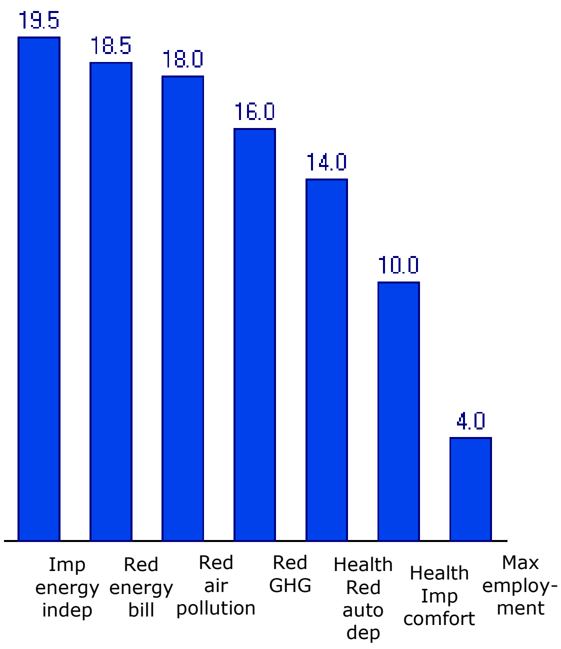


Figure 67 – Weights of the objectives (in percentages).

Note that the weighting procedure described in this section included group judgements that required the acceptance of compensations between performances in two different objectives. The fact that the group accepted to express these judgements validates the working hypothesis of compensability between objectives (referred in section 3.5), which is a required premise for additive aggregation (section 5.10).

5.10 Aggregating partial value functions

The M-MACBETH decision support system calculated an overall benefit score for each alternative by weighted summation of its individual value scores, i.e. by applying the additive model presented in section 4.8.3. At the end of the decision conference, it was possible to visualise the overall benefit scores of each of the six alternatives created (see column ‘Overall’ in Table 32).

The alternative A4 ranked first with 143.83 benefit units and alternative A3 ranked second with 128.25 benefit units. Both A4 and A3 obtained overall scores higher than that of a hypothetical alternative ‘all Good’, i.e. an alternative with a ‘good’ performance in all attributes (see Figure 62). The fact that those two alternatives are better than the hypothetical alternative ‘all Good’ shows that they are very attractive alternatives. The remaining alternatives also had positive overall scores, i.e. higher scores than that of a hypothetical alternative ‘all Neutral’, which means that all of them are globally attractive.

Table 32 – Partial and overall benefit value scores of the alternatives.

Alternatives	Benefit value scores							
	O1 [Red GHG]	**O2** [Red air pollution]	**O3** [Max employment]	**O4** [Imp energy indep]	**O5** [Health Imp Comfort]	**O6** [Health Red auto dep]	**O7** [Red energy bill]	**Overall**
A4	211.60	103.10	74.67	141.89	86.90	100.00	208.36	**144.31**
A3	100.00	136.58	74.67	103.06	94.53	100.00	228.24	**129.34**
[all Good]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	**100.00**
A2	30.00	106.20	57.33	80.90	103.55	80.00	147.60	**90.85**
A6	10.00	51.05	50.67	77.46	69.83	80.00	177.66	**78.95**
A1	0.00	39.15	34.67	74.44	92.07	60.00	62.14	**52.13**
A5	0.00	48.30	42.00	75.48	95.63	40.00	55.87	**50.59**
[all Neutral]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Weights	0.1600	0.1800	0.0400	0.1950	0.1000	0.1400	0.1850	-

Figure 68 displays the benefit value scores of each alternative, including the hypothetical 'all Good', on each objective. Alternative A4 stands out for its high value scores in objectives O1, O4 and O7, going beyond the 'good' reference levels defined by the local actors for those objectives. Alternative A3 surpasses slightly A4 in objectives O7 and O2. For the objective 'reduce energy bill' (O7) it is observed that four out of six alternatives have value scores greater than the 'good' reference level, while for the objective 'maximise employment benefits' (O3) all alternatives are considerable below the 'good' reference level. Other objective for which alternatives are slightly below the 'good' reference level is the objective 'minimise negative impacts on human health by improving the thermal comfort of homes and offices' (O5). Alternatives A1 and A5 are the less attractive alternatives; in overall terms they are placed midway between the hypothetical 'all Good' and 'all Neutral' alternatives. The alternative created by the local actors (A6) stands out in objective O7, being in the remaining objectives below the 'good' reference levels.

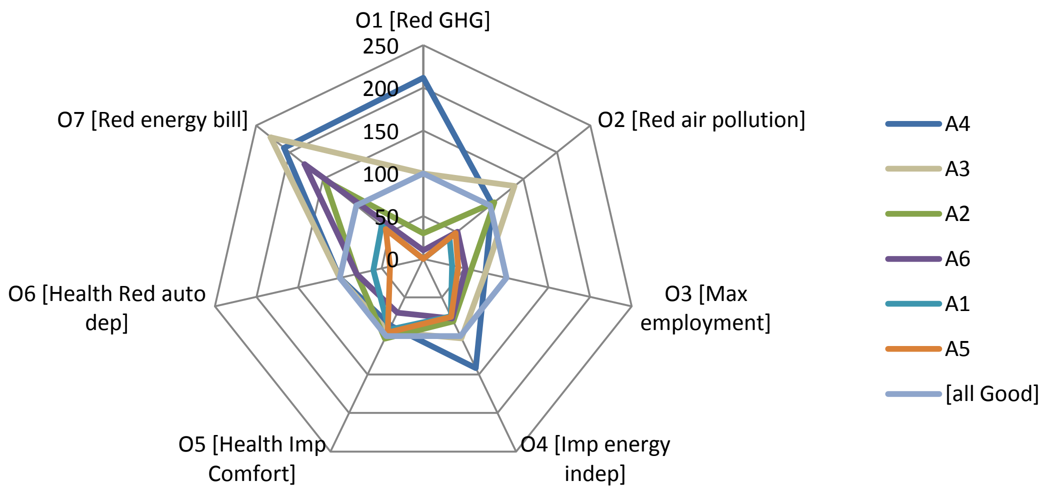


Figure 68 – Benefit value scores of alternatives for each objective.

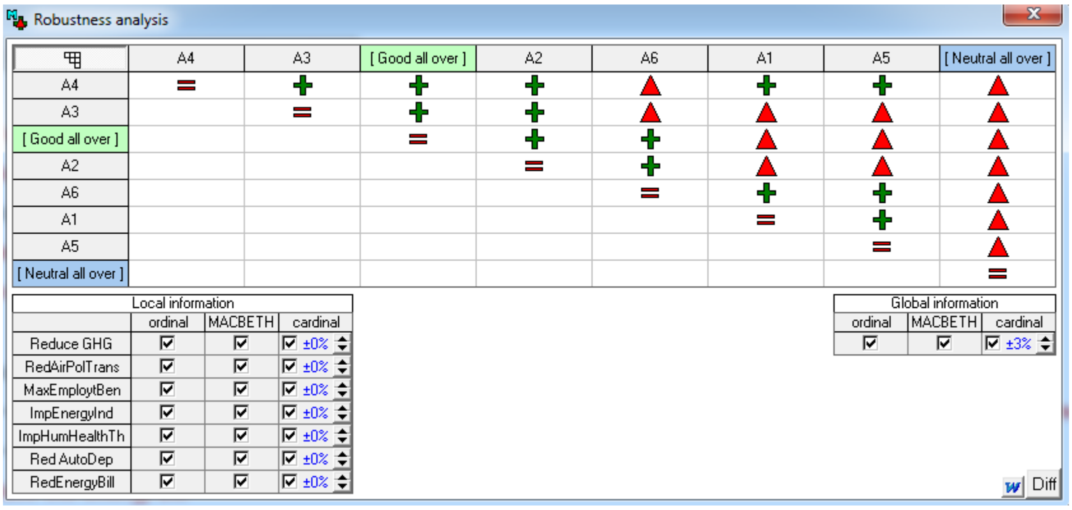
5.11 Performing the robustness analysis

Although there were not significant hesitations in the weighting process besides the initial ranking change described in section 5.9, it was decided to analyse if the ranking of the alternatives continues to be the same if small variations on the weights of objectives occur.

A robustness analysis made with M-MACBETH considering that the objectives' weights (w_i, i=1,…,7) could vary within intervals of [w_i–3%; w_i+3%] (i=1,...,7), but at the same time respecting the weights ranking and the group weighting judgements, revealed that A4 continues to be the most attractive alternative from the set of six alternatives evaluated. Figure 69 shows the results of the robustness analysis carried out, in which it is possible to visualise the dominance from alternative A4 upon all the other alternatives (see, in Figure 69, the first row filled in with symbols showing dominance from alternative A4 upon all the other alternatives referred in the columns to the right of column A4).

A red triangle in a cell of Figure 69 indicates dominance in the classic sense – the alternative in row is always preferred to the alternative in column irrespectively of the constraints defined upon the parameters of the model. For example, in Figure 69 alternative A4 dominates alternative A6, which can be easily detected because alternative A4 scores higher than A6 in all the objectives (see Figure 68). A green cross in a cell of Figure 69 means that the alternative in row additively dominates the alternative in column – this dominance relationship depends on the constraints defined upon the parameters of the additive model (in this case, the variation of ±3% on the criteria weights). The additive dominance relationship requires M-MACBETH to solve a linear programming problem subject to the defined constraints (rank order, MACBETH judgements and weights' intervals) between each two alternatives.

Moreover, the robustness analysis showed that the ranking of the alternatives was kept unchanged (in comparison to Table 32) and consequently that the results are stable for the uncertainty considered in the objectives' weights. In this case, the choice of 3% variation in the objectives' weights was based on the objective with the lower weight (equal to 4%) so that its weight would not be zero.



Legend:

'Dominance': an option dominates another if it is at least as attractive as the other in all attributes and it is more attractive than the other in at least one attribute.

'Additive dominance': an option additively dominates another if it is always found to be more attractive than the other through the use of an additive model under a set of information constraints.

Figure 69 – Robustness analysis.

5.12 Analysing benefit vs. investment

After having obtained the overall benefit value scores for the alternatives, these benefit value scores were plotted and analysed against the investment needs of each of the alternatives. This allows the decision-makers to have a better understanding of the balance between benefits and expected investment for each of the alternatives.

The investment needs were determined by using the end-use energy model developed, in which data on the investments per action determined by Souza (2011) was inserted. For the investments concerning actions on renewable electricity it was assumed the investment for photovoltaic decentralised system from Gomes (2008), since it was the most common installed micro-generation technology, due to the more favourable feed-in tariff which contributes to reduce the return of the investment.

The investment data used refers to the overall amount of money that is required from the different stakeholders in the society to implement the actions that make part of an alternative, i.e. purchase of new equipment and associated installation costs. This data, expressed in euros per kWh for households and services sectors and in euros per pkm for transport sector, is applied to the difference in final energy consumed or saved per end-use and in pkm by mode of transport of each alternative in relation to the reference scenario.

Table 33 presents the estimated investment by sector and the total investment for each of the alternatives evaluated. It is possible to see that investments range from 300 million up to almost 700 million euros for the full implementation of an energy action plan by 2020. As this corresponds to the investment of the whole society, the local authority will need to identify and apply the financing mechanisms better suitable to foster the implementation of the defined actions.

Table 33 – Estimated investment needs for the implementation of the alternatives.

Alternative		Investment cost (million €)				
		Households	**Services**	**Transport**	**Decentralised electricity generation**	**Total**
A1	Diversified policies	95	90	174	77	436
A2	High diversified policies	116	94	164	76	450
A3	Lifestyles changes	123	67	201	114	505
A4	Great resilience	117	94	302	158	671
A5	Business changes	87	92	191	116	486
A6	Sustainable Barreiro	57	65	105	76	303

Figure 70 contrasts each alternative's overall benefit value score (presented in Table 32) with its respective investment in million euros (presented in Table 33). The red line in Figure 70 identifies the efficient frontier, which is the line that connects the dots that represent efficient alternatives. An alternative *E* is efficient when there is no alternative *F* that provides more benefit than alternative *E* without costing more than alternative *E*, or that costs less than alternative *E* without having less benefit than alternative *E*.

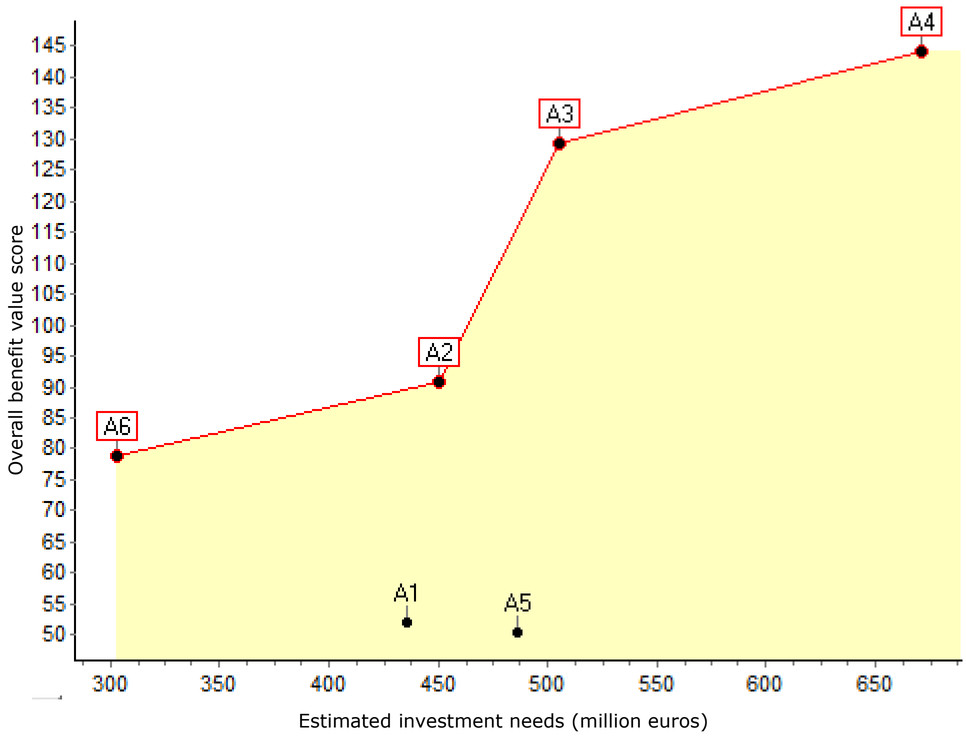


Figure 70 – Benefit vs. investment graph for the six alternatives.

Alternatives A6, A2, A3 and A4 are efficient alternatives. The alternatives A1 and A5 are dominated by alternative A6, which provides more benefit and is less expensive than alternatives A1 and A5. Alternative A4, which ranked first in terms of its overall benefit score, is the most expensive efficient alternative. The alternative created by the local actors, alternative A6, is the efficient alternative that provides less benefit but is also the less expensive one.

In face of the information presented above, a decision-maker should select an alternative from the set of efficient alternatives. The decision-maker may select the cheapest efficient alternative (A6), the efficient alternative with the highest overall benefit (A4) or one of the remaining efficient alternatives (A2 or A3). The procedure for helping the decision-maker in the choice of one alternative from the efficient frontier is described below (Edwards and Newman, 1986 *fide* Goodwin & Wright, 2004).

The calculations show that alternative A2 costs more 147 million euros than alternative A6 to add only 11.90 overall benefit units. Hence, alternative A2 represents an additional investment upon alternative A6 of 12.32 million euros per each extra overall benefit unit. Alternative A3 costs more 202 million euros than alternative A6 but it provides more 50.39 benefit units. Hence, alternative A3 implies an additional investment upon alternative A6 of 4.01 million euros per each extra overall benefit unit. This is far less expensive than the 12.32 million euros per each extra overall benefit unit that alternative A2 adds upon alternative A6. This may suggest that selecting alternative A2 may not be a wise choice. If the decision-maker considers that is not worth paying 4.01 million euros per each extra overall benefit unit, then alternative A6 should be selected. If by the contrary, the decision-maker considers acceptable to pay 4.01 million euros per each extra overall benefit unit, then alternative A6 should be dropped from the analysis and the analysis should proceed with alternatives A3 and A4. Selecting alternative A4 instead of alternative A3 implies paying more 166 million euros to obtain more 14.97 overall benefit units, which corresponds to an investment of 11.10 million euros per each extra overall benefit unit. Once more, the decision-maker is faced with the question of whether it is worth paying that amount of money per each extra overall benefit unit. If the answer is positive alternative A4 should be selected, otherwise the decision-maker should select alternative A3.

Based on the incremental investment and benefits reasoning described above, and summarised in Table 34, alternative A3 would be the selected one.

Table 34 – Incremental benefit and investment analysis of efficient alternatives.

	Benefit value score	Investment (million €)	Comparison of efficient alternatives	Incremental benefit value	Incremental investment	Incremental investment/ benefit ratio	Choice
A6	78.95	303	-	-	-	-	-
A2	90.85	450	A6 and A2	11.90	146.57	12.32	pick A6
A3	129.34	505	A6 and A3	50.39	201.90	4.01	pick A3
A4	144.31	671	A3 and A4	14.97	166.21	11.10	pick A3

When analysing the actions that make part of alternative A4, it is possible to observe that the main action responsible for the higher investment in A4 in relation to the other alternatives is the introduction of hydrogen buses. This action is particularly expensive but makes alternative A4 stand out in what concerns three out of four of the most attractive objectives, namely ‘improve long-term energy independence’ (O4), ‘reduce air pollution from road transport’ (O2) and ‘reduce GHG emissions’ (O1).

Both alternatives A3 and A4 achieve the greatest benefit value scores but require the highest investment. Alternative A3 has the highest investment from all the alternatives in the households sector. The main difference relies in changes in space heating technologies, namely shift to solar-based space heating which is a considerable expensive technology. In transport, A3 is characterised by a greater introduction of electric vehicles than alternative A4, but similar to alternative A5. Also, with a considerable contribution for the accomplishment of most of the objectives is the modal shift to cycling and walking foreseen in both A3 and A4. In what concerns decentralised renewable electricity generation, A4 is the alternative with the highest degree of implementation regarding renewables. This is also a reason for its increased investment cost.

Alternative A6 is composed by actions with low degree of implementation, particularly in solar thermal for hot water when comparing to the other alternatives. The main difference to alternative A1 is the consideration of a greater modal shift to cycling and walking which was not at all considered in A1. Alternative A2 includes a greater degree of implementation of actions in comparison to A1 and A6, considerably in the case of solar thermal for hot water, but in what regards the modal shift to walking and cycling is less ambitious than A6. Thus, the reason for the low investment costs of A6 relies greatly in the degree of implementation of the action oriented to shift passenger-km from passenger cars to cycling and walking modes.

Finally, alternative A5, which targets mostly the services sector, presents a high investment for the low benefits delivered comparing to the other alternatives. The main difference relies in the foreseen actions in the transport sector, since this alternative is much less ambitious than the other alternatives in modal shift-related actions. Actions oriented to shift passenger-km from passenger cars to collective transport and to cycling and walking have proven to contribute greatly to the achievement of the objectives.

5.13 Final notes

This chapter was dedicated to the application of the methodology proposed in chapter 4 with the following purposes:

1) to demonstrate how the steps of the methodology can be applied to a practical case;
2) to identify bottlenecks and make adjustments to the methodology;
3) to explore the outcomes.

Regarding point 1) the steps of the methodology related to energy modelling were made operational via the development of the local energy planning assistant tool which implemented the end-use energy model developed. Section 5.3 presented the results of the energy modelling exercise for Barreiro and sections 5.6 and 5.7 focused on the process of generating and assessing the performance of alternatives, further used for the multi-criteria evaluation process. With respect to the steps related to decision analysis, the operationalization was possible via the use of the M-MACBETH software tool (sections 5.8, 5.9, 5.10, 0 and 5.12).

The end-use energy model implemented in the local energy planning assistant tool (section 5.3.1) was able to provide a very comprehensive characterisation of current and future energy demand (shown in section 5.3). The disaggregation level of energy demand into end-use categories was essential to study the effects of the application of different actions, and in this way to construct alternatives to the reference scenario.

The use of the M-MACBETH software tool allowed visualising the construction of the model and its results on the spot. Initially, the local actors experienced difficulty in judging the differences of attractiveness required by MACBETH between each two levels of performance in each attribute (section 5.8) as well as the differences of attractiveness during pairwise comparison of the objectives to assess the weights (section 5.9). The origin of such difficulty was in the technical information regarding the performance of the alternatives presented to the local actors (Table 30). They were not familiar with the absolute values of the attributes. In order to overcome this difficulty the impact matrix with the attributes expressed in cardinal numbers (Table 30) was converted into relative values (Table 31) expressing the percentage of reduction or increase of each alternative in relation to the reference scenario. For the local actors, looking at the relative values with the absolute values in mind contributed to ease the understanding of the variation of the attributes and thus to judge the differences of attractiveness.

The judgements of attractiveness given by the group of local actors were always unanimous and no conflict situations were experienced. Some minor disagreements were observed but as soon as the group discussed the different points of view, they were afterwards able to reach an agreement regarding the judgements to provide as inputs to M-MACBETH. For this case, it was also useful the ability of M-MACBETH to allow insertion of more than one category referring to the difference of attractiveness in the matrix of judgements. For instance, as shown in the matrix of judgements in Figure 63 the group considered the improvements from neutral to good in 'reduce GHG emissions' to be *very weak* or *weak* more attractive than the improvements from neutral to good in 'improve long-term energy independence'. The fact that the group was to some extent homogeneous might have been a reason for general agreement in all the steps of the process. Note that in the presence of conflicts the process could be for instance based in a voting system (e.g. Bana e Costa *et al., forthcoming*) or in the construction of more than one model representing the different points of view (e.g. Bana e Costa *et al.*, 2001).

The application of the proposed methodology to Barreiro also led to the identification of a major bottleneck (point 2). The level of disaggregation of the end-use energy model by end-use has shown that intensive data collection is required and that most of the necessary data is still lacking at the municipal scale. Data availability is thus considered a bottleneck on the application of the proposed methodology, and currently this can only be overcome by making assumptions and scaling-down from top-down data, or through bottom-up processes of data collection promoted by local authorities. The former was adopted in this thesis. There were a few adjustments made to the methodology in order to accommodate data availability. For instance, this was the case in the use of services' GVA instead of services' floor area (because energy consumption varies with the building's size) as the key socio-economic variable to determine future energy demand in the services sector. This data was not available at the local level neither other indicators that could be used for scaling-down and thus estimate local services' floor area. The issue on local energy data availability herein raised is subject of current discussions at EU level (e.g. CoR, 2012) and it is out of the scope of this thesis.

From the analysis of the outcomes of the application of the methodology in Barreiro (point 3), it was possible to observe the following:

- The reference scenario showed that the needs for energy services (useful energy) are expected to increase by 23% until 2020, while overall final energy demand is expected to increase by 17%. This shows that improvements in end-use energy efficiency are expected to occur in the reference evolution, based on the policies in place today. The sectoral analysis revealed that the services sector leads the future increase in energy demand, which is explained by the growing trend of focusing in less energy-intensity mix of economic activity, in particular in commercial activities. Total GHG emissions are expected to rise by 10% which means that Barreiro needs to produce efforts to tackle this increase as well as the 20% GHG emissions reduction below the 2008 levels.
- The evaluation of the six alternatives to the reference scenario ranked alternatives A4 and A3 as the preferred ones in terms of overall benefit value scores. These alternatives were also positioned above the hypothetical alternative with 'good' performances in all objectives, which shows that they are indeed very attractive alternatives. The better performance of A4 and A3 is explained by the higher degree of implementation of individual actions in comparison to the other alternatives, in particular greater introduction of renewables for hot water, space heating and decentralised renewable electricity generation as well as greater modal shift from passenger cars to collective transport and walking and cycling.
- When comparing the benefit value score with estimated investment needs for the implementation of each alternative, it was observed that the alternatives delivering the greatest benefit (A4 and A3) were also the ones requiring a larger investment. Four out of six alternatives were identified as efficient alternatives (Figure 70), leading the analysis of the choice of an alternative to be restricted to this set of efficient alternatives rather than the full range. The incremental benefit and investment analysis performed led to the choice of alternative A3. The difference between A3 and A4 in terms of investment was essentially related to the introduction of hydrogen buses in A4, which considerably raise the investment needs. Low investment alternatives such as A6 concentrated in lower degree of implementation of actions and greatly on modal shift to cycling and walking.

5.14 Summary

In this chapter the methodology developed in chapter 4 was applied to the municipality of Barreiro. Issues on data collection at the local level have been identified and ways of estimating the input data that was lacking were explored. The local energy planning assistant tool presented in this chapter had the purpose to determine future energy demand under a reference scenario, and to help in the process of generating alternatives. The quantification of the impacts of the generated alternatives on each objective was performed using the tool and then transferred as inputs for the multi-criteria evaluation model. The local actors were engaged in the construction of this model, and afterwards the generated alternatives were evaluated by combining the technical information resulting from the energy modelling with local actors' preferences. At the end, an analysis of the benefits versus the expected investment of the alternatives was performed.

6. Conclusions

As discussed in chapter 1, the aim of this thesis was to develop a decision support methodology for local sustainable energy planning, focused on modelling energy demand at end-use level and on the evaluation of alternative scenarios based on multiple strategic objectives and local actors' preferences. In this context, the research question underlying this thesis was: *How to develop a methodology for decision support on local energy planning, which allows selecting a mid-term energy action plan based on local actors' sustainability objectives and preferences?*

The research question was delved in the following chapters of this thesis. Chapter 2, motivated by the wide variation and limitation of indicators being adopted in local energy planning practices, initiated the research by reviewing and proposing a set of indicators that could potentially be used in the choice of alternative energy action plans. Chapter 3 provided a review of energy models, problem structuring and multi-criteria evaluation methods. The objective was to identify the 'fitness for purpose' methods, i.e. the appropriate methods to fulfil the desired characteristics of the new methodology: end-use energy modelling and evaluation of alternative scenarios in which the multiplicity of sustainability objectives and local actor's preferences are taken into account. While 'fitness for purpose' methods were identified for problem structuring (cognitive/causal mapping and decision conferencing) and for multi-criteria evaluation (multi-attribute value theory and MACBETH), the same did not happen for energy models. It was necessary to build a new end-use energy model, which accommodates changes at energy services and technology levels according to the energy management actions selected and evaluates the impact of alternative scenarios on multiple sustainability objectives. Chapter 4 addressed the development of the decision support for local sustainable energy planning, the main objective of this thesis. The result was a patchwork of the methods identified in chapter 3 plus the development of the end-use energy model. Chapter 5 completed this work by applying the methodology to a practical case in order to demonstrate the operationalization of the methodological steps, identify potential bottlenecks, make adjustments to the methodology, if necessary, and explore the outcomes.

The main conclusions of this thesis are summarised as follows:

- Local sustainable energy planning problems are complex problems where multiple actors are involved and multiple objectives are exposed which contribute to the accomplishment of the major objective of sustainable development. Due to its different nature (environmental, economic and social) objectives are incommensurable. These characteristics put local energy planning problems in the family of ill-structured problems, for which problem structuring and multi-criteria evaluation are particularly suited in helping to solve them. Thus, the existence of multiple perspectives and of incommensurability was operationalised by means of a multi-criteria evaluation model, which allowed taking into account the multidimensional nature of the problem and the diverse units of measurement of the impacts of the alternatives on the objectives. As experienced in the case of Barreiro, the methods employed helped in promoting group interaction and shared understanding of the problem.

- The identification of a set of local energy sustainability indicators in chapter 2, which were then analysed in chapter 4, showed that the majority of those indicators needed to be adapted and others were too specific (e.g. sectoral-specific) for considering them for the evaluation of alternatives on the accomplishment of strategic sustainability objectives. Only GHG emissions from energy use and emissions of air pollutants from road transport activities were included in the selection of attributes. Indeed, it was seen that the recommended approach to define attributes was to rely on a problem structuring method and to engage the local actors in identifying the objectives of local sustainable energy planning. Attributes should then be defined for each objective by respecting the conditions specified in section 4.5.1. Nevertheless, the purpose of chapter 2 was much wider and aimed at developing a comprehensive framework of local energy sustainability indicators, which until date was lacking both in the scientific literature and on practices on the ground. This first contact with metrics in chapter 2 allowed as well performing an extensive analysis of local data availability for the case of Portugal which showed that energy and transport-related disaggregated data are still lacking at the municipal scale.

- The end-use energy model developed had the purpose of accommodating hypothetic future changes at the level of energy services, technologies and energy carriers. For this, the structure of energy demand was disaggregated by end-use for each sector of economy. This resulted in a very comprehensive model with the ability to capture the relevant aspects of a local energy system in the context of the new energy paradigm. Special emphasis was put on the energy services and on the technologies and energy carriers with which the energy services could be satisfied. Nevertheless, such level of disaggregation turned out to be data-intensive, which can constitute a drawback. Although difficulties on local data collection have been identified when drafting this thesis, this should not constitute a barrier towards the shift to an energy services-oriented planning.

- With respect to the identification of objectives of local sustainable energy planning, the methods chosen – cognitive and causal mapping – complemented with the means-ends objective procedure, revealed to be helpful for the purpose, particularly in having a good understanding of the strategic or fundamental objectives. The identification of objectives was initially made through literature review, but it was complemented with interviews to local actors. It was possible to observe that the main areas of objectives (local and global environment, economic development and quality of life) were both identified via the literature review and via the interviews. The main difference was in the means-ends objectives for which the information gathered on the individual cognitive maps was of great detail for identifying the relationships between means and fundamental objectives and consequently for specifying the meaning of the fundamental objectives in the fundamental objectives hierarchy. The interviews were made to five local actors from different contexts. It was observed a general agreement on the fundamental objectives by those actors, which might indicate that the fundamental objectives hierarchy developed and consequently the local energy planning assistant tool, can be replicated to other contexts. Even if it is not possible to guarantee that the model as implemented in the tool will fit every local situation, the rationale for its adaptation to other contexts was made clear.

- The phase of generation of alternatives was applied to Barreiro and the local actors were also invited to build one alternative by adopting the alternative generation table developed in the local energy planning assistant tool. The testing of the alternative generation table procedure suggested that it is a simple and user-friendly procedure that can be used by the local actors themselves to generate alternatives to be evaluated. Since GHG emissions reduction is the main indicator used at international level, this was defined as a constraint when building alternatives. The local actors acknowledged the feature of real-time visualisation of the degree of fulfilment of the target by the constructed alternative as useful. The option for having discrete alternatives instead of continuous alternatives was based on the fact that the methodology and tool are aimed to be used by local actors in strategic rather than in operational planning. Their involvement in the phase of creating alternatives also contributes to ensure the legitimacy of the process, since contrarily to the concept of 'black-box' they have a more 'transparent' perception of how the model works. Therefore, the main features relied on ease of use and ease of understanding, while ensuring a theoretically sound methodological basis.

- The application of MACBETH to the case of Barreiro showed that the method was suitable to be employed in the context of local energy planning, in particular when involving the local actors in decision conferencing mode. The following distinctive features were encountered:
  - After a short introduction, the method was easily understood by the group and they did not experience significant difficulties in expressing their preferences using the MACBETH semantic categories, both for building value functions for each objective and for weighting the objectives. The numerical scales proposed by the M-MACBETH software tool only needed small adjustments and in some cases no adjustment at all, to be accepted by the group.
  - The visual interface of M-MACBETH software tool worked well in the interactive environment created in the decision conference. It promoted the debate among local actors and contributed to the development of a shared understanding of the local energy planning model. The group was faced with the final and intermediate results of the model immediately on the spot, which contributed to the transparency of the process and to the sense of ownership of the model.

- Multi-criteria evaluation allowed incorporating the three sustainability dimensions (environment, economic and social) in energy planning processes, bringing a holistic perspective into the process; alternatives are evaluated not only based on the objective of reducing GHG emissions but also based on other local objectives which were identified by the local actors. This is a significant contribution in integrating different sustainability considerations into local energy planning processes.

Finally, it is believed that this thesis contributes to an emerging field, by implementing a socio-technical approach – combining technical modelling with the involvement of local actors – instead of a technocratic one to local energy planning and by considering multiple sustainability objectives into the planning process. The combination of different disciplines is the key ingredient of the methodology proposed in this thesis, which addresses the whole energy planning process – from structuring to the choice of the action plan, with a quantitatively sound basis. Thus, the methodology proposed seeks to pave the way towards sustainable and inclusive local energy planning.

Nonetheless, there are many issues that could be the basis for further research:

- The use of other multi-criteria evaluation methods – it could be interesting to use other methods in order to explore the differences in the results or in their applicability with local actors. Examples of other methods are: 1) multi-objective programming, in which the feasible alternatives are implicitly defined by a set of constraints and the aim of the optimisation is to select the efficient alternatives; 2) outranking methods such as ELECTRE, which can be interesting to apply in problems where objectives of non-compensatory nature exist; 3) portfolio decision analysis, may be applied to indicate optimal alternatives (i.e. portfolios of actions) for several levels of investment considering all possible combinations of individual actions and their different degrees of implementation, even though this requires further research on how to resolve the issues surrounding the combined effects of actions.

- The development of methods for bottom-up data collection, particularly for the transport sector – this could provide a great contribution in overcoming the major bottleneck of energy-related data collection at the local level, in particular data disaggregated by sector, end-use and energy carrier.

- Application to municipalities in different contexts/countries – in order to identify possible adjustments of the methodology dependent from the context. For instance, improve the database of energy management actions for agriculture, fisheries and forestry for the case of rural municipalities; for industry for the case of large-sized municipalities owning industrial facilities; and for energy supply for the case of municipalities (such as in Northern Europe) which directly own energy production facilities and have the power to decide on fuel shift or improved efficiency in the energy supply chain.

- The study of policy mechanisms to foster implementation of technical actions – as this thesis was particularly focused on the technical/physical actions, the political/financial mechanisms to put some of those actions in place were left for a second phase of the decision process, which can be object of research as well. Thereafter, research on finding the most effective policy mechanisms to the technical actions here identified would have a great contribution in complementing this work. It would be particularly interesting to analyse how these policies mechanisms vary from country to country, since policies are usually tailored to the political conditions of different countries.

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Appendix I: Local Energy Sustainability Assessment – Methodological guide for the application of energy sustainability indicators at the local level

Local Energy Sustainability Assessment

Methodological guide for the application of energy sustainability indicators at the local level

Version draft 1.0

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

MIT Portugal

Local Energy Sustainability Assessment

Methodological guide for the application of energy sustainability indicators at the local level

Version draft 1.0

Ana Rita Neves ana.neves@fe.up.pt
Vítor Leal vleal@fe.up.pt

Porto, May 2009

Contents

1. Introduction

Because so many of the problems and solutions being addressed by Agenda 21 have their roots in local activities, the participation and cooperation of local authorities will be a determining factor in fulfilling its objectives. Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and subnational environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilizing and responding to the public to promote sustainable development.

in Agenda 21, Chapter 28 (UN, 1992)

Energy systems of today are largely driven by the combustion of fossil fuels. Associated emissions of greenhouse gases of intensive energy use are considered to be the principal cause of climate change. Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1970 (IPCC, 2007). The concern is to take action to tackle climate change, putting sustainable energy planning at the top of actions to be undertaken. We assist nowadays to the emergence of a new energy paradigm, which focuses on the need to use less primary energy providing the same energy service and on the generation of energy from more sustainable sources. This implies a change of the current paradigm, moving from a centralized energy supply, intensively based on large scale production, to a decentralized management approach, where local energy resources play a vital role. Energy challenges encompass the promotion of sustainable energy systems which require action at different levels of governance.

Agenda 21, the global action plan for Sustainable Development for the 21st Century highlights the need to "think globally, act locally" (UN, 1992). The Aalborg Charter emphasises the capacity of local authorities to solve some of the global environmental problems, as they are close to where environmental problems are perceived and closest to the citizens (Charter of European Cities & Towns Towards Sustainability, 1994). And so it is with a "global" problem such as climate change, which derives from the intensive use of energy, which is in turn used "locally" to sustain local activities. The same with the effects of climate change which are also felt locally, as for instance the sea level rise, heat waves, floods and droughts.

Therefore, local authorities have a crucial role to play on promoting sustainable energy systems. In what regards energy, their roles are: consumer and service provider, as responsible for many public buildings, street lighting and public transport, consuming high amounts of energy; planner, developer and regulator, by taking strategic decisions on land use planning such as avoiding urban sprawl and as a regulator by setting energy performance standards; advisor and motivator, as responsible to inform and motivate citizens on how to use energy more sustainably, and; as producer and supplier, by promoting the use of renewables in local energy production (CEMR, 2006).

Initiatives, such as the Covenant of Mayors and the Clinton Climate Initiative stress the fact that cities are important actors for implementing sustainable energy policies and that their actions must be encouraged and supported. The Covenant consists of the formal commitment of cities which aim to go beyond the objectives of the European Union for 2020 in terms of reducing their carbon dioxide emissions through the implementation of a Sustainable Energy Action Plan (EC, 2008). More recently, local governments formally requested the adoption of a United Nations Climate Change Conference – Conference of Parties decision recognising and empowering the role of cities and local authorities in the implementation of National Climate Change Strategies and Action Plans (ICLEI, 2008).

Several processes of energy planning have been emerging in the European Union and in other parts of the world. However, it is noticeable the lack of a common and systematic methodology for the assessment of the impact of their actions in the achievement of energy sustainability. The development of energy and climate change policies, as well as the implementation of sustainable energy action plans, stresses the need for monitoring and reporting the status and the progress towards sustainable energy goals.

The adoption of energy sustainability indicators is fundamental to assess energy sustainability at the local level and in this way to assist the energy planning process. The set of indicators proposed seek to provide insights to the local decision-makers and the social actors by measuring and tracking progress towards the several dimensions of sustainability in what regards the local energy system and its management structure. It will also prove essential to establish the link between planning measures and their effects.

The aim of this guide is to provide technical support to the application of the local energy sustainability set of indicators proposed. In this first version, we also expect to collect feedback from the local authorities involved in the calculation of the indicators in order to improve this work.

2. Set of Indicators for Local Energy Sustainability

The development of the set of indicators for local energy sustainability involved the adoption of a methodology (Figure 1) initially based in a literature review of existing sets of energy and sustainable development indicators (step 1 in Figure 1). These sets were: the Energy Indicators for Sustainable Development (IAEA, 2005); the United Nations Commission of Sustainable Development (CSD) Indicators of Sustainable Development (UN, 2007); Sustainable Development Indicators proposed by Eurostat Task-Force (Eurostat, 2005); European Environment Agency core set of indicators (EEA, 2005); European Common Indicators (AIRI, 2003), and; Study on Indicators for Sustainable Development at the local level (JRC, 2004). Publications on Sustainable Development sets of indicators in Portugal (APA, 2007) and Switzerland (Montmollin and Altwegg, 2000) were also included in the literature review.

Afterwards, it was conducted an identification of the energy-related indicators contained in these publications (step 2). This stage has lead to the identification of 110 indicators from a total of 491 listed in the publications above. However, some of these indicators presented similarities among them, and so it was necessary to eliminate repetitions (step 3). After such repetitions were removed, it was reached a number of 59 distinct indicators. These indicators were then subjected to another selection process (step 4) by applying three selection criteria: 1) the relevance of the indicator for local energy sustainability; 2) its potential measurability at the local level, and; 3) the likelihood that the indicator can be influenced by the action of the local authorities. There were 20 indicators that have fulfilled simultaneously these three criteria.

Step 5 consisted in a critical analysis of the set with the aim of identifying possible remaining gaps. This stage has lead to the adaptation of six existing indicators (including merging two of them) and in seven new indicators being added.

The process has reached a final set of local energy sustainability composed by 26 indicators. Due to the need of keeping the indicator set concise and manageable, it was decided to define a core set of indicators (Table 1) and a larger set of complementary indicators (Table 2) in step 6. The choice of the indicators that make part of the core set took into consideration their relevance for sustainable development and that the set would assure the coverage of the main dimensions of sustainability. More details on the process of identification of the indicators can be found in Neves and Leal, 2009.

The next stage (step 7) encompasses the testing phase with pilot municipalities, for what this guide has been developed. It is of great relevance to engage local authorities in this stage in order to collect feedback on the set of indicators proposed. The aim of this testing stage is to collect feedback from the main users on the difficulties found and also on potential proposals for improvement. The considerations received from the municipalities involved will then be taken into account in the review of the set of indicators.

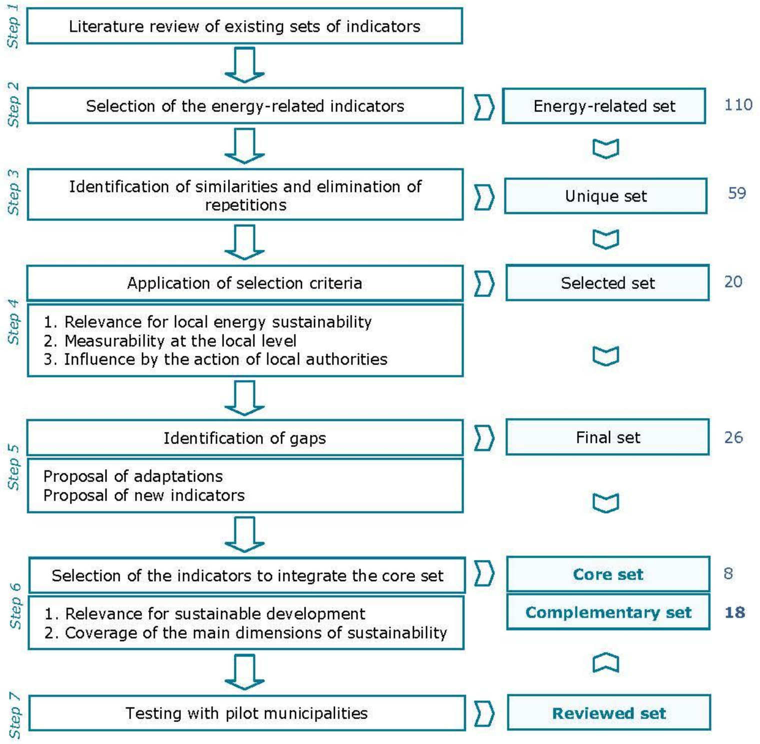


Figure 1 – Methodology adopted for the identification of the core and the complementary set of indicators for local energy sustainability.

Table 1 - Core set of local energy sustainability indicators.

Sub-theme	Core Indicators		Units
Climate Change	CR1	GHG emissions from energy use, per capita and per unit of GDP	tonnes CO_2 eq. per capita and per Euro
Use and production patterns	CR2	Primary Energy use per capita	toe (p.e.) per capita
	CR3	Annual energy consumption by main use category	toe (f.e.)
	CR4	Ratio of local renewables production to local consumption of energy and electricity	%
Employment	CR5	Ratio of energy-related jobs to population	Jobs/10000 inhabitants or %
Financial resources	CR6	Locally available finance schemes for energy efficiency and renewable energy	% or qualitative
Air quality	CR7	Emissions of air pollutants from road transport activities	tonnes/capita
Governance and Public engagement	CR8	Active public participation in energy-related policy-making	% or qualitative

p.e. – primary energy | f.e. – final energy

Table 2 - Complementary set of local energy sustainability indicators.

Sub-theme	Complementary Indicators		Units
Climate Change	CP1	GHG emissions by sector	tonnes CO_2 eq. per capita and per Euro
Use and production patterns	CP2	Industrial energy intensity	toe (f.e.) per Euro
	CP3	Agricultural energy intensity	toe (f.e.) per Euro
	CP4	Service/commercial energy intensity	toe (f.e.) per Euro
	CP5	Household energy intensity	toe (f.e.) per capita
	CP6	Transport energy intensity	toe (f.e.) per pkm or tkm
	CP7	Energy consumption by transport mode	toe
	CP8	Modal split of passenger transport	% of pkm
	CP9	Travel distance by mode of transport	pkm/year
	CP10	Access to public transport	%
	CP11	Fuel shares in energy and electricity	%
	CP12	Renewable energy share in energy and electricity	%
	CP13	Energy production from microgeneration projects	%
Affordability	CP14	Share of household income spent on fuel and electricity	%
Governance and Public engagement	CP15	Responses to public consultations of energy-related projects	%
	CP16	E-government on-line energy-related information availability	qualitative
	CP17	Awareness raising campaigns on energy issues	%
	CP18	Local Authority advice and assistance to the citizens on energy issues	qualitative

p.e. – primary energy | f.e. – final energy

3. Methodology sheets

This chapter provides the methodology sheets for the calculation of the indicators for local energy sustainability. It is expected to support and guide the work of the technical staff of local authorities and energy agencies in the assessment process of energy sustainability.

For each indicator a sheet sets out the indicator definition, the units of measurement, the data needed to compute the indicator and the calculation method. For some indicators, it is provided a calculation example so that the method can be easily understood and replicated. These indicators are calculated to the municipality of Porto in Portugal in the year 2006. Required data improvements are also listed and target the improvements needed in the future to compute the indicator. Robustness assessment will be provided in the next version of the guide and will be based in the feedback provided by the local authorities during the testing stage of the set of indicators.

3.1 Core set

CR1: Greenhouse gas emissions from energy use, per capita and per unit of GDP	
Environmental	Climate Change

Definition

This indicator measures the status and progress in the emissions of greenhouse gases (GHG) from energy use in terms of primary energy, per capita and per unit of Gross Domestic Product (GDP). It includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Unit of measurement

Tonnes of CO_2 equivalents (CO_2 eq.) per capita and per million €

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity	National Directorate for Energy National Statistics Office
Production of electricity (national mix)	IEA country energy balances (*http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Balance*)
Population	National Statistics Office
Municipal GDP	National Statistics Office (hardly available at municipal scale) Specific studies on municipal GDP
Default Emission factors for CO_2, CH_4 and N_2O	IPCC Guidelines for National GHG Inventories for stationary combustion and mobile combustion (IPCC, 2006)
GWPs	(UNFCCC, n.d.) *(http://unfccc.int/ghg_data/items/3825.php)*

Calculation method

The measuring method adopted is based in the IPCC Guidelines for National GHG Inventories (IPCC, 2006) available at *http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html.* The method consists in the estimation of emissions from all combustion sources on the basis of the quantities of fuel combusted and average emission factors. It is necessary to gather data on the consumption of petroleum products, natural gas and electricity by municipality.

The next step consists in multiplying the fuel use by the default emission factor (Box 3.1).

Box 3.1 – GHG emissions by type of fuel.

$$Emissions\ GHG\ by\ type\ of\ fuel = Fuel\ Use\,(p.e.) \times Emission\ factor\ of\ GHG\ by\ type\ of\ fuel$$

The default emission factors for CO_2, CH_4 and N_2O by type of fuel are given by the IPCC Guidelines. Box 3.2 shows the emission factors used for the main fuels.

Box 3.2 – Default emission factors for CO_2, CH_4 and N_2O by type of fuel. Source: (IPCC, 2006).

Default emission factors for road transport (kg of GHG per TJ)			
Fuel	CO_2	CH_4	N_2O
Motor gasoline	69300	25	8,0
Gas/Diesel Oil	74100	3,9	3,9
LPG	63100	62	3,9
CNG	56100	-	-
LNG	56100	92	3

Default emission factors for stationary combustion (kg of GHG per TJ)			
Fuel	CO_2	CH_4	N_2O
Crude Oil	73300	3	0,6
Gas/Diesel Oil	74100	3	0,6
Residual Fuel Oil	77400	3	0,6
LPG	63100	1	0,1
Anthracite	98300	1	1,5
Natural gas	56100	1	0,1

The GHG emission indicator is expressed in CO_2 eq. This means that it is necessary to use the Global Warming Potentials (GWPs) of the GHG emissions in order to convert the emissions of various gases into this common measure. GWP is a measure of how much a given mass of GHG contributes to global warming over a given time period compared to the same mass of CO_2, whose GWP is by definition 1. Box 3.3 presents the GWPs for a 100-year time horizon.

Box 3.3 – GWPs for a 100-year time horizon. Source: (UNFCCC, n.d.)

	CO_2	**CH_4**	**N_2O**
GWPs (100-year)	1	21	310

Having this data it is then possible to calculate the GHG emissions per type of fuel by applying the equation in Box 3.1.

Porto example

Box 3.4 exemplifies the calculation of GHG emissions deriving from the natural gas use in Porto. Data on the natural gas use is available in m^3 for Porto municipality, so a conversion must be made into TJ (conversion units available in chapter 4.2). The same method is used for the determination of GHG emissions from petroleum products.

Box 3.4 – Exemplification of the determination of GHG emissions from the use of natural gas in Porto.

Fuel	TJ	kg CO_2/TJ	kg CH_4/TJ	kg N_2O/TJ	kg CO_2 eq./TJ (using GWPs)	**ton CO_2eq.**
Natural gas	1353	56100	1	0,1	1×56100+21×1+310×0,1=56152	75983

In what regards electricity, it is necessary to analyse the primary energy resources used to produce electricity at the national level, as well as the national electricity consumption in order to determine the tonnes of CO_2 eq. per MWh of electricity produced. This factor is then applied to the municipal electricity consumption, as showed in Box 3.5.

Box 3.5 – Exemplification of the determination of GHG emissions from the use of electricity in Porto.

2006 IEA Energy Balance for Portugal

available at http://www.iea.org/Textbase/stats/balancetable.asp?COUNTRY_CODE=PT&Submit=Submit (IEA, 2009)

SUPPLY and CONSUMPTION	Coal and Peat	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro	Geothermal, Solar, etc.	Combustible Renewables and Waste	Electricity	Heat	Total*
Production	0	0	0	0	0	946	363	3016	0	0	4326
Imports	3497	13863	3586	3661	0	0	0		742	0	25347
Exports	-4	0	-3410	0	0	0	0	0	-274	0	-3688
International Marine Bunkers**	0	0	-628	0	0	0	0	0	0	0	-628
Stock Changes	-184	-84	360	-22	0	0	0	0	0	0	71
TPES	**3309**	**13779**	**-93**	**3639**	**0**	**946**	**363**	**3016**	**468**	**0**	**25428**
Transfers	0	266	-240	0	0	0	0	0	0	0	27
Statistical Differences	27	-43	-53	-1	0	0	0	0	0	0	-71
Electricity Plants	-3310	0	-608	-1558	0	-946	-329	-246	3665	0	-3332
CHP Plants	0	0	-499	-562	0	0	0	-179	513	330	-397
Heat Plants	0	0	0	0	0	0	0	0	0	0	0
Gas Works	0	0	0	0	0	0	0	0	0	0	0
Petroleum Refineries	0	-14002	13855	0	0	0	0	0	0	0	-148
Coal Transformation	0	0	0	0	0	0	0	0	0	0	0
Liquefaction Plants	0	0	0	0	0	0	0	0	0	0	0
Other Transformation	0	0	0	0	0	0	0	0	0	0	0
Own Use	0	0	-343	-89	0	0	0	0	-221	0	-652
Distribution Losses	0	0	-7	-93	0	0	0	0	-317	0	-417
TFC	**27**	**0**	**12012**	**1336**	**0**	**0**	**34**	**2591**	**4108**	**330**	**20438**

Box 3.5 – Exemplification of the determination of GHG emissions from the use of electricity in Porto (cont.).

Determination of the emission factor for Portugal electricity mix

Plants	Primary resources	ktoe	TJ	kg CO_2 eq./ TJ	ton CO_2 eq.	Elect. Produced or consumed MWh	ton CO_2 eq./ MWh
Electricity Plants	Coal and peat	3310	138583	98786	13690068	42593023	**0,43**
	Petroleum products	608	25456	77530	1973586		
	Natural gas	1558	65230	56152	3662814		
CHP Plants	Petroleum products	304*	12714	77530	985695	5965116	
	Natural gas	342*	14319	56152	804032		
Own use	-	-	-	-	-	-2570	
Distribution losses	-	-	-	-	-	-3686	
Total	-	-	-	-	21116196	48551884	

* CHP Plants produce both electricity and heat, so we need to affect the primary resources used to produce only electricity. This is done by calculating the shares of electricity and heat produced. The electricity share (61% in this case) is then applied to the primary resources (e.g. 499×0,61=304).

Application of the emission factor to the electricity consumed in Porto municipality

	MWh	ton CO_2 eq.
Electricity consumed in Porto*	1380926	1380926×0,43=**600593**

* available at *http://www.dgge.pt* (DGEG, 2009a)

By the end it is required to sum the emissions of CO_2 eq., obtaining the total emissions expressed in tonnes of CO_2 eq.. Afterwards, it should be performed a ratio of the total emissions of CO_2 eq. by the population and by the municipal GDP.

The municipal GDP is sometimes difficult to be available. For instance, in the case of Portugal, the closest level of GDP data available at the National Statistics Office is by NUTS III. However, it was possible to find two studies which estimate the GDP per capita for the Portuguese municipalities in 1994 (Ramos, 1998) and in 2000 (Cravo, Ramajo and Márquez, 2005). Having this data for 2000, it was possible to estimate the GDP for Porto in 2006, based in the GDP growth rate of the NUTS III Grande Porto, as shown in Box 3.6.

Box 3.6 – GDP estimates for the municipality of Porto.

	2000	2001	2002	2003	2004	2005	2006
Porto GDP per capita (€)[1]	22361	-	-	-	-	-	-
Grande Porto GDP per capita (€)	12700	13300	13200	13200	13700	14100	14400
Grande Porto GDP growth rate	-	4,7%	-0,8%	0,0%	3,8%	2,9%	2,1%
Estimation of Porto GDP per capita (€)	-	23418	23241	23241	24122	24826	**25354**

[1] data from (Cravo, Ramajo and Márquez, 2005).

Having estimated the GDP per capita for Porto municipality, it is then needed to multiply it by the population in order to have the total GDP in million €.

	GDP per capita (€)	Population	GDP (million €)
Porto	25354	227790	**5775**

Box 3.7 presents the results of GHG emissions for Porto municipality. A figure of approximately 2,6-3,3 tonnes of CO_2 eq. per capita per year can be found in the literature and termed as a sustainable GHG

emission rate. This value is based on the IPCC's estimates of the reduction in anthropocentric emissions necessary to stabilize GHG concentrations at present levels (Byrne et al., 1998).

Box 3.7 – Results of GHG emissions for Porto municipality.

	tonnes CO_2 eq.	tonnes CO_2 eq./capita	tonnes CO_2 eq./million €
Porto	1254723	5,5	217,3

This indicator only determines the GHGs emitted into the atmosphere from energy use. It does not consider non-energy sources, such as agriculture.

Required data improvements

The indicator requires data on the municipal GDP that in most cases is not regularly collected by the national statistics office.

CR2: Primary energy use per capita	
Economic/Environment	Use and production patterns

Definition

This indicator measures the level of energy use in a per capita basis in terms of primary energy. Primary energy refers to the energy that is gathered directly from natural resources (mined coal, crude oil, natural gas, hydro and other non-combustible and combustible renewables).

Unit of measurement

Tonnes of oil equivalent (toe) per capita

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity	National Directorate for Energy National Statistics Office
Production of electricity (national mix)	IEA country energy balances (*http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Balance*)
Population	National Statistics Office

Calculation method

The previous indicator required the collection of data on the consumption of petroleum products, natural gas and electricity (final energy) for the municipality. The electricity expressed in terms of final energy must now be converted into primary energy. For this, it is required an analysis of the primary energy resources used to produce the electricity at the national level, as well as the national electricity consumption. With this data it is possible to determine the conversion factor from primary to final energy. This conversion factor is then applied to the electricity consumption (final energy) in order to determine the primary energy needed to produce the electricity consumed at the municipal scale. Total primary energy use is then calculated by the sum of primary energy resources: petroleum products, natural gas and the resources used to generate electricity.

Porto example

Box 3.8 demonstrates the calculation method used to determine the conversion factor of primary to final energy for the Portuguese case.

Box 3.8 – Calculation of the conversion factor of primary to final energy for Portugal.

2006 IEA Energy Balance for Portugal

available at http://www.iea.org/Textbase/stats/balancetable.asp?COUNTRY_CODE=PT&Submit=Submit (IEA, 2009)

SUPPLY and CONSUMPTION	Coal and Peat	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro	Geothermal, Solar, etc.	Combustible Renewables and Waste	Electricity	Heat	Total*
Production	0	0	0	0	0	946	363	3016	0	0	4326
Imports	3497	13863	3586	3661	0	0	0		742	0	25347
Exports	-4	0	-3410	0	0	0	0	0	-274	0	-3688
International Marine Bunkers**	0	0	-628	0	0	0	0	0	0	0	-628
Stock Changes	-184	-84	360	-22	0	0	0	0	0	0	71
TPES	**3309**	**13779**	**-93**	**3639**	**0**	**946**	**363**	**3016**	**468**	**0**	**25428**
Transfers	0	266	-240	0	0	0	0	0	0	0	27
Statistical Differences	27	-43	-53	-1	0	0	0	0	0	0	-71
Electricity Plants	-3310	0	-608	-1558	0	-946	-329	-246	3665	0	-3332
CHP Plants	0	0	-499	-562	0	0	0	-179	513	330	-397
Heat Plants	0	0	0	0	0	0	0	0	0	0	0
Gas Works	0	0	0	0	0	0	0	0	0	0	0
Petroleum Refineries	0	-14002	13855	0	0	0	0	0	0	0	-148
Coal Transformation	0	0	0	0	0	0	0	0	0	0	0
Liquefaction Plants	0	0	0	0	0	0	0	0	0	0	0
Other Transformation	0	0	0	0	0	0	0	0	0	0	0
Own Use	0	0	-343	-89	0	0	0	0	-221	0	-652
Distribution Losses	0	0	-7	-93	0	0	0	0	-317	0	-417
TFC	**27**	**0**	**12012**	**1336**	**0**	**0**	**34**	**2591**	**4108**	**330**	**20438**

$$\frac{\sum(\textit{primary fuels for electricity plants}) + \sum(\textit{primary fuels for CHP plants}) \times \left(\frac{\textit{Electricity produced by CHP}}{\textit{Electricity} + \textit{Heat}}\right)}{\textit{Electricity produced} - \textit{own use} - \textit{distribution losses} + \textit{Electricity produced by CHP}}$$

$$\frac{(3310 + 608 + 1558 + 946 + 329 + 246) + (499 + 562 + 179) \times \left(\frac{513}{513 + 330}\right)}{3665 - 221 - 317 + 513} = 2{,}13$$

For Portugal, 1 unit of electricity (final energy) requires **2,13** units of primary energy. This means, that this is the factor that we have to multiply to electricity (final energy) in order to have electricity expressed in primary energy.

Box 3.9 shows the application of the conversion factor to determine the electricity consumption in terms of primary energy to Porto municipality.

Box 3.9 – Determination of the electricity consumption expressed in primary energy for Porto.

Consumption of electricity in Porto in 2006

Consumption of electricity in terms of final energy – 118760 toe
available at *http://www.dgge.pt* (DGEG, 2009a)

Determination of the consumption of electricity in terms of primary energy – 118760×2,28 = 252906 toe

Finally, it is just needed to add the use of oil products, natural gas and electricity to have the total primary energy use. As the indicator is measured in toe per capita, it is necessary to divide the total amount of primary energy use by the population of Porto municipality. Box 3.10 shows the results for Porto municipality.

Box 3.10 – Primary energy use in Porto municipality.

	Oil products*	Natural gas**	Electricity	Total	Total/capita
Primary energy (toe)	161769	35530	252906	450205	**1,98**

* available at *http://www.dgge.pt* (DGEG, 2009b)
** available at *http://www.dgge.pt* (DGEG, 2009c)

Required data improvements

National statistics should provide every year the conversion factor to express electricity in terms of primary energy, which is dependent of the electricity national mix.

CR3: Annual energy consumption by main user category	
Economic	Use and production patterns

Definition

This indicator measures the level of energy use in a per capita basis in terms of final energy and by main user category. Final energy refers to delivered energy which is made available to the consumer, not taking upstream transformation and transportation losses into account.

Unit of measurement

Tonnes of oil equivalent (toe)

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office

Calculation method

In the case where consumption data by sector is available at the municipal scale, it is just needed to add the consumption of electricity, natural gas and petroleum products separately for the following sectors: Households, Transport, Industry, Services, Agriculture and Fisheries, and Others. The indicator is then calculated by the ratio between the final energy use and the population. In cases where this data is not available at a municipal scale, it will be needed to estimate it from the closest level of governance.

Porto example

With respect to electricity, the data is available at the municipal level by sectors (DGEG, 2009a) and is presented in Box 3.11.

Box 3.11 – Electricity consumption by sectors in Porto municipality.

Sector	Electricity consumption (toe)
Agriculture and Fisheries	51
Industry	8225
Transport	1185
Households	43459
Services	64355
Others	1485

In what regards the data on the consumption of natural gas and petroleum products was not yet available at the municipal level, so estimates had to be performed based in the district level data. Box 3.12 demonstrates the estimation method for the consumption of natural gas and petroleum products for Porto.

Box 3.12 – Estimates of the consumption of natural gas and petroleum products for Porto municipality.

Although the consumption of fuel is known at the municipal level, its share by sector is only available by districts.
It is then needed to perform an estimate based on the data of the District of Porto which comprises 18 municipalities.
Based on this data, it is determined the share of consumption of petroleum products and natural gas in the district by sectors which is then applied to the municipality of Porto. However, it is important to pay careful attention to possible differences of the municipality in relation to the average of the district. For instance, it is known that the industries are mainly located in the municipalities surrounding Porto, while Porto has more services. So, there is this need to adjust the share to the known reality of the municipality, which can only be performed by experts with knowledge of the local reality.

Determination of the district share of natural gas (NG) consumption and adjustment to Porto municipality

Sector	NG consumption (DGEG, 2009b) 10^3 Nm^3	Share by sector in the district	Adjusted to Porto	Adjustment justification
Agriculture and Fisheries	4517	0,1%	1%	-
Industry	3425342	88,8%	5%	Industry located outside Porto municipality.
Transport	11313	0,3%	22%	Data from municipal transport companies. Source: SCTP, 2007.
Households	220341	5,7%	36%	-
Services	190118	4,9%	35%	Services are very concentrated in Porto municipality.
Others	4638	0,1%	1%	-

Box 3.12 – Estimates of the consumption of natural gas and petroleum products for Porto municipality (cont.).

Determination of the natural gas consumption of Porto municipality by sectors

Sector	Porto NG consumption 10^3 Nm^3 (DGEG, 2009c)	Adjusted share to Porto	Application of the share to Porto NG consumption 10^3 Nm^3	toe
Agriculture and Fisheries	34697	1%	347	355
Industry		5%	1735	1776
Transport		22%	7781	7968
Households		36%	12343	12639
Services		35%	12144	12435
Others		1%	347	355

Petroleum products consumption of Porto municipality by sectors
The same method was performed to determine the share of the consumption of petroleum products by sectors (DGEG, 2009b; DGEG, 2009d) leading to the following results.

Sector	Petroleum products consumption (toe)
Agriculture and Fisheries	1649
Industry	33
Transport	119563
Households	5559
Services	31041
Others	3955

Box 3.13 presents the final energy consumption determined by sector for Porto municipality.

Box 3.13 – Final energy consumption by sectors in Porto municipality.

Sector	Final energy consumption in Porto (toe)
Agriculture and Fisheries	2056
Industry	10034
Transport	133031
Households	61657
Services	103564
Others	5796

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector.

CR4: Ratio of local renewable production to local consumption of energy and electricity	
Economic	Use and production patterns

Definition

This indicator aims to investigate the relationship between local energy production from renewable energy sources and local energy consumption.

Unit of measurement

% of local renewable production from local energy and electricity consumption

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity	National Directorate for Energy National Statistics Office
Energy and electricity production from local renewable energy sources	Survey to energy companies and to the local authority

Calculation method

This indicator is constructed by dividing the local renewable production by the local energy consumption and local electricity consumption.

There could be some difficulties in gathering the data on local renewable energy production. The local authority should have available the data of energy produced from renewable energy in the public buildings, facilities and street lighting, as well as on medium/large-scale projects using renewables within the municipality. Regarding the use of renewables in private buildings, it is recommended to elaborate a survey (Box 3.14) to the local energy companies, such as renewable energy installers in order to collect the data in the capacity installed by these companies. Another alternative might be through the energy certification system of buildings which should be available from the national energy agency.

Box 3.14 – Survey questions regarding the local energy production from renewables.

Local authority

1. Please provide data on the installed capacity and the energy produced from renewable energy in public buildings, facilities and lighting.
   Installed capacity: Solar thermal ___ m^2 | PV ___ kW | Wind generators ___ kW | Others* ___ kW
   Energy produced: Solar thermal ___ kWh | PV ___ kWh | Wind generators ___ kWh | Others* ___ kWh
   Electricity produced: PV ___ kWh | Wind generators ___ kWh | Others* ___ kWh

2. Are there any medium/large-scale projects using renewable energy within the municipality? Please specify the installed capacity and the energy produced.
   Installed capacity: Solar plants ___ MW | Wind power ___ MW | Hydro ___ MW | Biogas ___ MW |
   Geothermal ___ MW | Wave power ___ MW | Others* ___ MWh
   Energy produced: Solar plants ___ MWh | Wind power ___ MWh | Hydro ___ MWh | Biogas ___ MWh |
   Geothermal ___ MWh | Wave power ___ MWh | Others* ___ MWh
   Electricity produced: Solar plants ___ MWh | Wind power ___ MWh | Hydro ___ MWh | Biogas ___ MWh |
   Geothermal ___ MWh | Wave power ___ MWh | Others* ___ MWh

Local Energy companies

1. Please specify the capacity of renewable energy technologies installed by your company in the municipality.
   Solar thermal ___ m^2 | PV ___ kW | Wind generators ___ kW | Others* ___ kW

* Others – Please specify.

Please note that there are more indicators requiring data which is collected from a survey. It is recommended to gather all the data needs in one survey and then send it to the respective entities.

Required data improvements

Data needs to be collected on the production of energy through renewable energy sources in the municipality.

CR5: Ratio of energy-related jobs to population	
Economic/Social	Employment

Definition

This indicator aims to provide information on the number of jobs created at the local level by the renewable energies and energy efficiency sectors.

Unit of measurement

% of energy-related jobs to population

Data requirements and sources

Data required	Data source
Working age population[1]	National Statistics Office (might not be available at the municipal level and then assumptions must be made, e.g. based on the population and considering the same activity level of the closer administrative level (district, region))
Number of employed population in energy-related jobs	Survey to the local energy companies and local authority

Calculation method

The indicator consists in a ratio between the number of employed population in energy-related jobs and working age population. Data for the number of jobs from the energy sector should be derived from a survey (Box 3.15), once this data might not be available.

Box 3.15 – Survey questions regarding the jobs created by the energy sector at the local level.

Local Energy Agency
1. How many people are employed in the energy agency?

Local energy companies
1. How many people are employed in your company?

Local authority
1. How many people are working in the energy focus area, such as in an energy department/unit inside the local authority?

[1] Persons aged 15 years and older involved in economic activities or available for such involvement during the survey reference period.

Required data improvements

National statistics should improve the collection of data on the working age population at the municipal level. Data also needs to be collected on the number of jobs created by the energy sector in the municipality.

CR6: Locally available finance schemes for energy efficiency and renewable energy	
Economic/Governance	Financial resources

Definition

This indicator provides a measure of the finance schemes available at the local level to support energy efficiency and renewable energy initiatives. Local finance schemes can be defined as co-funding provided by the local authority; loans provided by the local authority; energy performance contracting, and; third party financing mechanism.

Energy Performance Contracting is a form of optimising energy use, in which companies are employed to carry out energy saving measures at their own expense and are responsible for running the system for a fixed period of time. The payment of this service is based on the proportion of real energy savings achieved each year. The Third Party Financing mechanism consists on the identification, analysis and installation of a facility owned by the promoter but in which the Energy Service Company (ESCO) can be responsible for joint implementation of all the stages of the project until the investment is recovered. This investment is usually paid over the medium to long term by the power generated, either by the income produced by the project or by the savings the promoter achieves from avoiding to buy power from elsewhere. It is a highly suitable mean of promoting renewable energies and energy efficiency projects, where the degree of maturity does not reach sufficient levels to enable access to capital markets (Altener, 2002).

Unit of measurement

% of the local authority annual budget per capita available to funding energy-related initiatives, and number of renewables and energy efficiency initiatives that use energy performance contracting and third party financing mechanisms

Data requirements and sources

Data required	Data source
Annual budget of the local authority	Local authority financial department
Funding or loans given to renewables and energy efficiency initiatives	Local authority and/or energy agency
Programmes on energy performance contracting and third party financing mechanism	Survey to the local authority, energy agency and ESCOs

Calculation method

The measuring method depends on the type of finance scheme available. In the case of funding or loans by local authority, it should be determined which share of the annual budget was made available for supporting renewables and energy efficiency initiatives. These initiatives shall include: insulation in residential, commercial and public buildings, construction of low-energy houses; renovation of buildings promoting energy use reduction, and; microgeneration in residential, commercial and public buildings and facilities. In the case of energy performance contracting (EPC) and third party financing mechanisms (TPF), it would be required to determine the number of projects which have used these finance schemes. Box 3.16 presents the required data for the calculation of this indicator.

Box 3.16 – Financial schemes framework to be filled with the surveys data.

Financial schemes

Areas		Funding (€)	Loans (€)	EPC	TPF	Other
Renewables	Solar thermal					
	PV					
	Wind					
	Bioenergy					
	Other					
Energy Efficiency	Insulation (roof, wall, windows)					
	Construction of low-energy houses					
	Renovation of buildings					
	Other					

This indicator does not consider subsidies and tax reductions on renewables and energy efficiency available from the National Government, once it is out of the scope of action of the local authority.

Required data improvements

Further work is needed at the municipal level to ensure the collection of data on financial schemes to support the implementation of renewables and energy efficiency projects.

CR7: Emissions of air pollutants from road transport activities	
Environment	Air quality

Definition

This indicator provides a measure of the state of air quality in terms of emissions of air pollutants from road transport activities in the municipality. Pollutants covered include: carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), methane (CH_4), particulate matter (PM) and carbon dioxide (CO_2).

Road vehicles are powered by internal combustion engines which operate on fossil fuels combustion. This combustion produces CO_2 and H_2O as the main products, but also produces several by-products originated from incomplete fuel oxidation (CO, hydrocarbons, PM) or from the oxidation of non-combustible species present in the combustion chamber (NO_x from N_2 in the air, etc.) (EEA, 2007).

Unit of measurement

tonnes/capita

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Population	National Statistics Office
Number of passengers per km	Municipal passenger transport companies reports Eurostat (only available at the national level and then estimates must be made)
Number of tonnes per km	Eurostat (only available at the national level and then estimates must be made)
Vehicle fleet by type of vehicle and fuel	Emission Inventory Guidebook (EEA, 2007) – data for EU-15 countries (*http://www.eea.europa.eu/publications/EMEPCORINAIR5/page016.html* - road transportation) Energy and transport in figures Statistics Pocketbook (DG TREN, 2009) (*http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2006_en.htm)* (more aggregated data)
Emission factors	Emission Inventory Guidebook (EEA, 2007) – for EU-15 countries

Calculation method

The calculation of emissions from road vehicles is a complicated and demanding procedure. It requires availability of good quality activity data and emission factors (EEA, 2007). However, the availability of data at the municipal scale is very scarce, which requires the use of estimation methods. Due to this lack of data, it is adopted the simplified methodology proposed by EEA (2007).

The methodology consists in combining the emission factors with fuel consumption for specific vehicle category in order to provide total emission estimates. Box 3.17 shows the methodology adopted.

Box 3.17 – Methodology for total emissions estimates. Source: EEA, 2007.

$$E_{ij} = \sum_j (FC_j \times EF_{ij})$$

where,
Ei,j : emission of pollutant i from vehicles of category j [g pollutant],
FCj : fuel consumption of vehicle category j [kg fuel],
EFi,j : fuel consumption specific emission factor of pollutant i for vehicle category j [g/kg fuel].

This simplified methodology does not deal with LPGs, 2-stroke and gasoline heavy-duty vehicles because of their small contribution to the inventory.

In cases where the final energy use by type of transport is not available at the municipal scale, there is the need to estimate it based on the vehicle fleet data. However, this data is also hardly to find available at the municipality level. For the example of Portugal, this is due to the fact that the registrations of vehicles generally take place in the head offices of the brand, which means that the place where the vehicles are registered not always coincide with the place where the owner lives. The Emission Inventory Guidebook (EEA, 2007) provides data on the vehicle fleet by type of vehicle (including fuel type) for the EU-15 countries in 2002. From Eurostat, it is possible to find national data on the vehicle fleet by the following types: passenger cars, power two-wheelers, buses & coaches and freight vehicles.

Porto example

In this case, it was not possible to gather data on the vehicle stock at the municipal level. As so, the data was estimated based on the National level (vehicle stock and population) as shown in Box 3.18.

Box 3.18 – Estimation of the vehicle fleet by vehicle and fuel type for Porto municipality.

Estimation of the vehicle fleet of Porto municipality

Category	Vehicle fleet (thousand vehicles)					
	Portugal					Porto
	2002	2003	2004	2005	2006	2006
PC[1]	3885,0	3996,0	4100,0	4200,0	4290,0	*111,1*
Growth rate	-	2,1%	3,4%	2,4%	2,1%	-
Gasoline PC[2]	2807,2	*2865,8*	*2962,6*	*3034,8*	*3099,9*	*74,7*
Diesel PC[2]	311,9	*318,4*	*329,2*	*337,2*	*344,4*	*8,3*
Power two-wheelers[1]	387,0	402,8	418,7	588,4	558,7	-
Growth rate	-	4,1%	3,9%	40,5%	-5,0%	-
Gasoline PC[2]	*794,7*	*827,2*	*859,9*	*1208,3*	*1147,4*	*27,7*
Buses & Coaches[1]	21,4	21,7	n.a.	14,7	15,0	-
Growth rate	-	1,2%	-	-16,1%	2,0%	-
Diesel PC[2]	17,0	*17,2*	-	*14,3*	*17,6*	*0,4*
Goods vehicles[1]	1377,3	1208,3	1609,3	1308,0	1320,0	*26,2*
Growth rate	-	-12,3%	33,2%	-18,7%	0,9%	-
Diesel LDV[2]	613,9	*538,6*	*717,3*	*583,0*	*588,4*	*14,2*
Diesel HDV[2]	522,2	*458,1*	*610,1*	*495,9*	*500,4*	*12,1*

[1] Source: DG TREN, 2009.
[2] Source: EEA, 2007.
Estimates in italics.

Definitions:
Passenger cars (PC) – Power driven vehicles having at least four wheels or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of passengers.
Light Duty Vehicle (LDV) – Vehicles used for the carriage of goods and having a maximum weight not exceeding 3.5 metric tonnes.
Heavy Duty Vehicle (HDV) – Vehicles used for the carriage of goods and having a maximum weight exceeding 3.5 but not exceeding 12 metric tonnes, and the ones exceeding the 12 metric tonnes.
Two-Wheelers - Motor vehicles with less than four wheels. Includes motorcycles, mopeds, scooters and 3-wheel motorcycles.

The estimates of the vehicle fleet use data from both EEA Emission Inventory Guidebook and Eurostat, because EEA although more disaggregated is only available for 2002. With Eurostat data is possible to determine the growth rate from 2002 to 2006 and apply it to the disaggregated data of EEA. Afterwards, due to the lack of data available at the local level, it is performed an estimate of the vehicle fleet based in the population of Porto and Portugal.

By this time, it is possible to calculate the share of vehicles by type in Porto and then to determine the final energy use by crossing data of the municipal transport companies (Box 3.19).

Box 3.19 – Estimation of the final energy by mode of transport.

Category	Energy vector	Share of mode of transport by fuel	Final energy (toe)
Passenger	-	-	**80606**
Metro	Electricity	95%	*1121*
Tram	Electricity	5%	64[1]
Passenger cars	Gasoline	73%	*34745*
	Diesel	24%	*15213*
	Gas auto	100%	493[2]
Power two-wheelers	Gasoline	27%	*12860*
Buses & Coaches	Diesel	-	8141[1]
	Natural gas	100%	7968[1]
Goods vehicles	-	-	**48092**
LDV	Diesel	41%	*25988*
HDV	Diesel	35%	*22104*

[1] Source: STCP, 2007.
[2] from indicator CR2.
Estimates in italics.

Some public transport companies provide data on the final energy use. It is then recommended to subtract these values in the respective energy vector. For instance, it was known the electricity used by tram from STCP (2009), as well as the total electricity used in transport. Electricity is only used for metro and tram, as so the difference between the total electricity used and the electricity used by tram gives the electricity used by metro. The same with diesel consumption by buses & coaches.

For the rest, it is applied the share of vehicles to the total final energy use data by energy vector.

After estimating the final energy use by type of vehicle, it is necessary to determine the associated emissions of air pollutants. Box 3.20 presents the fuel consumption specific emission factors for main pollutants in Portugal.

Box 3.20 - Bulk emission factors (g/kg fuel) for Portugal, year 2005. Source: EEA, 2007.

Category	CO	NO_x	NMVOC	CH_4	PM	CO_2
Gasoline PC	61,56	9,18	8,5	0,71	0,03	3,18
Diesel PC	3,2	11,28	0,57	0,04	0,72	3,14
Mopeds	403,89	3,62	360,25	6,55	6,32	3,18
Motorcycles	590,71	5,89	128,94	4,57	2,8	3,18
Buses	11,88	40,75	4,18	0,31	1,85	3,14
Diesel LDV	9,39	17,91	1,72	0,11	2,05	3,14
Diesel HDV	7,14	34,09	1,14	0,24	1,04	3,14

The next step encompasses the multiplication of the emission factor by the respective fuel consumption (Box 3.21).

Box 3.21 – Emission from road transport vehicles of main air pollutants in Porto municipality.

Category	Fuel use (kg)	Emission of air pollutants (g)					
		CO	NOx	NMVOC	CH4	PM	CO2
Gasoline PC	32472094	1998982093	298093821	276012797	23055187	974163	103261258
Diesel PC	22564799	72207356	254530932	12861935	902592	16246655	70853469
Power two-wheelers	12018915	5977006250	57149939	2939766426	66825165	54806251	38220149
Buses & coaches	7866011	93448206	320539933	32879924	2438463	14552120	24699273
Diesel LDV	25109365	235776934	449708720	43188107	2762030	51474197	78843405
Diesel HDV	21356618	152486254	728047114	24346545	5125588	22210883	67059781
Total	-	8529907093	2108070459	3329055734	101109025	160264269	382937335

Required data improvements

Data needs to be improved at the municipal level in what regards the vehicle fleet by type of vehicle and by type of fuel. Statistics should also disaggregate the final energy use by mode of transport.

CR8: Active Public Participation in energy-related policy making	
Social	Governance and public engagement

Definition

This indicator aims to investigate the active engagement of citizens in energy-related policy making processes. According to OECD (2001) in the report 'Citizens as Partners', active participation is defined as a relation based on partnership with Government, in which citizens actively engage in the policy-making process. It acknowledges a role for citizens in proposing options and shaping the policy dialogue – although the responsibility for the final decision or policy formulation rests with Government. Examples are open working groups, and dialogue processes. Active participation is different from Consultation which is defined by OECD (2001) as a two-way relation in which citizens provide feedback to Government. It is based on the prior definition by Government of the issue on which citizens views are being sought and requires the provision of information. Examples include comments on draft legislation and public opinion surveys. Active public participation should be promoted in the drafting of energy action plans which make parte for instance of regional land use plans.

Unit of measurement

% of participants in active participation initiatives

Data requirements and sources

Data required	Data source
Number of tools used for active public participation for energy policy-making processes	Survey to the local authority
Number of participants	Survey to the local authority

Calculation method

The indicator is constructed by identifying the tools used for active public participation for energy policy-making processes as well as the number of participants in each of them. According to OECD (2001), Box 3.22 presents available tools to be used for active participation.

Box 3.22 – Tools for active public participation. Source: OECD, 2001.

Tools involving broader public engagement:

Open working groups – Involve a broad group of citizens and works out concrete proposals for policy-making. The conclusion can be an agreement on a policy or on an alternative draft law, and may involve shared implementation, as through public-private partnerships.

Participatory vision and scenario-development – In a facilitated process, a group of citizens, government officials and experts develop a vision or several diverging scenarios about future developments. The citizens are engaged in an active discussion on policy options feeding back into policy-making. As an example, the European Awareness Scenario Workshop (EASW) methodology was developed by the European Commission in 1994 (Cordis, 1998).

Citizens' Forum – It gathers a broad group of civil society representatives around a specific policy area or issue. It provides a framework to deliberate and cooperate, to develop policy proposals as well as to engage a wide number of citizens. The direct outcome is a direct input for governmental policy.

Dialogue processes – Directly engage broad group of citizens in policy-making. Several tools can be used, such as interactive workshops to gather citizens' input. This input is then used in conferences with experts and representatives of interest groups and government, which work out to draft policy proposals. These proposals can still be checked through citizens' workshops before the proposal is finalised.

Tools for engaging citizens in the policy agenda (more national scope):

Consensus conferences – Composed by a group of 10-15 citizens (non-experts randomly selected) to question experts on a policy issue. After the questioning, they discuss the issue among themselves. At the end, they publicly present the conclusions they share – the consensus.

Citizens' juries – Questioning takes place as in a courtroom, open to the public at large (non-experts). The conclusions do not have to yield a broad consensus. It is the government that announces the initiative including the selection procedure for jury members.

Tools to involve expert publics:

Evaluation by stakeholders – The evaluation of governmental policies is putted into the hands of a group of experts and representatives of interest groups and civil society organisations. Government gives access to data needed and commits itself to publish the results of the evaluation. The results contain analysis of the present policy and recommendations for policy changes.

Traditional tripartite commissions and joint working groups – A selected group of expert representatives from organisations is placed in a joint group with government representatives. The group works out concrete proposals for policy-making. It operates on its own and is often subject to a degree of secrecy until a negotiated conclusion is reached. The conclusion can be an agreement on a policy or on an alternative draft law, and may involve shared implementation, as through public-private partnerships.

The survey questions aim to investigate whether any of these tools has been being used by the local authority for energy policy-making processes and the participation of the citizens.

For the municipalities with Local Agenda 21, these tools are usually incorporated into the process. In the case of energy being identified as a priority area in the Local Agenda 21 process, we can account the tools used in this focus area.

To note that environmental impact assessment studies only require public consultation by law (e.g. European Union), and that cannot be considered for this indicator.

Required data improvements

Data needs to be collected at the municipal level on the public participation initiatives and the participants involved.

3.1 Complementary set

CP1: Greenhouse gases emissions by sector	
Environmental	Climate Change

Definition

This indicator measures the status and progress in the emissions of GHG from energy use in terms of primary energy, by sector. It includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Unit of measurement

Tonnes CO_2 equivalents (CO_2 eq.) per capita

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Production of electricity (national mix)	IEA energy balances (*http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Balances*)
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Population	National Statistics Office
Municipal GDP	National Statistics Office (hardly available at municipal scale) Specific studies on municipal GDP
Default Emission factors for CO_2, CH_4 and N_2O	IPCC Guidelines for National GHG Inventories for stationary combustion and mobile combustion (IPCC, 2006)
GWPs	(UNFCCC, n.d.) *(http://unfccc.int/ghg_data/items/3825.php)*

Note: Consumption of final energy per sectors is available from indicator CR3.
Emission factor in tonnes CO_2 eq. per MWh is available from indicator CR1.

Calculation method

The calculation of this indicator requires the multiplication of the final energy consumption of electricity, natural gas and petroleum products (available from indicator CR3) by the respective fuel emission factor. In the case of electricity, it is used the emission factor already determined in indicator CR1 to express the tonnes of CO_2 eq. per MWh of electricity produced.

Porto example

Box 3.24 presents the determination of GHG emissions per sector from electricity use in Porto municipality.

Box 3.23 – Determination of the GHG emissions regarding the electricity use by sector in Porto.

Electricity

Sector	Electricity consumption (toe) (from indicator CR3)	Electricity consumption (MWh)	Tonnes CO_2 eq. *
Agriculture and fisheries	51	598	260
Industry	8225	95634	41593
Transport	1185	13777	5992
Households	43459	505337	219781
Services	64355	748313	325456
Others	1485	17268	7510

* multiplying the electricity consumption (MWh) by the emission factor 0,43 ton CO_2 eq./MWh (from indicator CR1).

In what regards the oil products and natural gas, the final energy consumption by sector is multiplied by the respective fuel emission factor. Box 3.24 exemplifies this method to the municipality of Porto, for the case of natural gas.

Box 3.24 – Calculation of the GHG emissions deriving from the natural gas use by sector.

Natural gas

Sector	Natural gas	Emission factor (IPCC)	Emissions
	TJ	kg CO_2 eq./TJ	tonnes CO_2 eq
Agriculture and Fisheries	14	56152	760
Industry	68		3799
Transport	303		17040
Households	481		27031
Services	474		26594
Others	14		760

By the end, it is performed a sum of the associated emissions from electricity, oil products and natural gas by sectors, which leads to the total emissions by sector presented in Box 3.25.

Box 3.25 – Total emissions of GHG by sectors in Porto municipality.

Sector	tonnes CO2 eq.				
	Electricity	Natural gas	Petroleum products	Total	Total/capita
Agriculture and Fisheries	260	760	5150	6170	0,03
Industry	41593	3799	105	45498	0,20
Transport	5992	17040	384088	407120	1,79
Households	219781	27031	14787	261599	1,15
Services	325456	26594	85590	437641	1,92
Others	7510	760	12649	20918	0,09

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector.

CP2: Industrial energy intensity	
Economic	Use and production patterns

Definition

Industrial energy intensity measures the energy use of the industrial sector per corresponding value added. Energy intensity provides information about the energy use per unit of economic output. The analysis of energy intensities gives insights on the structure of the manufacturing sector as well as in how energy efficiency and other factors affect energy use. However, municipalities with energy-intensive industries will have high energy intensity, even if industry is energy efficient.

Unit of measurement

Tonnes of oil equivalent (toe) per million €

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Value added per sector	National Statistics Office (in some countries might be only available at NUTS III level, and then estimates must be made)

Note: Industry and Others final energy use is available from indicator CR3.

Calculation method

This indicator is calculated by dividing the final energy use of the industry sector by the value added of the industry sector.

Porto example

Box 3.26 presents the calculation of this indicator to Porto municipality.

Box 3.26 – Calculation of the industrial energy intensity of Porto municipality.

Final energy use (toe)*	Value added (million €)	Energy intensity (toe/million €)
15830	579	27

* The value added available from the National Statistics Office in Portugal is for Industry, including energy and construction. So, the final energy use presented in this table is the sum of the final energy use in Industry plus the Others sector which include Construction and energy losses.

With respect to the value-added per sector, the data is not available for municipalities in Portugal. The closest level is by NUTS III. In this case, we had to estimate it based upon the indicator: "Number of workers according to the activity sector in the municipality" of the NUTS III (Grande Porto) and the municipality of Porto.

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work is needed to calculate the value added by sectors at the municipal level.

CP3: Agricultural and fisheries energy intensity	
Economic	Use and production patterns

Definition

The agricultural and fisheries energy intensity measures the energy requirements per unit of economic output in these sectors.

Unit of measurement

Tonnes of oil equivalent (toe) per million €

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Value added per sector	National Statistics Office (in some countries might be only available at NUTS III level, and then estimates must be made)

Note: Agriculture and Fisheries final energy use is available from indicator CR3.

Calculation method

Agricultural and Fisheries energy intensity consists in the ratio of the final energy use in the agriculture and fisheries sector to the respective value added.

Porto example

Box 3.27 presents the determination of the energy intensity of agricultural and fisheries for Porto municipality. These two sectors are put together due to the existence of aggregated data in the Portuguese statistics. However, in case where data is disaggregated for the two sectors, they should be analysed separately.

Box 3.27 - Calculation of the agricultural and fisheries energy intensity of Porto municipality.

Final energy use (toe)	Value added (million €)	Energy intensity (toe/million €)
2056	11	190

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work is needed to calculate the value added by sectors at the municipal level. National statistics should provide data for the sectors of agriculture and fisheries separately.

CP4: Service/commercial energy intensity	
Economic	Use and production patterns

Definition

The service/commercial energy intensity measures the energy requirements per unit of economic output in these sectors. It is used to monitor trends in energy use in the service/commercial sector. Service/commercial buildings include offices, schools, hospitals, restaurants, warehouses and retail stores.

Unit of measurement

Tonnes of oil equivalent (toe) per million €

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Value added per sector	National Statistics Office (in some countries might be only available at NUTS III level, and then estimates must be made)

Note: Service/commercial final energy use is available from indicator CR3.

Calculation method

Service/commercial energy intensity consists in the ratio of the final energy use in the service/commercial energy sector to the respective value added.

Porto example

The example for Porto municipality in what regards the determination of the energy intensity of service/commercial energy intensity is presented in Box 3.28.

Box 3.28 - Calculation of the service/commercial energy intensity of Porto municipality.

Final energy use (toe)	Value added (million €)	Energy intensity (toe/million €)
107832	4890	22

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work is needed to calculate the value added by sectors at the municipal level.

CP5: Household energy intensity	
Economic	Use and production patterns

Definition

This indicator aims to measure the energy requirements of the household sector in a per capita basis. The household energy use encompasses energy used in residential buildings for cooking, water heating, space heating and cooling, lighting, electrical appliances, among other purposes.

Unit of measurement

Tonnes of oil equivalent (toe) per capita

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Population	National Statistics Office

Note: Household final energy use is available from indicator CR3.

Calculation method

Household energy intensity consists in the ratio of the final energy use in the household energy sector to the respective value added.

Porto example

Box 3.29 presents the data and the results of the calculation of household energy intensity for Porto municipality.

Box 3.29 - Calculation of the household energy intensity of Porto municipality.

Final energy use (toe)	Population	Energy intensity (toe/capita)
61657	227790	0,3

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector.

CP6: Transport energy intensity	
Economic	Use and production patterns

Definition

The transport energy intensity indicator measures the energy used to transport both people and goods. The separation of freight transport and passenger travel is essential in the energy analysis. There are two distinct measures: tonnes per km in the freight transport and passengers per km in the passenger travel.

Unit of measurement

Tonnes of oil equivalent (toe) per million pkm

Tonnes of oil equivalent (toe) per million tkm

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Population	National Statistics Office
Number of passengers per km	Municipal passenger transport companies reports Eurostat (only available at the national level and then estimates must be made)
Number of tonnes per km	Eurostat (only available at the national level and then estimates must be made)
Vehicle fleet by type of vehicle and fuel	Emission Inventory Guidebook (EEA, 2007) – data for EU-15 countries (*http://www.eea.europa.eu/publications/EMEPCORINAIR5/page016.html* - road transportation) Energy and transport in figures Statistics Pocketbook (DG TREN, 2009) (*http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2006_en.htm)* (more aggregated data)

NOTE: Final energy use is available from indicator CR7.

Calculation method

The final energy use by passenger and by freight transport is available from indicator CR7. The next step consists in the determination of the number of passenger-kilometre (pkm) and tonnes-kilometre (tkm). Again, this data is easy to find at the national level, but at the level of the municipality is very difficult, especially for passenger cars. In what regards the metro, tram, buses & coaches, it is possible to gather data from the public transport companies. With respect to passenger cars, estimates can be made based on the population.

The indicator is then calculated by the ratio of final energy use by transport and the number of pkm or tkm.

Porto example

Box 3.31 presents the data on pkm collected from the public transport companies.

Box 3.30 – Number of pkm in metro, tram and buses & coaches in Porto.

Porto transport companies data

Mode of transport	pkm	Obs.
Metro[1]	202473000	Covers 7 municipalities
Tram[2]	317546	-
Buses & coaches[2]	467194000	Covers 6 municipalities

[1] Source: MP, 2008.
[2] Source: STCP, 2007.

The data of the transport companies covers not only the municipality of Porto, but also its surroundings. However, it is not performed any estimates due to the movements of people in and out the municipality.

Box 3.31 presents the number of pkm estimated for passenger cars and railways in Porto. These estimates were based on the population of Portugal and Porto and on the number of pkm in Portugal.

Box 3.31 – Estimation of pkm in passenger cars and railways in Porto.

Mode of transport	Thousand million pkm in Portugal	Estimation for Porto in pkm
Passenger cars[1]	72,0	1547384942
Railways[1]	3,9	83816684

[1] Source: DG TREN, 2009.

The estimates of tkm are based on the national data of tkm and in the consumption of petroleum products for freight road transport both at national and municipal scale.

Having all this data gathered it is possible to compute the indicator. The final energy use for passenger travel should be divided by the pkm expressing in this way the transport energy intensity. The same is also performed for the freight transport. Box 3.32 presents the results for Porto municipality.

Box 3.32 – Transport energy intensities for Porto municipality.

Passenger travel f.e. (toe)	Freight transport f.e. (toe)	Million pkm	Million tkm	Energy intensity (toe per million pkm)	Energy intensity (toe per million tkm)
81984	48092	2301	1496	36	34

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work is needed to develop reliable statistics on pkm and tkm at the municipal level.

CP7: Energy consumption by transport mode	
Economic	Use and production patterns

Definition

This indicator refers to the final energy consumption of transport by mode of transport. Energy used for aviation is excluded because it makes only sense in a national context.

Unit of measurement

Tonnes of oil equivalents (toe)

Data requirements and sources

Data required	Data source
Consumption of electricity by sector	National Directorate for Energy National Statistics Office
Consumption of petroleum products and natural gas by sector	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Population	National Statistics Office
Number of passengers per km	Municipal passenger transport companies reports Eurostat (only available at the national level and then estimates must be made)
Number of tonnes per km	Eurostat (only available at the national level and then estimates must be made)
Vehicle fleet by type of vehicle and fuel	Emission Inventory Guidebook (EEA, 2007) – data for EU-15 countries (*http://www.eea.europa.eu/publications/EMEPCORINAIR5/page016.html* - road transportation) Energy and transport in figures Statistics Pocketbook (DG TREN, 2009) (*http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2006_en.htm)* (more aggregated data)

NOTE: Final energy use by transport mode is available from indicator CR7.

Calculation method

This indicator consists in the calculation of the final energy use by the following modes of transport: metro, tram, passenger cars, buses % coaches, and goods vehicles. The calculation method is explained in indicator CR7.

Porto example

The results reached for Porto are presented in Box 3.33. It is possible to observe a high energy consumption from the individual passenger cars, followed by the goods vehicles. Less intensive are the other means of transport, such as the public passenger transports.

Box 3.33 – Energy consumption by transport mode in Porto.

Category	f.e. (toe)
Metro	1121
Tram	64
Rail	504
Passenger cars	64186
Buses & coaches	16109
Goods vehicles	50834

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work is needed to develop reliable statistics on pkm and tkm by modal split at the municipal level.

CP8: Modal split of passenger transport	
Economic	Use and production patterns

Definition

This indicator provides the share of each mode in total transport of passengers. It includes transport by passenger cars, buses & coaches, metro, tram and rail.

Unit of measurement

% relating to the pkm of the different modes of transport

Data requirements and sources

Data required	Data source
Number of passengers-km	Municipal passenger transport companies reports Eurostat (only available at the national level and then estimates must be made)
Population	National Statistics Office

NOTE: The number of pkm is available from indicator CP6.

Calculation method

The indicator is calculated by determining the share of the different modes of passenger transport considered from the total pkm.

Porto example It is notable the high share of passengers dependent of their individual mean of transport, while buses are the public mean of transport most used.

Box 3.34 presents the results for the case of Porto municipality. It is notable the high share of passengers dependent of their individual mean of transport, while buses are the public mean of transport most used.

Box 3.34 – Share of pkm by mode of transport in Porto.

Mode of transport	pkm	% pkm
Metro	202473000	9%
Tram	317546	0%
Rail	83816684	4%
Passenger cars	1547384942	67%
Buses & coaches	466876454	20%

Required data improvements

Further work is needed to develop reliable statistics on pkm by modal split at the municipal level.

CP9: Travel distance by mode of transport	
Economic	Use and production patterns

Definition

This indicator aims to measure the transport performance by mode of transport expressed in pkm. It identifies the modes of transport and the average distance travelled in each year per person.

Unit of measurement

Pkm/capita

Data requirements and sources

Data required	Data source
Number of passengers-km	Municipal passenger transport companies reports Eurostat (only available at the national level and then estimates must be made)
Population	National Statistics Office

NOTE: The number of pkm is available from indicator CP6.

Calculation method

The calculation method consists in the number of pkm transported by the different modes of transport divided by the population.

Porto example

For the example of Porto, the number of pkm in each mode of transport is determined in indicator CP6. It is then performed the division of the pkm by the population of Porto for the case of the passenger cars, rail and tram. With respect to the metro and buses & coaches, the pkm are divided by the total population served by theses means of transport which includes the population of seven and six municipalities respectively. Box 3.35 presents the results for the case of Porto municipality.

Box 3.35 – pkm by mode of transport in Porto.

Mode of transport	pkm	pkm/capita
Metro	202473000	198
Tram	317546	1
Rail	83816684	6793
Passenger cars	1547384942	422
Buses & coaches	466876454	368

Required data improvements

Further work is needed to develop reliable statistics on pkm by modal split at the municipal level.

CP10: Access to public transport	
Economic	Use and production patterns

Definition

It aims to measure the access to public transport services for the local community. This includes the ease of reaching public transport nodes.

Unit of measurement

% of population within 500m walking distance to a public transport node

Data requirements and sources

Data required	Data source
Population	National Statistics Office
Public transport node, including metro, bus and train	Database of passenger transport companies Transport or land use planning department of the local authority

Calculation method

The calculation method requires the use of a Geographic Information System (GIS) tool. The passenger transport stops should be georeferenced and the population within a 500m walking distance from these stops should be accounted, providing in this way the share of population within 500m walking distance to a public transport node. Alternatively, a survey can be made to a sample population.

Required data improvements

Data on public transport access at the municipal level needs to be improved by measuring the distribution of the population against walking distance to public transport nodes. Ideally, this should be measured together with the public transport frequency.

CP11: Fuel shares in energy	
Economic	Use and production patterns

Definition

This indicator disaggregates the primary energy use by fuel source, namely petroleum products, natural gas, coal and peat, crude oil, non-combustible renewables, combustible renewables and waste, and nuclear. It also disaggregates the final energy use by the following fuel sources: electricity, natural gas, gasoline, diesel and other petroleum products.

Non-combustible renewables include geothermal, solar, wind, hydro, wave and tide energy. The combustible renewables and waste consist of biomass (fuelwood, vegetal waste and ethanol), animal materials/wastes, municipal waste (e.g. biogas from landfill sites) and industrial waste.

Unit of measurement

%

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Production of electricity (national mix)	IEA energy balances (*http://www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Balances*)

NOTE: Primary energy use is available from indicator CR2 and final energy use from indicator CR3.

Calculation method

This indicator is computed by calculating two ratios: the first between final energy use of the specific fuel sources to total final energy use, the second between the primary energy use of the specific fuel sources to total primary energy use.

Porto example

Having the primary energy use and the final energy use by type of fuels available from previous indicators, it is simple to calculate the fuel share in energy. Box 3.37 shows the final energy use by type of fuel and the fuel share regarding the final energy use in Porto municipality.

Box 3.36 – Determination of the fuel shares in final energy use in Porto municipality.

Fuel type (toe)					Total
Gasoline	Diesel	Other petroleum products	Natural gas	Electricity	
47735	85896	28138	35530	118760	316059
15%	27%	9%	11%	38%	100%

Box 3.37 presents the primary energy use by type of fuel and the fuel share in primary energy use. For this it became necessary to analyse the types of fuels used for the generation of electricity in the country (national electricity mix), and then apply the same shares to the municipal electricity consumption.

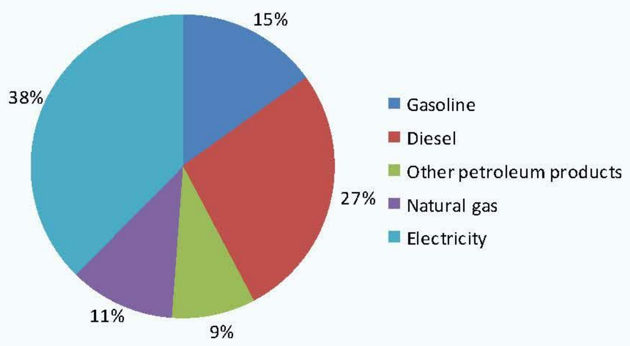
Box 3.37 – Determination of the fuel shares in primary energy use in Porto municipality.

Fuel type (toe)							Total
Petroleum products	Natural gas	Coal and peat	Crude oil	Non-combustible renewables	Combustible renewables and waste	Nuclear	
183746	91843	119639	0	46085	8892	0	450205
41%	20%	27%	0%	10%	2%	0%	100%

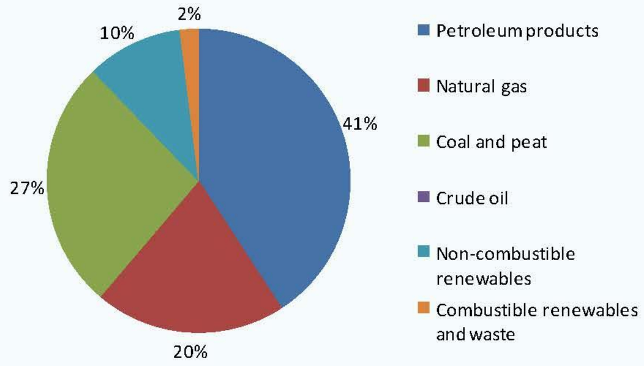
Box 3.39 presents the results graphically.

Box 3.38 – Fuel shares in energy in Porto municipality.

Fuel shares in final energy use



Fuel shares in primary energy supply



Required data improvements

Data is available at the municipal level.

CP12: Renewable energy share in energy	
Economic	Use and production patterns

Definition

This indicator measures the share of renewable energy in the total primary energy use and final energy use. Renewable energy includes both combustible and non-combustible renewables.

Unit of measurement

%

Unit of measurement

% energy produced in relation to consumption

Data requirements and sources

Data required	Data source
Consumption of petroleum products, natural gas and electricity	National Directorate for Energy (in some cases might be only available by district or NUTS III and then estimates must be made) National Statistics Office
Microgeneration power installed	Survey to the local installers and to the local authorities (Data can be also collected from the Ministry responsible for the authorization of micro producers, usually the Ministry of Economy and Energy)

NOTE: Final energy consumption is available from indicator CR3.

Calculation method

This indicator is computed by calculating the ratio of energy produced by microgeneration to local energy consumption. With respect to the energy produced from microgeneration, it is needed to collect information on the power installed in the municipality. This data can be collected through a survey sent to the local installers.

Required data improvements

Further data is required at the municipal level on the consumption of oil products and natural gas by sector. More work on collecting data on the energy produced from microgeneration in the municipality is needed.

CP14: Share of household income spent on fuel and electricity	
Social	Affordability

Definition

This indicator aims to provide a measure of the energy affordability for the average household. It corresponds to the average household expenditures on commercial energy divided by the total average income per household.

Unit of measurement

%

Data requirements and sources

Data required	Data source
Average income per household	National Statistics Office (usually by NUTS II and then assumptions must be made)
Average expenditure on fuel and electricity per household	National Statistics Office (usually by NUTS II and then assumptions must be made)

Calculation method

The calculation method consists in dividing the average expenditure on fuel and electricity per household by the average income per household.

Porto example

The mean expenditure per household with fuel as well as the mean income per household is only available by NUTS II (Norte region). As so, it was assumed that these mean values are the same within Porto municipality. Box 3.41 presents this data and the result of the indicator to Porto municipality.

Box 3.41 – Share of household income spent on fuel and electricity in Porto.

Type	Mean expenditure per household (€)[1]
Electricity	501
Gas	192
Solid fuel for heating and lighting	41
Fuel and lubricants for personal vehicles	918
Total	1652

Mean expenditure per household (€)[1]	Mean income per household (€)[1]	Share of household income spent on fuel and electricity (%)
1652	19906	8

[1] Source: INE, 2008. available at *http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=26973702&PUBLICACOESmodo=2*

An alternative method can be based on the final energy use by fuel type and in the application of the current rates of the respective fuels to the energy consumed. It should be then divided by the population and then aggregated into household, by identifying the average household dimension from the national statistics.

Required data improvements

Data needs to be collected at the municipal level both for the mean expenditure and the mean income per household.

CP15: Responses to public consultations of energy-related projects	
Social	Governance and public engagement

Definition

This indicator aims to investigate the engagement of citizens through processes of public consultation in energy-related projects. This means, whether citizens are providing feedback to the Local Government bodies during policy-making processes.

Unit of measurement

% of citizens' attendance to public consultation initiatives

Data requirements and sources

Data required	Data source
Number of tools used for public consultation in energy policy-making processes	Survey to the local authority
Number of citizens involved in public consultation processes	Survey to the local authority

Calculation method

This indicator is computed by the ratio of citizens' attendance to public consultation initiatives organised by the local authority to total population.

The existing tools of public consultation are very broad. In Box 3.43 is presented some of the tools collected by OECD (2001).

Box 3.42 – Tools for active public consultation. Source: OECD, 2001.

Tools to support solicited feedback from citizens:

Questioning, listening and reporting - Consist in asking questions and listening to citizens, being open to their answers.

Comment periods and actions - Government defines a period of time for receiving comments from citizens on a policy proposal, such as the environmental impact of a planned activity.

Focus group - It gathers a group of stakeholders which should be representatively selected in terms of the population or of specific publics and are facilitated by a moderator. The participants of the focus group receive information and are interviewed individually and in plenum about their views and reactions.

Surveys - Governments presents a series of questions to citizens, collect their responses and analyse them.

Public Opinion Polls – It aims to portray population opinions on a given issue at a certain moment in time. It involves random samples, trained interviewers, and pre-tested questionnaires.

Tools for *ad hoc* consultation (for a specific issue or task):

Inclusion of individual citizens in consultative bodies - Governments ask individual citizens such as experts or representatives of civil society organisations to join as members of review boards evaluating government policies or programmes.

Workshop, seminars and conferences - Government may present information, ask participants to respond and then enter into an open discussion.

Public hearings
May be required in certain decision-making processes, such as environmental impact assessment. They are open to all citizens who want to attend. A panel led by a governmental official chairs the event. Panel members may be nominated by the government and civil society organisations.

Non-binding referenda - It is used for a concrete consultation of the entire population on a specific issue with a choice of answers.

Tools for ongoing consultation:

Open hours - It allows for citizens to have opportunities to meet and talk to decision-makers. Open hours allow for direct consultation.

Citizens' panels - The panels are composed of citizens selected on the basis of a representative sample of population. Governments consult the citizens' panel in order to receive reactions on a variety of policy initiatives.

Advisory committees – Composed of representatives of public interest who are chosen by government bodies, with the aim of ensuring broad representation and providing a forum on ongoing consultation.

As in indicator CR8, the municipalities with processes of Local Agenda 21 implemented, may be easier to quantify the number of citizens involved. The monitoring at meetings could be performed through minutes.

A greater attendance to public consultations initiatives can be indicative of an increasing of social capital. However, it can be also a reaction to specific and short-term concerns. These concerns that can influence temporarily the indicator should be identified.

Required data improvements

Data needs to be gathered on the number of citizens which participate in the public consultation processes in the municipality.

CP16: E-government on-line energy-related information availability	
Social	Governance and public engagement

Definition

This indicator provides a measure of the access to information made available by the local authority in the internet. Internet is considered as an important medium to spread information, due to its penetration, interactive characteristics and the fact of being unconstrained by time or distance. According to OECD (2004), internet offers powerful tools for searching, selecting and integrating the vast amounts of information held by governments as well as presenting the results in a form that can be immediately used by citizens.

On the contrary of public consultation and active participation, information flows from the government to citizens in a one-way relationship. It is a condition for further consultation and active participation to work (OECD, 2001).

Unit of measurement

Qualitative scale:
Poor – only simple information;
Fair – simple information + access to official documents;
Good – simple information + access to official documents (updated databases) + interactive website with interfaces for questions from citizens and to receive newsletters.

Data requirements and sources

Data required	Data source
Websites, on-line databases, newsletters, access to official documents providing information on energy issues	Survey to the local authority

Calculation method

This indicator consists in the identification of the information on energy issues available in the local authority website. The analysis also takes into account the degree of online sophistication, which ranges from simple information to interactive websites and updated databases.

Required data improvements

The on-line tools made available by the local authority which involve dissemination of information should be investigated.

CP17: Awareness raising campaigns on energy issues	
Social	Governance and public engagement

Definition

The indicator measures the promotion of awareness raising campaigns on energy issues by the local authority. The objectives of these campaigns should cover the overall energy awareness among citizens and target specific groups where energy use is significant. Schoolchildren are an important audience to involve. The success of the campaigns is expected to have impact on the reduction of energy consumption in the municipality.

Unit of measurement

% of population targeted by the awareness raising campaigns

Data requirements and sources

Data required	Data source
Number of citizens targeted by the awareness raising campaigns	Survey to the local authority
Awareness raising campaigns and subjects covered	Survey to the local authority

Calculation method

The calculation of this indicator encompasses the identification of energy awareness raising campaigns promoted or supported by the local authority and the population covered by them.

Awareness raising campaigns can make use of the following useful tools:

- Posters, leaflets, brochures and guides – more easy to understand and more attractive information to citizens;
- Exhibitions and events (e.g. Sustainable Energy Week);
- Workshops and seminars;
- Information centres – fixed information centres accessible to citizens;
- Demonstration projects on renewable energy and energy saving – to demonstrate the feasibility of the technology.

Required data improvements

Data needs to be collected on the number of citizens targeted by the awareness raising campaigns in the municipality.

CP18: Local Authority advice and assistance to the citizens on energy issues	
Social	Governance and public engagement

Definition

This indicator measures the activities of the local authority in what regards its role as energy advisor. The local authority should help to inform and motivate the citizens on how they can use energy more efficiently. The use of renewable energy technologies should also be encouraged and supported (CEMR, 2006).

Unit of measurement

Qualitative scale:

Poor – general advice is provided through brochures and guides. There is no technical support or assistance to the citizens within the local authority;

Fair – advice is provided according to citizens' needs, through the contact with local authority staff;

Good – existence of an organized structure such as an energy advice centre/office which provides direct advice in areas such as technical support in energy efficiency measures and renewables in buildings construction or refurbishing or the access to grants.

Data requirements and sources

Data required	Data source
Advice and assistance provided by the local authority to the citizens	Survey to the local authority

Calculation method

For this indicator we need to know in which cases the local authority has provided advice and assistance to citizens, professionals or to the business. There are some local authorities which have created an energy advice centre. In this case, the register of the processes received in the centre

Local authorities may provide advice in the following areas:

- Elaboration of practical guides on energy efficiency and renewable energy technologies and suppliers;
- Expert advice on measures to reduce energy consumption in buildings in the case of new construction or rehabilitation;
- Choice and installation of renewable energy technologies in buildings;
- Access to financial support schemes for energy efficiency and renewables from national, regional or local authority funding.

Required data improvements

Further work requires the investigation of advice and assistance provided by the local authority to the citizens in what regards energy projects.

4. Supporting Resources

4.1 Glossary

CO_2-equivalent emission – is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its GWP for the given time horizon. For a mix of GHGs it is obtained by summing the equivalent CO_2 emissions of each gas. Equivalent CO_2 emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses (IPCC, 2007).

Global Warming Potential (GWP) – An index, based upon radiative properties of well mixed GHG, measuring the radiative forcing of a unit mass of a given well mixed greenhouse gas in today's atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame (IPPC, 2007).

Greenhouse Gases (GHG) – Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (IPPC, 2007).

Gross Domestic Product (GDP) – GDP is the monetary value of all goods and services produced within a nation (IPPC, 2007).

Energy carriers (vectors) – Primary energy is first converted into secondary energy (gasoline, charcoal, electricity).

Energy efficiency – a ration between an output of performance, service, goods or energy, and an input of energy (EC, 2006).

Energy efficiency improvement – an increase in energy end-use efficiency as a result of technological, behavioural and/or economic changes (EC, 2006).

Energy intensity – Energy intensity is the ratio of energy use to economic or physical output. At the national level, energy intensity is the ratio of total primary energy use or final energy use to Gross Domestic Product. At the activity level, one can also use physical quantities in the denominator, e.g. litre fuel/vehicle km (IPCC, 2007).

Energy savings – an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of one or more energy efficiency improvement measures, whilst ensuring normalisation for external conditions that affect energy consumption (EC, 2006).

Energy service – the physical benefit, utility or good derived from a combination of energy with energy efficient technology and/or action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to lead to verifiable and measurable or estimable energy efficiency improvement and/or primary energy savings (EC, 2006).

Energy service company (ESCO) – a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria (EC, 2006).

Final energy – refers to delivered energy which is made available to the consumer, not taking transformation losses into account.

NUTS – The Nomenclature of Territorial Units for Statistics (NUTS) was established by Eurostat in order to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union (Eurostat, 2008a). There are three levels of NUTS defined. At a more detailed level, there are the districts and municipalities. These are called "Local Administrative Units" (LAU) and are not subject of the NUTS Regulation (Eurostat, 2008b).

Petroleum products – comprise refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other petroleum products. Petroleum products are any oil-based products which can be obtained by distillation and are normally used outside the refining industry (IEA, 2007).

Primary energy – refers to the energy that is gathered directly from natural resources (mined coal, crude oil, natural gas, hydro and other non-combustible and combustible renewables).

Useful energy – The part of energy that is used to provide the energy service (work, heat).

4.2 Conversion Units

Table 3 presents the conversion units that can be useful in the calculation of the indicators.

Table 3 – Conversion factors used in the calculation of the indicators.

Electricity	1 toe =	11630 kWh
	1 toe =	0,041868 TJ
	1MWh =	0,086 toe
	1kWh =	0,000086 toe
Natural gas	10^3 Nm^3 =	1,02 toe
	1m^3 =	39 MJ
	1m^3 =	0,000039 TJ
Petroleum products	1t =	1,02 toe
LPG	1t =	1,13 toe
Gasoline	1t =	1,07 toe
Diesel	1t =	1,035 toe
Fuel oil	1t =	0,96 toe

A Unit converter can be found available at *http://www.iea.org/Textbase/stats/unit.asp*.

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Porto example:

Cravo, J., Hernández, J. R. & Márquez, M.A. 2004, 'Estimação de Variáveis Económicas Sujeitas a Dependências Espaciais: 'O Caso dos Municípios de Portugal Continental', *Revista Portuguesa de Estudos Regionais*, no. 5, pp. 57-78.

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DGEG 2009c, Estatísicas e Preços – Gás natural – Consumo de gás natural por concelho (2001 a 2007), viewed 6 April 2009, <http://www.dgge.pt>.

DGEG 2009d, Estatísticas e Preços - Petróleo e Derivados-Vendas de Combustíveis - Por distrito e actividade económica, viewed 6 April 2009, <http://www.dgge.pt>.

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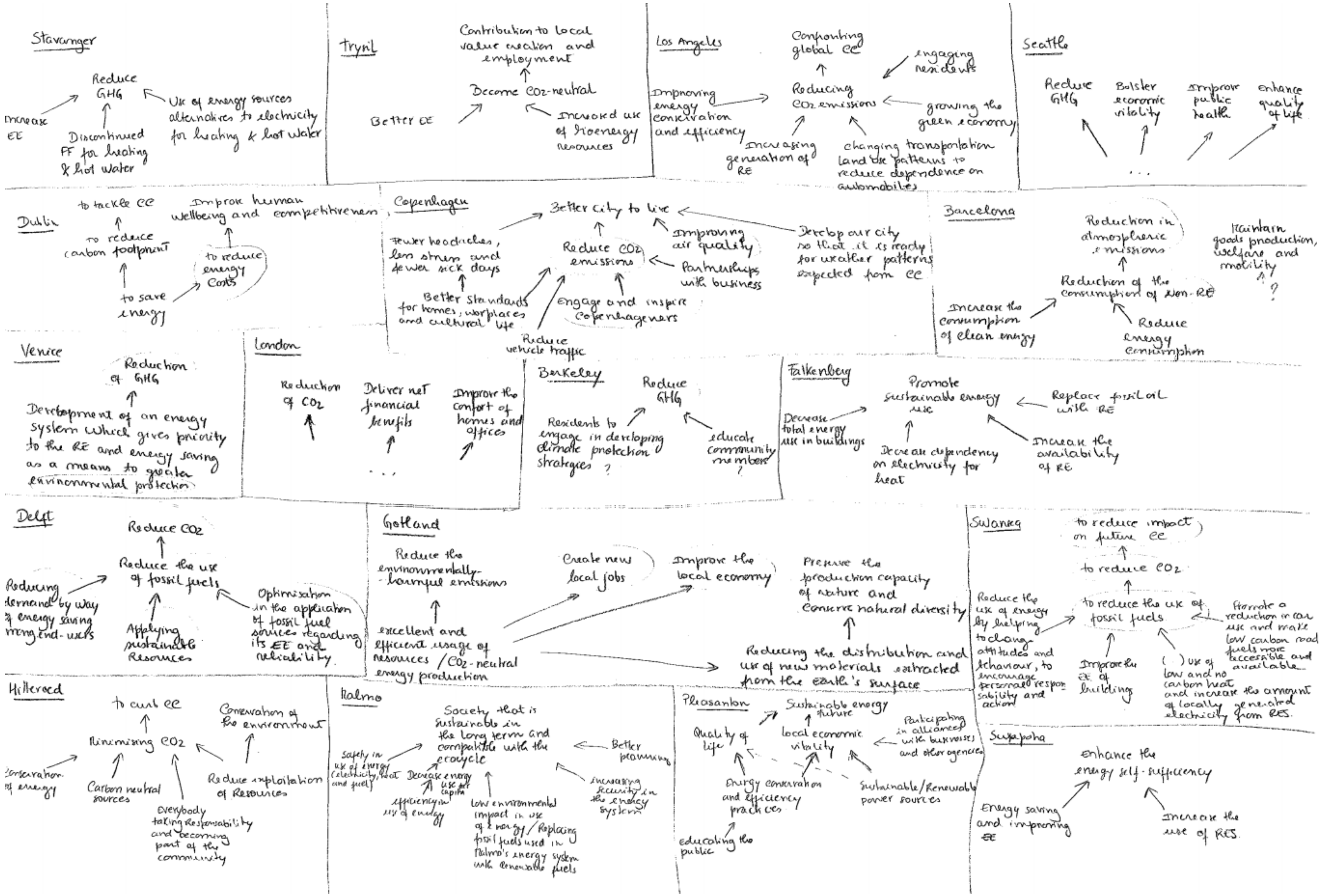
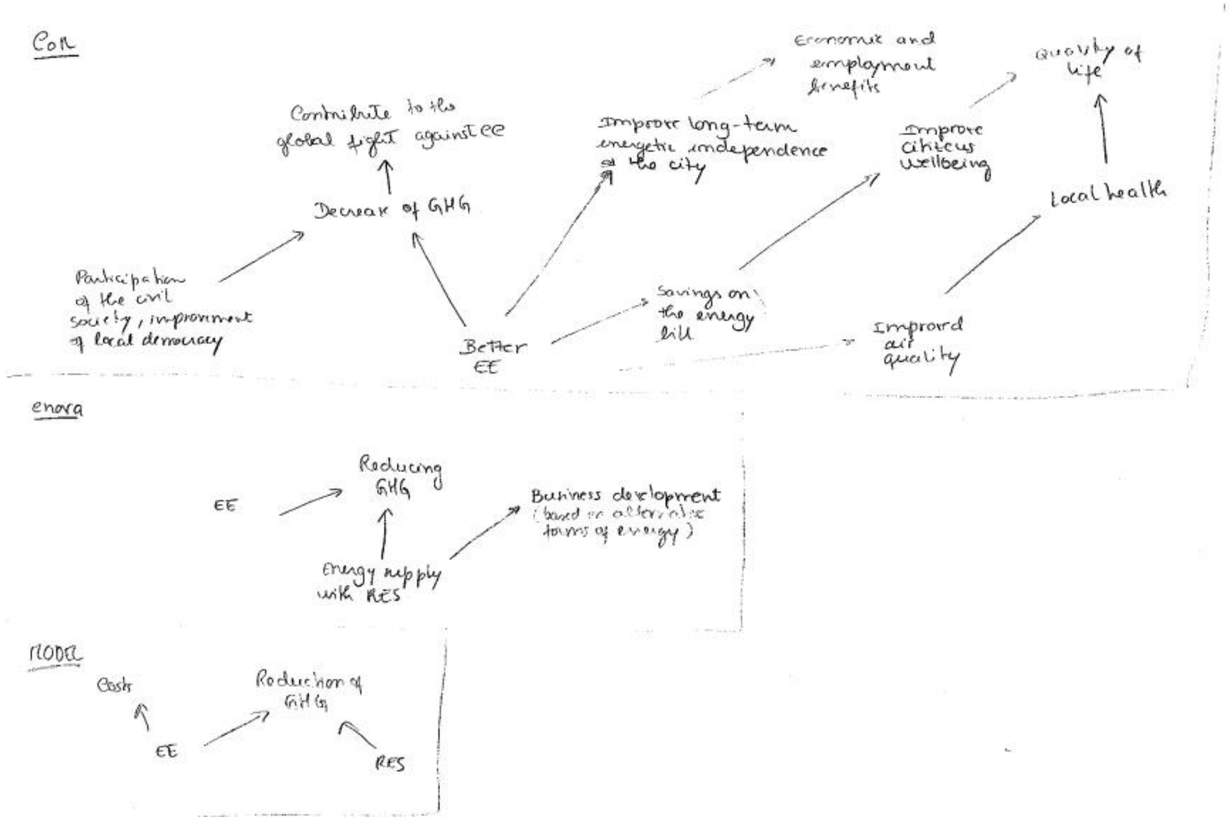
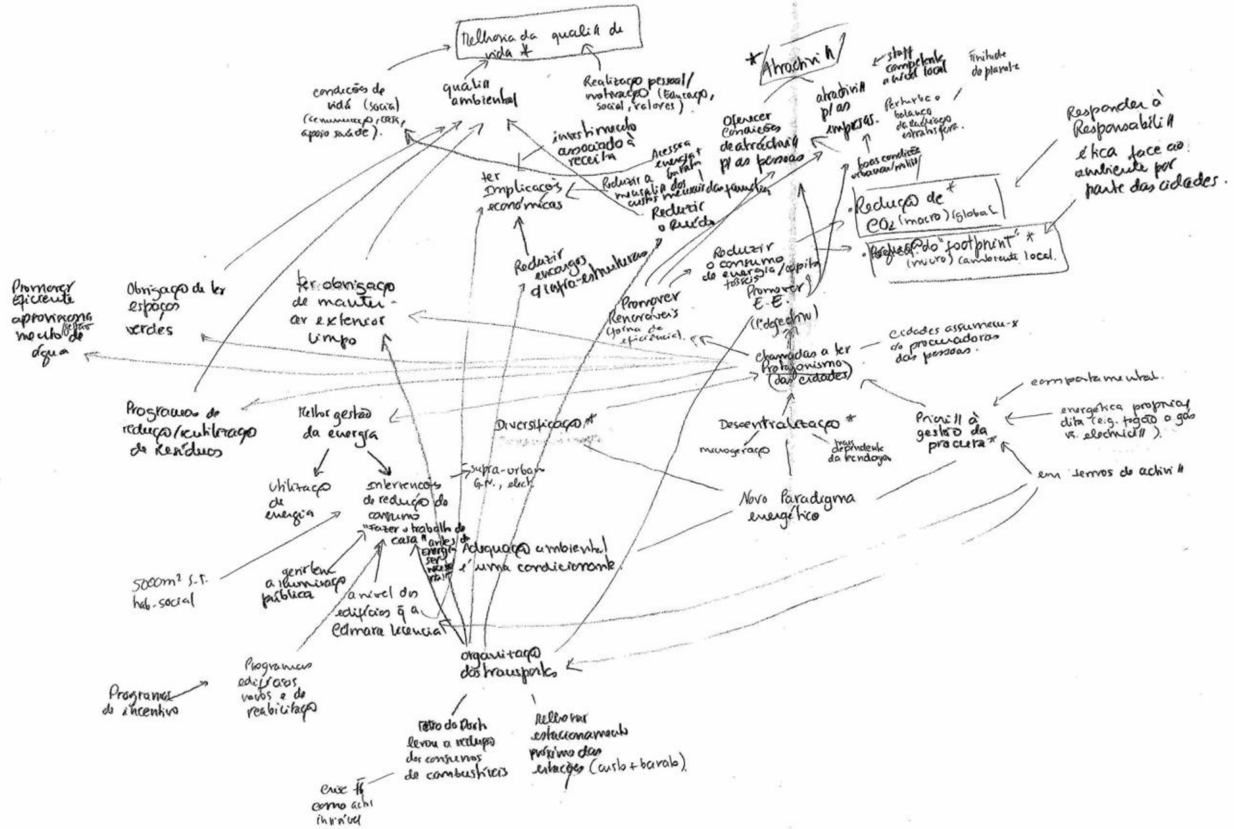
Appendix II: Causal maps derived from the literature review on objectives


Stavanger
Reduce GHG
Increase EE
Discontinued FF for heating & hot water
Use of energy sources alternatives to electricity for heating & hot water
Tryril
Contribution to local value creation and employment
Become CO2-neutral
Better EE
Increased use of bioenergy resources
Los Angeles
Confronting global CC
Reducing CO2 emissions
engaging residents
Improving energy conservation and efficiency
growing the green economy
Increasing generation of RE
changing transportation land use patterns to reduce dependence on automobiles
Seattle
Reduce GHG
Bolster economic vitality
Improve public health
enhance quality of life
Dublin
to tackle CC
Improve human wellbeing and competitiveness
to reduce carbon footprint
to reduce energy costs
to save energy
Copenhagen
Better city to live
Fewer headaches, less stress and fewer sick days
Reduce CO2 emissions
Improving air quality
Develop our city so that it is ready for weather patterns expected from CC
Partnerships with business
Better standards for homes, workplaces and cultural life
Engage and inspire Copenhageners
Reduce vehicle traffic
Barcelona
Reduction in atmospheric emissions
Maintain goods production, welfare and mobility
Reduction of the consumption of non-RE
Increase the consumption of clean energy
Reduce energy consumption
Venice
Reduction of GHG
Development of an energy system which gives priority to the RE and energy saving as a means to greater environmental protection
London
Reduction of CO2
Deliver net financial benefits
Improve the comfort of homes and offices
Berkeley
Reduce GHG
Residents to engage in developing climate protection strategies
educate community members
Falkenberg
Promote sustainable energy use
Decrease total energy use in buildings
Replace fossil oil with RE
Decrease dependency on electricity for heat
Increase the availability of RE
Delft
Reduce CO2
Reduce the use of fossil fuels
Reducing demand by way of energy saving among end-users
Applying sustainable Resources
Optimisation in the application of fossil fuel sources regarding its EE and reliability
Gotland
Reduce the environmentally-harmful emissions
Create new local jobs
Improve the local economy
Preserve the production capacity of nature and conserve natural diversity
excellent and efficient usage of resources / CO2-neutral energy production
Reducing the distribution and use of new materials extracted from the earth's surface
Swansea
to reduce impact on future CC
to reduce CO2
to reduce the use of fossil fuels
Reduce the use of energy by helping to change attitudes and behaviour, to encourage personal responsibility and action
Promote a reduction in car use and make low carbon road fuels more accessible and available
Improve the EE of building
Hilleroed
to curb CC
Conservation of the environment
Minimising CO2
Conservation of energy
Carbon neutral sources
Reduce exploitation of Resources
Everybody taking Responsibility and becoming part of the community
Malmo
Society that is sustainable in the long term and compatible with the ecocycle
Better planning
Safety in use of energy (electricity, heat and fuel)
Decrease energy use per capita
efficiency in use of energy
Low environmental impact in use of energy / Replacing fossil fuels used in Malmo's energy system with renewable fuels
Increasing security in the energy system
Pleasanton
Sustainable energy future
Quality of life
local economic vitality
Participating in alliances with businesses and other agencies
Energy conservation and efficiency practices
Sustainable/Renewable power sources
educating the public
Suupohja
Enhance the energy self-sufficiency
Energy saving and improving EE
Increase the use of RES

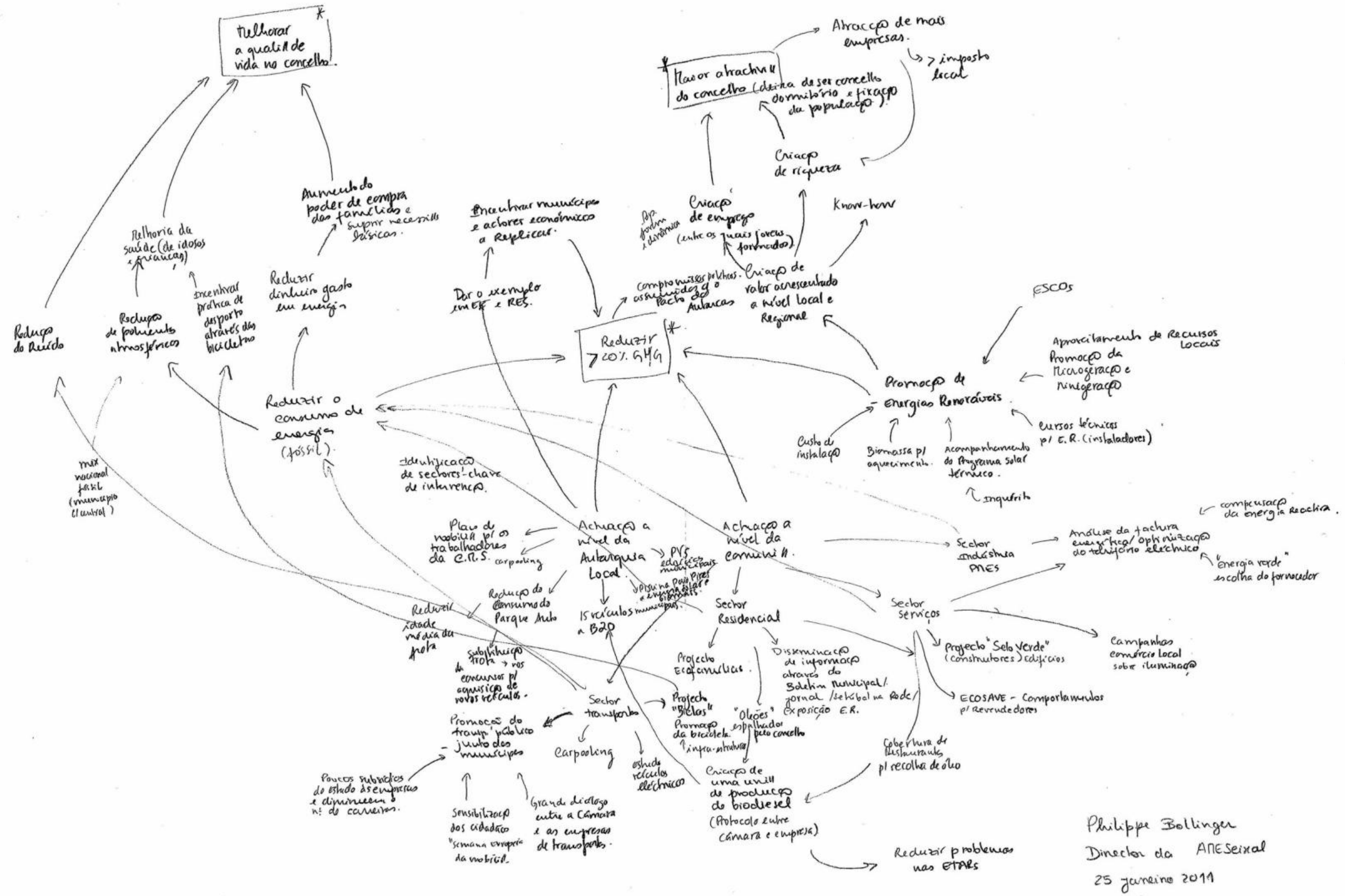

CoR
Contribute to the global fight against CC
Decrease of GHG
Participation of the civil society, improvement of local democracy
Better EE
Improve long-term energetic independence of the city
Economic and employment benefits
Savings on the energy bill
Improve citizens wellbeing
Quality of life
Local health
Improved air quality
enora
Reducing GHG
EE
Business development (based on alternative forms of energy)
Energy supply with RES
MODEL
Costs
Reduction of GHG
EE
RES

Appendix III: Cognitive maps on objectives of local sustainable energy planning

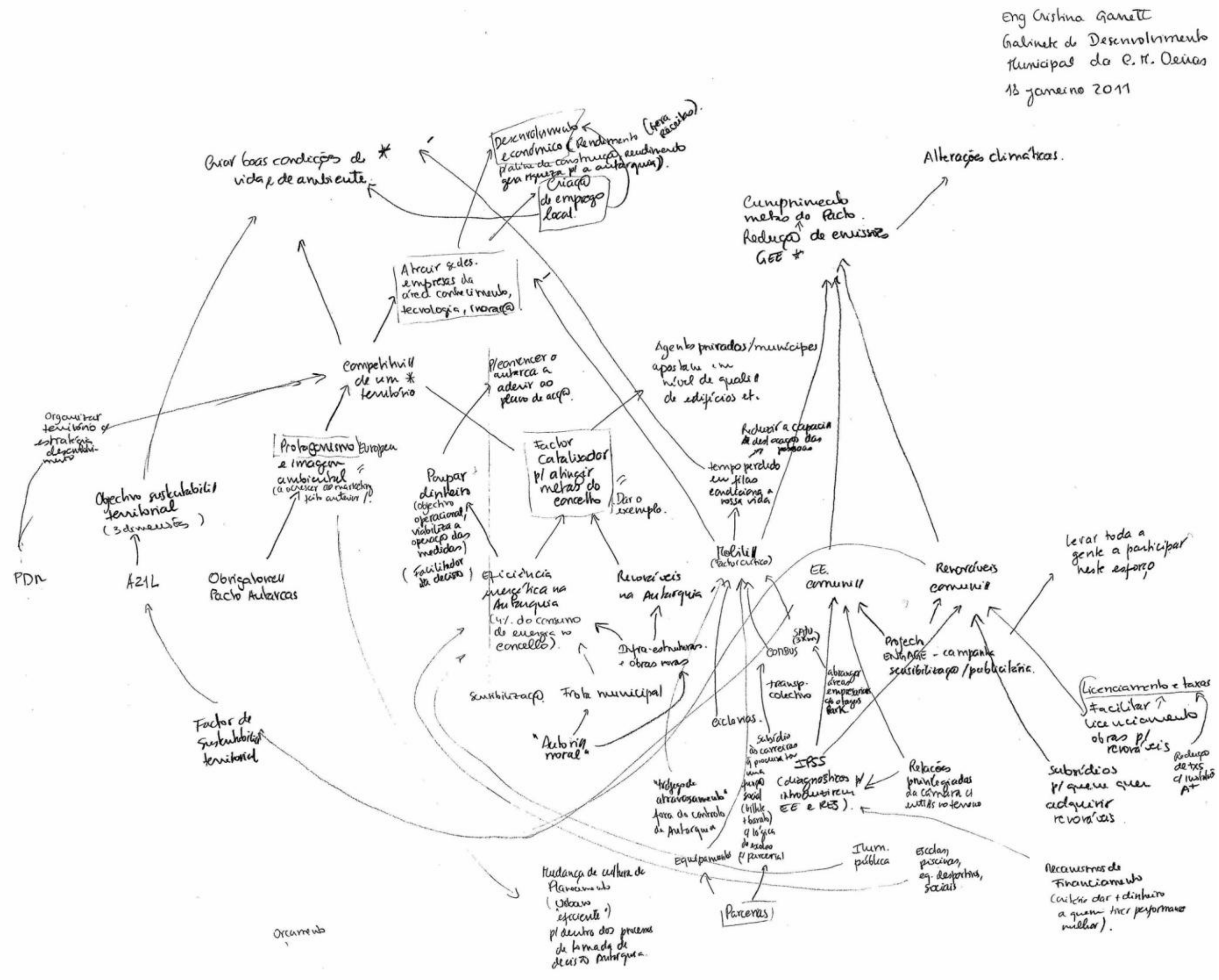


* vectores / instrumentos de intervenção

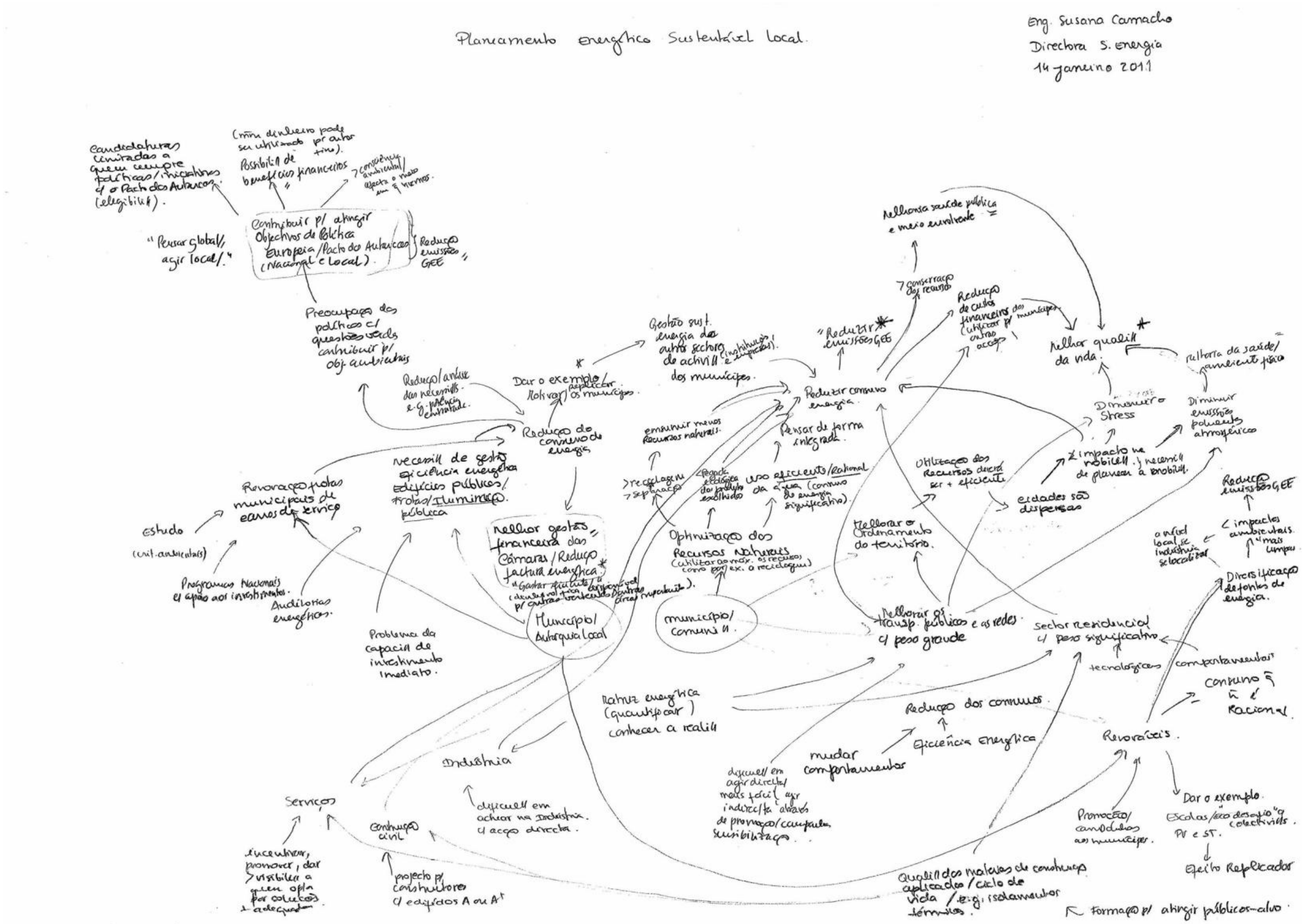
Prof. Doutor Oliveira Fernandes
AdE Porto
31 Janeiro 2011



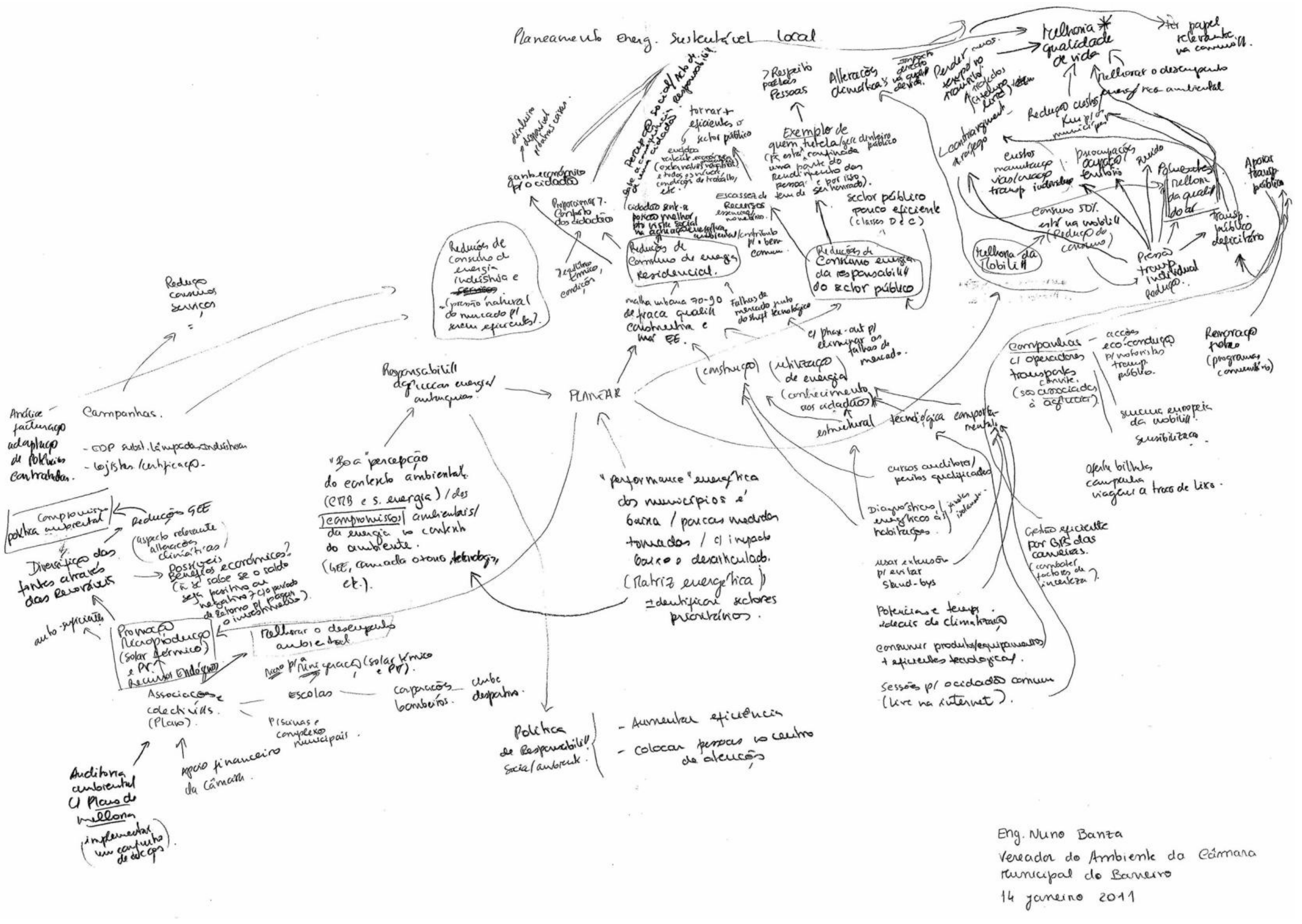
Melhorar a qualidade de vida no concelho
Maior atractividade do concelho
Atracção de mais empresas.
imposto local
Criação de riqueza
Know-how
Criação de emprego
Aumento do poder de compra das famílias
Encontrar munícipes e actores económicos a Replicar.
Dar o exemplo em EE e RES.
Reduzir 20% GHG
Compromisso político. Pacto dos Autarcas
Melhoria da saúde (de idosos e crianças)
Redução do Ruído
Redução de poluentes atmosféricos
Incentivar prática de desporto através das bicicletas
Reduzir dinheiro gasto em energia
Reduzir o consumo de energia (fóssil).
ESCOs
Aproveitamento de Recursos locais
Promoção da microgeração e minigeração
Promoção de Energias Renováveis
Custo de instalação
Biomassa p/ aquecimento.
Acompanhamento do Programa Solar térmico.
Inquérito
cursos técnicos p/ E.R. (instaladores)
Identificação de sectores-chave de intervenção.
Plano de mobilidade p/ os trabalhadores da C.M.S.
carpooling
Acção a nível da Autarquia Local.
Acção a nível da comunidade.
Sector Indústria PMES
Análise da factura energética/ optimização do tarifário eléctrico
compensação da energia Reactiva.
"energia verde" escolha do fornecedor
Redução do Consumo do Parque Auto
15 veículos a B20
Sector Residencial
Sector Serviços
Projecto "Selo Verde" (construtores) edifícios
Campanhas comércio local sobre iluminação
ECOSAVE - Comportamentos p/ Revendedores
Projecto Ecofamílias.
Disseminação de informação através do Boletim Municipal/ jornal/ Exposição E.R.
Sector transportes
Projecto "Bicicletas"
Promoção do transp. público junto dos munícipes
Carpooling
estudo veículos eléctricos
Criação de uma unidade de produção de biodiesel (Protocolo entre Câmara e empresa)
Cobertura de Restaurantes p/ recolha de óleo
Reduzir problemas nas ETARs
Sensibilização dos cidadãos "Semana Europeia da mobilidade"
Grande diálogo entre a Câmara e as empresas de transportes.
Philippe Bollinger
Director da AMESeixal
25 Janeiro 2011



Eng Cristina Garrett
Gabinete de Desenvolvimento Municipal da C. M. Oeiras
13 janeiro 2011
Criar boas condições de vida e de ambiente *
Desenvolvimento económico
Criação de emprego local
Alterações climáticas.
Cumprimento metas do Pacto. Redução de emissões GEE *
Atrair sedes. empresas da área conhecimento, tecnologia, inovação
Competitividade de um território *
Agentes privados/munícipes apostam num nível de qualidade de edifícios etc.
Protagonismo Europeu e imagem ambiental
Poupar dinheiro
Factor catalizador p/ atingir metas do concelho
Dar o exemplo.
Objectivo sustentabilidade territorial (3 dimensões)
PDM
A21L
Obrigatoriedade Pacto Autarcas
Eficiência energética na Autarquia
Renováveis na Autarquia
Mobilidade (factor crítico)
EE. comunidade
Renováveis comunidade
Levar toda a gente a participar neste esforço
Infra-estruturas + obras novas
Sensibilização
Frota municipal
Factor de sustentabilidade territorial
Combus
transp. colectivo
ciclovias.
IPSS
Relações privilegiadas da Câmara c/ entidades no terreno
Licenciamento e taxas
Facilitar licenciamento obras p/ renováveis
Subsídios p/ quem quer adquirir renováveis
Mecanismos de Financiamento
Equipamentos
Ilum. pública
Parcerias
Orçamento



Planeamento energético Sustentável Local
Eng. Susana Camacho
Directora S. energia
14 janeiro 2011
Contribuir p/ atingir Objectivos de Política Europeia/Pacto dos Autarcas (Nacional e Local)
Possibilid de benefícios financeiros
"Pensar global/, agir local/."
Redução emissões GEE
Preocupação dos políticos c/ questões verdes contribuir p/ obj. ambientais
Dar o exemplo/ Motivar/ replicar os munícipes
Redução do consumo de energia
Reduzir consumo energia
Pensar de forma integrada
Optimização dos Recursos Naturais
Melhorar o Ordenamento do território
Melhorar os transp. públicos e as redes c/ peso grande
Sector residencial c/ peso significativo
Melhor qualid da vida
Diminuir o Stress
Diminuir emissões poluentes atmosféricos
cidades são dispersas
Diversificação de fontes de energia
Redução emissões GEE
Município/ Autarquia Local
município/ comunid.
Melhor gestão financeira das Câmaras/ Redução factura energética
necessid de gestão eficiência energética edifícios públicos/ frota/ Iluminação pública
Renovação frotas municipais de carros de serviço
Estudo (crit. ambientais)
Programas Nacionais c/ apoio aos investimentos
Auditorias energéticas
Problema da capacid de investimento imediato
Matriz energética (quantificar) conhecer a realid
Redução dos consumos
Eficiência Energética
mudar comportamentos
Renováveis
tecnológicas
comportamentais
Consumo ñ racional
Dar o exemplo.
Efeito Replicador
Indústria
Serviços
Construção civil
Formação p/ atingir públicos-alvo


Planeamento Energ. Sustentável Local
Melhoria qualidade de vida
PLANEAR
Campanhas.
Redução de consumo de energia residencial.
Reduções de consumo energ. da responsabilid. do sector público
Sector público pouco eficiente (classes D e C)
Exemplo de quem tutela
Alterações climáticas
Melhoria da Mobilid.
Apoiar transp. público
Transp. público deficitário
(construção)
(utilização de energia)
(conhecimento dos cidadãos)
estrutural
tecnológica
comportamental
Responsabilid. de fiscalizar energias/autarquias
"Boa" percepção do contexto ambiental
"performance" energética dos municípios é baixa / poucas medidas tomadas / c/ impacto baixo e desarticulado.
(Matriz energética)
Identificar sectores prioritários.
Política de Responsabilid. Social/ambiental
- Aumentar eficiência
- colocar pessoas no centro de atenções
Compromisso política ambiental
Reduções GEE
Diversificação das fontes através das Renováveis
auto-suficiente
Melhorar o desempenho ambiental
Associações colectividades (Plano)
escolas
capacidades bombeiros.
Auditoria ambiental c/ Plano de melhoria
Apoio financeiro da Câmara.
Eng. Nuno Banza
Vereador do Ambiente da Câmara Municipal do Barreiro
14 janeiro 2011

Appendix IV: Literature review of actions

- **Journal articles**

NON-RESIDENTIAL BUILDINGS		References					
Action		[1]	[2]	[3]	[4]	[5]	[6]
Renewable energy	Installation of solar collectors for sanitary hot water production	25-80% e.s.	-	-	-	-	-
	Installation of wind turbines for the partial coverage of the electricity load	-	-	-	-	-	Higher performance for the CO_2 reduction criteria.
	Installation of a geothermal heat-exchanger system for initial warming and cooling of the air	-	-	-	-	-	Higher performance for the CO_2 reduction criteria.
	Installation of electricity-heat cogeneration unit	-	-	-	-	-	✓
	Installation of solar systems for cooling-air conditioning purposes	-	-	-	-	-	✓
	Installation of PV for the partial coverage of the electricity load	-	-	-	-	-	✓
	Installation of geothermal systems (heat pumps) for cooling-air conditioning	-	-	-	-	-	✓
Lighting	Installation of energy efficient lamps	60% e.s.	6% e.s.	-	✓	-	✓
	Installation of lighting's intensity control systems	-	-	-	✓	-	✓
Building envelope	Thermal insulation of external walls for buildings without or inadequate insulation	28-44% t.s. 4-5% e.s.	2% e.s.	-	✓	20.3%	✓
	Installation of double glazing	10-28% t.s.	7% e.s.	-	✓	64.9%	✓
	Installation of external shading	10-20% e.s.	-	-	✓	-	-
	Thermal insulation of roofs for buildings without or inadequate roof installation	4-8% t.s. 2% e.s.	2% e.s.	-	✓	18.2%	✓
	Installation of a rooftop garden	-	-	1-15% t.s. 17-79% space cooling load savings	-	-	-
	Weather stripping of windows/doors	-	-	-	✓	-	-
	Replacement of window frames in bad condition	-	-	-	✓	-	-
Space heating & cooling	Installation of Building Management System	20% t.s. 30% e.s.	-	-	✓	-	-
	Installation of ceiling fans	60% e.s.	-	-	✓	-	-
	Replacement of inefficient boilers with energy efficient natural gas burners	21% t.s.	-	-	✓	-	-
	Replacement of inefficient boilers with energy efficient oil burners	17% t.s.	-	-	✓	-	-
	Maintenance of central heating installations	11% t.s.	-	-	-	-	-
	Installation of temperature balance controls for central space heating	5% t.s.	5%	-	-	-	-
	Installation of space thermostats and use	5% t.s.	-	-	-	-	✓
	Decrease set-point temperature for Winter and increase for Summer	-	3-4% e.s.	-	✓	-	-
	Using a Variable Air Volume system instead of the current Constant Air Volume system	-	17% e.s.	-	-	-	-

NON-RESIDENTIAL BUILDINGS		References					
Action		[1]	[2]	[3]	[4]	[5]	[6]
	Use of mechanical night ventilation	-	-	-	✓	-	-

t.s. – thermal energy savings; e.s. – electrical savings

[1] Gaglia, AG, Balaras CA, Mirasgedis, S, Georgopoulou, E, Sarafidis, Y & Lalas, DP 2007, 'Empirical assessment of the Hellenic non-residential building stock, energy consumption, emissions and potential energy savings', *Energy Conservation and Management*, no. 28, pp. 1160-1175.

[2] Iqbal, I & Al-Houmoud, MS 2009, 'Parametric analysis of alternative energy conservation measures in an office building in hot and humid climate', *Building and Environment,* no. 42, pp.2166-2177.

[3] Wong, NH, Cheong, DKW, Yan, H, Soh, J, Ong, CL, Sia, A 2003, 'The effects of rooftop garden on energy consumption of a commercial building in Singapore', *Energy and Buildings,* no 35, pp. 353-364.

[4] Dascalaki, E, Santamouris, M 2002, 'On the potential of retrofitting scenarios for offices', *Building and Environment*, no 37, pp. 557-567.

[5] Papadoulos, AM, Theodosiou, TG & Karatzas, KD 2002, 'Feasibility of energy saving renovation measures in urban buildings The impact of energy prices and the acceptable pay back time criterion', *Energy and Buildings*, no. 34, pp. 455-466.

[6] Doukas, H, Nychtis, C & Psarras, J 2009, 'Assessing energy-saving measures in buildings through an intelligent decision support model', *Building and Environment*, no. 44, pp. 290-298.

RESIDENTIAL BUILDINGS		References				
Action		[7]	[8]	[9]	[10]	[11]
Renewable energy	Installation of solar collectors for sanitary hot water production	50-80% e.s.	60-74% en.s.	-	✓	-
Lighting	Installation of energy efficient lamps	60% e.s.	63-85%	-	-	-
Building envelope	Thermal insulation of external walls for buildings without or inadequate insulation	33-60% en. s.	21-42%	-	-	-
	Weather proofing (sealing) of openings/ Reduced infiltration rate due to envelope and window cracks	16-21% en. s.	7-18%	-	-	-
	Installation of double glazing	14-20% en. s.	7-27%	-	✓	-
	Installation of external shading/shading of houses with threes/ Installation of awning	10-20% e.s.	0-10%	26-47% cooling en.s.	-	-
	Thermal insulation of roofs for buildings without or inadequate roof insulation	2-14% en.s.	1-7%	-	✓	-
	Insulation of the floor	-	4-28%	-	✓	-
	Insulation of heat distribution pipes	-	2.4-5.2%	-	-	-
	Painting the external wall with light colors	-	2-4%	-	-	-
Space heating & cooling	Replacement of old and inefficient local air-conditioning units	72% e.s.	-	-	-	-
	Installation of ceiling fans	60% e.s.	57-68%	-	-	-
	Replacement of inefficient boilers with energy efficient natural gas-burners	21% en.s.	-	-	✓	-
	Replacement of inefficient boilers with energy efficient oil-burners	17% en.s.	~18%	-	-	-
	Maintenance of central heating installations	10-12% en. s.	-	-	-	-
	Installation of temperature balance controls for central space heating	3-6% e.s.	-	-	-	-

RESIDENTIAL BUILDINGS		References				
Action		[7]	[8]	[9]	[10]	[11]
	Installation of space thermostats	3-6% e.s.	-	-	-	-
	Installation of thermostatic valves	-	10-30%	-	-	-
	Installation of natural gas-fuelled micro-cogeneration systems	-	-	-	-	24-34% *
	Installation of ground-coupled heat pumps	-	-	-	-	29% **

en. s. – energy saving for space heating; e.s. – electricity saving; * reduction in non-renewable primary energy (NRPE) demand in European electricity mix; ** reduction in NRPE demand in combined cycle power plant mix. (representative for an alternative natural gas technology).

[7] Balaras, CA 2007, 'European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings', *Building and Environment*, no. 42, 1298-1314.

[8] Balaras, CA, Droutsa K, Argiriou, AA & Asimakopoulos, DN 1999, 'Potential for energy conservation in apartment buildings', *Energy and Buildings*, no. 31, pp.143-154.

[9] Akbari, H, Kurn, DM, Bretz, SE & Hanford, JW 1997, 'Peak power and cooling energy savings of shade trees', *Energy and Buildings*, no. 25, pp. 139-148.

[10] Verbeeck, G & Hens, H 2005, 'Energy savings in retrofitted dwellings: economically viable?', *Energy and Buildings*, no. 37, pp. 747-754.

[11] Dorer, V & Weber, A 2009, 'Energy and CO_2 emissions performance assessment of residential micro-cogeneration systems with dynamic whole-building simulation programs', *Energy Conservation and Management,* no. 50, pp. 648-657.

TRANSPORT		References				
Action		[12]	[13]	[14]	[15]	[16]
Private transport	Reduce urban car kilometers travelled (vehicle-km traveled)	✓	-	✓	✓	✓
	Increase urban car occupancy rates (passengers/car).	✓	-	-	-	✓
Collective transport	Increase public transport's mode share of urban motorized trips.	✓	-	✓	✓	✓
Non-motorized transport	Increase the share of urban trips performed by walking and cycling.	✓	-	✓	✓	✓
Cleaner fuels & efficient technology	Switch to alternative low-carbon fuels or other energy carriers: biofuel, electrical vehicles.	-	✓	✓	✓	-
	Increase of efficient vehicles.	✓	✓	✓	✓	-
Urban form	Reintegration of development around transit systems in the form of high density and mixed urban villages	-	-	✓	-	✓

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[15] Michaelis, L & Davidson, O 1996, 'GHG mitigation in the transport sector', *Energy Policy*, Vol. 24, no. 10/11, pp. 969-984.

[16] Kenworthy, JR & Laube, FB 1996, 'Automobile dependence in cities: An international comparison of urban transport and land use patterns with implications for sustainability', *Environment Impact Assessment Review*, no. 16, pp. 2799-308.

- **Local energy and climate action plans**

Note: Actions in italics were found exclusively in local energy and climate action plans and associated monitoring reports.

Ca – Cambridge; Ch – Chicago; LA – Los Angeles; SF – San Francisco; Se – Seattle; Co – Copenhagen; St – Stockholm; Lo – London; Ba – Barcelona; Ve – Venice; Al – Almada; Mi – Milan; Be – Berkeley; Du – Dublin; Te – Terrasa; Sw – Swansea; Go – Gotland; C – Camborne, Pool and Redruth

RESIDENTIAL BUILDINGS		Local energy and climate action plans																	
	Action	Ca	Ch	LA	SF	Se	Co	St	Lo	Ba	Ve	Al	Mi	Be	Du	Te	Sw	C	Go
Renewable energy	Installation of solar collectors for sanitary hot water production	✓								✓	✓	✓ pf		✓			✓ s	✓	✓
	Installation of wind turbines for the partial coverage of the electricity load								✓								✓ b		
	Installation of PV for the partial coverage of the electricity load				✓				✓	✓	✓	✓ pb	✓	✓		✓	✓ s	✓ s	✓
	Installation of a geothermal heat-exchanger system for initial warming and cooling of the air								✓										
	Installation of solar systems for cooling-air conditioning purposes									✓									
	Installation of geothermal systems (heat pumps) for cooling-air conditioning								✓										
Lighting	Installation of energy efficient lamps	✓										✓		✓	✓	✓	✓ s		
Building envelope	Thermal insulation of external walls (external insulation, internal dry lining or cavity wall pump fill)											✓							
	Installation of double glazing											✓							
	Installation of external shading																✓ s		
	Thermal insulation of roofs for buildings without or inadequate roof installation											✓							
	Installation of a rooftop garden/green roofs										✓								
	Weather stripping of windows/doors																		

RESIDENTIAL BUILDINGS		Local energy and climate action plans																	
Action		Ca	Ch	LA	SF	Se	Co	St	Lo	Ba	Ve	Al	Mi	Be	Du	Te	Sw	C	Go
	Replacement of window frames in bad condition																		
	Installation of 'cool roofs' (reflect solar radiation) in commercial buildings													✓					
Space heating & cooling	Installation of Building Management System														✓		✓		
	Installation of ceiling fans																		
	Installation/replacement of inefficient boilers with energy efficient natural gas burners	✓															✓		
	Installation/replacement of inefficient boilers with energy efficient oil burners	✓																	
	Maintenance of central heating installations																		
	Installation of temperature balance controls for central space heating																		
	Installation of space thermostats and use																		
	Decrease set-point temperature for Winter and increase for summer																		
	Using a Variable Air Volume system instead of the current Constant Air Volume system																		
	Use of mechanical night ventilation																		
	District heating & cooling network for specific sites									✓			✓		✓				
	Installation of electricity-heat cogeneration unit		✓						✓	✓	✓	✓			✓	✓			
	Replacement of diesel boilers with methane												✓						
	Upgrade Heating, ventilation and Air conditioning (HVAC) systems														✓				
	Replacement of boilers with energy efficient biomass boilers															✓			

[pf] public facilities; [pb] public buildings; [s] schools; [b] business park

RESIDENTIAL BUILDINGS		Local energy and climate action plans																	
Action		**Ca**	**Ch**	**LA**	**SF**	**Se**	**Co**	**St**	**Lo**	**Ba**	**Ve**	**Al**	**Mi**	**Be**	**Du**	**Te**	**Sw**	**C**	**Go**
Renewable energy	Installation of solar collectors for sanitary hot water production											✓		✓	✓	✓			✓
	Installation of renewables for electricity generation (micro-generation)	✓	✓		✓				✓		✓			✓					✓
	Use of distributed generation and combined heat and power		✓						✓										
Lighting	Installation of energy efficient lamps					✓				✓		✓			✓				
Building envelope	Thermal insulation of external walls (external insulation, internal dry lining or cavity wall pump fill)									✓		✓			✓			✓	
	Weather proofing (sealing) of openings/ Reduced infiltration rate due to envelope and window cracks																		
	Installation of double glazing									✓		✓			✓				
	Installation of external shading/ Installation of awning																		
	Thermal insulation of roofs for buildings without or inadequate roof insulation									✓		✓							
	Insulation of the floor																		
	Insulation of heat distribution pipes																		
	Painting the external wall with light colors																		
	Insulation of attics														✓				

RESIDENTIAL BUILDINGS		Local energy and climate action plans																	
Action		**Ca**	**Ch**	**LA**	**SF**	**Se**	**Co**	**St**	**Lo**	**Ba**	**Ve**	**Al**	**Mi**	**Be**	**Du**	**Te**	**Sw**	**C**	**Go**
Space heating & cooling	Replacement of old and inefficient local air-conditioning units																		
	Installation of ceiling fans																		
	Replacement of inefficient boilers with energy efficient natural gas-burners									✓					✓				
	Replacement of inefficient boilers with energy efficient oil-burners									✓									
	Maintenance of central heating installations																		
	Installation of temperature balance controls for central space heating																		
	Installation of space thermostats																		
	Installation of thermostatic valves																		
	Installation of natural gas-fuelled micro-cogeneration systems																		
	Installation of ground-coupled heat pumps																		
	Replacement of diesel boilers with methane												✓						
	Installation of energy efficient biomass boilers														✓				✓
	District heating for new housing districts														✓				

TRANSPORT		Local energy and climate action plans																	
Action		Ca	Ch	LA	SF	Se	Co	St	Lo	Ba	Ve	Al	Mi	Be	Du	Te	Sw	C	Go
Private transport	Increase urban car occupancy rates (passengers/car)/car pooling													✓					
	Increase car sharing									✓	✓		✓	✓				✓	
Freight transport	*Reduction of freight transport kilometres travelled in urban areas*												✓						
Collective transport	Increase public transport's mode share of urban motorized trips (bus, rail, metro, tram).					✓						✓	✓	✓	✓			✓	
	Implementation of bus booking system												✓						
Non-motorized transport	Increase the share of urban trips performed by walking and cycling.	✓				✓				✓		✓	✓	✓	✓			✓	
Cleaner fuels & efficient technology	Switch to alternative low-carbon fuels or other energy carriers: biodiesel, bioethanol, electric vehicles, CNG.					✓					✓	✓	✓	✓	✓ Biof.	✓	✓		✓
	Increase of efficient vehicles.	✓				✓				✓	✓	✓	✓	✓ Mun.					
Travel Plans	*Workplace travel plans*														✓				
	School travel plans														✓				
Urban form	Reintegration of development around transit systems in the form of high density and mixed urban villages													✓	✓				

STREET LIGHTING		Local energy and climate action plans																	
Action		Ca	Ch	LA	SF	Se	Co	St	Lo	Ba	Ve	Al	Mi	Be	Du	Te	Sw	C	Go
Street lighting	Installation of lighting's intensity control systems								✓		✓					✓	✓		
	Installation of more energy-efficient lamps for street lighting								✓		✓	✓	✓						
Traffic lights	Installation of LED traffic lights								✓	✓	✓	✓	✓						✓

OTHERS	Local energy and climate action plans																	
Action	**Ca**	**Ch**	**LA**	**SF**	**Se**	**Co**	**St**	**Lo**	**Ba**	**Ve**	**Al**	**Mi**	**Be**	**Du**	**Te**	**Sw**	**C**	**Go**
Increase green areas												✓	✓					
Use of conservative techniques in agriculture												✓						
Thermal valorisation of waste for district heating									✓			✓						
Increase of local food production													✓					
Purchase energy efficient office equipment													✓	✓				
Increase recycling and composting													✓		✓			
Water conservation, recycling and gray water use													✓		✓			
Demolition of older housing stock													✓					
Tidal-powered power plant																✓		
Biomass power plant																✓		
Wind power plant																		✓
Introduction of energy efficient electric motors in Industry																		✓
Introduction of cleaner fuels in Industry																		✓

Appendix V: Input data for energy modelling of Barreiro municipality

1. HOUSEHOLDS INPUTS

Step 1: Provide final energy demand by energy carrier.

Return to Start page

Go to Services Inputs

Conversion factors	toe
Electricity	7334
Natural gas	5149
Oil products	2214
Wood	282
Solar radiation	148
Fossil Heat	0
Renewable Heat	0

Step 2: Provide the data in the green cells to estimate the number of occupied dwellings in the base year and in the time horizon or introduce directly the values in the white cells.

	2001	2002	2003	2004	2005	2006	2007	**2008**	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**2020**
Classic familiar	38451	39572	40156	40558	40926	41276	41871	42186	42431											
% occupied dwellings	84%	84%	84%	84%	84%	84%	84%	84%	84%	-	-	-	-	-	-	-	-	-	-	-
Occupied Dwellings	32274	33215	33705	34043	34351	34645	35145	35409	35615	36219	36478	36810	37168	37530	37886	38226	38598	38961	39282	39651
																				12%

Step 3: Adjust the default values provided in the white cells to adapt to local circumstances. Optionally, adjust the default values provided in the brown cells.

Base year

Step 3.1. Breakdown of energy carrier by end-use			Step 3.2. Share of conversion technology in each energy carrier		Step 3.3. Conversion technology efficiency
Energy carrier	End-use	Input	Technology	Input	Optional Input
Electricity 100%	Hot water	5%	Conventional storage water heater	94%	88%
			Conventional storage water heater for solar auxiliary heating	6%	88%
			Heat pump water heater	0%	400%
			Heat pump water heater for solar auxiliary heating	0%	400%
				100%	
	Space heating	15%	Electrical heater	90%	100%
			Electrical heater for solar auxiliary radiant floors	0%	100%
			Heat pump	10%	400%
			Heat pump for solar auxiliary radiant floors	0%	400%
				100%	
	Space cooling	2%	Heat pump	100%	300%
	Refrigerators	22%	A++	0%	61%
			A+	3%	60%
			A	13%	55%
			B	11%	45%
			C	74%	40%
				100%	
	Freezers	10%	A++	0%	61%
			A+	3%	60%
			A	13%	55%
			B	11%	45%
			C	74%	40%
				100%	
	Washing machines	5%	A+	0%	52%
			A	11%	50%
			B	6%	45%
			C	84%	40%
				100%	
	Driers	2%	A	0%	55%
			B	0%	50%
			C	100%	45%
			D	0%	40%
				100%	
	Dishwashers	3%	A	70%	55%
			B	15%	50%
			C	15%	45%
			D	0%	40%
				100%	
	Televisions	9%	Televisions	100%	50%
	Computers	2%	Computers	100%	50%
	Others	8%	Others	100%	50%
	Lighting	12%	Incandescent	46%	5%
			Compact Fluorescent Lamps	22%	21%
			Fluorescent tub lamps	10%	25%
			Tungsten halogen	22%	5%
			LED	0%	21%
				100%	
	Cooking	5%	Oven/Stove/Microwave	100%	65%
Natural gas 100%	Hot water	50%	Gas tankless water heater	50%	65%
			Gas tankless water heater for solar auxiliary heating	0%	65%
			Conventional storage water heater	50%	78%
			Conventional storage water heater for solar auxiliary heating	1%	78%
				100%	
	Space heating	15%	Central boiler and hot water radiators	100%	87%
			Central boiler for solar auxiliary radiant floors	0%	87%
				100%	
	Cooking	35%	Oven/Stove	100%	60%
Oil products 100%	Hot water	55%	Gas tankless water heater	100%	65%
	Space heating	5%	Central boiler and hot water radiators	100%	80%
	Cooking	40%	Oven and Stove	100%	60%
Wood 100%	Space heating	100%	Fireplace	100%	42%
			Pellet stove	0%	82%
				100%	
	Cooking	0%	Oven/Stove	100%	45%
Solar radiation 100%	Hot water	100%	Solar water heater	100%	100%
	Space heating	0%	Hydronic Radiant Floors with Solar water heater	100%	100%
Fossil heat/cold 100%	Hot water	0%	Water heater	100%	100%
	Space heating	100%	Central radiators/ventilators	100%	100%
	Space cooling	0%	Central radiators/ventilators	100%	100%
Renewable heat/cold 100%	Hot water	0%	Water heater	100%	100%
	Space heating	100%	Central radiators/ventilators	100%	100%
	Space cooling	0%	Central radiators/ventilators	100%	100%

Reference Scenario

Step 3.4. Evolution factor for energy services needs per dwelling		Step 3.5. Share of end-use supplied by conversion technology				Step 3.6. Conversion technology efficien
End-use	2020 Input	Energy carrier	Technology	2008 Output	2020 Input	2020 Optional Input
Hot water	1,2	Electriciy	Conventional storage water heater	8,0%	7%	94%
			Conventional storage water heater for solar auxiliary heating	0,5%	1%	94%
			Heat pump water heater	0,0%	0%	400%
			Heat pump water heater for solar auxiliary heating	0,0%	0%	400%
		Natural gas	Gas tankless water heater	29,9%	40%	95%
			Gas tankless water heater for solar auxiliary heating	0,0%	0%	95%
			Conventional storage water heater	29,3%	39%	95%
			Conventional storage water heater for solar auxiliary heating	0,6%	1%	95%
		Oil products	Gas tankless water heater	28,3%	8%	95%
		Solar radiation	Solar water heater	3,4%	4%	100%
		Fossil heat/cold	Water heater	0,0%	0%	100%
		Renewable heat/cold	Water heater	0,0%	0%	100%
					100%	
Space heating	1,2	Electricity	Electrical heater	43,7%	38%	100%
			Electrical heater for solar auxiliary radiant floors	0,0%	0%	100%
			Heat pump	4,9%	10%	400%
			Heat pump for solar auxiliary radiant floors	0,0%	0%	400%
		Natural gas	Central boiler and hot water radiators	34,1%	39%	100%
			Central boiler for solar auxiliary radiant floors	0,0%	0%	100%
		Oil products	Central boiler and hot water radiators	4,9%	0%	80%
		Wood	Fireplace	12,5%	10%	42%
			Pellet stove	0,0%	3%	82%
		Solar radiation	Hydronic Radiant Floors with Solar water heater	0,0%	0%	100%
		Fossil heat/cold	Central radiators/ventilators	0,0%	0%	100%
		Renewable heat/cold	Central radiators/ventilators	0,0%	0%	100%
					100%	
Space cooling	1,2	Electricity	Heat pump	100,0%	100%	300%
		Fossil heat/cold	Central radiators/ventilators	0,0%	0%	100%
		Renewable heat/cold	Central radiators/ventilators	0,0%	0%	100%
					100%	
Refrigerators	1,0	Electricity	A++	0,0%	6%	61%
			A+	2,5%	35%	60%
			A	13,0%	42%	55%
			B	10,5%	11%	45%
			C	74,0%	5%	40%
					100%	
Freezers	1,2	Electricity	A++	0,0%	6%	61%
			A+	2,5%	35%	60%
			A	13,0%	42%	55%
			B	10,5%	11%	45%
			C	74,0%	5%	40%
					100%	
Washing machines	1,1	Electricity	A+	0,0%	5%	52%
			A	10,5%	54%	50%
			B	5,5%	25%	45%
			C	84,0%	16%	40%
					100%	
Driers	1,7	Electricity	A	0,0%	10%	55%
			B	0,0%	30%	50%
			C	100,0%	60%	45%
			D	0,0%	0%	40%
					100%	
Dishwashers	1,7	Electricity	A	70,0%	80%	55%
			B	15,0%	15%	50%
			C	15,0%	5%	45%
			D	0,0%	0%	40%
					100%	
Televisions	1,0	Electricity	Televisions	100,0%	100%	60%
					100%	
Computers	1,3	Electricity	Computers	0,0%	100%	60%
					100%	
Others	1,0	Electricity	Others	100,0%	100%	60%
					100%	
Lighting	1,0	Electricity	Incandescent	46,0%	0%	5%
			Compact Fluorescent Lamps	22,0%	77%	21%
			Fluorescent tub lamps	10,0%	13%	25%
			Tungsten halogen	22,0%	5%	5%
			LED	0,0%	5%	21%
					100%	
Cooking	1,0	Electricity	Oven/Stove/Microwave	12,0%	15%	78%
		Natural gas	Oven/Stove	59,0%	74%	66%
		Oil products	Oven/Stove	29,0%	11%	66%
		Wood	Oven/Stove	0,0%	0%	52%
					100%	

2. SERVICES INPUTS

Step 1: Provide final energy demand by energy carrier.

Return to Start page

Go to Transport Inputs

Conversion factors	toe
Electricity	6454
Natural gas	1707
Oil products	18
Wood	0
Solar radiation	43
Fossil heat/cold	0
Renewable heat/cold	0

Step 2: Provide the Gross Value Added (GVA) (in euros) in the base year and the annual % change in GVA in the green cells in order to estimate GVA in the time horizon or insert the value in the white cell.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual % change in GVA	-	1,86%	1,86%	1,97%	1,97%	1,97%	1,97%	1,97%	2,12%	2,12%	2,12%	2,12%	2,12%
Services GVA	551349350	561597098	572035318	583317241	594821670	606552995	618515690	630714318	644076594	657721962	671656420	685886093	**700417235**
													27%

Step 3: Adjust the default values provided in the white cells to adapt to local circumstances. Optionally, adjust the default values provided in the brown cells.

Base year

Step 3.1. Breakdown of energy carrier by end-use | Step 3.2. Share of conversion technology in each energy carrier | Step 3.3. Conversion technology efficiency

Energy carrier	End-use	Input	Technology	Input	Optional Input
Electricity 100%	Hot water	2%	Conventional storage water heater	99%	88%
			Conventional storage water heater for solar auxiliary heating	1%	88%
			Heat pump water heater	0%	400%
			Heat pump water heater for solar auxiliary heating	0%	400%
	Space heating	11%	Electrical heater	20%	100%
			Electrical heater for solar auxiliary radiant floors	0%	100%
			Heat pump	80%	400%
			Heat pump for solar auxiliary radiant floors	0%	400%
	Space cooling	8%	Heat pump	100%	300%
	Refrigerators & Freezers	13%	A++	0%	61%
			A+	3%	60%
			A	13%	55%
			B	11%	45%
			C	74%	40%
	Dishwashers	4%	A	70%	55%
			B	15%	50%
			C	15%	45%
			D	0%	40%
	Computers	3%	Computers	100%	50%
	Others	19%	Others	100%	50%
	Lighting	33%	Incandescent	6%	5%
			Compact Fluorescent Lamps	32%	21%
			Fluorescent tub lamps	52%	25%
			Tungsten halogen	10%	5%
			LED	0%	21%
	Cooking	8%	Oven/Stove/Microwave	100%	65%
Natural gas 100%	Hot water	50%	Gas tankless water heater	50%	65%
			Gas tankless water heater for solar auxiliary heating	0%	65%
			Conventional storage water heater	50%	78%
			Conventional storage water heater for solar auxiliary heating	1%	78%
	Space heating	30%	Central boiler and hot water radiators	100%	87%
			Central boiler for solar auxiliary radiant floors	0%	87%
	Cooking	20%	Oven/Stove	100%	60%
Oil products 100%	Hot water	42%	Gas tankless water heater	100%	65%
	Space heating	20%	Central boiler and hot water radiators	100%	80%
	Cooking	38%	Oven/Stove	100%	60%
Wood 100%	Space heating	100%	Fireplace	100%	42%
			Pellet stove	0%	82%
	Cooking	0%	Oven/Stove	100%	45%
Solar radiation 100%	Hot water	100%	Solar water heater	100%	100%
	Space heating	0%	Hydronic Radiant Floors with Solar water heater	100%	100%
Fossil heat/cold 100%	Hot water	0%	Water heater	100%	100%
	Space heating	100%	Central radiators/ventilators	100%	100%
	Space cooling	0%	Central radiators/ventilators	100%	100%
Renewable heat/cold 100%	Hot water	0%	Water heater	100%	100%
	Space heating	100%	Central radiators/ventilators	100%	100%
	Space cooling	0%	Central radiators/ventilators	100%	100%

Reference Scenario

Step 3.4. Evolution factor for energy services needs per unit of GVA | Step 3.5. Share of end-use supplied by conversion technology | Step 3.6. Conversion technology efficien

End-use	2020 Input	Energy carrier	Technology	2008 Output	2020 Input	2020 Optional Input
Hot water	1,0	Electriciy	Conventional storage water heater	12,4%	3,0%	94%
			Conventional storage water heater for solar auxiliary heating	0,1%	1,5%	94%
			Heat pump water heater	0,0%	0%	400%
			Heat pump water heater for solar auxiliary heating	0,0%	0%	400%
		Natural gas	Gas tankless water heater	41,3%	42%	95%
			Gas tankless water heater for solar auxiliary heating	0,0%	0%	95%
			Conventional storage water heater	40,9%	42%	95%
			Conventional storage water heater for solar auxiliary heating	0,4%	1,5%	95%
		Oil products	Gas tankless water heater	0,7%	0%	95%
		Solar radiation	Solar water heater	4,2%	10%	100%
		Fossil heat/cold	Water heater	0,0%	0%	100%
		Renewable heat/cold	Water heater	0,0%	0%	100%
					100%	
Space heating	1,2	Electricity	Electrical heater	11,4%	5%	100%
			Electrical heater for solar auxiliary radiant floors	0,0%	0%	100%
			Heat pump	45,4%	48%	400%
			Heat pump for solar auxiliary radiant floors	0,0%	0%	400%
		Natural gas	Central boiler and hot water radiators	42,9%	47%	100%
			Central boiler for solar auxiliary radiant floors	0,0%	0%	100%
		Oil products	Central boiler and hot water radiators	0,3%	0%	80%
		Wood	Fireplace	0,0%	0%	42%
			Pellet stove	0,0%	0%	82%
		Solar radiation	Hydronic Radiant Floors with Solar water heater	0,0%	0%	100%
		Fossil heat/cold	Central radiators/ventilators	0,0%	0%	100%
		Renewable heat/cold	Central radiators/ventilators	0,0%	0%	100%
					100%	
Space cooling	1,2	Electricity	Heat pump	100,0%	100%	300%
		Fossil heat/cold	Central radiators/ventilators	0,0%	0%	100%
		Renewable heat/cold	Central radiators/ventilators	0,0%	0%	100%
					100%	
Refrigerators & Freezers	1,0	Electricity	A++	0,0%	6%	61%
			A+	2,5%	35%	60%
			A	13,0%	42%	55%
			B	10,5%	11%	45%
			C	74,0%	5%	40%
					100%	
Dishwashers	1,0	Electricity	A	70,0%	80%	55%
			B	15,0%	15%	50%
			C	15,0%	5%	45%
			D	0,0%	0%	40%
					100%	
Computers	1,2	Electricity	Computers	100,0%	100%	60%
					100%	
Others	1,0	Electricity	Others	100,0%	100%	60%
					100%	
Lighting	1,0	Electricity	Incandescent	6,0%	0%	5%
			Compact Fluorescent Lamps	32,0%	77%	21%
			Fluorescent tub lamps	52,0%	13%	25%
			Tungsten halogen	10,0%	5%	5%
			LED	0,0%	5%	21%
					100%	
Cooking	1,0	Electricity	Oven/Stove/Microwave	59,7%	50%	78%
		Natural gas	Oven/Stove	39,5%	50%	66%
		Oil products	Oven/Stove	0,8%	0%	66%
		Wood	Oven/Stove	0,0%	0%	52%
					100%	

3. TRANSPORT INPUTS

Step 1. Provide final energy demand by energy carrier.

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Go to Industry Inputs

Conversion factors	toe
Electricity	139
LPG	6
Diesel	27954
Gasoline	9103
CNG	0
Biodiesel	0
Hydrogen	0

Step 2. Provide the Passenger Transport Activity and the Passenger Transport Energy Intensity.

2.1. If you have the Passenger transport activity (pkm) for the base year, please fill in the white cells. In case you need to estimate the number of pkm in the base year go to step 2.2 and in the time horizon go to step 2.3.

Estimates in italics

	2008			2020		
	pkm	% pkm		pkm	% pkm	% pkm
Passenger car	*740903226*	77%	Passenger car	939536627	78%	78%
Bus	41400000	4%	Bus	43083117	4%	4%
Powered-Two Wheelers	*3788746*	0%	Powered-Two Wheelers	4804495	0%	0%
Rail	*70547534*	7%	Rail	83346303	7%	7%
Metro	0	0%	Metro	0	0%	0%
Tram	0	0%	Tram	0	0%	0%
Boat	106744690	11%	Boat	128374007	11%	11%
Cycling & walking	0	0%	Cycling & walking	0	0%	0%
Total	963384196		Total	1199144550		

2.2. Provide the reference values for Passenger Transport Energy Intensity in the base year. These values can be used to estimate the number of pkm.

			2008	*Estimates in italics*
		toe/pkm	toe	pkm
Passenger car	Electricity	0,0000101	0	*0*
	LPG	0,0000387	6	*162066*
	Diesel	0,0000362	19149	*528488429*
	Diesel hybrid	0,0000213	0	*0*
	Gasoline	0,0000424	8994	*212252731*
	Gasoline hybrid	0,0000244	18	*738915*
	CNG	0,0000367	0	*0*
	Biodiesel	0,0000362	0	*0*
	Total		28167	*740903226*
Bus	Electricity	0,0000024	0	*0*
	LPG	0,0000160	0	*0*
	Diesel	0,0000338	1398	41400000
	Gasoline	0,0000187	0	*0*
	CNG	0,0000238	0	*0*
	Biodiesel	0,0000338	0	*0*
	Hydrogen	0,0000341	0	*0*
	Total		1398	41400000
Power two-wheelers	Gasoline	0,0000240	91	*3788746*
	Total		91	*3788746*
Rail	Electricity	0,0000038	125	*32884336*
	Diesel	0,0000052	196	*37663198*
	Total		321	*70547534*
Metro	Electricity	0,0000000	0	0
	Total		0	0
Tram	Electricity	0,0000000	0	0
	Total		0	0
Boat	Diesel	0,0000602	6429	106744690
	Total		6429	106744690

2.3. In order to estimate the Passenger transport activity in the time horizon, please provide the annual % change in pkm in the green cells.

Annual % change in pkm	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**2020**
Passenger car		3,0%	3,0%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%
	740903226	763130323,1	786024233	800172669	814575777	829238141	844164428	859359387	874827856	890574758	906605103	922923995	**939536627**
Bus		-0,5%	-0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%	0,5%
	41400000	41193000	40987035	41191970	41397930	41604920	41812944	42022009	42232119	42443280	42655496	42868774	**43083117**
Powered-Two Wheelers		3,0%	3,0%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%	1,8%
	3788746	3902409	4019481	4091831	4165484	4240463	4316791	4394494	4473595	4554119	4636093	4719543	**4804495**
Rail		0,4%	0,4%	1,6%	1,6%	1,6%	1,6%	1,6%	1,6%	1,6%	1,6%	1,6%	1,6%
	70547534	70829724	71113043	72250852	73406865	74581375	75774677	76987072	78218865	79470367	80741893	82033763	**83346303**
Metro		0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Tram		0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Boat		2,3%	2,3%	1,4%	1,4%	1,4%	1,4%	1,4%	1,4%	1,4%	1,4%	1,4%	1,4%
	106744690	109199818	111711414	113275373	114861229	116469286	118099856	119753254	121429799	123129817	124853634	126601585	**128374007**

Step 3. Provide the Freight Transport Activity and the Freight Transport Energy Intensity.

3.1. If you have the Freight transport activity (tkm), please fill in the white cells. In case you need to estimate the number of pkm in the base year go to step 3.2 and in the time horizon go to step 3.3.

Estimates in italics	2008 tkm	% tkm		2020 tkm	% tkm	% tkm
Road LDV	*9799685*	17%	**Passenger car**	12575377	17%	17%
Road HDV	*3876798*	7%	**Bus**	4974874	7%	7%
Rail	*45539744*	77%	**Powered-Two Wheelers**	58553088	77%	77%
Total	59216227		Total	76103338		
				29%		

3.2. Provide the reference values for Passenger Transport Energy Intensity in the base year. These values can be used to estimate the number of tkm.

		2008 toe/tkm	toe	*Estimates in italics* tkm
Road LDV	Diesel	0,0000399	391	*9799685*
	Biodiesel	0,0000399	0	*0*
	Total			*9799685*
Road HDV	Diesel	0,0000505	196	*3876798*
	Biodiesel	0,0000505	0	*0*
	Total			*3876798*
Rail	Electricity	0,0000034	14	*4027247*
	Diesel	0,0000047	196	*41512498*
	Total			*45539744*

3.3. In order to estimate the Freight transport activity in the time horizon, please provide the annual % change in tkm in the green cells.

Annual % change in tkm	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**2020**
Road LDV		2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%
	9799685	10005478	10215593	10430120	10649153	10872785	11101114	11334237	11572256	11815273	12063394	12316725	**12575377**
Road HDV		2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%
	3876798	3958211	4041333	4126201	4212852	4301322	4391649	4483874	4578035	4674174	4772332	4872551	**4974874**
Rail		2,2%	2,2%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%	2,1%
	45539744	46541619	47565534	48564411	49584263	50625533	51688669	52774131	53882388	55013918	56169210	57348764	**58553088**

Step 3. Adjust the default values provided in the white cells to adapt to local circumstances. Adjusting the default values provided in the brown cells is optional.

Base year

Step 3.1. Breakdown of energy carrier by end-use				Step 3.2. Share of conversion technology in each energy carrier		Step 3.3. Conversion technology efficiency
Energy carrier	End-use		Input	Engine fuel type	Input	Optional Input
Electricity 100%	Passenger	Passenger car	0%	Electric	100%	82%
		Bus	0%	Electric	100%	82%
		Rail	90%	Electric	100%	82%
		Metro	0%	Electric	100%	82%
		Tram	0%	Electric	100%	82%
	Freight	Rail	10%	Electric	100%	82%
LPG 100%	Passenger	Passenger car	100%	Liquified Petroleum Gas	100%	20%
		Bus	0%	Liquified Petroleum Gas	100%	20%
Diesel 100%	Passenger	Passenger car	68,5%	Diesel with 5% biodiesel (B5)	100%	20%
				Diesel hybrid	0%	48%
		Bus	5%	Diesel with 5% biodiesel (B5)	100%	20%
		Rail	0,7%	Diesel with 5% biodiesel (B5)	100%	20%
		Boat	23%	Diesel with 5% biodiesel (B5)	100%	20%
	Freight	Road LDV	1,4%	Diesel with 5% biodiesel (B5)	100%	20%
		Road HDV	0,7%	Diesel with 5% biodiesel (B5)	100%	20%
		Rail	0,7%	Diesel with 5% biodiesel (B5)	100%	20%
Gasoline 100%	Passenger	Passenger car	99%	Gasoline	99,8%	15%
				Gasoline hybrid	0,2%	37%
		Bus	0%	Gasoline	100%	15%
		Powered Two-wheelers	1%	Gasoline	100%	15%
CNG 100%	Passenger	Passenger car	0%	Compressed Natural Gas	100%	20%
		Bus	100%	Compressed Natural Gas	100%	20%
Biodiesel 100%	Passenger	Passenger car	0%	Non-blended Biodiesel (B100)	100%	20%
		Bus	100%	Non-blended Biodiesel (B100)	100%	20%
	Freight	Road LDV	0%	Non-blended Biodiesel (B100)	100%	20%
		Road HDV	0%	Non-blended Biodiesel (B100)	100%	20%
Hydrogen 100%	Passenger	Bus	100%	Hydrogen	100%	56%

Reference Scenario

Step 3.4. Efficiency change factor in Transport energy intensity (toe/pkm and toe/tkm) *

Step 3.5. Share of Passenger-km (% pkm) and Tonne-km (% tkm) by means of transport and by energy carrier

Step 3.6. Conversion technology efficiency

End-use		2020 Input	Energy carrier	Engine fuel type	2008 Output		2020 Input		2020 Optional Input
Passenger	Passenger car	-10%	Electricity	Electric	77%	0%	78%	0%	82%
			LPG	Liquified Petroleum Gas		0,02%		0,1%	30%
			Diesel	Diesel with 5% Biodiesel (B5)		71%		76%	30%
				Diesel Hybrid		0,0%		1,9%	48%
			Gasoline	Gasoline		29%		20%	20%
				Gasoline Hybrid		0,1%		2%	37%
			CNG	Compressed Natural Gas		0%		0%	20%
			Biodiesel	Non-blended Biodiesel (B100)		0%		0%	30%
								100%	
	Bus	-10%	Electricity	Electric	4%	0%	4%	0%	82%
			LPG	Liquified Petroleum Gas		0%		0%	20%
			Diesel	Diesel with 5% Biodiesel (B5)		100%		100%	30%
			Gasoline	Gasoline		0%		0%	20%
			CNG	Compressed Natural Gas		0%		0%	20%
			Biodiesel	Non-blended Biodiesel (B100)		0%		0%	30%
			Hydrogen	Hydrogen		0%		0%	70%
								100%	
	Powered Two-Wheelers	-10%	Gasoline	Gasoline	0%	0%	0%	100%	20%
	Rail	-10%	Electricity	Electric	7%	47%	7%	100%	82%
			Diesel	Diesel with 5% Biodiesel (B5)		53%		0%	30%
								100%	
	Metro	0%	Electricity	Electric	0%	0%	0%	100%	82%
	Tram	0%	Electricity	Electric	0%	0%	0%	100%	82%
	Boat	-10%	Diesel	Diesel with 5% Biodiesel (B5)	11%	100%	11%	100%	30%
	Cycling & Walking	0%	No energy carrier		0%	100%	0%	100%	-
					100%		100%		
Freight	Road LDV	-5%	Diesel	Diesel with 5% Biodiesel (B5)	17%	100%	17%	100%	30%
			Biodiesel	Non-blended Biodiesel (B100)		0%		0%	30%
								100%	
	Road HDV	-5%	Diesel	Diesel with 5% Biodiesel (B5)	7%	100%	7%	100%	30%
			Biodiesel	Non-blended Biodiesel (B100)		0%		0%	30%
								100%	
	Rail	-5%	Electricity	Electric	77%	9%	77%	100%	82%
			Diesel	Diesel with 5% Biodiesel (B5)		91%		0%	30%
					100%		100%	100%	

* If you need to estimate the efficiency change factor, please provide the changes in % per year for passenger and freight transport activity in the green cells.

Passenger transport

	Changes in % per year in toe/pkm	toe/pkm
2008	-	0,000038
2009	-1,0%	0,000037
2010	-1,0%	0,000037
2011	-0,9%	0,000037
2012	-0,9%	0,000036
2013	-0,9%	0,000036
2014	-0,9%	0,000036
2015	-0,9%	0,000035
2016	-0,9%	0,000035
2017	-0,9%	0,000035
2018	-0,9%	0,000034
2019	-0,9%	0,000034
2020	-0,9%	0,000034
		-10%

Freight transport

	Changes in % per year in toe/tkm	toe/tkm
2008	-	0,000013
2009	-0,3%	0,000013
2010	-0,3%	0,000013
2011	-0,5%	0,000013
2012	-0,5%	0,000013
2013	-0,5%	0,000013
2014	-0,5%	0,000013
2015	-0,5%	0,000013
2016	-0,5%	0,000013
2017	-0,5%	0,000013
2018	-0,5%	0,000013
2019	-0,5%	0,000013
2020	-0,5%	0,000013
		-5%

5. INDUSTRY INPUTS (including CONSTRUCTION)

Step 1: Provide final energy demand by energy carrier.

Return to Start page

Go to Agriculture Inputs

Conversion factors	toe
Electricity	22372
Natural gas	5009
Oil products	208011
LPG	295
Gasoline	0
Diesel	1096
Fuel oil	14474
Other petroleum products	192146
Wood	2459
Fossil heat/cold	52661
Renewable heat/cold	0
Coal	302

Step 2: Provide the annual % change in GVA in the green cells in order to estimate GVA in the time horizon or insert directly the value in the white cell. Insert the GVA in the base year.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**2020**
Annual % change in GVA	-	1,22%	1,22%	1,70%	1,70%	1,70%	1,70%	1,70%	1,62%	1,62%	1,62%	1,62%	1,62%
Municipal GVA	**158572439**	160501141	162453303	165218606	168030982	170891230	173800165	176758617	179623350	182534511	185492854	188499143	**191554155**
													21%

Step 3: Adjust the default values provided in the white cells to adapt to local circumstances. Optionally, adjust the default values provided in the brown cells.

Base year

Step 3.1. Breakdown of energy carrier by end-use				Step 3.2. Share of conversion technology in each energy carrier		Step 3.3. Conversion technology efficiency
Energy carrier	End-use		Input	Technology	Input	Optional Input
Electricity 100%	Direct process use	Process heating	12,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	7,0%	Cooling compressors	100%	80%
		Machine drive	52,0%	Motors	100%	90%
		Electro-chemical processes	7,0%	Electro-chemical reaction	100%	80%
		Other process use	2,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	10,0%	Motors	100%	90%
		Facility lighting	7,0%	Incandescent	1%	5%
				Fluorescent tub lamps	39%	25%
				High-bay lamps	60%	25%
		Onsite transportation	0,5%	Electric vehicle	100%	82%
		Others	2,5%	*undefined*	100%	50%
Natural gas 100%	Direct Process use	Process heating	77,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	1,0%	Cooling compressors	100%	80%
		Machine drive	4,0%	Motors	100%	90%
		Other process use	4,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	12,0%	Motors	100%	90%
		Onsite transportation	0,0%	CNG vehicle	100%	20%
		Others	2,0%	*undefined*	100%	50%
Oil products 100%	Direct Process use	Process heating	43,5%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	0,0%	Cooling compressors	100%	80%
		Machine drive	9,0%	Motors	100%	90%
		Other process use	4,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	6,5%	Motors	100%	90%
		Onsite transportation	24,0%	Diesel vehicle	100%	20%
		Others	13,0%	*undefined*	100%	50%
Wood 100%	Direct Process use	Process heating	100,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	0,0%	Cooling compressors	100%	80%
		Machine drive	0,0%	Motors	100%	90%
		Other process use	0,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	0,0%	Motors	100%	90%
		Others	0,0%	*undefined*	100%	50%
Fossil heat/cold 100%	Direct Process use	Process heating	95,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	0,0%	Cooling compressors	100%	80%
		Machine drive	0,0%	Motors	100%	90%
		Other Process Use	0,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	5,0%	Motors	100%	90%
		Others	0,0%	*undefined*	100%	50%
Renewable heat/cold 100%	Direct Process use	Process heating	95,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	0,0%	Cooling compressors	100%	80%
		Machine drive	0,0%	Motors	100%	90%
		Other Process Use	0,0%	*undefined*	100%	70%
	Non-process use	Facility HVAC	5,0%	Motors	100%	90%
		Others	0,0%	*undefined*	100%	50%
Coal 100%	Direct Process use	Process heating	100,0%	Furnaces, ovens, kilns	100%	80%
		Process cooling and refrigeration	0,0%	Cooling compressors	100%	80%
		Machine drive	0,0%	Motors	100%	90%
		Other Process Use	0,0%	*undefined*	100%	70%
	Non-process use	Others	0,0%	*undefined*	100%	50%

Reference Scenario

Step 3.4. Evolution factor for energy services needs per unit of GVA | **Step 3.5. Share of end-use supplied by conversion technology** | **Step 3.6. Conversion technology efficier**

End-use		2020 Input	Energy carrier	Technology	2008 Output	2020 Input	2020 Optional Input
Direct Process use	Process heating	1,0	Electricity	Furnaces, ovens, kilns	2%	2%	80%
			Natural gas	Furnaces, ovens, kilns	3%	12%	80%
			Oil products	Furnaces, ovens, kilns	60%	26%	80%
			Wood	Furnaces, ovens, kilns	2%	2%	80%
			Fossil heat/cold	Furnaces, ovens, kilns	33%	57%	80%
			Renewable heat/cold	Furnaces, ovens, kilns	0%	0%	80%
			Coal	Furnaces, ovens, kilns	0%	0%	80%
						100%	
	Process cooling and refrigeration	1,0	Electricity	Cooling compressors	97%	98%	80%
			Natural gas	Cooling compressors	3%	2%	80%
			Oil products	Cooling compressors	0%	0%	80%
			Wood	Cooling compressors	0%	0%	80%
			Fossil heat/cold	Cooling compressors	0%	0%	80%
			Renewable heat/cold	Cooling compressors	0%	0%	80%
			Coal	Cooling compressors	0%	0%	80%
						100%	
	Machine drive	1,0	Electricity	Motors	38%	52%	90%
			Natural gas	Motors	1%	0%	90%
			Oil products	Motors	61%	48%	90%
			Wood	Motors	0%	0%	90%
			Fossil heat/cold	Motors	0%	0%	90%
			Renewable heat/cold	Motors	0%	0%	90%
			Coal	Motors	0%	0%	90%
						100%	
	Electro-Chemical Processes	1,0	Electricity	Electro-chemical process	100%	100%	80%
						100%	
	Other Process Use	1,0	Electricity	*undefined*	5%	8%	80%
			Natural gas	*undefined*	2%	2%	80%
			Oil products	*undefined*	93%	90%	80%
			Wood	*undefined*	0%	0%	80%
			Fossil heat/cold	*undefined*	0%	0%	80%
			Renewable heat/cold	*undefined*	0%	0%	80%
			Coal	*undefined*	0%	0%	80%
						100%	
Non-process use	Facility HVAC	1,0	Electricity	Motors	12%	27%	90%
			Natural gas	Motors	3%	3%	90%
			Oil products	Motors	71%	51%	90%
			Wood	Motors	0%	0%	90%
			Fossil heat/cold	Motors	14%	19%	90%
			Renewable heat/cold	Motors	0%	0%	90%
						100%	
	Facility Lighting	1,0	Electricity	Incandescent	1%	0%	5%
				Fluorescent tub lamps	39%	40%	25%
				High-bay lamps	60%	60%	25%
	Onsite transportation	1,0	Electricity	Electric vehicle	0%	0,5%	82%
			Natural gas	CNG vehicle	0%	1,5%	20%
			Oil products	Diesel vehicle	100%	98,0%	20%
						100%	
	Others	1,0	Electricity	*undefined*	2%	1%	60%
			Natural gas	*undefined*	0%	0%	60%
			Oil products	*undefined*	98%	99%	60%
			Wood	*undefined*	0%	0%	60%
			Fossil heat/cold	*undefined*	0%	0%	60%
			Renewable heat/cold	*undefined*	0%	0%	60%
			Coal	*undefined*	0%	0%	60%
						100%	

6. AGRICULTURE & FISHERIES INPUTS

Step 1: Provide final energy demand by energy carrier.

Return to Start page

Go to Street Lighting Inputs

Conversion factors	toe
Electricity	61
Natural gas	0
Oil products	314
Fossil heat/cold	0
Renewable heat/cold	0
Biodiesel	0

Step 2: Provide the annual % change in GVA in the green cells in order to estimate GVA in the time horizon or insert directly the value in the white cell. Insert the GVA in the base year.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**2020**
Annual % change in GVA	-	2,00%	2,00%	0,50%	0,50%	0,50%	0,50%	0,50%	1,00%	1,00%	1,00%	1,00%	1,00%
Municipal GVA	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**n.a.**

Step 3: Adjust the default values provided in the white cells to adapt to local circumstances. Optionally, adjust the default values provided in the brown cells.

Base year

Step 3.1. Breakdown of energy carrier by end-use — Step 3.2. Share of conversion technology in each energy carrier — Step 3.3. Conversion technology effici

Energy carrier	End-use	Input	Technology	Input	Optional Input
Electricity 100%	Irrigation	99%	Electric pump	100%	55%
	Heating/cooling of livestock facilities and greenhouses	0%	Heat pump	100%	400%
	Lighting	1%	Incandescent	10%	5%
			Compact fluorescent lamps	30%	21%
			Fluorescent tub lamps	50%	25%
			Tungsten halogen	10%	5%
			LED	0%	21%
				100%	
Natural gas 100%	Heating/cooling of livestock facilities and greenhouses	100%	Boiler	100%	87%
Oil products 100%	Irrigation	0%	Diesel pump	100%	25%
	Farm machinery/ fishing boats	100%	Tractors, treshers, boats	100%	20%
	Heating/cooling of livestock facilities and greenhouses	0%	Boiler	100%	80%
Fossil heat/cold 100%	Heating/cooling of livestock facilities and greenhouses	100%	Heat pump	100%	400%
Renewable heat/cold 100%	Heating/cooling of livestock facilities and greenhouses	100%	Heat pump	100%	400%
Biodiesel 100%	Farm machinery/ fishing boats	100%	Tractors, treshers, boats	100%	20%

Reference Scenario

Step 3.4. Evolution factor for energy services needs per unit of GVA — Step 3.5. Share of end-use supplied by conversion technology — Step 3.6. Conversion technology effici

End-use	2020 Input	Energy carrier	Technology	2008 Ouput	2020 Input	2020 Optional Input
Irrigation	1,0	Electricity	Electric pump	100%	100%	55%
		Oil products	Diesel pump	0%	0%	25%
Farm machinery/ fishing boats	1,0	Oil products	Tractors, treshers, boats	100%	100%	20%
		Biodiesel	Tractors, treshers, boats	0%	0%	20%
Heating/cooling of livestock facilities and greenhouses	1,0	Electricity	Heat pump	0%	50%	20%
		Natural gas	Boiler	0%	50%	87%
		Oil products	Boiler	0%	0%	80%
		Fossil heat/cold	Heat pump	0%	0%	400%
		Renewable heat/cold	Heat pump	0%	0%	400%
Lighting	1,0	Electricity	Incandescent	0%	0%	5%
			Compact fluorescent lamps	0%	35%	21%
			Fluorescent tub lamps	0%	55%	25%
			Tungsten halogen	0%	10%	5%
			LED	0%	0%	21%

5. STREET LIGHTING INPUTS

Step 1: Provide final energy demand by energy carrier.

Return to Start page

Go to Energy Supply Inputs

Conversion factors	toe
Electricity	560

Step 2: Use the number of dwellings inserted in the Households inputs.

	2008	2020
Occupied Dwellings	35409	39651

Step 2: Adjust the default values provided in the white cells to adapt to local circumstances. Optionally, adjust the default values provided in the brown cells.

Base year

Step 2.1. Breakdown of energy carrier by end-use | **Step 2.2. Share of end-use supplied by conversion technology** | **Step 2.3. Conversion technology efficiency**

Energy carrier	End-use	Input	Technology	Input	Optional Input
Electricity 100%	Street Lighting	80%	High pressure sodium	60%	41%
			Mercury vapor	40%	16%
			LED	0%	21%
				100%	
	Traffic Lights	20%	Incandescent	100%	5%
			LED	0%	21%
				100%	

Reference Scenario

Step 2.4. Evolution factor for energy service needs per dwelling | **Step 2.5. Share of end-use supplied by conversion technology** | **Step 2.6. Conversion technology efficiency**

End-use	2020 Input	Technology	2008 Output	2020 Input	2020 Optional Input
Street Lighting	1,05	High pressure sodium	60%	90%	41%
		Mercury vapor	40%	0%	16%
		LED	0%	10%	21%
				100%	
Traffic Lights	1,05	Incandescent	100%	90%	5%
		LED	0%	10%	21%
				100%	

8. ENERGY SUPPLY INPUTS

Step 1: For the base year, provide primary energy consumption for electricity and heat/cold production as well as electricity and heat/cold produced.

	Primary energy resources	National energy production mix: Primary energy consumption (toe)	National energy production mix: Electricity production (toe)	National energy production mix: Heat/cold production (toe)	Small-scale local electricity production: Primary energy consumption (toe)	Small-scale local electricity production: Electricity production (toe)	Small-scale local electricity production: Heat/cold production (toe)	Green electricity purchases: Electricity purchased (toe)
Power Plants	Coal	2444703			0	0		
	Diesel	20049	2206279		0	0		
	Fuel oil	455522			0	0		
	Natural gas	1970751			0	0		
	Wood and wood waste	61957			0	0		
	Urban Solid Waste	182765	119291		0	0		
	Biogas	19729			0	0		
	Total	5155476	2325570		0	0		
Renewable Plants	Hydro	627456	1142338		0	0		0
	Wind, geothermal and solar	514882			0	0		
	Total	1142338			0	0		
Combined Heat and Power Plants	Diesel	363			0	0	0	
	Fuel oil	747261	291187	878659	70694	8293	52661	
	Other petroleum products	86896			0	0	0	
	Natural gas	626392			0	0	0	
	Wood and wood waste	182133			0	0	0	
	Sulphite lyes (black liquor)	789311	194239	586117	0	0	0	
	Biogas	3070			0	0	0	
	Total	2435426	485426	1464776	70694	8293	52661	
	Amount of fuel attributed to electricity and heat	-	606203	1829223		9618	61076	
	Imports	-	923984	-				
	Exports	-	112918	-				

	Own use and losses	Energy carrier consumption (toe)
Energy industry own use	LPG	55
	Lubricants	5100
	Electricity for Electricity Plants	136439
	Electricity for Hidroelectric Pumping	54954
Transport and distribution losses	Electricity	362576

Step 2: If local energy plants are planned to be built until the time horizon, provide the expected primary energy consumption and electricity and heat/cold produced.

	Primary energy resources	Primary energy consumption (toe)	Electricity production (toe)	Heat production (toe)	Overall efficiency of CHP
Combined Heat and Power Plants	Diesel	0	0	0	0%
	Fuel oil	0	0	0	0%
	Other petroleum products	0	0	0	0%
	Natural gas	85627	18081	55749	86%
	Wood and wood waste	0	0	0	0%
	Sulphite lyes (black liquor)	0	0	0	0%
	Biogas	0	0	0	0%
	Total	85627	18081	55749	
	Amount of fuel attributed to electricity and heat		20970	64657	
Renewable Plants	Hydro	0	0		
	Wind, geothermal and solar	0	0		
	Total	0	0		

Step 4: Provide primary energy consumption of oil products and oil products available for final energy use.

Primary energy resources	Primary energy consumption (toe)	Energy carriers	toe
Crude oil	12188085	LPG	421097
Intermediate products	219844	Gasoline	2252347
		Diesel	4756333
		Petroleums	1265
		Jets	767426
		Fuel oil	1476065
		Naphtha	1174938
		Non-energetic petroleum	566217
Total	12407929		11415688

Appendix VI: Input data for the attributes and for investment

- **Greenhouse Gas Emissions factors used in the attribute 'Tonnes of CO_2 equivalent emissions reduced'**

Energy carrier		**kg CO2 eq./TJ** (IPCC, 2006; UNFCC, 2011)
Oil products	Liquefied Petroleum Gases (LPG)	63152
	Gasoline	69549
	Diesel	74349
	Fuel oil	77649
	Other petroleum products	73549
Natural gas		56152
Wood		0
Solar radiation		0
Coal		98786
Compressed Natural Gas (CNG)		56152
Biodiesel		0
Hydrogen		0

- **NO_x emission factors for road transport used in the attribute 'Tonnes of NO_x emissions reduced'**

Road transport category	**Bulk emission factors for Portugal, 2005 (g/kg fuel)** (EEA, 2007)
Gasoline Passenger Cars	9.180
Diesel Passenger Cars	11.280
Power two-wheelers	4.760
Diesel Buses	40.750
Diesel Light Duty Vehicle (LDV)	17.910
Diesel Heavy Duty Vehicle (HDV)	34.090
Biodiesel Buses and Passenger Cars	11.380
CNG Buses	3.384
CNG Passenger Cars	3.384

- **Households end-use energy cost used in the attribute 'Euros saved per household per year'**

Energy carrier	**Eur/toe**	
	2008	**Estimated in 2020**
Electricity	1747	2201
Natural Gas	810	2015
Oil products	1544	2349
LPG	1159	1743
Diesel	1457	2139
Gasoline	1861	2612
Wood	600	855
Fossil Heat	572	590
Biodiesel (B100)	1120	2011
Hydrogen	1879	2557
Solar	0	0
Renewable Heat	0	0

** based on several sources (DGEG 2010, Estatísticas e Preços, http://www.dgeg.pt/)*

*** Estimates in 2020 performed using a trend function or assuming a yearly variation rate.*

Means of transport	**Eur/pkm**	
	2008	**Estimated in 2020**
Passenger cars	0.060	0.076
Bus	0.053	0.067
Train	0.085	0.108

* based on Fiorello *et al*. (2009)

*** Estimates in 2020 performed assuming a yearly variation rate.*

- **Investment data for the technical actions**

Source: Souza (2011)

End-use	Energy carrier	Technology	euro/kWh used	
			Households	Services
Hot water	Electricity	Heat pump water heater	2.73	1.90
	Natural gas	Gas tankless water heater	0.29	-
		Conventional storage water heater	0.22	-
	Solar radiation	Solar water heater	2.73	1.65
	Renewable Heat	Water heater	0.22	0.16
Space heating	Electricity	Heat pump	7.09	-
	Natural gas	Central boiler and hot water radiators	0.42	-
	Wood	Pellet stove	0.43	-
	Solar radiation	Hydronic Radiant Floors with Solar water heater	3.14	1.73
	Renewable Heat	Central radiators/ventilators	0.42	0.09
Space cooling	Electricity	Heat pump	2.36	0.81
	Renewable Heat	Central radiators/ventilators	0.42	0.09
Refrigerators	Electricity	A++ /A+	2.88	1.11
Freezers	Electricity	A++ /A+	1.64	-
Washing machines	Electricity	A+	1.64	-
Driers	Electricity	A	5.05	-
Dishwashers	Electricity	A	2.89	-
Lighting	Electricity	Compact Fluorescent Lamps	1.17	0.36
		Fluorescent tub lamps	19.28	0.41
		Tungsten halogen	0.70	-
		LED	6.68	0.83
Cooking	Electricity	Stove and Microwave	2.85	0.30
	Natural gas	Stove	2.12	0.12

End-use	Energy carrier	Technology	euro/kWh saved	
			Households	Services
Thermal insulation	-	-	3.27	3.27

End-use	Energy carrier	Technology	euro/pkm
			Transport
Passenger car	Electricity	Electric	0.41
	LPG	Liquefied Petroleum Gas	0.32
	Diesel	Diesel with 5% Biodiesel (B5)	0.46
		Diesel Hybrid	0.59
	Gasoline	Gasoline	1.68
		Gasoline Hybrid	1.82
	CNG	Compressed Natural Gas	0.47
	Biodiesel	Non-blended Biodiesel (B100)	0.46
Bus	Electricity	Electric	0.53
	LPG	Liquefied Petroleum Gas	0.47
	Diesel	Diesel with 5% Biodiesel (B5)	0.29
	Gasoline	Gasoline	0.50
	CNG	Compressed Natural Gas	0.32
	Biodiesel	Non-blended Biodiesel (B100)	0.41
	Hydrogen	Hydrogen	1.33
Rail	Electricity	Electric	0.34
	Diesel	Diesel with 5% Biodiesel (B5)	0.34
Cycling & walking	-	-	0.00

Source: Gomes (2008)

	Technology	euro/kWh generated
Decentralised renewable electricity generation	Photvoltaic system (BP Solar 20; BP Solar 17; SunPower)	4.64