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Multiple Criteria Assessment of Low-Carbon Energy Technologies at the European Level

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Summary

The transition to a low-carbon economy should begin, ideally, at the local level where energy consumption takes root. Significant opportunities for electricity production are available within city borders, and these call for the involvement of local authorities in policy matters. Additionally, development planning and decision making in the energy sector necessitates for the participation of relevant stakeholders, such as government authorities and electricity producers.

Each stakeholder group, however, has its own objectives, priorities, and preferences. Nevertheless, the multiple, often conflicting views of stakeholders have to be taken into account in order to reach a consensus as well as to ensure transparency in the process. Moreover, in selecting low-carbon energy technologies for electricity production, there is a variety of evaluation criteria, ranging from economic costs to environmental impacts, for consideration.

One method for structuring a multi-actor, multi-objective, and multi-criteria complexity is through a Multiple Criteria Analysis. This research study, which aimed to analyze local stakeholders' preferences for the evaluation criteria of selected low-carbon energy technologies in electricity production at the European level, made use of such analysis. Moreover, the low-carbon energy technologies in Europe were evaluated from a local stakeholders' perspective.

This study involved a review of sustainability assessment frameworks which revealed the commonly-used criteria and indicators in the urban energy context. The pre-selected indicator set was validated by local stakeholders. Majority of the respondents agreed with the retention of the evaluation criteria and indicators. As such, this study concludes that the indicator set fulfilled the basic principles, such as relevance, comprehensiveness, and non-redundancy.

The final indicator set was applied in the elicitation of weighting preferences. The survey-based weighting elicitation process made use of an integrated weighting methodology which combines two approaches: an initial ranking and a series of pair-wise comparisons. The initial ranking allowed the stakeholders to be familiarized with the process, while the pair-wise comparisons enabled them to provide their preferences verbally, numerically, and graphically.

The results of the elicitation process show how local stakeholders highly value economic, environmental, and social criteria, such as carbon emissions, levelised costs, ecosystem damages, mortality and morbidity, resilience to climate change, radioactive waste, accident fatalities, employment generation, and fuel use. Local stakeholders show implied responsibility towards local environmental protection, human health and safety, and economic and employment returns.

The low-carbon energy technologies were assessed based on the weights for each criterion as well as on the results of experts' judgment impact assessment. The weighted summation rule by aggregating final indexes per low carbon technology was applied. This study concludes that wind off-shore, solar photovoltaic, hydropower, wind-onshore, and Gas Turbine Combined Cycle are the top-five low-carbon energy technologies that best reflect local stakeholders' preferences.

As this research study enabled the mapping – albeit limited - of local stakeholder' preferences, it is recommended that future studies should focus on a wider scale as well as on in-depth analysis. This study mapped only the preferences of three broad local stakeholder groups, namely public authorities, energy industry actors, and technical professionals. It would be substantive to map the preferences of distinct local stakeholder groups within the urban energy context.

The study provided insights as to how local stakeholders value the selected evaluation criteria and indicators as well as low-carbon energy technologies. The study highlighted some discrepancies on local stakeholders' preferences which could indicate areas of potential conflict during local energy planning and implementation of low-carbon energy technologies. As such, results of this study may be substantive in conflict resolution by way of preference mapping.

Keywords

Multiple Criteria Analysis, Low-Carbon Energy Technologies, Evaluation Criteria and Indicators, Elicitation of Weighting Preferences, European Level

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Abbreviations

AHP	Analytic Hierarchy Process
CCS	Carbon capture and storage
$C0_2$	Carbon dioxide
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CHP	Combined heat and power
DCLG	Department of Communities and Local Government
EEA	European Environment Agency
ELECTRE	Elimination Et Coix Traduisant la Realite
EPR	Nuclear European Pressure Water Reactor
EU	European Union
GHG	Greenhouse gas emissions
GTCC	Gas Turbine Combined Cycle
IAEA	International Atomic Energy Agency
ICLEI	International Council for Local Environmental Initiatives
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
MAUT	Multi-Attribute Utility Theory
MCA	Multiple Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
MODM	Multi Objective Decision Making
NAIADE	Novel Approach to Imprecise Assessment and Decision Environment
NEEDS	New Energy Externalities Developments for Sustainability
NGOs	Non-government organizations
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PVs	Photovoltaics
RE	Renewable Energy

RES	Renewable energy systems
SAW	Simple Additive Weighting
SEAPs	Sustainable Energy Action Plans
SMAA	Stochastic Multi-Objective Acceptability Analysis
SMART	Simple Multi-Attribute Rated Technique
SNG	Synthetic Natural Gas
UES	Urban Energy Systems
UN DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Energy Programme
UNFCCC	United Nations Framework Convention on Climate Change

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background

The 21st century, dubbed as the century of the cities, entails development challenges. The United Nations Department of Economic and Social Affairs (UN DESA) - Population Division (2011) projected that the world population will increase from 7 billion in 2011 to 9.3 billion by 2050. Urban areas around the world are expected to accommodate such population growth while absorbing rural migration. It is estimated that the urban population will grow from 3.6 billion in 2011 to 6.3 billion in 2050.

Cities and municipal governments have the immense task of addressing the interdependent concerns associated with rapid urbanization. As applied to cities, sustainable development consists of meeting the present economic, political, social, cultural, environmental, and health needs. Ensuring sustainability, however, entails meeting the present needs “without a level of resource use and waste generation which threatens local, regional and global ecological sustainability” (Mitlin and Satterthwaite, 1996, p. 33).

The world’s urban centers draw on natural or environmental capital, such as mineral resources, fresh water, and forest products. Economic activities, which propel a city’s prosperity, require vast amounts of renewable and non-renewable resources. The energy sector, in particular, is highly reliant on fossil fuels, such as natural gas, coal, and oil. However, the dependency on fossil fuels has significant environmental impacts, such as depletion of finite resources and increase in carbon dioxide ($C0_2$) emissions.

The built environment of modern cities needs energy services for heating, cooling, lighting, and transport, among others. In the European Union (EU), the industry, transport, and household sectors account for majority (85%) of the final energy consumption, while agriculture, services, and other sectors are responsible for the remaining share (Eurostat, 2009). With the intensity of anthropogenic activities, urban centres account for two-thirds of the total energy consumption worldwide (Hurst, et al., 2012).

Ultimately, cities and towns are responsible for more than 70% of global energy-related $C0_2$ emissions (International Energy Agency or IEA, 2009). Certainly, there is a direct relationship between the amount of energy consumption and the level of pollution discharge (Hurst, et al., 2012). As such, the ecological costs that arise from urban demands necessitate for low-carbon growth trajectories. The energy sector, particularly electricity generation, can bank on low-carbon technological interventions.

Energy use and supply, a prime driver of greenhouse gas (GHG) emissions, is projected to increase continuously. According to the Intergovernmental Panel on Climate Change or IPCC (2007, p. 97), “should there be no substantial change in energy policies, the energy mix supplied to run the global economy in the 2025–2030 time frames will essentially remain unchanged – more than 80% of the energy supply will be based on fossil fuels, with consequent implications for GHG emissions.”

The EU provides its Member States with a long-term framework that addresses the issue of sustainability. The European Commission presented a roadmap for moving to a low-carbon economy by 2050, and proposed the Europe 2020 Strategy which has climate change and energy sustainability as one of its key targets. The strategy aims to achieve the following objectives:

20% GHG emission reduction; 20% renewable energy sources; and 20% increase in energy efficiency (European Commission, 2011a).

The electricity sector in the EU is considered well-developed with some regions e.g. the Nordic market having a high level of integration. Almost 90% of power generation is attributed to nuclear (29%), coal (29%), gas (21%), and hydro (10%), while also relying on oil (4%), biomass (3%), and other sources (4%). The installed capacity for nuclear and hydro provides stability in the power supply. On the other hand, the share from natural gas, wind, and biomass continues to rise through the years. (Eurostat, 2009)

By and large, the development, utilization, and deployment of low-carbon technologies in the electricity sector play a key role in the pursuit of resource-efficient growth. Technologies that have low-carbon foot prints include carbon capture and storage (CCS) and renewable energy systems (RES), such as solar, wind, geothermal, hydro and biogas. All these can contribute not only to energy security and efficiency but also in the provision of socio-economic and environmental benefits.

According to the European Commission (2011a, p. 6), "the share of low-carbon technologies in the electricity mix is estimated to increase from 45% today to around 60% in 2020, including through meeting the renewable energy target, to 75 to 80% in 2030, and nearly 100% in 2050. As a result, and without prejudging Member States' preferences for an energy mix which reflects their specific national circumstances, the EU electricity system could become more diverse and secure."

With the different energy directives and policy objectives, local and regional initiatives have been established to contribute in achieving EU-wide and national targets. Local governments in Europe have come up with electricity generation and distribution systems within the confines of their own territories. Although energy policies usually come from central governments, local authorities pro-actively come up with local solutions, such as the use of renewable energy sources, for energy sustainability.

In Europe, 4, 992 regions, cities, and municipalities (as of August 2013) have signed up to the Covenant of Mayors. With their commitment in implementing sustainable energy policies, the signatories can carry out the promotion of local energy production and the use of renewable energy sources as outlined in their Sustainable Energy Action Plans (SEAPs). One of the activities that the signatories can implement includes combined heat and power (CHP) district heating systems using biomass. (Covenant of Mayors, 2013)

Essentially, the transition to a low-carbon economy should happen in the local level where the energy is consumed. Together with international organizations and national governments, local and regional authorities have significant roles to play in the pursuit of sustainable energy systems. Within the context of their own cities and municipalities i.e. depending on local characteristics, economic conditions, and resource base, among others, local governments can develop their own energy policy approaches and local climate actions.

1.2 Problem Statement

The growing demand for energy services poses significant challenges to national and local governments. Different factors, ranging from environmental to economic, come into play in energy planning and decision making. Governments have to respond to energy demands while considering a wide range of evaluation criteria: economic costs, energy savings, environmental impacts, pollutant emissions, market maturity, technology performance, and other sustainability benefits.

The energy system within the context of an urban area entails different processes, deals with demand and supply, and is influenced by social factors. There are significant opportunities for electricity production within city borders, and these call for the involvement of local authorities in policy matters. In developing urban energy strategies, local authorities should formulate low-carbon plans and strategies that reflect unique circumstances and local conditions backed by strategic evidence.

Additionally, development planning and decision making in the energy sector necessitates for the participation of relevant stakeholders, from electricity producers and energy associations to environmental groups and local communities. Urban energy stakeholders include those who have legitimate responsibilities for energy projects (e.g. government authorities – national, regional, and local), those who support and oppose these initiatives (e.g. NGOs, consumer associations, homeowner groups) as well as those who depend on it (e.g. energy users and customers).

Each stakeholder group, however, has its own objectives, priorities, and preferences. For example, local authorities purchase energy services to meet the needs of their constituents, while energy producers are responsible for energy generation. Meanwhile, the local population are directly or indirectly impacted by these energy initiatives. Nevertheless, the multiple, often conflicting views of stakeholders have to be taken into account in order to reach a consensus as well as to ensure transparency in the process.

Structuring and analyzing multi-criteria, multi-actor, and multi-objective complexity is crucial. One method for addressing this problem is through a Multiple Criteria Analysis (MCA). This method, which has been used for sustainable energy planning, is a useful tool in facilitating decision making among different stakeholder groups, in expanding the range of possible outcomes, and in assessing the performance of technologies against a set of evaluation criteria selected by stakeholders.

In the selection of low-carbon energy technologies for electricity production, evaluation criteria and indicators cover economic, environmental, social, energy, and technological aspects. For this research study, the list of evaluation criteria and indicators were made available through a review of literature as well as a validation process from various local stakeholders in Europe. Furthermore, experts' judgments on the impact assessment of these technologies were crucial in the final evaluation.

Local stakeholders at the European level might have different preferences for selected low-carbon energy technologies, namely: Nuclear European Pressure Water Reactor (EPR), Wind Onshore, Wind Offshore, Solar Photovoltaics (PVs), Hydropower, Biogas, Integrated Gasification Combined Cycle (IGCC) coal; IGCC coal with CCS; Gas Turbine Combined Cycle (GTCC); and GTCC with CCS. Table 1 shows the list of low-carbon energy technologies, including their general descriptions.

Local stakeholders needed to provide their preferences for the evaluation criteria and indicators in evaluating the low-carbon energy technologies under investigation. The results were used as basis for conducting a sustainability assessment of low-carbon energy technologies in electricity production. In general, this research looked into the preferences of local stakeholders at a larger scale i.e. European level, which, to the best of the researcher's knowledge, has not been previously studied.

Table 1. Low-carbon energy technologies under evaluation (Grafakos, 2013)

Technology	Description
IGCC coal	Future reference technology for 2030 is an IGCC power plant. IGCC technology is an emerging advanced power generation system having the potential to generate electricity from coal with high efficiency and lower air pollution (NO_x, SO2, CO and PM10) than other current coal-based technologies.
IGCC coal with CCS	IGCC technology lends itself very well to carbon capture and storage (CCS) due to the higher pressure of the gas stream and the possibility to achieve the highly concentrated formation of CO2 prior to combustion. For this to be possible then after having been cleaned of particulates the syngas enters a shift reaction unit in which the methane is reacted with steam to produce hydrogen and CO2. The preferred technique for CO2 separation in applications at higher pressure (i.e. IGCC) is currently physical absorption using solvents commonly used in commercial processes. Once captured, the CO2 can then be treated in the same way as for the other technologies incorporating CCS. The resulting power plant net efficiency for this technology scenario is 48.5%. CO2 transport and storage is modelled in the same way as for Pulverized Coal power plants.
GTCC	GTCC power plant involves the direct combustion of natural gas in a gas turbine generator. The waste heat generated by this process is then used to create steam for use in a steam generator, in a similar manor to that of IGCC technologies. In this combined cycle power plant around two-thirds of the overall plant capacity is provided by the gas turbine. Reference technology for large natural gas power plants is a 500 MW Combined Cycle (CC) unit. The analysis focuses on a base load power plant. Technology development until 2030 is taken into account with higher power plant efficiencies.
GTCC with CCS	The electricity generation aspect of this technology is exactly the same as the GTCC without CCS. The flue gas from the GTCC then enters the same CO2 separation, stripping, drying, transportation and sequestration process to that used for coal and lignite CO2 capture.
EPR	This 'Generation III' design of nuclear reactor uses either uranium oxide enriched to 4.9% fissile material (uranium-235) or a mix of uranium-235 and mixed uranium plutonium oxide (MOX), with pressurized water as the moderator and cooling agent. The heat from the reaction is used to produce steam to drive a steam turbine generator. It features not only superior reliability and safety over its current 'Generation II' counterparts but also higher efficiency. This results in less high-level radioactive waste per unit of electricity generated that requires either reprocessing or long term storage in geological repositories.
Wind onshore	The exploitation of wind energy has increased exponentially during the last decades, and there is still large unexploited wind energy potential in many parts of the world – both onshore and offshore. However, the success story of onshore wind energy has led to a shortage of land sites in many parts of Europe, particular in north-western Europe. Vestas' V80 2 MW turbine serves as current reference technology for onshore wind power in Germany The capacity factor for a generic optimal site near to the coast of the North Sea is assumed to be 0.29. Future wind turbines in 2030 with higher capacities are assumed to be located at the same or similar sites.
Wind offshore	The shortage of land sites for onshore wind energy has spurred the interest in exploiting offshore wind energy. Offshore wind farms consisting of multiple wind turbines all connected to a single transformer station are more financially viable than individual turbines. Offshore sites also enjoy the advantage of having significantly more stable and higher wind speeds than onshore sites and which leads to a longer turbine life. Future wind turbines in 2030 with higher capacities than the current ones are assumed to be located at the Danish part of the North Sea (HornsRev) or similar sites. The whole park is assumed to consist of eighty Vestas V80 turbines with monopile steel foundations.
Solar PVs -	The PV installation is small and integrated onto a new or existing building. At 420 kW, this is

Technology	Description
crystalline silicon	suited to the roof of a public or commercial building and is too large for most domestic residences. Photovoltaic (PV) reference technology for crystalline silicon is the laminated, integrated slanted-roof multicrystalline-Si module in, which is adapted to the electricity production of 850 kWh kWp. Not only efficiency increase for the PV-cells as such, but also reduced energy demand in the production steps of the PV chains are taken into account for the modeling of the future 2030 reference PV units.
Hydropower	The hydro plant Illanz/Panix (Switzerland) is used as the reference reservoir site. Lifetime of the dam is assumed to be 150 years.
Biogas	Biogas (SNG) from forest wood gasification is assumed to fuel CHP units. Basis for the production of SNG via wood gasification is the assessment of a 50 MW demonstration plant. A commercialized methanation unit with double capacity and increased efficiency, as well as improved CHP unit SNG combustion, reflect the expected technology development until 2030.

1.3 Research Objectives

The general objective of this research study is to analyze local stakeholders' preferences for the evaluation criteria of selected low-carbon energy technologies in electricity production at the European level.

Specifically, this research study aimed to achieve the following objectives:

- Review and identify the criteria and indicators for evaluating low carbon energy technologies;
- Determine the factors of relative importance of the evaluation criteria and indicators based on local stakeholders' priorities; and
- Evaluate the selected low carbon energy technologies in Europe from a local stakeholders' perspective.

1.4 Provisional Research Questions

- Which criteria and indicators can be selected for the evaluation of low carbon energy technologies in Europe?
- What is the relative importance of the evaluation criteria and indicators among the local stakeholders in the energy sector?
- Based on the local stakeholders' preferences, what is the overall evaluation of low-carbon energy technologies?

1.5 Significance of the Study

The results of this research study are significant in the process of evaluating low-carbon energy technologies for selection and introduction at the local level and within the urban context. The study enabled the mapping, albeit limited, of local stakeholders' preferences and therefore, is useful in providing interpretations about their true objectives and interests, including similarities and differences in their value judgments.

This research provided insights on how local stakeholders value the selected evaluation criteria and low-carbon energy technologies. This study highlighted discrepancies on local stakeholders' preferences which could indicate areas of potential conflict during local energy planning and implementation of low-carbon energy technologies. As such, results of this study may be significant in conflict resolution by way of preference mapping,

The study entailed the participation of different local stakeholders, such as government authorities (national and local), electricity and energy associations, electricity producers, academe - research, consultants - advisors, and non-government organizations (NGOs). Findings of this study may advance the promotion of a stakeholder-driven process in low-carbon energy evaluation and planning.

It is also important to note that there has been no other study conducted, to the best of the researcher's knowledge, that map local stakeholders' preferences with regard to multiple evaluation criteria and objectives regarding low-carbon energy technologies at the European level. MCA studies that have been reviewed were primarily at the local contexts and specific to certain geographical locations.

1.6 Scope and Limitations

This research study utilized a survey-based approach to elicit stakeholders' preferences for the evaluation criteria of low-carbon energy technologies. The preference elicitation survey was preceded by a criteria validation and refinement process. Survey respondents participated in the screening process, considering their local circumstances. Moreover, a desk study was conducted to assess sustainability assessment frameworks in the urban energy context.

The evaluation criteria and indicators encompassed five (5) categories, namely economic, environmental, social, energy, and technological. Moreover, there were ten (10) low-carbon energy technologies under investigation. The number of options might be a cognitive challenge for the survey respondents. Hence, the research study involved a computer-aided excel which was designed to be user-friendly and interactive.

This research study needed the participation of different local stakeholders at the European level. As such, members - both individual and institutional - of different associations and networks within the urban energy sector were invited. Moreover, the study was supported by the International Council for Local Environmental Initiatives - Local Governments for Sustainability, European Secretariat (ICLEI Europe).

The elicitation weighting process aimed for the participation of a large number of respondents. Originally, the study aimed for the participation of at least five (5) respondents from 11 different stakeholder groups, namely government – national, government – local, electricity and energy associations, electricity producers, electricity consumers, utilities, academic – research, consultants – advisors, regulators and network operators, financial and trading sector, and NGOs.

However, the study had to contend with the extent of stakeholder participation as well as response rate. As the primary data collection methods were carried out through electronic means and considering practical reasons, such as time and geographical constraints, the study had to get by with the actual number of respondents which was below the expected target. Also, the study had to address the challenge of ensuring balance and distribution among the groups.

Chapter 2: Literature Review

The review of literature focused on the following topics: energy sector, assessment methods, multi-criteria analysis, MCA methodology, evaluation criteria and indicators, stakeholder engagement, and MCA applications and related studies particularly with focus at the local level. A conceptual framework, which shows the links among the different concepts, is demonstrated at the end of this chapter.

2.1 Energy Sector

The energy sector is inextricably linked with economic growth. Urban centers rely on energy services for productive processes. The current energy system, however, is highly dependent on fossil fuels. With the environmental and economic trade-offs associated with fossil fuel consumption, sustainable means of energy production is crucial. Hence, there is a need for low-carbon technological interventions which can contribute to energy security and environmental sustainability.

2.1.1 Energy-related GHG Emissions and Low-Carbon Policies

The rate of GHG emissions has increased by 70% between 1970 and 2004, according to IPCC (2007). Between those years, the energy supply sector proved to be the largest contributor in GHG emissions with an increase of 145%. Direct emissions from the transport sector grew by 120%; the industry sector by 65%; and for land use, land use change, and forestry by 40%. Additionally, direct emissions from agriculture grew by 27% while the building sector rose by 26% between 1970 and 1990.

According to IPCC (2007), the primary energy use around the world has almost doubled within a period of 30 years, with an annual average growth rate of 2.2%. In 1970, the global primary energy use was estimated at 5, 363 Mtoe (225 EJ) and this has doubled to 11, 223 Mtoe (470 EJ) in 2004. Fossil fuels accounted for 81% of the primary energy use in 2004 compared to 86% in 1970. This slight reduction in the use of fossil fuels was mainly attributed to the increase in nuclear energy use.

In 2004, 40% of the global primary energy was used as fuel in generating electricity. Electricity generation is expected to rise at 2.5-3.1% per year until 2030 (IEA, 2006; Enerdata, 2004 in IPCC, 2007). The world's electricity production in 2005 relied on hard coal and lignite fuels, natural gas, hydro, oil, and other renewables (IEA, 2006 in IPCC, 2007). However, even with renewable energy, its share in the primary energy mix did not alter compared with 1970 (IPCC, 2007).

With the current climate change mitigation policies and sustainable development practices, the Special Report on Emission Scenarios anticipates a rise in global GHG emissions (IPCC, 2007). In these non-mitigation scenarios, fossil fuels will dominate the global energy mix until 2030 and beyond. Without any significant interventions to minimize the rate of fossil fuel consumption – and the amount of GHG emissions, $C0_2$ emissions from energy use will grow from 40 to 110% between 2000 and 2030.

Through the years, there has been diversification in the electricity production mix, which can be attributed to the "rise of natural gas" and the "push for renewables" (Eurostat, 2009, p. 15), in the

EU. Coal and natural gas technology was responsible for 70% of power generation in 1991, but by 2006, the share of these sources dropped to less than 60%. There has been a rapid increase in the share of 'new renewables', such as wind and biomass, while also relying on 'old renewables' like hydro.

As outlined in its roadmap to a low-carbon economy, the EU aims to reduce GHG emissions by 80-95% by the year 2050 compared with 1990 levels (European Commission, 2011a). Also, with the Europe 2020 Strategy, there is a concerted effort to achieve the following targets: 20% GHG emissions reduction; 20% renewable energy shares; and 20% increase in efficiency (European Commission, 2011a). Member States have signified their commitments and are on working on their targets for domestic emissions.

At the local level, cities and municipalities have come up with initiatives to contribute in mitigating GHGs, in ensuring energy efficiency, and in promoting renewable energy. The Covenant of Mayors, a network of local and regional authorities committed in the implementation of sustainable energy policies, was established. More than 4,000 signatories have pledged their commitments and outlined their specific actions through their SEAPs (Covenant of Mayors, 2013).

2.1.2 An Overview of Urban Energy Systems

According to the IEA (2009), half of the world's population, which are located in urban areas, consume two-thirds of the total primary energy. Commercial buildings as well as small-to-medium scale industries account for this large share in energy consumption. By 2030, it is projected that cities and towns will accommodate 60% of the world's population. Moreover, urban dwellers will consume about three-quarters of the annual global energy demand.

The overall efficiency of energy systems that provide necessary services to city dwellers has been gauged to be below 10%. As such, the IEA (2009, p. 39) acknowledged that "there is good potential to improve the process throughout the supply chain. Electricity is one energy carrier that can help provide city consumers with greater and more diverse energy access in the future, but ideally it needs to become more efficient system than it is at present".

Centralised supply systems are the conventional way of delivering electricity services. Large-scale power plants, fuelled by coal, natural gas, or nuclear technology, are constructed to provide high voltages into the electricity grid (IEA, 2009). With the advancement of renewable energy technologies, discussions on whether cities can become more independent from distant energy sources or whether they could produce their own energy have arose (Grubler and Fisk, 2012 in Steinberg and Lindfield, 2012).

2.1.2.1 Definition of Urban Energy Systems

Urban energy systems are defined as the "combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area" (Keirstead, J., 2013, p. 25). Urban dwellers create demand for energy services which require the needed infrastructure for energy supply. Corollary, this steers urban metabolism which is governed by the laws of thermodynamics. As such, cities are characterized as "thermodynamic, metabolic and complex systems." (Keirstead, J., 2013, p. 20)

Urban energy systems are regarded as having three features: “combined processes” which alludes to the “thermodynamic and metabolic views of the city as an open system”; “acquiring and using” which represents the dynamics between demand and supply, and “given society or economy” which accounts for markets, culture, institutions, and consumer behaviour, among other factors (Keirstead, J., 2013, p. 24-25).

With urban energy systems reflecting local natural resource, economic conditions, cultural and political preferences, market structures, and technology decisions (Hammer, et al., 2009), policy makers can look into the local energy system for development within its specific context. Keirstead and Schulz (2010) in Hammer, et al., (2009) has noted the increasing re-engagement of local authorities in energy policy matters in developed as well as developing countries.

2.1.2.2 Formulating an Urban Energy Strategy

However, formulating a “holistic, long-term, urban energy strategy” that is suitable to a specific city’s context necessitates for certain approaches in an integrated manner. In Hurst, et al. (2012, p. 137), successful urban energy strategies are preceded by three major development phases: (1) “building a knowledge base”, (2) “performing a strategy analysis”; and (3) “formulating low-carbon-use programs”.

A strong knowledge base depending on the specific context at hand would facilitate the formulation of suitable energy-related decisions. The next stage involves strategy synthesis which enables the identification of the most suitable strategy for implementation. Over all, the Energy Strategy Continuum shows an iterative process as each output in each stage is crucial in the development cycle. (Hurst, et al., 2012)

Also, the strategy development process emphasizes the significant role of stakeholders and the key or leading skills necessary in planning and implementing urban energy strategies. Stakeholders should take part in the strategy development process, with their likely contribution clearly identified as well as properly communicated. Stakeholders should be well-versed with the goals of the urban energy strategy and most importantly, agree with them. (Hurst, et al., 2012)

2.1.3 Electricity Generation and Renewable Energy Sources

Electricity generation technologies play an important role in the transition of national and local governments to a low-carbon economy and in the pursuit of a sustainable energy system. However, energy supply diversification entails additional investment in infrastructure, further technological development, and behavioural change in the society. Nevertheless, the associated costs are minimal compared to the benefits in terms of energy security (Hurst, et al, 2012).

Cities are envisioned to have considerable shares from renewable energy sources, such as solar, wind, and hydropower, in electricity generation. Renewable energy sources, except for large hydropower, are widely distributed. Fossil fuels, on the other hand, are concentrated in certain locations, requiring distribution. Renewable energy shares should either be distributed or concentrated to meet the high energy demands of the urban population (IEA, 2009).

Key technologies and practices that are commercially available include the following: nuclear power; renewable heat and power; combined heat and power; and CSS. On the other hand, these are the technologies and practices that will be commercially available before 2030: CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar and solar PV (IPCC, 2007).

2.1.4 Theoretical Framework on Local Sustainability

Del Rio and Burguillo (2008) developed an integrated theoretical framework which enables a comprehensive analysis of the impacts of renewable energy on local sustainability. In their paper, Rio and Burguillo (2008) argue that a sustainable development strategy in the local level should integrate both top-down or triangular sustainability and bottom-up or procedural sustainability approaches.

According to Del Rio and Burguillo (2008), both approaches are considered significant in analyzing how RES contribute to local as well as regional sustainability. They argue that renewable energy deployment can contribute to sustainability at the regional level. Also, local participatory processes are significant in implementing renewable energy projects as this would facilitate the acceptance of initiatives by different actors in the area.

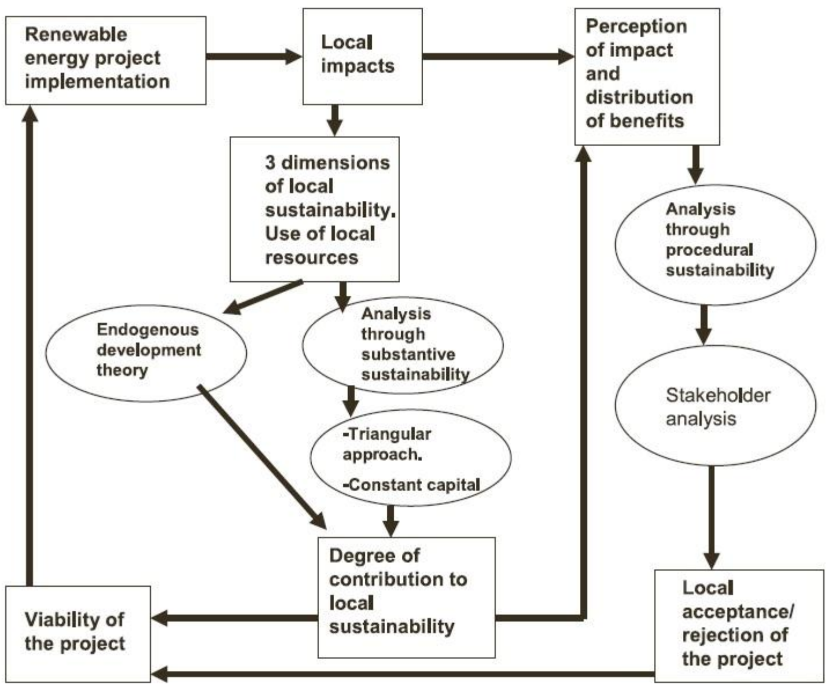


Figure 1. Theoretical framework for assessing the impact of renewable energy deployment on local sustainability (Del Rio and Burguillo, 2008, p. 1335)

2.1.4 Assessment of Selected Low-Carbon Energy Technologies

Low-carbon energy technologies vary in technological maturity, industry status, and market potential. Each one has its corresponding advantages and disadvantages as well as constraining and facilitating factors in development. Also, a wide range of technologies are in the process of research, development, and demonstration. The following sub-section focuses on selected low-carbon energy technologies, namely solar PV, wind, hydropower, biogas, and nuclear technology.

2.1.4.1 Solar PV

Among the available solar technologies is solar PV which has undergone tremendous development through the years and is expected to offer further progress in terms of efficiency and reliability. The production of solar PVs grew from 46 MW in 1990 to 23.5 GW in 2010 (Jager-Waldau, 2011 in European Commission, 2011b). The use of solar PVs in buildings is not yet main stream but market implementation in cities which have favourable policies is already on track.

Solar PV systems had a total installed capacity of 29.8 GW in the EU in 2010 or 3.7% of the total electrical generation capacity in the EU (Jager-Waldau, 2011; PV Barometer, 2011 in European Commission, 2011b). According to IEA (2009, p. 68), barriers to better market penetration of solar PV systems often include "initial capital cost" and "length of payback period." However, with solar PV systems, investment costs continuously decrease (European Commission, 2011b).

Freiburg, a town in Germany, is aiming towards a sustainable city. The local politics, which aim for a larger share from renewable energy for its energy supply, has attracted research institutes and solar businesses. Schlierburg, which is located in Vauban suburb, has solar PV installations. Around 60 local buildings, including schools, churches, factories, supermarkets and private houses, have installed solar PV systems. (IEA, 2009)

2.1.4.2 Wind Energy

Wind energy is considered as having the widest as well as most successful renewable energy deployment, from 3GW to 200GW of worldwide cumulative capacity, over the last twenty years (European Commission, 2011b). In 2010, five countries in Europe generated 10% of their electricity from wind energy. Also, it is expected that this energy source will generate at least 12% of electricity in Europe by 2020. As such, wind energy is crucial in the fulfilment of the Europe 2020 strategy.

Wind speed, the most significant factor affecting turbine performance, depends on location, season, and surface obstacles (European Commission, 2011b). Wind resource data, however, can be drawn from weather stations or from commercial databases. Wind turbines can be constructed on city boundaries and offshore, depending on wind speeds (IEA, 2009). The main barriers to implementation include high-levelised cost of electricity and social acceptance (European Commission, 2011b).

El Hierro, located in Canary Islands, Spain, has its own electricity grid. With its geographical location and topographical features, El Hierro has wind farms that contribute to energy supply. The island also relies on other renewable energy sources, such as hydro and solar. Samso in Denmark also sources its electricity from both land-and-offshore based wind turbines. In 2008, the off-shore wind farm produced 77 GWh of electricity. Excess energy from the wind farm is sold to the electricity grid in the mainland (IEA, 2009).

2.1.4.3 Hydropower

"Hydropower is the most widely used form of renewable energy with 3,190 TWh generated worldwide in 2010" (European Commission (2011b, p. 31). In the EU, hydropower represents 11.6% of the gross electricity generation. Hydropower plants generate electricity when necessary, offer reserve capacity, and respond to immediate load changes, among other benefits. Moreover, hydropower plants operate for more than 50 years (European Commission, 2011b).

However, hydropower plants also have its share of disadvantages which include environmental impacts and high capital costs. The carbon footprint, however, of hydropower plants are considered small, ranging from 2 to 10 g $C0_2$ eq/kWh. More than 21,000 small hydropower plants are located within the EU which has a market share of 13% in installed capacity. (European Commission, 2011b).

In Vienna, Austria, the city has 14 drinking water hydropower plants which contribute in electricity generation. This water supply network generates 65 million kWh of electricity annually. The electricity generated from the hydropower plants provides for the electricity needs of about 50, 000 inhabitants. The hydropower plants are funded by public-private partnerships. (Vogl, 2012)

2.1.4.4 Biogas

In the EU, there are available aerobic digestion plants for treating feed stocks, sewage sludge, organic residues, and other materials. However, this requires the availability of inexpensive food stock, feed-in tariffs, and wastes with gate fees. Biogas is used for heating- both local and district. Also, this can be upgraded to natural gas as biomethane or Synthetic Natural Gas (SNG) for use in vehicles. At present, there are upgrading technologies for biogas that are available commercially. (European Commission, 2011b)

The conversion of organic residues offers environmental as well as health benefits (Eriksson and Olsson, 2007 in European Commission, 2011b). A biogas plant, which has an installed gas turbine or engine, entails a capital cost between €2,500 and 5,000/kWe (Van Tilburg, 2008; BOKU-IFA, 2006 in European Commission, 2011b). The technical performance of biogas plants are being improved so as to decrease reliance on feed-in tariffs and other economic support (European Commission, 2011b).

The energy supply in the city of Vaxjo in Smaland, Sweden comes from renewable energy sources, primarily from biomass e.g. wood waste and peat. The city uses biomass for CHP generation, and this initiative has reduced the electricity-related $C0_2$ emissions by 24%. Gussing in Austria, the first community in the EU to derive from renewable sources for its total energy demand, also relies on biomass (IEA, 2009).

2.1.4.5 Nuclear Technology

The Nuclear European Pressure Water Reactor, also known as EPR, is a third generation nuclear reactor. The EPR design integrates the outputs of research and development programs, particularly those from the French Atomic Energy Commission and the German Karlsruhe Research Center. Moreover, the design takes into consideration the European Utility Requirements as well as safety requirements on nuclear reactors from the French and German authorities (AREVA, n.d.)

With an “optimized core design” and “higher overall efficiency”, the EPR has the following advantages, which supports sustainable development, according to AREVA (n.d., p.3): (1) “7-15% saving on uranium consumption per produced MWh”; (2) “10% reduction on long –lived actinides generation per MWh, through improved fuel management”; and (3) “10% gain on the electricity generation versus thermal release ratio". In addition, the EPR technology provides decreased power generation costs.

According to AREVA (n.d., p.3), the EPR has a "high level of competitiveness" due to the following: "a unit power in the 1,600 + MWe range"; "a 36-37% overall efficiency depending on site conditions"; "a design for a 60-year service life"; "an enhanced and more flexible fuel utilisation"; and "an availability design target above 92%". As of January 2013, there are four EPRs under construction. These are located in Finland (Olkiluoto), France (Flamanville), and China (two in Taishan) (European Nuclear Society, 2013).

2.2 Assessment Methods

The selection, adoption, and deployment of low-carbon energy technologies necessitate for the utilization of assessment methods to come up with an overall informed decision and possible best result based on current data and preferences. Making an informed decision about a future action follows a systematic process which includes the analysis of options. There are quantitative methods that can be applied in the analysis. However, an emphasis on monetary valuations normally does not reflect the interests of different societal groups – or of society as a whole.

2.2.1 Cost-Benefit Analysis (CBA)

CBA takes into account the costs and benefits to society - or the social costs and social benefits. Hence, CBA is also referred to as social cost-benefit analysis. In CBA, the costs and benefits are monetized and adjusted over time. However, there are considerations in pricing certain goods (e.g. life). Ex-ante CBA, one of the major types of CBA, is carried out while a policy or project is under consideration and this enables the government to decide whether resources should be deployed.

In practice, the decision rule in CBA is to "adopt all policies that have positive net benefits". In situations that involve multiple policies which interfere or enhance each other, the decision rule is to "choose the combination of policies that maximizes net benefits" (Boardman, et al., 2011, p. 31). As CBA is a normative tool, it does not take into consideration the dynamics of the public arena. CBA disregards the priorities and preferences of stakeholders, making it a prescriptive tool in decision making.

2.2.2 Cost -Effectiveness Analysis (CEA)

CEA enables comparison of the costs between alternative options. As such, CEA can identify the most economically efficient way possible to meet an objective. CEA is applied when impacts can be quantified but not monetized. As there are impacts that cannot be monetized (e.g. health effects), it is impossible to calculate the net benefits. As such, a ratio can be constructed that involve the "quantitative, but non monetized, benefit and the total dollar costs" (Boardman, et al., 2011, p. 42).

For example, in a situation that necessitates the evaluation of two alternative options for electricity generation (i.e. one option has a higher investment cost but lower operating expenses, and vice versa), the decision can be made based on economic efficiency. CEA can be applied in ex-ante evaluations to provide support and guidance in decision making, such as in fostering debate among decision makers and in underlining the preferences of different stakeholder groups.

2.3 Multiple Criteria Analysis (MCA)

Utilizing a single criterion such as, for example, minimized cost has been a popular choice in selecting the most efficient option. However, due to the growing awareness of social and environmental impacts in the 1980s, there has been a modification in the decision framework which resulted to the use of multiple criteria approaches (Pohekar and Ramachandran, 2003). In fulfilling sustainability goals, different criteria have to be taken into consideration in the development planning and decision making process.

Energy issues operate within a dynamic context that is characterized by multiple actors, conflicting objectives, trade-offs, and high uncertainties. In assessing a sustainable energy system, this entails compromise and consensus between and among actors with varied interests. Taking into account the multi-dimensional complexity in decision making, MCA methods allow for a systematic approach in assessing decision problems.

Multi-criteria analyses are used to determine the most preferred option and in ranking or short-listing alternatives, or at the least, to "distinguish acceptable from unacceptable possibilities" (Department of Communities and Local Government or DCLG, 2009, p. 19) in the presence of varying objectives among stakeholders. The solution(s) in decision problems depends on the preferences of stakeholders as this requires exercise of judgment in establishing objectives, criteria, and weighting (DCLG, 2009).

MCA allows for better understanding of the decision problem, enables compromise as well as collective decisions, help improve quality of decisions (Pohekar and Ramachandran, 2003), and enables transparency in the process (Grafakos, et al., 2010). Also, MCA integrates different preferences of stakeholders, highlights different perspectives; considers a wide range of criteria in the evaluation; and incorporates objective and subjective information and data in the assessment (Grafakos, et al., 2010).

The use of participatory methods, including MCA application, in decision-making processes has been recognized in the public arena. For example, the United Nations Framework Convention on Climate Change (UNFCCC) highlighted the application of MCA on certain contexts. So does the United Nations Energy Programme (UNEP) which emphasized the significance of MCA in "ranking national technical options and assessing GHGs mitigation strategies" (Grafakos, et al., 2010, p. 435).

2.3.1 Multi-Criteria Methods

According to Zimmermann (1991) in Braune, et al. (2009), multi-criteria methods are divided into two main groups: (1) Multi Criteria Decision Analysis or Making (MCDA/MCDM), which involves a limited number of known alternatives for evaluation and ranking and enables either complete or partial ranking, depending on the method used, and (2) Multi Objective Decision Making (MODM), which entails finding an optimal solution from an indefinite list of alternatives.

With the foundation of MCDM in the 1960s, two main schools have evolved, according to Braune, et al. (2009). These two main schools are the European School with the Multi-Criteria Decision Aid (MCDA) approach and the American School with the Multi Criteria Decision Making (MCDM) approach. Roy (1996) in Braune, et al. (2009, p. 3) concluded that the European School "seeks to give recommendations" while the American School "tries to find an ideal solution".

Braune, at al. (2009, p. 2-3) explained that between MCDM and MCDA, the latter puts more emphasis on the decision-aid process rather on the "mathematical process" and the "final result". Moreover, MCDA allows for comparison of the pros and the cons of the alternatives as well as enables learning from relevant stakeholders. Omann (2004) in Braune, et al. (2009) surmised that MCDM is not suitable for application on decision problems within the context of sustainable development.

2.3.2 MCDA Advantages and Disadvantages

In one study on sustainable energy planning, MCDA was selected as it: (1) investigates and integrates varied objectives and interests of multiple actors; (2) deals with complexity by supplying output information that is easy to communicate; (3) is a known assessment method, which has different versions applicable to specific problems or contexts; and (4) allows for objectivity and inclusiveness of actors' interests without entailing a lot of energy and cost (Tsoutsos, et.al., 2009).

Braune, et al. (2009, p.3) also enumerated some reasons for MCDA application: "ability to deal with subjective elements and qualitative criteria"; "able to incorporate different perspectives of stakeholders by adding subjective elements, such as weighting of the different evaluation criteria"; transparency of the process as "subjective opinions are clearly communicated and are not hidden in underlying assumptions"; and "opportunity to incorporate qualitative as well as quantitative criteria."

However, according to Braune, et al. (2009, p. 3), "trying to incorporate all these aspects (subjective judgments, stakeholder participation, modelling of the complex environment, sustainability issues) in one method, can lead to a bulky approach, thus making it too complex to handle. The risk is that the decision maker cannot follow the method and feels uncomfortable with the solution. The main challenge is therefore to build a scientifically valid, thus manageable method (Omann, 2004)".

MCDA also has its weaknesses. This relates primarily to the "subjectivity of the weights and to the ranking method". Translating qualitative information "encompasses a degree of responsibility and subjectivity from the analyst. Every actor is accountable for the preferences (s)he communicated to the analysts and the analysts should be consistent and transparent in the ranking method used to translate these preferences into weights" (Tsoutsos, et al, 2009, p. 1589)

2.3.3 MCDA Methods and Techniques

A wide range of MCDA methods are available for use in assessing decision problems. None of these methods, however, is considered the best in all kinds of situations (Guitouni and Martel, 1998; Salminen, et al., Salminen, et al., 1998; and Simpson, 1996 in Polatidis, et al., 2006). Polatidis (2006, p. 192) emphasized that "there are no better or worse techniques, only techniques that fit better to a certain situation or not." The following are the main MCDA families of methodologies (Polatidis, et al., 2006):

2.3.3.1 Outranking methods

This approach aims to build a binary or outranking relation on a set of decision alternatives (Braune, et al., 2009). Outranking methods eliminate decision alternatives that are "dominated", and "dominance within the outranking frame of reference uses weights to give more influence to some criteria than others" (DCLG, 2009, p. 27).

Outranking methods include the Elimination Et Coix Traduisant la Realite (ELECTRE) family; Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) 1 and II methods; and REGIME Method Analysis (Polatidis, et al., 2006).

2.3.3.2 Value or Utility-based methods

Utility-based methods "rank the alternatives according to an aggregated single value that represents the overall performance of the alternatives" (Braune, et al, 2009, p. 3). Multi-Attribute Utility Theory (MAUT), Simple Multi-Attribute Rated Technique (SMART), Analytic Hierarchy Process (AHP), and Simple Additive Weighting (SAW) belong to this family (Polatidis, et al., 2006).

2.3.3.3 Other Multi-Criteria Methods

Other multi-criteria methods include the Novel Approach to Imprecise Assessment and Decision Environment (NAIADE); Flag Model; and Stochastic Multi-Objective Acceptability Analysis (SMAA) (Polatidis, et al., 2006). Programming methods in tackling energy problems are also well known. However, these programming methods sometimes result to an "infeasible alternative" (Polatidis, et al., 2006, p. 184).

2.3.3.5 Most practiced methods

The AHP is the most practiced MCDA method, followed by ELECTRE and PROMETHEE, and its rate of application is increasing (Pohekar, et al., 2004 and Huang et al., 1995 in Braune, et al., 2009). AHP is designed to solve multi-criteria decision problems. It enables users to carry out pair-wise comparisons among the criteria – and of the decision alternatives – to come up with a ranking. Also, it allows subjective judgments of decision makers to be incorporated in the process (Anderson, et al., 2008).

In one study (Macharis, et al., 2007), AHP was utilized as it is simple and transparent; breaks down the complexity of the problem into manageable parts; synthesizes the decision process; allows for testing of the consistency in the pair-wise comparison and in the decision procedure; handles both qualitative and quantitative data; provides a complete – and transitive - final ranking; and is supported by a software package which allows for sensitivity analysis.

2.3.4 Prerequisites and Practical Requirements

As there are different multi-criteria methods and techniques, the challenge is how to select the most suitable approach. For RES planning, Polatidis, et al., (2006) prepared operational requirements for using an MCDA technique. Important parameters were also identified. These include operationalizing the sustainability issue, modelling of decision makers' preferences, technical features, uncertainty treatment, and practical considerations. Annex 1 shows the prerequisites of MCA techniques for RES planning.

As for the practical requirements for using an MCDA method in energy planning, these were "ease of use", "ability to support a large number of decision makers", "capacity to handle many criteria and alternatives", "ability to handle inaccurate or uncertain criteria", "low requirements on time and money", and "direct interpretation of parameters" (Polatidis, et al., 2006, p. 189). Annex 2 shows a comparison of multi-criteria techniques in the context of renewable energy problems.

2.4 MCA Methodological Aspects

Understanding the decision context is the first step in MCA (DCLG, 2009; Grafakos, et al., 2010). The decision context encompasses the objectives, current situation, administrative and political environment, social structures, decision makers, and other people who may be affected by the decision (DCLG, 2009). Part of this step is the identification of stakeholders. The classification, analysis, and engagement of stakeholders for MCA are discussed in Section 2.6.

The analysis of the decision context is followed by the identification of options. Although options may already be provided, these can still be further explored. According to DCLG (2009), it might also be important to consider the objectives first, especially in situations when the options are not provided and have yet to be developed. Also, there is the possibility of adding or modifying options as the analysis moves on.

Criteria are "measures of performance" by which the different options will be judged (DCLG, 2009, p. 32). In establishing a set of criteria in which options or alternatives will be assessed against, fundamental requirements, such as completeness, non-redundancy, measurability, and operationality (DCLG, 2009; Burgherr, P. and Paul Scherrer Institut, 2005), should be fulfilled. Further information about the selection of criteria and indicators are found in Section 2.5.

In Grafakos, et al. (2010), the performance of each individual option towards the entire evaluation criteria should be measured. The objective of this step is to determine the impact of each alternative against the criteria identified. There are models that can calculate the impacts. In the absence of these models, information can also be gathered to provide the possible impacts. This could be made possible through data analysis or from getting experts' judgments.

2.4.1 Elicitation of Weighting Preferences

Weights refer to "coefficients of importance" or "scaling factors", and this is connected to the idea of "compensability" or the "existence of trade-offs, i.e. the possibility of offsetting a disadvantage on some criteria by a sufficiently large advantage on another criterion, whereas smaller advantages would not do the same" (European Commission, 2003, p. 30). Weights are assigned to each criterion to reveal their relative importance.

There are different methods to elicit preferences via criteria weighting. Generally, these methods are classified into the two primary approaches: (1) direct estimation of weights and (2) indirect estimation of weights. These methods vary in terms of complexity, time needed, and transparency. Moreover, the performance is dependent on the type of decision problem. (Nijkamp et.al., 1990 in European Commission, 2003)

2.4.2 Integrated Weighting Methodology

Grafakos, et al, (2010) developed an integrated weighting methodology that incorporates weighting preferences for evaluating climate and energy policy interactions. This aimed to address the "lack of an integrated multi-criteria weighting method that combines different techniques' to derive stakeholders' preferential information and perspectives in a structured, transparent, interactive manner and to address the main potential biases of the weighting methods" (Grafakos, et al., 2010, p. 439).

The weighting methodology entails a direct ranking which allows the stakeholders to be familiarized with the ranking process as well as in comparing criteria. This is followed by an indirect ranking through the use of pair-wise comparison. This approach "minimizes problems with path dependency" and "maximizes the ranking consistency of stakeholders' preferences" (Grafakos, et al., 2010, p. 441). This methodology allows stakeholder preferences to be derived verbally, numerically as well as graphically.

In assessing options, stakeholders can provide their preferences on the criteria weights using a computer-aided excel tool. After the completion of the pair-wise comparisons, the weighting factors as well as criteria ranking are obtained automatically. For a more detailed description of this weighting methodology, see Grafakos, et al. (2010).

Through this method, the challenges that surround the elicitation of criteria weights are addressed. These challenges include impact range sensitivity, inconsistency, splitting or hierarchical bias, and numerical evaluation scale. Furthermore, this method reduces the burden to respondents; combines the strengths of different techniques; and is an interactive process that enables stakeholders to make revisions and check for consistency. (Grafakos, et al., 2010)

2.5 Evaluation Criteria and indicators

In the selection of low-carbon energy technologies, it is crucial to take into consideration the consequences on the economy, society, and environment. As such, there is a need to establish a set of criteria and indicators for use in evaluation. These criteria and indicators offer an overview of the whole system, including inter-linkages, trade-offs, and long-term implications; and provides information to the public and decision makers (International Atomic Energy Agency or IAEA, 2005; Burgherr, P. and Paul Scherrer Institut, 2005).

In defining the sustainability criteria for assessment of the energy system, different considerations are taken into account. Geiz and Kutzmark, (1998) in Afgan, et al, (2000) mentioned the following considerations in defining the sustainability criteria: reflective of the sustainability concept and of a strategic view, measurability (quantitative and qualitative); based on reliable and timely information; performance optimisation; and design longevity.

Indicators have to be well defined and properly selected. Otherwise, this can lead to "over-aggregation"; "measurement of unimportant parameters"; "dependence on a false model"; "deliberate falsification"; "diverting attention from direct experience"; "overconfidence"; and "incompleteness" (Meadows, 1998 in Burgherr, P. and Paul Scherrer Institut, 2005, p. 9). At the least, indicators for use in sustainability assessment should meet the fundamental requirements (Burgherr, P. and Paul Scherrer Institut, 2005). See Annex 3 for the fundamental requirements.

2.5.1. Urban Energy Indicators

Based on literature that delves on measuring urban energy sustainability, it has been noted that there is no particular indicator framework that is suitable to all applications (Keirstead, 2007). Hence, it is necessary to take into account the intended goals for the use of the indicators as well as to choose measures selectively in order to maximize effectiveness and relevance.

In Taiwan, Y.-C. Shen et al (2010) gauged the 3E goals, namely energy, environmental, and economic, as well as renewable energy sources regulated by the Renewable Energy Development Bill. The study adopted the framework proposed by Komor and Bazilian (2005) in preparing a model for assessing renewable energy sources in the country. Moreover, other research studies were used as reference. See Annex 4 for the list of indicators.

Keirstead (2007) explored the selection of indicators for urban energy use (See Annex 5) by referring to the works of Maclaren (1996) and Ravetz (2000). The study incorporated the expertise of researchers in the field of urban energy systems (UES) as well as interests of future stakeholders. Keirstead (2007) concluded that in evaluating urban energy systems as well as urban sustainability as a whole, a mix of data sources should be supported by a robust theoretical framework.

The Work Package 2 of SF Energy Invest (2010) aimed to develop sustainability assessment criteria (See Annex 6) in identifying and evaluating RES and energy efficiency projects in 9 campaigning regions as well as 5 pilot regions by managing authorities. The sustainability assessment criteria were identified using existing criteria available which were derived from various initiatives on sustainability assessment.

For the European Commission (2003), the commonly used evaluation criteria in RES applications were grouped in six general categories, namely energy, economic, social, environmental, technical, and risk. These evaluation criteria and indicators were also derived from other research studies. See Annex 7.

In the assessment of Y.-C. Shen et al (2010), and as supported by other research studies, energy criteria, such as energy price stability, security for energy supply, low energy prices, and stability for energy generation, should be used in evaluation. As the electricity sector is vulnerable to price fluctuations due to significant factors, such as production, policy matters, natural disasters, and unstable geopolitics, energy price stability should be be taken into account. Security of energy supply, another important criterion, can be increased by taking advantage of local renewable energy sources.

Also, as electric power from renewable energy can be intermittent, it is important to ensure electricity production. As such, it is also necessary to consider the stability of energy generation. Various studies (e.g. Komor and Bazilian 2005; Shaw and Peteves, 2008) as mentioned in Y.-C. Shen have also emphasized the importance of low energy prices as it is important to maintain the standard of living of citizens.

Within the environmental goal, Y.-C. Shen, et al (2010) highlighted the significance of carbon emissions reduction, environmental sustainability, SO_x and NO_x emissions reductions, and low land requirements. It has been established though numerous studies that CO_2 emissions of renewable energy system is an important criterion in assessing renewable energy sources. Also, renewable energy sources are expected to diminish air pollutants, such as $SO_x$and NO_x. Thus, reduction of SO_x and NO_x emissions as a criterion has been recommended by many studies, too (e.g. Diakoulaki and Karangelis, 2007).

Environmental sustainability, within the context of electricity, refers to the shift from fossil fuels to, justifiably, renewable energy. However, the evaluation of the impacts brought by the use of renewable energy should be according to acoustic emissions, landscape impact, electromagnetic interferences, microclimatic changes, and unpleasant odors (Beccali et al, 2003 in Y.-C. Shen, et al (2010).

In SF Energy Invest (2010) as well as for the European Commission (2003), specific criteria were included under the environmental dimension. These include waste creation and disposal, including hazardous waste, noise, impact on landscapes and land use. Low land requirement has also been cited by many studies (e.g. Afgan and Carvalho, 2002; Beccali, et al. 2003) as an important criterion. This is due to the fact that demand for land can cause economic losses which are comparative to the site value, for example. (Y.-C. Shen, et al (2010).

As for economic goal, the following criteria for evaluation were identified by Y.-C. Shen, et al (2010): local economic development, increasing employment, technical maturity, potential for commercialization, market size, and reasonableness for investment cost. In Taiwan, the adjustment of the industrial structure is expected in order to facilitate the growth of the economy through the development of renewable energy. Moreover, the economic benefit brought *by* renewable energy development has been cited by several studies (e.g. Komor and Bazilian, 2005).

The creation of employment opportunities is included in the renewable energy policy to address the unemployment rate which has become a key concern in Taiwan. Many studies also support the inclusion of job creation in the evaluation of renewable energy projects (e.g. Haralambopoulos and Polatidis, 2003). Employment creation, however, is included in the social dimension instead of economic by the European Commission (2003).

Technology maturity is also a salient consideration for evaluation as more mature technologies are expected to have high success rates (Huang et al., 2008 in Y.-C. Shen, et al (2010). However, there are also technologies that are deployed in pilot sites and hence, are not subject to large-scale utilization. In some countries, policy measures enable the commercialization of these renewable energy technologies. Hence, the potential for commercialization has been considered in the assessment.

Studies (e.g. Lee et al, 2007) have underlined the significant role of potential market size in industrial competitiveness. The market size – whether domestic or international – needs evaluation; a larger market size would naturally attract investments which would facilitate industry development. Investment cost, which involves all costs related to purchase of equipment, engineering services, and technological installations, among others is another important consideration. Investment cost is a commonly used economic criterion that has been presented in many studies (e.g. Mamlook et al., 2001).

It has been earlier mentioned that employment creation was included under the social dimension by the European Commission (2003) whereas in the Taiwan context, this indicator was part of the economic goal. The European Commission (2003) was also replete with specific criteria and indicators that were commonly used in RES applications. These range from impacts to local flora and fauna and biodiversity loss to net present value of investment and internal rate of return to social cohesion and stability and public acceptance.

Burgherr, P. and Paul Scherrer Institut (2005, p. 51) concluded that "although there are similarities in their overarching goals, indicator sets are often not easily comparable because they differ in their specific scope and focus: sustainable development in general, sustainable development of energy sector, sustainable development of specific energy carriers. Data availability and comparability with other indicator sets may a strong argument for using indicators from already existing indicator sets."

"Many of the indicator sets suggest similar indicators with regard to the energy sector. For example, energy use, energy efficiency, energy intensity, energy mix, renewable resources, GHG emissions, emissions of acidifying and eutrophicating substances, waste generation and management, accident facilities, energy prices, taxes and subsidies. Generally, economic and environmental criteria and associated indicators are relatively well developed, whereas social indicators are poor and rather subjective."

Considering the weaknesses on the social indicators, the EU Integrated Project, New Energy Externalities Developments for Sustainability (NEEDS) aimed to target this issue through participative procedures (Burgherr, P. and Paul Scherrer Institut, 2005). NEEDS involved the establishment of a set of criteria and indicators for use in evaluation of future electricity generating technologies in four European countries: France, Germany, Italy and Switzerland (Hirschberg, et al., 2007).

Grafakos (2011) developed an integrated indicators' framework for sustainability assessment of climate mitigation technologies in the energy sector. The list of criteria and indicators has been selected based on relevance, comprehensiveness, non-redundancy, understandability, measurability, operationality, and availability of data, among other principles. The table below shows the list of evaluation criteria and indicators with their corresponding descriptions.

Table 2.Evaluation criteria and indicators for low-carbon energy technologies (Grafakos, 2011).

Criteria categories	Indicators	Description
Economic	Levelised costs (including capital, operations and maintenance, fuel costs)	Levelised costs of energy (LCOE): investment costs, operational and maintenance costs, capacity factor, efficiency, material use
	Employment (short run)	The extent to which the application of the technology can create jobs at the investment stage. Furthermore, the criterion of employment reflects partly the extent of the impact that the technology has to the local economic development by providing jobs and generating income
	Employment (long run)	The extent to which the application of the technology can create jobs at the operation and maintenance stage
Environmental	CO_2 emissions	The indicator reflects the potential impacts of global climate change caused by emissions of GHGs for the production of 1 kwh
	Climate resilience	The degree of resilience of the energy technology to the future climactic changes and extreme weather events
	Noise pollution	Part of population feeling highly affected by the noise

Criteria categories	Indicators	Description
		caused due to the function of the energy facility. This indicator is case sensitive and could have been measured as a factor of the noise generation by the energy technology estimated in dB multiplied by the number of people affected by the noise. However, since we are investigating different energy technologies and systems at a European scale we cannot measure precisely this indicator and therefore we will use an ordinal relevant scale to measure the perceived noise
	(Radioactive) waste	Amount of (radioactive) waste generated by the plant divided by energy produced
	Waste disposal (infrastructure)	Waste generation during the life cycle of the fuel and technology or availability of waste disposal infrastructure
	Ecosystem damages	This criterion quantifies the impacts of flora and fauna due to acidification and eutrophication caused by pollution from the production of 1 kWh electricity by the energy system and technology
	Land use requirement	The land required by each power plant and technology to be installed
	Fuel use	Amount of fuel use per kWh of final electricity consumption
Social	Level of public resistance/opposition	Energy system induced conflicts that may endanger the cohesion of society (e.g. nuclear, wind, CCS). Opposition might occur due to the perceptions of people regarding the catastrophic potential or other environmental impacts (aesthetic, odor, noise) of the energy technology/system. This indicator also integrates the aspect of participatory requirement for the application of the technology. The higher the public opposition, the higher the participatory requirement is.
	Aesthetic/functional impact	Part of population that perceives a functional or aesthetic impairment of the landscape area caused by the energy system. The aesthetic impairment is judged subjectively and therefore this criterion fits in the social category than the environmental one. In addition this is also a very location specific indicator and therefore an average metric will be determined measured in relative ordinal scale.
	Mortality and morbidity	Mortality and morbidity due to air pollution caused by normal operation of the technology. This indicator is considered as an impact and composite indicator since it integrates all human health impacts caused from air pollution emissions as NOx, SO2, and PM.
	Accidents and fatalities	Loss of lives of workers and public during installation and operation. Surrogate for risk aversion. This criterion partly integrates the catastrophic potential of the energy system/technology.

Criteria categories	Indicators	Description
Energy	Energy cost stability/sensitivity to fuel price fluctuation	The sensitivity of technology costs of electricity generation to energy and fuels prices fluctuations. The fraction of fuel cost to the overall electricity generation cost.
	Stability of energy generation	Stability of output of electric power generated depending on the technology used. This reflects whether the energy supply is being interrupted. The presence of these interruptions impacts the electricity network stability. This criterion reflects whether the energy supply faces any interruptions due to the type of energy technology. This criterion reflects whether the energy supply faces any interruptions due to the type of energy technology.
	Peak load response	Technology specific ability to respond swiftly to large variation of demand in time/% representing the possibility to satisfy the required load.
	Market concentration on supply	The market concentration on the supply of primary sources of energy that could lead to disruption due to economic or political re
Technological	Technological maturity	The extent to which the technology is technically mature. The criterion refers to the level of technology's technological development and furthermore the spread of the technology at the market.
	Market size (domestic)	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.
	Market size (potential export)	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.
	Innovative ability	Flexibility and potential of the technology to integrate technological innovations.

Keirstead (2007) conveyed that choosing indicators entails determining the approximate number of indicators needed and identifying the spatial as well as temporal boundaries. According to Keirstead (2007), the number of indicators would depend on stakeholders' needs as well as their capacity to understand various data types. However, the selection of criteria as well as the development of measurement scales, among other relevant consideration depends on the goals of the evaluator.

2.6 Stakeholder Engagement

Selecting low-carbon technologies for inclusion in the energy mix or to substitute conventional energy options requires the engagement of different actors. These actors, ranging from government authorities and local communities to environmental groups and academic institutions, participate in the planning and decision making process as their interests and resources are at stake, hence the term stakeholder.

In one study (Tsoutsos, et al., 2009, p. 1593), it has been shown that there is interdependency between and among the stakeholders, given the existence of overlapping interests which implies the "network perspective of the energy system." By and large, it has been argued that attention should be given to the decision-making group composition in order to reflect all possible perspectives (European Commission, 2003).

2.6.1 Stakeholder Classification

Stakeholders can be classified into two: (1) standard stakeholders or actors who have legitimate responsibility in participating in the process and (2) interest groups. Standard stakeholders include experts and planners, while interest groups typically come from civic organizations and local communities (European Commission, 2003). Also, in studies on energy planning, actors are classified on the basis of power and interest (e.g. Tsoutsos, et al., 2009).

In Rio and Burgillo (2008), the primary local stakeholders in the deployment of RES projects include renewable energy generators and investors who need to overcome investment risks and benefit from public support; local governments which are interested in providing development alternatives as well as maximizing local benefits; local population – actors directly affected by energy projects, and local NGOs and organizations, among others.

Stakeholders, moreover, can be divided according to the following: social, economic, institutional, and scientific agents. Also, they can be classified according to their institutional level, namely local, regional, national, and supranational (Centre for Environmental Studies of the Autonomous University of Barcelona, 2000 in University of Aegean, et al., 2003).

2.6.2 Stakeholder Analysis

The extent of and arguments for the inclusion or exclusion of these stakeholders should be identified at the beginning. Also, these arguments are deemed useful in understanding the problem (Lahdelma, et al., 2000 in European Commission, 2003). According to Macharis, et al. (2007, p. 450), "stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders to be consulted and whose views should be taken into account in the evaluation process."

"Stakeholder analysis is a process of systematically gathering and analyzing quantitative information to determine whose interests should be taken into account when developing and/or implementing a policy or program... Policymakers and managers can use a stakeholder analysis to identify the key actors and to assess their knowledge, interests, positions, alliances, and importance related to the policy" (Rio and Burguillo, 2008, p. 1335).

The decision making process entails participation of different stakeholders and dissemination of information (European Commission, 2003). However, with the inclusion of stakeholder groups, which have their own objectives and value judgments, this inevitably becomes a source of conflict. Munda (2003) in the European Commission (2003) defined "the existence of multiple and conflicting legitimate values and interests in a decision-making process" as social incommensurability.

2.6.3 Stakeholder Participation

Involving different stakeholders in the energy planning and decision making process increases legitimacy, facilitates social learning, and allows for the integration of multiple perspectives (Omann in Braune, et al., 2009). Moreover, stakeholders feel responsible and obligated to participate in project-related activities. “However, participation has its risks and disadvantages. If participation fails it can lead to mistrust and resistance of the project” (Braune, et al., 2009, p.5).

In energy planning and decision making, problems on public resistance, for example, may arise. In one study, the installations of RES necessitated for societal support through public acceptance. “The active participation of the critical actors of the energy systems and the integration of their interests are essential in order to sustain cooperation and commitment for the implementation of the energy alternatives.” (Tsoutsos, et al., 2008 in Tsoutsos, et al., 2009, p. 1588)

Stakeholder participation, however, is considered as a challenge. Researchers had to contend with non-participation and dropping out of stakeholders (e.g. Kowalski, et al., 2009). In one study, for example, only two stakeholder groups participated in the process which obviously did not provide results that would represent all stakeholders (Renn, 2003 in Kowalski, et al., 2009). Kowalski, et al., (2009) further mentioned that in most cases, there is no clear explanation why participation of stakeholders fluctuated.

Braune, et al., (2009, p.2) established an increasing involvement of stakeholders. In their review, half of the studies “showed direct involvement of stakeholders in the respective case study or a tool that is built for a future participation of stakeholders”. The ARTEMIS project (Kowalski, et al., 2009), which involved different stakeholders and energy experts, was provided as an example. For the project, workshops and interviews were carried out for scenario development and criteria weighting.

2.6.4 Elicitation Process

With issues on public acceptance of energy supply systems, stakeholder participation is crucial to “ensure success and stability of energy systems” (Braune, et al., 2009, p. 2). Sub-section 2.4.1 described the elicitation process via criteria weighting. “The step of multi-criteria subjective judgment is the one that could foster direct participation of stakeholders and inclusion of their preferences into the decision-making process (Borges and Villavicencio, 2004 in Grafakos, et al., 2010, p. 436).

Cognitive limit is one of the challenges in preference elicitation. In a decision problem which involves a small set of alternatives and criteria, most people can make their selection intuitively. However, with a large set of alternatives and criteria, “intuition” and/or “experience” necessitate for support. The challenge is intensified by the mix of qualitative and quantitative indicators as well as preferences that are oftentimes “discontinuous”, “non-linear”, and “have threshold values”. (Makowski, et al., 2009, p. 7)

“It is commonly agreed that elicitation of stakeholders’ preferences must include computerized interaction with each stakeholder during which she/he is supported in the analysis of the correspondence between her/his desired goals and the corresponding outcomes/results” (Makowski, et al., 2009, p. 11). The design and implementation of such interaction, which is considered as a challenge, should be carried out carefully (Makowski, et al., 2009).

2.7 MCDA Applications and Related Studies

Huang, et al. (1995), Pohekar et al. (2004), and Kowalski et al (2008) as mentioned in Braune, et al. (2009) have carried out reviews on MCDA in the energy sector. The review showed that MCDA methods are used most especially in energy planning. Braune, et al. (2009, p. 7) found that there is a strong application for MCDA methods in RES which could be explained by the "increased commitment of national and local governments as well as a change in the public perception of energy systems"

MCDA has been used in "incorporating public values in energy future scenarios", "evaluating alternative integrated energy plans", "assessment of renewable and sustainable energy technologies", "indirect valuation of energy externalities", "participatory design of renewable energy (RE) policy instruments", "integrated assessment of energy analysis", and "evaluation of energy projects for electricity generation", among others (Grafakos, et al., 2010, p. 436).

Braune, et al. (2009, p. 8) also showed real world applications, or that "the decision process could be applied to the corresponding region and the results could be implemented", of the case studies reviewed. However, there is little evidence that decisions were implemented. Braune, et al. (2009, p. 8) also suggested that "another indication of for the real world potential of MCDA is the involvement of companies compared to a mere research environment".

For Kowalski, et al, (2009, p. 1065), "MCA is widely applied for decision aid in the energy management and energy policy contexts, including a few assessments of the environmental performance of energy systems. Most applications on energy issues focus on technical planning and typically do not include stakeholders in a systematic and participatory way. However, like in other research areas, a trend towards increased involvement of stakeholders can be observed in energy research."

Studies on energy planning on the regional, national or local levels that made use of MCDA include the following:

2.7.1 NEEDS Project

NEEDS, an EU Integrated Project, entailed an MCA of energy technologies in four European countries: France, Germany, Italy and Switzerland (Hirschberg, et al., 2007). The specific objectives were to "evaluate energy technologies and scenarios taking into account diverse preferences of stakeholders for trade-offs between economic, environmental, and social criteria characterizing the technologies" and "to investigate the sensitivity of the results of sustainability assessment to specific patterns in stakeholder preferences." (Makowski, et al., 2009, p. 2)

This project involved 60 criteria (20 higher-level criteria and 40 lower-level criteria) and four sets of alternatives (each set has 20 alternatives). The preferences of the stakeholders, which were conveyed through relative importance of the criteria, were obtained via a web-based MCA. The analysis of the stakeholders' preferences, as well as the set of solutions, was carried out by energy experts, policy makers, advisors, members of NGOs, and researchers. (Makowski, et al., 2009)

2.7.2 ARTEMIS Project, Austria

The ARTEMIS Project entailed the evaluation of renewable energy scenarios for Austria –in the national level and in two local communities - for the year 2020. In the national level, five renewable energy scenarios were assessed against 17 criteria. On the local level, on the other hand, four scenarios were evaluated against 15 criteria. Social, economic, technological, and environmental criteria were used in the assessment of the energy scenarios. (Kowalski, et al., 2009)

The project combined scenario development, multi-criteria evaluation, and a participatory process. Stakeholders actively participated in the evaluation process. Stakeholders in the national level included government bodies, private firms, NGOs, and research institutes. Local stakeholders involved local energy experts, regional and national energy experts, mayors, and citizens. (Kowalski, et al., 2009) The integrated appraisal made possible the ranking of scenarios (Madlener, et al., 2007, p. 6061).

2.7.3 Energy Planning, Crete, Greece

A multi-criteria methodology was conducted for sustainable energy planning in Crete, Greece. The installations of renewable energy sources prompted the identification of four energy planning alternatives: (1) install only wind farms; (2) install wind farms and PV systems; (3) install wind farms, PVs and 4 olive kernel units; and (4) install wind farms, PVs and oilstone biomass. These alternatives were assessed against different criteria, ranging from economic to environmental. (Tsoutsos, et al., 2009)

Different actors participated in the process. These were local authorities, potential investors, local communities, academic institutions, environmental groups, and governments and EU. In the analysis, Tsoutsos, et al. (2009) expressed that the multi-actor characteristic of energy systems can be an asset in the evaluation. An elaboration of the methodology used for the study can be found in Tsoutsous, et al. (2009).

2.8 Conclusions

The review of literature provided important insights on local energy planning and decision making. This chapter presented the applicability of MCA in complex decision problems which involve multiple, often conflicting objectives. MCA provides a strong framework that allows evaluation and ranking of options with the involvement of different relevant actors. MCA is applied in energy planning at the local, national, and regional levels.

As mentioned in the problem statement, there has been no other study conducted that map local stakeholders’ preferences with regard to multiple evaluation criteria and objectives regarding low-carbon energy technologies. The reviewed studies on energy planning primarily look at the local contexts and in specific geographical locations. As such, this research study will look at the local stakeholders’ perspectives in a larger scale, specifically at the European level.

2.9 Conceptual Framework

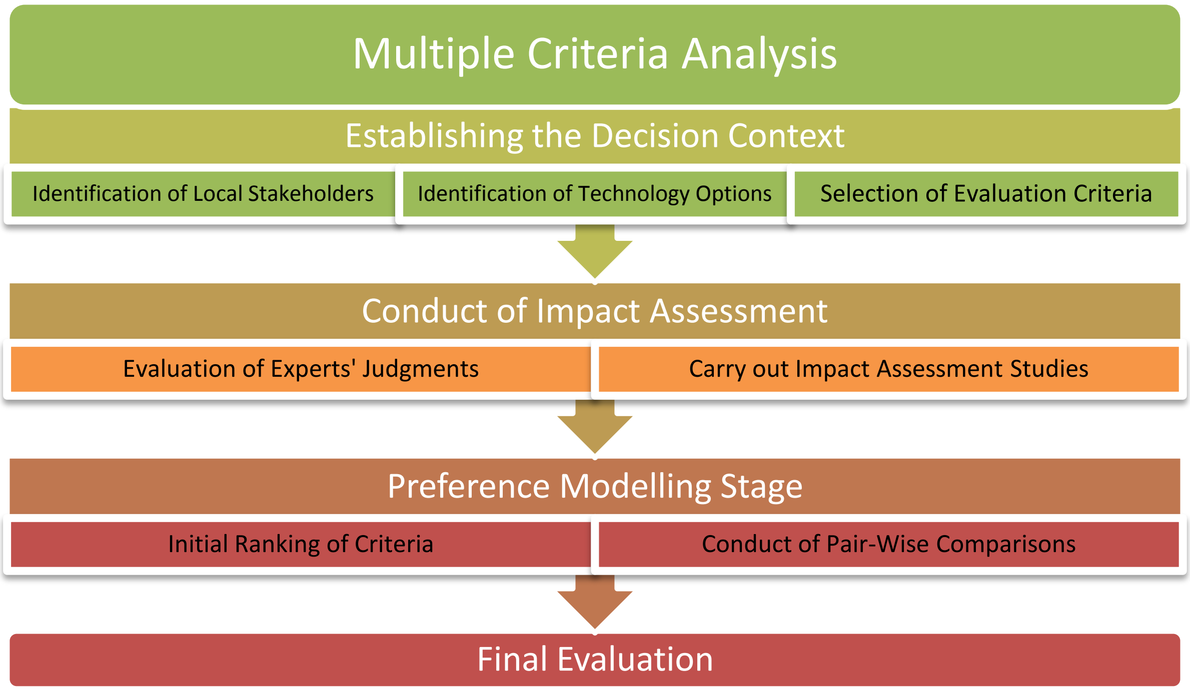


Figure 2.Conceptual framework of the study.

Chapter 3: Research Design and Methods

3.1 Research Approach and Techniques

An exploratory type of research, this study combined both qualitative and quantitative approaches in fulfilling the objectives and in answering the research questions. The research study primarily used a desk study (literature review), which enabled a review of evaluation criteria and indicators, and two (2) online surveys. The online surveys dealt with (1) the validation and refinement of the evaluation criteria and indicators and (2) the elicitation of weighting preferences.

3.2 Operationalization: Variables, Indicators

The following are the variables and indicators for multiple criteria assessment of low-carbon energy technologies. These indicators were made available through a review of literature and from the results of experts' judgment impact assessment (Grafakos, 2011).

Table 3.Variables and Indicators for Multiple Criteria Assessment.

No.	*Variables*	*Indicators*
1	Economic	Levelised costs, employment (short run), employment (long run)
2	Environmental	CO2eq emissions, climate resilience, noise pollution, (radioactive) waste, waste disposal (infrastructure), ecosystem damages, land use requirement, fuel use
3	Social	Level of public resistance/opposition, aesthetic/functional impact, mortality and morbidity, accidents and fatalities
4	Energy	Energy cost stability/sensitivity to fuel price fluctuation, peak load response, market concentration on supply
5	Technological	Technological maturity, market size (domestic), market size (potential export), innovative ability

3.3 Sample Size and Selection

The population of the respondents came from different associations and networks, such as ICLEI - Europe, an international association of local and metropolitan governments committed to sustainable development. Also, respondents were derived from online searches/databases. They were invited through mailing lists and e-mail messages.

Convenience sampling was utilized to get the sample population for this research study. Furthermore, the sample respondents were grouped based on three broad categories: public authorities; energy industry actors; and technical professionals. This grouping is significant in mapping out, to a limited extent, local stakeholder groups' preferences.

3.4 Validity and Reliability

The data collection instruments for the study underwent development, pre-testing, and finalization. This process carried out to ensure clarity in content, comprehensibility, understandability, and manageability.

In order to guarantee validity, the evaluation criteria and indicators that were used for the study were refined by the survey respondents. Moreover, results of the data analysis were subjected to testing and re-testing.

3.5 Data Collection Methods

This research study involved the following data collection methods:

3.5.1 Desk Study

The desk study entailed an analysis of assessment frameworks for sustainability criteria. Different reference materials were used in the review of evaluation criteria and indicators for use in the energy and sustainability context. These were selected based on relevance for projects in the field of low-carbon energy technologies or renewable energy sources.

3.5.2 Online Surveys

This research study employed two (2) distinct online surveys. The survey on refinement of criteria was administered prior to the elicitation of weighting preference. The objective was to come up with a list of finalized criteria and indicators for utilization in the second survey which sought to elicit preferences.

3.5.2.1 Refinement of Criteria

As mentioned, the list of evaluation criteria and indicators was refined and validated by the survey respondents. The respondents were asked to improve the selected evaluation criteria and indicators under investigation. Based on their local contexts and with their knowledge, expertise, and experience, the respondents were requested to add, remove, or adjust the criteria and indicators for evaluating low-carbon energy technologies.

This survey preceded the elicitation of weighting preferences as the validated list was used in the conduct of the latter activity. There were five broad categories for the evaluation criteria and indicators, namely economic, environmental, social, energy and technological. General descriptions were provided to respondents. The survey tool used for the study was accessed and completed online by the survey respondents. See Annex 8 for the survey tool.

3.5.2.2 Elicitation of Preferences

The final evaluation criteria and indicators generated from the survey on refinement and validation were used in the elicitation of weighting preferences. This elicitation process enabled the local stakeholders to provide their preferences for the evaluation criteria and indicators using a computer-aided excel tool (Grafakos, et al., 2010). See Annex 9.

An initial ranking introduced the respondents to the different evaluation criteria and indicators under investigation in the elicitation weighting process. This step allowed the respondents to be familiarized with the ranking process as well as in making comparisons. Moreover, the initial ranking provided the base for the consistency check.

At first, the respondents were asked to rate the list of evaluation criteria and indicators according to their level of importance: low, moderate, and high. For each level of importance, the respondents carried out direct ranking by assigning numbers (1 as the most important criterion, 2 as the second most important criterion, and so on).

The initial ranking was followed by a series of pair-wise comparisons. Pairs of criteria were sequentially arranged based on an abbreviated format (i.e. a-b, b-c, c-d, etc), considering the large number of criteria. The survey respondents selected which criterion they preferred for each pair-wise comparison. Moreover, they expressed their preferences verbally, numerically as well as graphically.

Survey respondents chose from five levels of intensity of preferences: equally, almost equally, moderately, strongly, and very strongly. These verbal expressions were associated with preference values (a ten-point scale between 0 and 1) that the survey respondents selected themselves. A graphical representation of preference was generated for each pair-wise comparison.

The survey tool enabled the generation of criteria weights as well as final ranking based on the results of the pair-wise comparisons. The first criterion among the list (i.e. levelised costs) is given the relative score of 1 which is the base reference value for calculating the relative scores of the criteria based on the series of pair-wise comparisons. The relative scores for the criteria are then transformed into weights using the formula:

$$Wi = \frac{RSi}{\sum_{n-1} RS} \quad (1)$$

The formula denotes that *RSi* is the relative score of criterion *i* in comparison to criterion *j*. Σ (RS), on the other hand, is the summation of the relative scores of all criteria (*n)* after the completion of the pair-wise comparisons (*n* -1) (Grafakos, et al., 2010). Survey respondents could observe the relative scores and weighting factors as well as the graphical representation of the criteria weights for reference.

The elicitation of weighting preferences included consistency test and revision. The ranking derived from the series of pair-wise comparisons is compared with the results of initial ranking. A consistency check, which is based on Spearman's rank order correlation coefficient, is generated (Grafakos, et al., 2010). A schematic representation of the integrated weighting methodology by Grafakos, et al. (2010) is shown below.

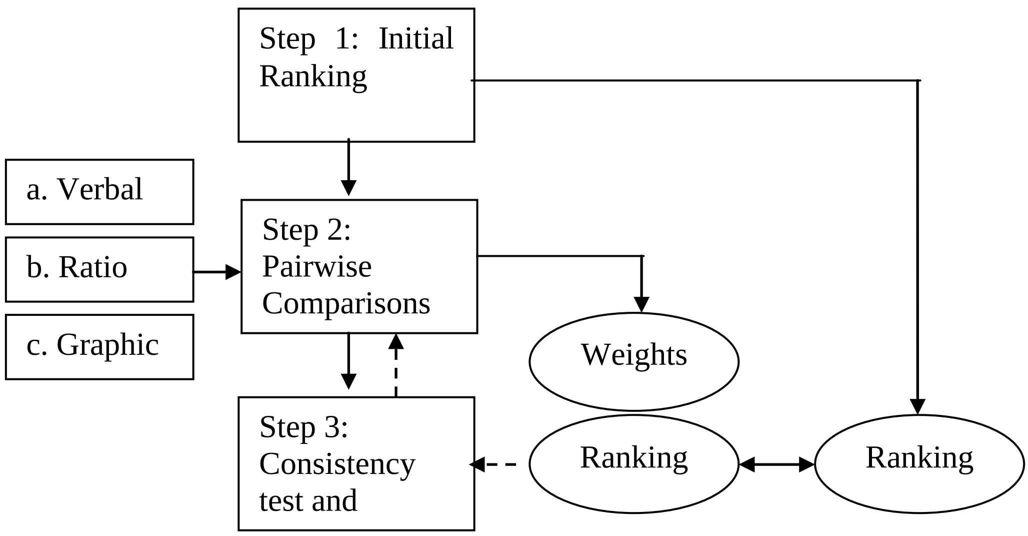


Figure 3. Schematic representation of the integrated weighting methodology (Grafakos, et al., 2010)

3.6 Data Analysis Methods

The integrated weighting methodology utilized the following aggregation additive rule:

$$V(p) = \sum_j w_j * v_j(p) \qquad (2)$$

where the "value of the overall effect of each decision alternative action, $v_{j,}$ to each criterion is multiplied with its respective criterion weight, $w_{j,}$ whereas the summation of these products determines the overall value of each alternative decision action *V(p)"* (Grafaskos, et al., 2010).

The value of the consistency threshold was set at 0.7. Low consistency was equivalent to or less than 0.5. Moderate consistency ranged from 0.5 to 0.7, while high consistency equalled to or exceeded 0.7.The survey respondents were asked to revise their preferences should the consistency index is below the threshold value.

If the consistency index equalled to or exceeded the threshold value, the weighting process is completed. Otherwise, the respondents had to re-visit the initial ranking and pair-wise comparison. In conditions where there were low consistencies as well as preferences for initial ranking over pair-wise comparisons, normalization of weights was applied using the formula:

$$NSi = \frac{x - \min}{\max - \min} \qquad (3)$$

On the other hand, the weights of those respondents who have achieved high consistencies as well as those who have preferred pair-wise comparisons were retained. Based on the average weights of all stakeholders and of the different local stakeholder groups, the different evaluation criteria and indicators were ranked accordingly. Comparison between the results among the different stakeholder groups was also carried out.

The review of literature on the assessment frameworks for sustainability criteria was followed by a qualitative analysis. The survey results on the refinement and validation of criteria and indicators were analyzed using quantitative and descriptive statistics. The quantitative data generated through this survey were analyzed using basic statistical calculations, such as means or averages. Furthermore, frequency tables and charts, among others were produced.

In order to obtain the preferences for the evaluation criteria of local stakeholders, a computer-based multiple criteria assessment was carried out. The analysis of the survey results involved aggregating stakeholders' preferences with regards to the evaluation criteria and analysis of possible correlations between the prioritized evaluation criteria and stakeholder groups.

The low-carbon energy technologies under investigation perform differently when assessed against the different evaluation criteria and indicators. How these technologies perform could be reviewed in the impact assessment matrix (Grafakos, 2013). The impact assessment matrix was developed by Grafakos through a review of literature, which include IEA (2010), Wei et al. (2010), NEEDS project (2009), Grafakos (2013), McDonald et al. (2009), and Streimiekene (2009).

Each low-carbon energy technology has an assigned score of performance for each criterion. These scores of performance were derived from experts' judgments (Grafakos, 2013), and are the expected performance values that these low-carbon energy technologies would achieve by 2030. In the process of assessing the low-carbon energy technologies, the impact scores were likewise normalized through the normalization formula (3). The weights provided by the respondents per criterion were taken into account in the evaluation.

This research study made use of a tool for assessing technologies against the different criteria and indicators. See Annex 10 for the assessment tool developed by Grafakos (2013). The low-carbon energy technologies were prioritized based on the final weighted scores per technology. The following is the formula for calculating the weighted scores (Haque, et al, 2012 :

$$WSj = Wi * Sji \quad (4)$$

where WS*j* is the weighted score of low-carbon energy technology *j*; W*i* is the weight of criterion *i*; and S*ji* is the score of low-carbon energy technology *j* to criterion *i*. The ranking of the low-carbon energy technologies was automatically generated. The final scores, including the contribution of each criterion, in the final weighted scores could be reviewed through the graphic representations that were automatically generated.

Table 4.Methods for data collection and analysis for the research study.

Research Objectives	Methodology	Analysis
Which criteria and indicators can be selected for the evaluation of low-carbon energy technologies in Europe from a local stakeholders' perspective?	Desk study (Literature review)	Qualitative analysis
	Online survey (Refinement and validation)	Quantitative and descriptive statistics
What is the relative importance of the different evaluation criteria among the local European stakeholders in the energy sector?	Online survey (Elicitation of Weighting Preferences)	Multiple criteria assessment
		Quantitative and descriptive statistics
Based on the local stakeholders' preferences, what is the overall evaluation of low-carbon energy technologies?	Summation and ranking	Multiple criteria assessment
		Quantitative and descriptive statistics

Chapter 4: Research Findings

4.1. Finalization of Criteria and Indicators

The review of literature on urban energy sustainability indicators presented in Chapter 3 combined with the survey on refinement of criteria and indicators produced the final set of criteria and indicators utilized in the elicitation of weighting preferences. The indicator set used in the criteria validation and refinement process was adopted from Grafakos (2011). The data below show the results of the survey that sought to validate the indicator set.

Thirty (30) respondents from 18 European countries participated in the survey on refinement and validation of evaluation criteria and indicators. Almost half (43%) of the respondents represented Southern Europe (Greece, Italy, Spain, Portugal, and Croatia). Twenty (20%) of the respondents came from Eastern Europe (Georgia, Bulgaria, Romania, and Turkey), while another 20% were from Northern Europe (United Kingdom, Denmark, Sweden, Ireland, and Lithuania). Seventeen percent (17%) of the respondents represented Western Europe (Belgium, Austria, France, and Germany).

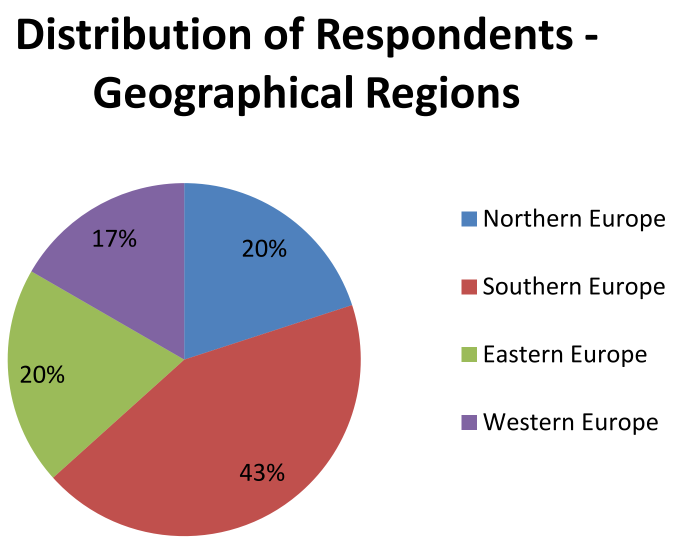


Figure 4. Distribution of respondents based on geographical regions.

The survey respondents were associated with nine (9) stakeholder groups. These were non-government organizations (27%), energy agencies (27%), government – local (20%), academic – research (7%), consultants – advisors (7%), government – national (3%), electricity and energy associations (3%), regulators and network administrators (3%), and electricity producers (3%).

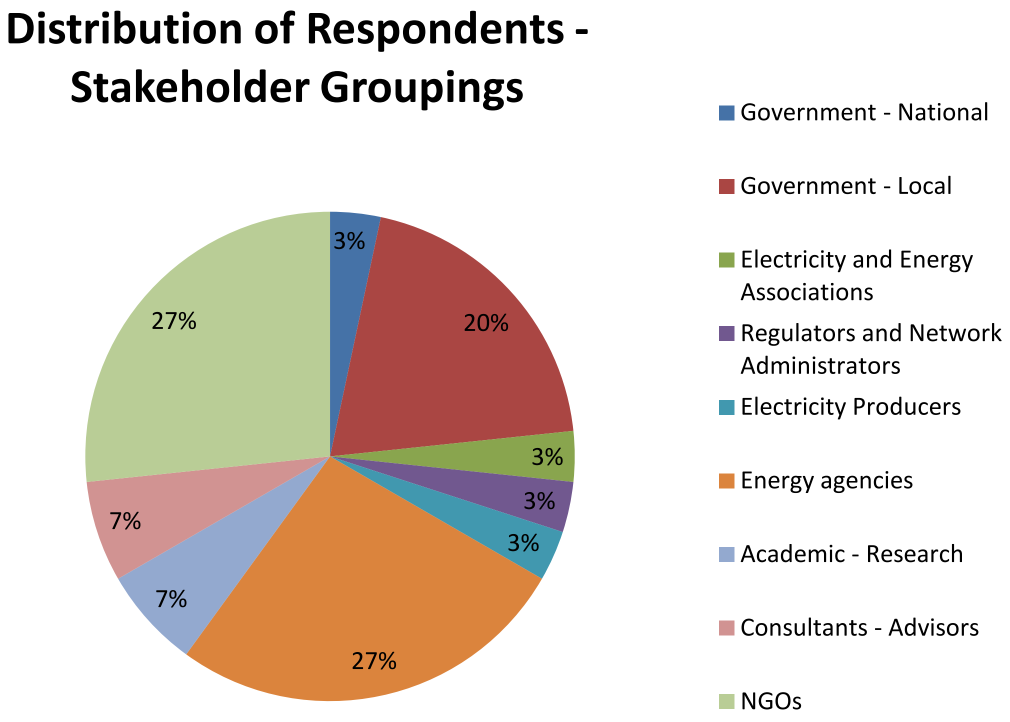
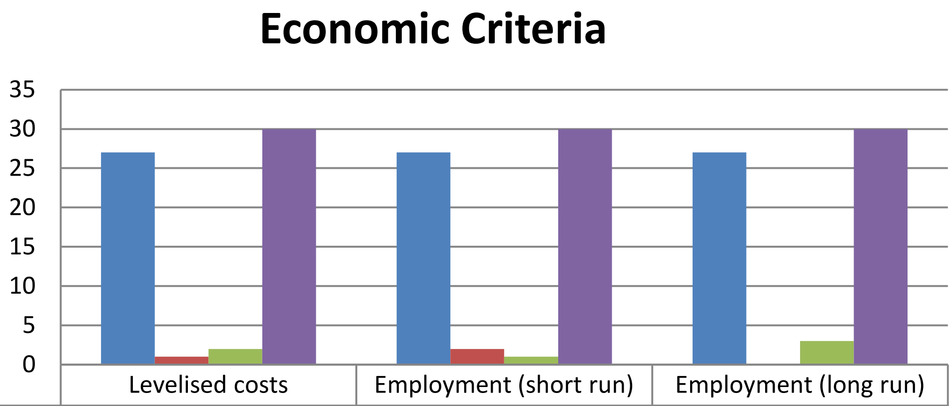


Figure 5. Distribution of respondents according to stakeholder grouping.

Majority of the respondents opted for the retention of all 23 criteria and indicators for evaluating low-carbon energy technologies. After the completion and analysis of the survey on refinement and validation, there was a modification in the final selection.

Two (2) economic criteria, namely employment (short run) and employment (long run), were integrated into one as employment generation. No additional criteria and indicators were added into the final selection. Over-all, the number of criteria and indicators for evaluation were reduced from the original list of 23 to 22.



	Levelised costs	Employment (short run)	Employment (long run)
Retain	27	27	27
Remove	1	2	0
Adjust	2	1	3
Total	30	30	30

Figure 6. Survey results for economic criteria.

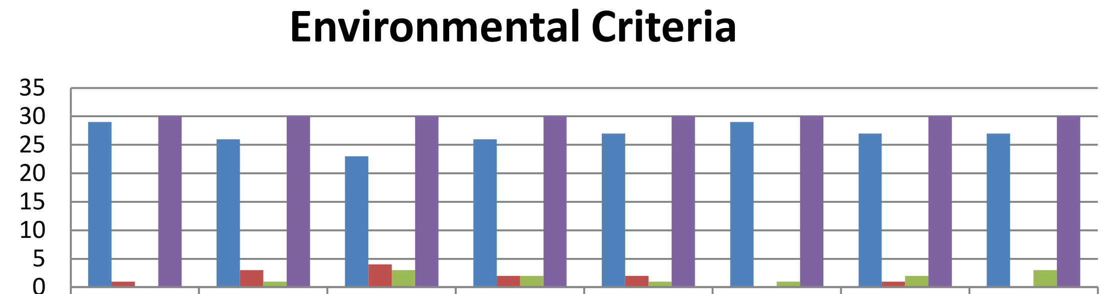
For levelised costs, 7% of the respondents opted for the adjustment of this indicator with the explanations that “costs need to be compared with the costs of another solution and/or of not acting” as well as the need “to identify costs and benefits” and “subsidies (for fossil fuels) and environmental cost should be included”. The comparison between the costs of technologies is already being addressed by this research study. Moreover, the MCA approach addresses the costs and benefits, including environmental-related ones (e.g. ecosystem damages) of the different low-carbon energy technologies.

According to literature, levelised costs of energy allows for comparison between technologies based on weighted average costs. Moreover, different variables (e.g. investment costs, taxation) factor in the computation. Within the context of electricity generation, levelised costs of energy reflect the costs of building, operating, and maintaining a facility within the life cycle of the project.

As for employment (short run), 3% of the respondents opted for the adjustment of this criteria with the comment that “local jobs solution (is) less interesting if the jobs are created elsewhere.” On the other hand, 10% of the respondents opted for the adjustment of the indicator employment (long term). One respondent thought that “long term impacts on employment are usually overestimated".

One conventional view conveys that renewable energy generation, for example, creates additional jobs as decentralisation provides more labour intensive employment. Moreover, it is argued that this sector puts the employment opportunities and the energy industry in domestic or local terrains where fossil resources are low (IEA, 2012). In the finalization of the indicator set, employment (short run) and employment (long run) were integrated into one: employment generation.

Suggested indicators for inclusion under economic criteria were the following: "net present value", "internal rate of return", "payback", "socio-economic", "money invested locally (e.g. via taxation, valorization of biomass, etc.)"; "innovation (indicator: no of patents)"; and "environmental sustainability". With the exception of “socio-economic” which does not satisfy the basic principle of clarity and “innovation” and “environmental sustainability” which clearly belong to technological and environmental criteria categories, the other suggested indicators are taken into account in the computation.



	CO2eq emissions	Climate resilience	Noise pollution	(Radioactive) waste	Waste disposal (infrastructure)	Ecosystem Damages	Land use requirement	Fuel Use
Retain	29	26	23	26	27	29	27	27
Remove	1	3	4	2	2	0	1	0
Adjust	0	1	3	2	1	1	2	3
Total	30	30	30	30	30	30	30	30

Figure 7. Survey results for environmental criteria.

CO2eq emissions and ecosystem damages were the most favoured with majority (97%) of the respondents voting for the retention of each criterion.

According to the respondents, “noise pollution is not that much important in global warming” and it is "difficult to assess and explain (to public) for the different technologies’, hence, the need for removal. Noise pollution, however, is an important criterion when evaluating energy technologies. Also, noise pollution has been measured by certain models, and this criterion has been subjected to assessment by experts.

Those who were in favour of adjustment explained that "this should not be a top criteria as there are technologies to reduce noise"; "may be different technologies need different measure scales"; and "depends on the noise level that already exists and should be relative to that level."As mentioned in the general description, however, an ordinal scale will be used to measure the perceived noise, considering the different low-carbon energy technologies under investigation and the lack of a precise measure for this criterion. Moreover, it is assumed that a baseline will be used for noise pollution for all energy technologies.

Climate resilience needed adjustment according to 3% of the respondents with the explanation that “climate change in the future might be less gradually altered” and that “changes will be more sudden”. Ten percent (10%) respondents who voted for the removal of this indicator mentioned its irrelevance “as nobody can predicate climate change” and that the objective is to “mitigate climate change”. These general assumptions, however, are contrary to experts’ judgments.

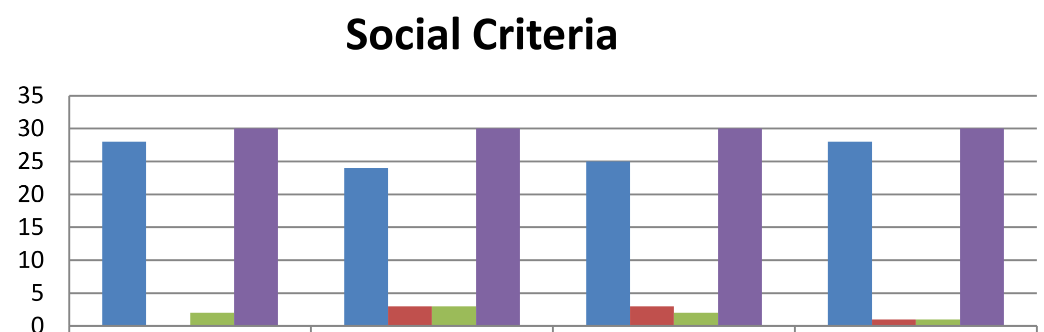
Seven percent (7%) of the respondents were in favour of the removal of (radioactive) waste as one explained that it is “not relevant”. (Radioactive) waste is an important criterion as this poses potential harmful impacts to environment and even when handled properly, is still subject to human aversion. Also, 7% of the respondents were in favour of adjustment with one respondent suggesting that waste and radioactive waste should be separated because it is not one and the same. The criterion under evaluation pertains solely to radioactive waste and thus, adjusted accordingly.

With regards to waste disposal (infrastructure), 7% of the respondents opted for its removal with one respondent explaining that it is “not widely acceptable”. Seven percent (7%) were in favour of adjustment as "no dangerous wastes can be treated as common waste". As for fuel use, 10% were in favour of adjustment with the following suggestions: "amount of primary energy should be used instead" and "fossil energy use (gas, coal, etc.)".

Three percent (3%) of the respondents were in favour of the removal of land use requirement as it is considered "minor compared to the others." However, for this research study, the methodology allows for the provision of weights on this criterion, depending on stakeholders' preferences, which enables ranking and prioritization. Seven percent (7%) of the respondents said that it needed adjustment as it "not very important" and "not only environmental criteria, [but] it is one of the most pressing social criteria as well." Land use requirement remains an important criterion, and is conventionally classified under environmental category.

Survey respondents provided the following suggestions for inclusion under environmental criteria: "distribution and transmission losses", "conformity with different land uses, impacts to the landscape", "change of land use as it will be stated in a new directive in the EU", "air pollutant emission (e.g. SO2, NOx, particles, CO, VOC, heavy metals and POPs): The impacts of suggested indicator are included in the criteria/indicator ecosystem damages [sic] [ecosystem damages], but if you consider GHG emission it is reasonable to include air pollutant emission", "water use", "landscape assessment", "risk for the environment (example: safety issues in a nuclear power plant), and "renewable (prerequisite for environmentally sustainable[sic])".

'Impacts to the landscape' and 'landscape assessment" are captured already by the criterion 'aesthetic/functional impact' while "change of land use" relates to 'land use requirement'. 'Water use' is not considered as Europe does not face water scarcity issues.



	Level of public resistance/opposition	Aesthetic/functional impact	Mortality and morbidity	Accidents and fatalities
Retain	28	24	25	28
Remove	0	3	3	1
Adjust	2	3	2	1
Total	30	30	30	30

Figure 8. Survey results for social criteria.

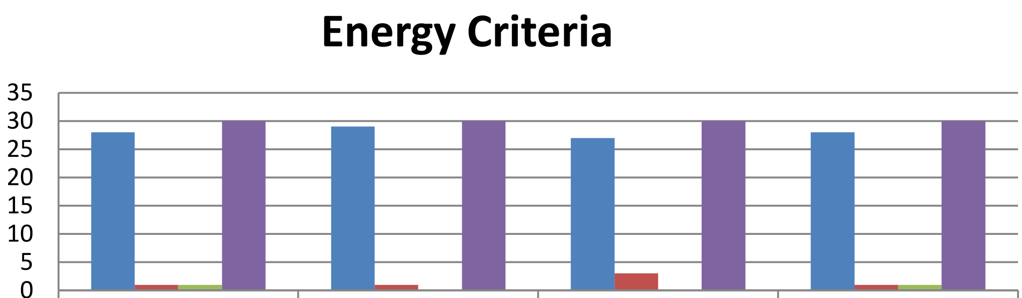
Level of public resistance/opposition and accidents and fatalities were the most favoured social criteria by the respondents. However, 7% of the respondents thought that the level of public resistance/opposition needed adjustment as "there should be differences between resistance to nuclear or wind". The latter comment, however, is already captured by expert's judgments which are reflected in the impact assessment matrix.

Ten percent (10%) of the respondents deemed that aesthetic/functional impact needed adjustment. The respondents thought that aesthetic/functional impact "fits better with the environmental indicators" and that "the criterion is interesting to know, if it's used to plan information sessions and offer participation for creative solutions. It should not lead to exclusion of a type of energy technology/system." Aesthetic/functional impact is an important criterion with the aesthetic component a crucial environmental issue.

One of the respondents who voted for the removal questioned how to measure aesthetic/functional impact. As provided in the general description, aesthetic/functional impact is measured in relative ordinal scale, and this can be reviewed in the impact assessment matrix.

Also, 7% of the respondents deemed it necessary to adjust the indicator mortality and morbidity. One respondent explained that "some installations may have positive benefits e.g. health benefits through a centralised heating system." This research study aims to evaluate low-carbon energy technologies which range from solar PV to EPR. Ten percent (10%) of the respondents, on the other hand, suggested for its removal with one respondent saying that it is "not needed". However, mortality and morbidity is certainly relevant as a criterion in the evaluation of low-carbon energy technologies.

The respondents suggested additional indicators for inclusion under social criteria, such as "health and safety protocols". The suggested criterion, however, already relates – to a certain extent – to mortality and morbidity as well as accident fatalities which provide risk estimates based on expert's judgments.



	Energy cost stability/sensitivity to fuel price fluctuation	Stability of energy generation	Peak load response	Market concentration on supply
Retain	28	29	27	28
Remove	1	1	3	1
Adjust	1	0	0	1
Total	30	30	30	30

Figure 9. Survey results for energy criteria.

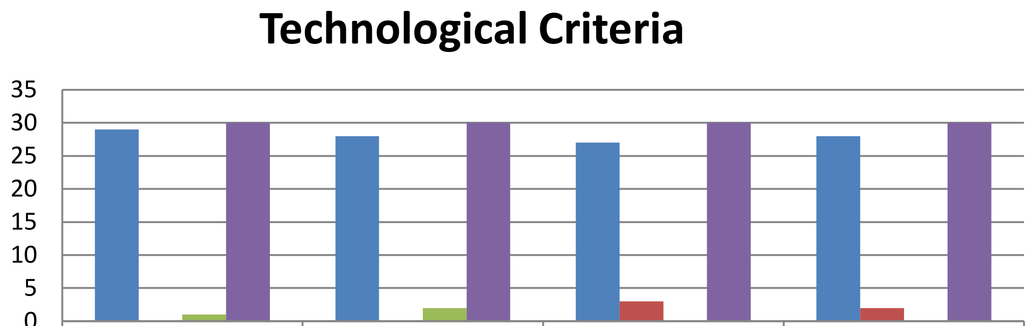
The most favoured energy indicator was stability of energy generation, followed by energy cost stability/sensitivity to fuel price fluctuation, market concentration on supply, and peak load response.

Three percent (3%) of the respondents said that energy cost stability/sensitivity to fuel price fluctuation needed adjustment as "[to] renewable's fuel prices fluctuation is not very significant". Energy cost stability/sensitivity to fuel price has already been studied, and the estimates were derived from expert's judgments as reflected in the impact assessment matrix.

Stability of energy generation needed to be removed, according to another 3% of the respondents as "it does not make sense to study the stability of energy generation of one renewable technology (e.g. wind solely), as the whole point of renewables is to combine various sources of energy."

Ten percent (10%) of the survey respondents thought that peak load response should be removed with one respondent explaining that it "can be solved by smart grids or other energy production". Market concentration on supply needed to be adjusted according to 3% respondents as "criteria [sic] is not very significant to renewable”. It is important to point out, however, that weighting elicitation enables one to derive the relative importance of one criterion compared to another. Three percent (3%) of the respondents were also in favour of its removal ("[already] included in energy cost stability).

Additional indicators suggested by the survey respondents are as follows: "energy supply contracts"; "energy performance contracting"; "penetration of smart grids"; and "adaptation of technologies to local climate conditions (for example use of RES)". The latter suggestion is difficult to measure, while ‘penetration of smart grids’ is not significant as different technologies are included in the assessment; smart grids will not provide differentiation in the assessment.



	Technological maturity	Market size (domestic)	Market size (potential export)	Innovative ability)
Retain	29	28	27	28
Remove	0	0	3	2
Adjust	1	2	0	0
Total	30	30	30	30

Figure 10. Survey results for technological criteria.

The most favoured technological criteria was technological maturity, followed by market size (domestic), innovative ability, and market size (potential export). Ten percent (10%) of the respondents thought that market size (potential export) needed to be removed, with one respondent explaining that it is “not relevant”. The relevance of market size – in general – should not be understated. This criterion is considered an important factor in the evaluation of RES as mentioned by various studies.

Seven percent (7%) of the respondents also voted for the removal of innovative ability as it is “not necessary [as] we need stable production.” There was no additional indicator suggested by the survey respondents for inclusion under the technological criteria.

4.2. Elicitation of Weighting Preferences

A total of 18 individuals responded to the survey on elicitation of weighting preferences. These respondents represented four (4) geographical regions. Half (50%) of the respondents represented North Europe (Finland and the United Kingdom). Twenty-two percent (22%) came from Eastern Europe (Romania, Turkey and Georgia), while 17% of the respondents represented Western Europe (Belgium and Germany). Lastly, 11% of the respondents came from South Europe (Spain, Greece, Italy, Slovenia, and Croatia).

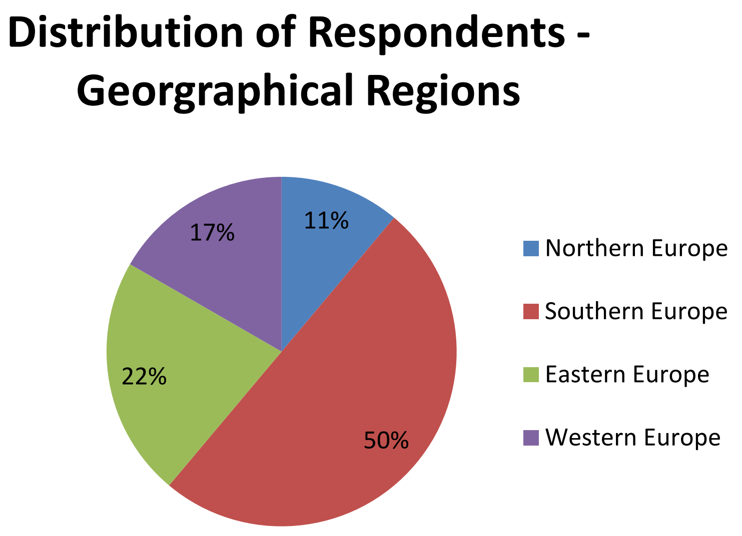


Figure 11. Distribution of respondents based on geographical regions.

Sixteen (16) out of the 18 responses were used for the data analysis as two (2) respondents did not provides sufficient answers. The survey respondents (n=16) represented eight (8) stakeholder groups, namely government – local (25%), consultants – advisors (19%), academic – research (13%), energy agencies (13%), electricity producers (13%), government – national (6%), electricity and energy associations (6%), and NGOs (6%).

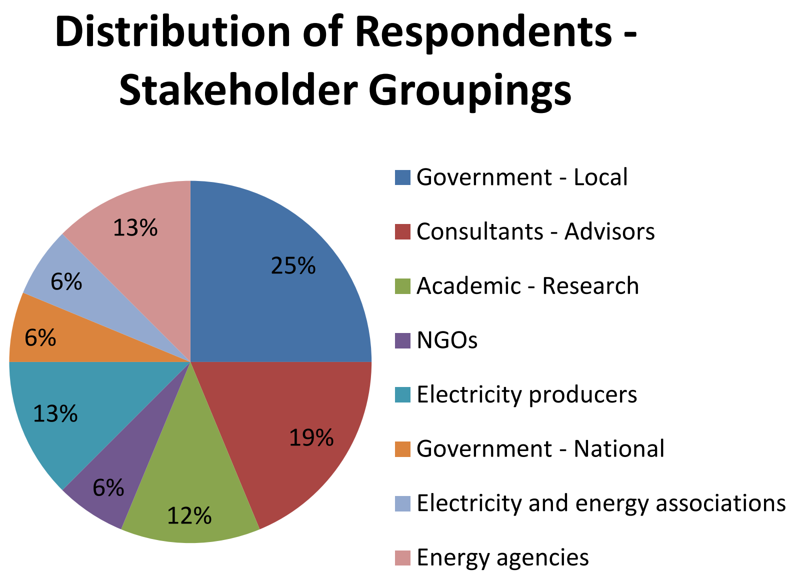


Figure 12. Distribution of respondents based on stakeholder groupings.

4.2.1. Initial Ranking

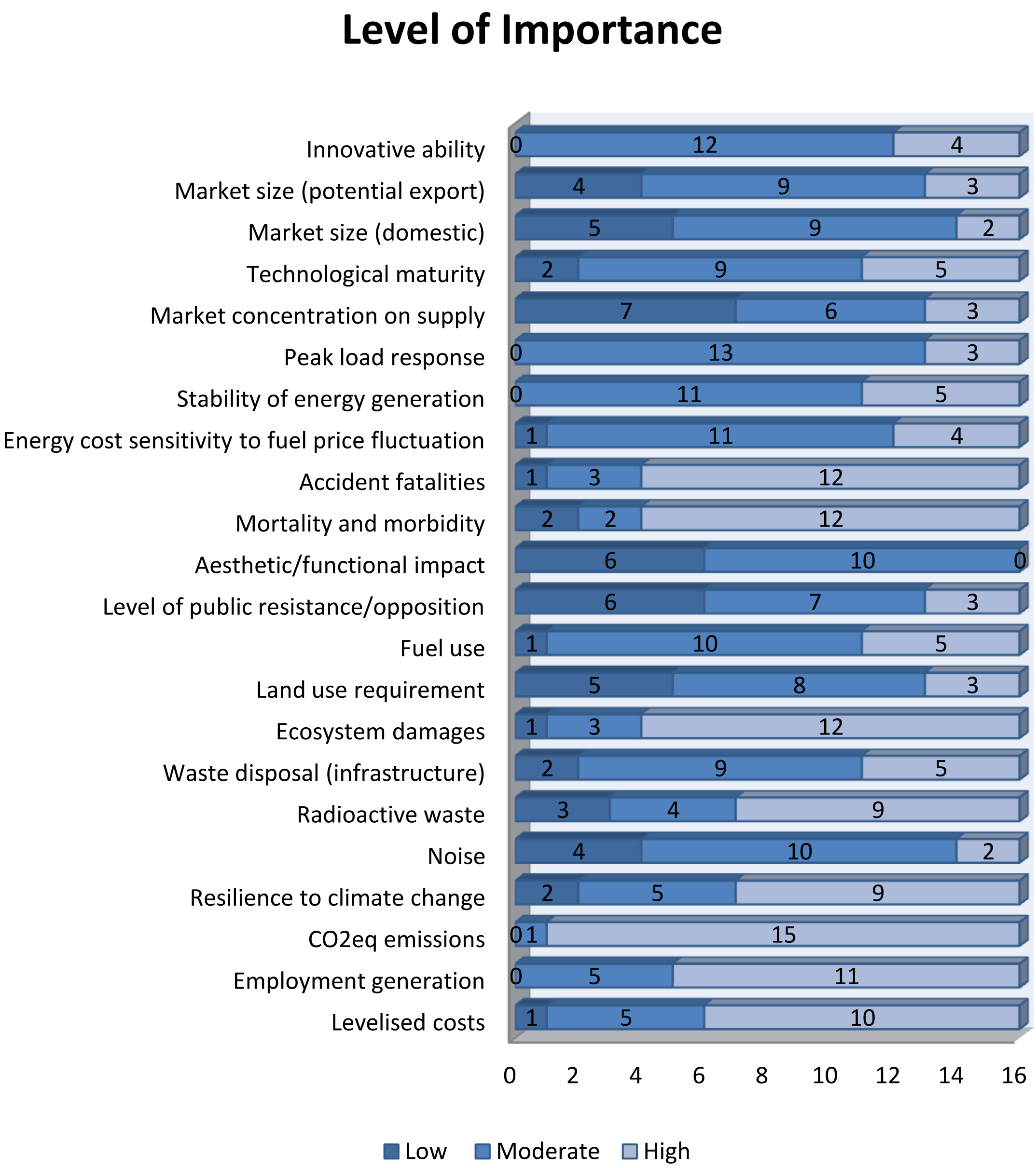


Figure 13. Level of importance of the evaluation criteria and indicators.

Based on frequency count and percentages, the criteria that were considered of high importance by the survey respondents were as follows: CO2eq emissions, ecosystem damages, mortality and morbidity, accident fatalities, employment generation, levelised costs, resilience to climate change, and radioactive waste.

The following were the criteria considered by the survey respondents as of medium-importance: peak load response, innovative ability, energy cost sensitivity to fuel, stability of energy generation, noise, fuel use, aesthetic/functional impact, waste disposal (infrastructure), technological maturity, market size (domestic), market size (potential export) land use requirement, and level of public resistance/opposition.

Lastly, market concentration of supply was considered of low-importance by the survey respondents.

For each level of importance: low, moderate, and high, the respondents ranked the different criteria by assigning numbers (1 as the most important criterion, 2 as the second most important criterion, and so on). The table below shows the results of the initial ranking, including the average ranking positions, of the different criteria.

Table 5. The initial rankings and the corresponding average ranking positions of the different evaluation criteria.

No.	Criteria	Average Ranking Position	Initial Ranking
1	Levelised costs	5.063	2
2	Employment generation	7.375	6
3	CO2eq emissions	3.500	1
4	Resilience to climate change	9.750	9
5	Noise	14.250	16
6	Radioactive waste	9.375	7
7	Waste disposal (infrastructure)	11.063	12
8	Ecosystem damages	5.938	3
9	Land use requirement	14.500	17
10	Fuel use	9.625	8
11	Level of public resistance/opposition	15.125	19
12	Aesthetic/functional impact	17.625	22
13	Mortality and morbidity	7.188	5
14	Accident fatalities	6.750	4
15	Energy cost sensitivity to fuel price fluctuation	10.500	10
16	Stability of energy generation	10.875	11
17	Peak load response	12.688	15
18	Market concentration on supply	15.375	20
19	Technological maturity	12.188	14
20	Market size (domestic)	15.813	21
21	Market size (potential export)	14.688	18
22	Innovative ability	11.125	13

The initial ranking shows that CO2eq emissions is the most preferred criterion with an average ranking position of 3.5. This is followed by levelised costs, ecosystem damages, accident fatalities, mortality and morbidity, employment generation, radioactive waste, fuel use, resilience to climate change, and energy cost sensitivity to fuel price fluctuation.

Rounding off the list are stability of energy generation, innovative ability, waste disposal (infrastructure), technological maturity, peak load response, noise, land use requirement, market size (potential export), level of public resistance/opposition, market concentration on supply, market size (domestic), and lastly, aesthetic/functional impact.

4.2.2. Pair-wise Comparisons Results

The initial ranking provided the base for the consistency check. As such, the results of the initial ranking were compared with the outcomes of the series of pair-wise comparisons.

Among the survey respondents, nine (9) respondents achieved low consistency levels (0.5 or less), four (4) had moderate consistency levels (0.5-0.7), and seven (7) were highly consistent (0.7 or more). Four (4) of those high consistent responses preferred initial ranking, while two (2) preferred the pair-wise comparisons. Two (2) respondents with moderate consistency levels preferred initial ranking, while the remaining two (2) respondents did not provide their preferences. Lastly, four (4) of the respondents with low consistency levels preferred initial ranking, while one (1) indicated no preference.

As there were responses that have achieved low and moderate consistencies as well as expressed preferences for the initial ranking approach, the weights were standardized for these cases. As such, the weighting results for selected responses were modified to reflect preferences for the initial ranking approach. Responses with high consistencies as well as preferences for initial ranking were not altered. So were the results of the rest of the responses.

Figure 14 shows the comparison between the results of the (1) pair-wise comparisons and (1) after the weights of selected responses were standardized based on initial ranking results. The latter, which took into account the standardization of weights, was used in the final analysis as it showed more consistency between the rankings derived from the preferences of the respondents.

It could be observed that in both cases, CO2eq emissions and levelised costs had the highest weights, occupying the first and second spots, respectively. Resilience to climate change, ecosystem damages, mortality and morbidity, accident fatalities, employment generation, fuel use, waste disposal (infrastructure) and radioactive waste were on the top ten lists of both rankings.

Based on the results of the approach wherein weights of selected responses were standardized, CO2eq emissions topped the list with an average weighting score of 0.083. Levelised costs, ecosystem damages, mortality and morbidity, resilience to climate change, radioactive waste, accident fatalities, employment generation, fuel use, and waste disposal (infrastructure) were on the list of top ten preferred criteria.

Next on the list were technological maturity, energy cost sensitivity to fuel price fluctuation, noise, stability of energy generation, innovative ability, peak load response, and land use requirement. The least preferred criteria were level of public resistance/opposition, market size (potential export), aesthetic/functional impact, market concentration on supply, and market size (domestic).

Even at the level of local stakeholders, taking action to mitigate CO2 emissions is on the forefront, which is also supported by the inclusion of the criterion “resilience to climate change” among the most preferred criteria. High preferences for ecosystem damages and waste disposal (infrastructure) show value for the local natural environment and consideration for waste creation and management.

Both economic criteria, namely levelised costs and employment generation, attained high preferences from the local stakeholders. Levelised costs, which include the costs for investment, operation, and maintenance, is understandably a key criterion for local stakeholders. Levelised costs, in essence, is the price in which a renewable energy facility, for example, would need to collect in order to recuperate for all the costs incurred.

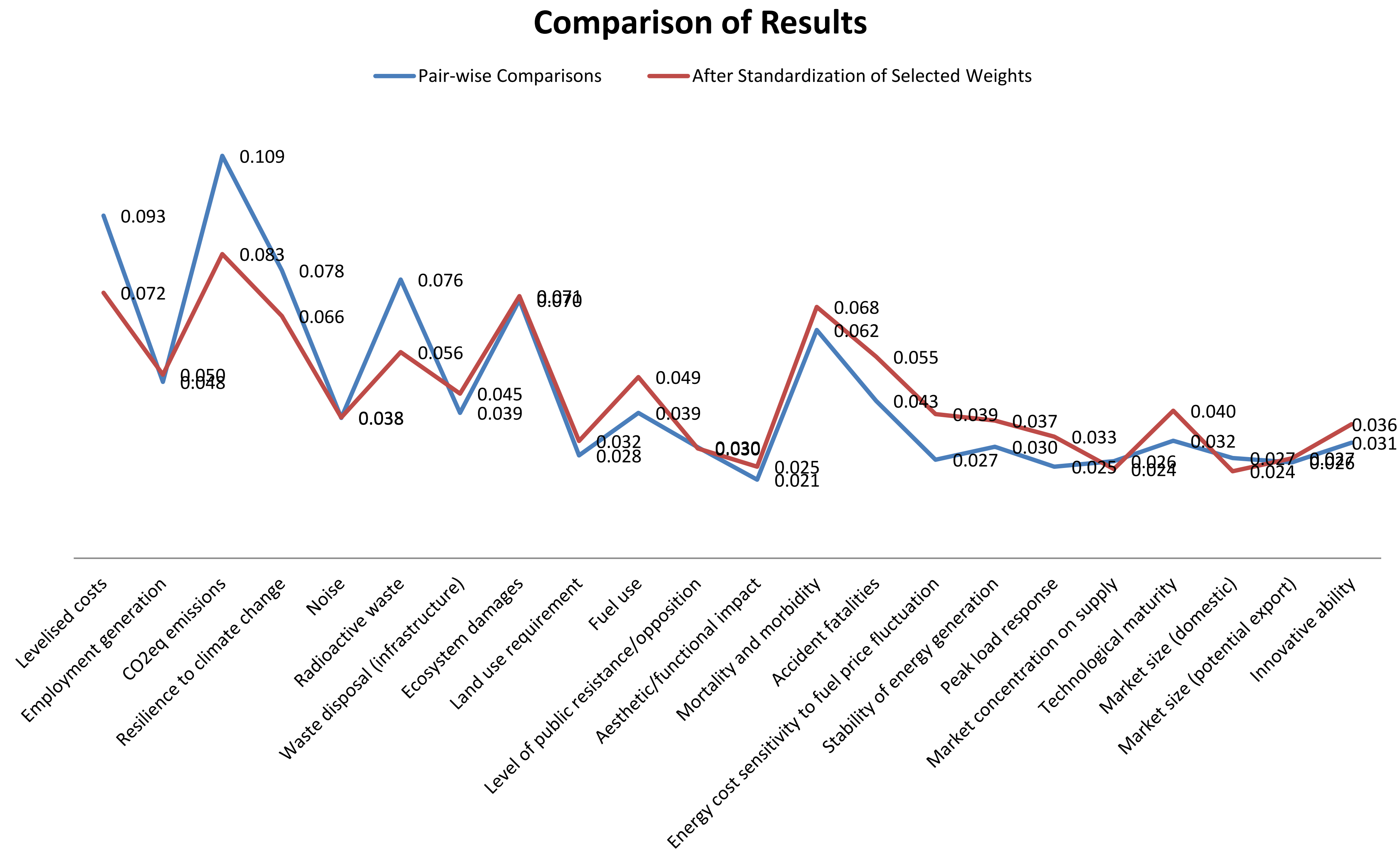


Figure 14. Comparison between the results of the (1) pair-wise comparisons and (2) after the weights of selected responses were standardized based on initial ranking.

The creation of employment opportunities is of public interest, especially if this is within the agenda of decision makers. With the results of this study however, it is important to point out that employment generation achieved relatively lower weights compared to mortality and morbidity as well as accident fatalities, which are two criteria with social dimension. Understandably, human health and safety are prime considerations. Though electricity generation provides invaluable benefits to society, it also carries health costs to citizens. For example, power stations that pollute outdoor air entail health burdens.

Table 6. Results of (1) pair-wise comparisons and (2) after standardization of weights of selected responses with the corresponding rankings of the different evaluation criteria.

		Results of Pair-wise Comparisons		**Results After Standardization of Selected Weights***	
No.	Criteria	Average Weights	Ranking	**Average Weights**	**Ranking**
1	Levelised costs	0.093	2	**0.072**	**2**
2	Employment generation	0.048	7	**0.050**	**8**
3	CO2eq emissions	0.109	1	**0.083**	**1**
4	Resilience to climate change	0.078	3	**0.066**	**5**
5	Noise	0.038	11	**0.038**	**13**
6	Radioactive waste	0.076	4	**0.056**	**6**
7	Waste disposal (infrastructure)	0.039	9	**0.045**	**10**
8	Ecosystem damages	0.070	5	**0.071**	**3**
9	Land use requirement	0.028	16	**0.032**	**17**
10	Fuel use	0.039	10	**0.049**	**9**
11	Level of public resistance/opposition	0.030	15	**0.030**	**18**
12	Aesthetic/functional impact	0.021	22	**0.025**	**20**
13	Mortality and morbidity	0.062	6	**0.068**	**4**
14	Accident fatalities	0.043	8	**0.055**	**7**
15	Energy cost sensitivity to fuel price fluctuation	0.027	18	**0.039**	**12**
16	Stability of energy generation	0.030	14	**0.037**	**14**
17	Peak load response	0.025	21	**0.033**	**16**
18	Market concentration on supply	0.026	19	**0.024**	**21**
19	Technological maturity	0.032	12	**0.040**	**11**
20	Market size (domestic)	0.027	17	**0.024**	**22**
21	Market size (potential export)	0.026	20	**0.027**	**19**
22	Innovative ability	0.031	13	**0.036**	**15**

*The final analysis made use of the results which incorporated the standardization of weights of selected responses based on initial ranking results.

Also, because of public concern, radioactive waste is a significant criterion for energy technologies among local stakeholders. It is but understandable for local stakeholders and society in general, to be concerned about radioactive waste because of the potential – whether likely or unlikely – for catastrophic accidents or terrorist attacks. In the aftermath of the Fukushima Daiichi nuclear disaster in Japan, radioactive waste remains a controversial topic.

Noise and land use requirement, did not generate high preferences compared to the other criteria in the environmental category which could be explained by the existence of noise abatement technologies and distributed generation systems. The latter minimizes the use of land for siting electricity generation facilities. Renewable energy plants in utility-scale, moreover, do not necessitate for the use of additional land for generation processes.

Also, aesthetic/functional impact did not achieve high preference among the local stakeholders. However, debate is inevitable regarding the aesthetics of current infrastructure of low-carbon energy technologies (e.g. wind and solar). There have been cases in which local communities block the construction of wind farms because of aesthetic concerns (Saito, Y., 2004). Mechanisms, however, are available for the deployment of these technologies in unobtrusive ways.

It is important to note though that, the level of public resistance/opposition, another social criterion, was not given much importance by the respondents compared to the other two (2) social criteria which directly relate to the public. However, it is widely accepted that energy projects, or electricity generation facilities in particular, need to be supported by the public sector. It could be a challenge for energy projects though to be recognized as a public good and not as a commercial endeavour.

Low-carbon energy technologies are at different levels of maturity. Certain technologies have acquired proofs of concept and are refined as commercial products. Driven by innovation, there are also technologies that are still in various stages of development, ranging from experimentation in laboratory environments to large-scale market deployment. More mature technologies have high success rates and are consistent in terms of efficiency and reliability.

4.2.4. Local Stakeholder Groups' Preferences

For the purpose of analyzing the preference of local stakeholder groups, the respondents were grouped into three broad categories, namely public authorities (n=5), energy industry actors (n=5), and technical professionals (n=5). There was one respondent from an NGO. However, this stakeholder group was excluded in this analysis. The results of the final ranking were considered in analyzing the local stakeholder groups' preferences.

4.2.4.1. Public Authorities

Public authorities were composed of respondents who came from the government sector – both national and local levels.

The top ten criteria for public authorities were the following: mortality and morbidity, ecosystem damages, accident fatalities, levelised costs, CO2eq emissions, radioactive waste, resilience to climate change, fuel use, waste disposal (infrastructure), and employment generation. The least preferred criteria, on the other hand, were market size (potential export), market size (domestic), aesthetic/functional impact, market concentration on supply, and peak load response.

Table 7. The average weights as well as corresponding ranking of the different criteria among public authorities.

No.	Criteria	Average Weights	Ranking
1	Levelised costs	0.076	4
2	Employment generation	0.060	10
3	CO2eq emissions	0.089	5
4	Resilience to climate change	0.072	7
5	Noise	0.041	15
6	Radioactive waste	0.035	6
7	Waste disposal (infrastructure)	0.038	9
8	Ecosystem damages	0.052	2
9	Land use requirement	0.029	13
10	Fuel use	0.036	8

11	Level of public resistance/opposition	0.040	14
12	Aesthetic/functional impact	0.033	20
13	Mortality and morbidity	0.069	1
14	Accident fatalities	0.040	3
15	Energy cost sensitivity to fuel price fluctuation	0.044	11
16	Stability of energy generation	0.048	17
17	Peak load response	0.038	18
18	Market concentration on supply	0.023	19
19	Technological maturity	0.038	12
20	Market size (domestic)	0.023	21
21	Market size (potential export)	0.030	22
22	Innovative ability	0.046	16

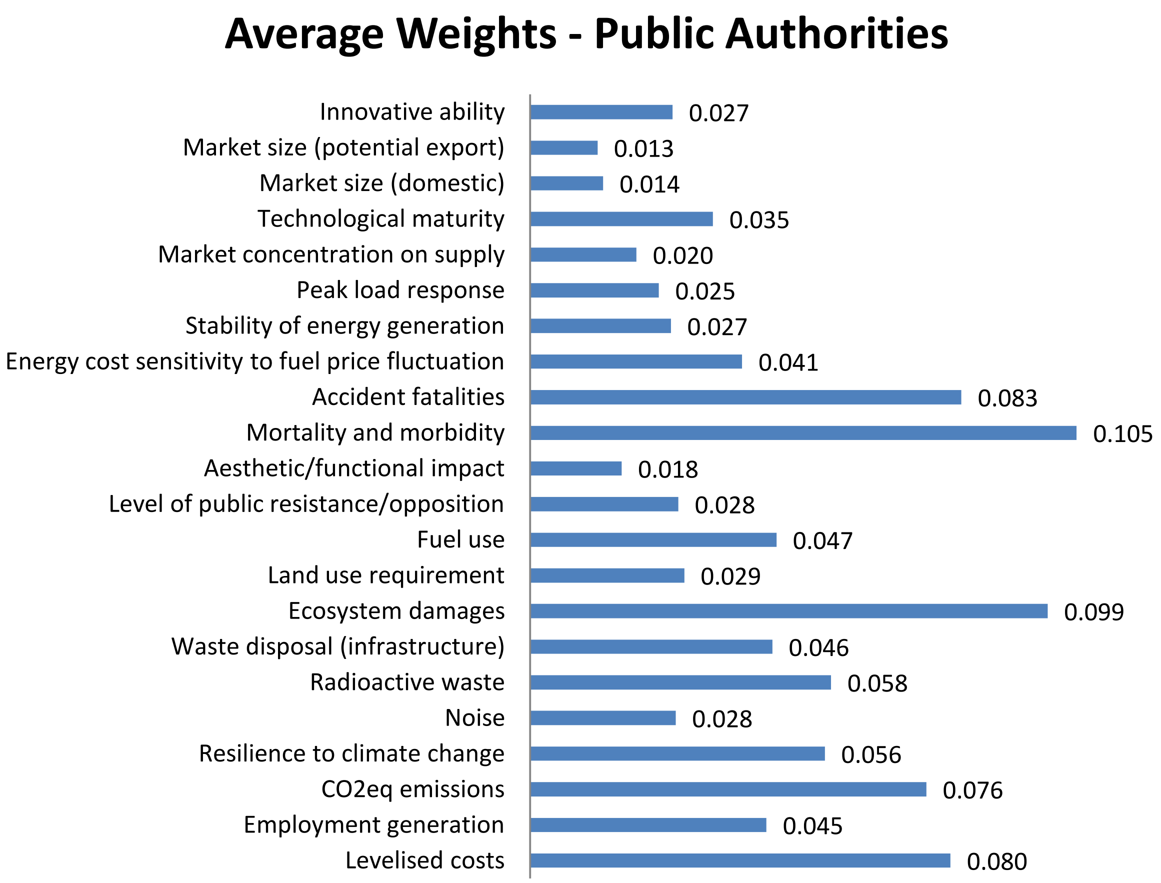


Figure 15.Average weights of the evaluation criteria and indicators based on the preferences of public authorities.

Based on the over-all ranking, it seemed that public authorities prioritize public health protection and safety as proven by this stakeholder group’s high preferences for mortality and morbidity and accident fatalities. Likewise, public authorities have high value judgments for environmental concerns, such as ecosystem damages and CO2eq emissions. Levelised costs is also a priority with the assumption that this criterion figures in their financial or budgetary concerns.

4.2.4.2. Energy Industry Actors

Energy industry actors were represented by respondents from the following stakeholder groups: electricity and energy associations, electricity producers, and energy agencies.

This group of stakeholders expressed high preferences for the following criteria and indicators: CO2eq emissions, levelised costs, resilience to climate change, mortality and morbidity, employment generation, ecosystem damages, stability of energy generation, innovative ability, energy cost sensitivity to fuel price fluctuation, and noise.

The least preferred criteria were market concentration on supply, market size (domestic), land use requirement, market size (potential export), and aesthetic/functional impact.

Table 8. The average weights as well as corresponding ranking of the different criteria among energy industry actors.

No.	Criteria	Average Weights	Ranking
1	Levelised costs	0.08	2
2	Employment generation	0.045	5
3	CO2eq emissions	0.076	1
4	Resilience to climate change	0.056	3
5	Noise	0.028	10
6	Radioactive waste	0.058	17
7	Waste disposal (infrastructure)	0.046	14
8	Ecosystem damages	0.099	6
9	Land use requirement	0.029	20
10	Fuel use	0.047	16
11	Level of public resistance/opposition	0.028	11
12	Aesthetic/functional impact	0.018	18
13	Mortality and morbidity	0.105	4
14	Accident fatalities	0.083	12
15	Energy cost sensitivity to fuel price fluctuation	0.041	9
16	Stability of energy generation	0.027	7
17	Peak load response	0.025	15
18	Market concentration on supply	0.02	22
19	Technological maturity	0.035	13
20	Market size (domestic)	0.014	21
21	Market size (potential export)	0.013	19
22	Innovative ability	0.027	8

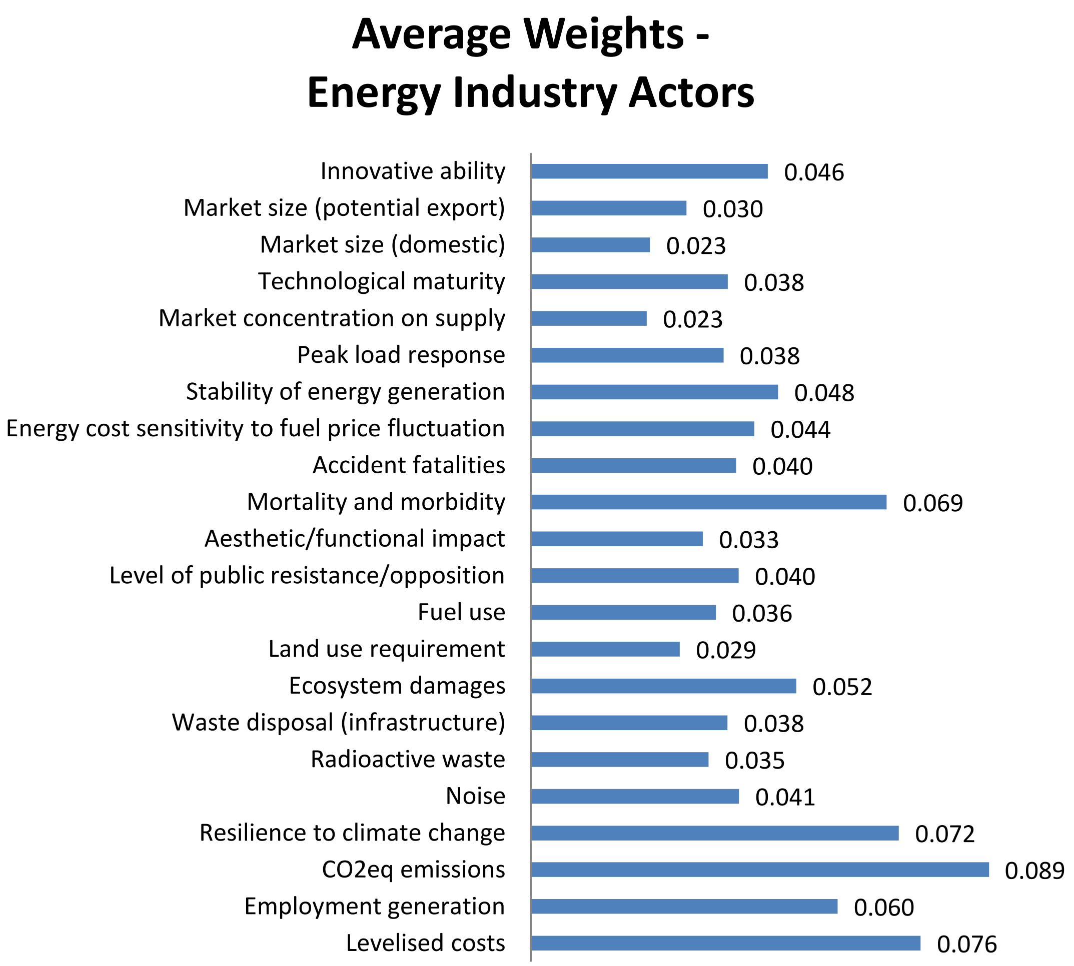


Figure 16. Average weights of the evaluation criteria and indicators based on the preferences energy industry actors.

4.2.4.3. Technical professionals

Technical professionals were respondents who belonged to the following stakeholder groups: consultants – advisors and academic – research.

This group of stakeholders conveyed preferences for CO2eq emissions, fuel use, levelised costs, radioactive waste, ecosystem damages, resilience to climate change, technological maturity, accident fatalities, stability of energy generation, and employment generation. The least preferred criteria were level of public resistance/opposition, aesthetic/functional impact, land use requirement, market concentration on supply, and noise.

Table 9. The average weights as well as corresponding ranking of the different criteria among technical professionals.

No.	Criteria	Average Weights	Ranking
1	Levelised costs	0.068	3
2	Employment generation	0.043	10
3	CO2eq emissions	0.071	1
4	Resilience to climate change	0.054	6
5	Noise	0.037	18
6	Radioactive waste	0.058	4
7	Waste disposal (infrastructure)	0.039	16

8	Ecosystem damages	0.055	5
9	Land use requirement	0.032	20
10	Fuel use	0.069	2
11	Level of public resistance/opposition	0.021	22
12	Aesthetic/functional impact	0.025	21
13	Mortality and morbidity	0.040	15
14	Accident fatalities	0.051	8
15	Energy cost sensitivity to fuel price fluctuation	0.040	14
16	Stability of energy generation	0.043	9
17	Peak load response	0.043	12
18	Market concentration on supply	0.034	19
19	Technological maturity	0.054	7
20	Market size (domestic)	0.038	17
21	Market size (potential export)	0.043	11
22	Innovative ability	0.043	13

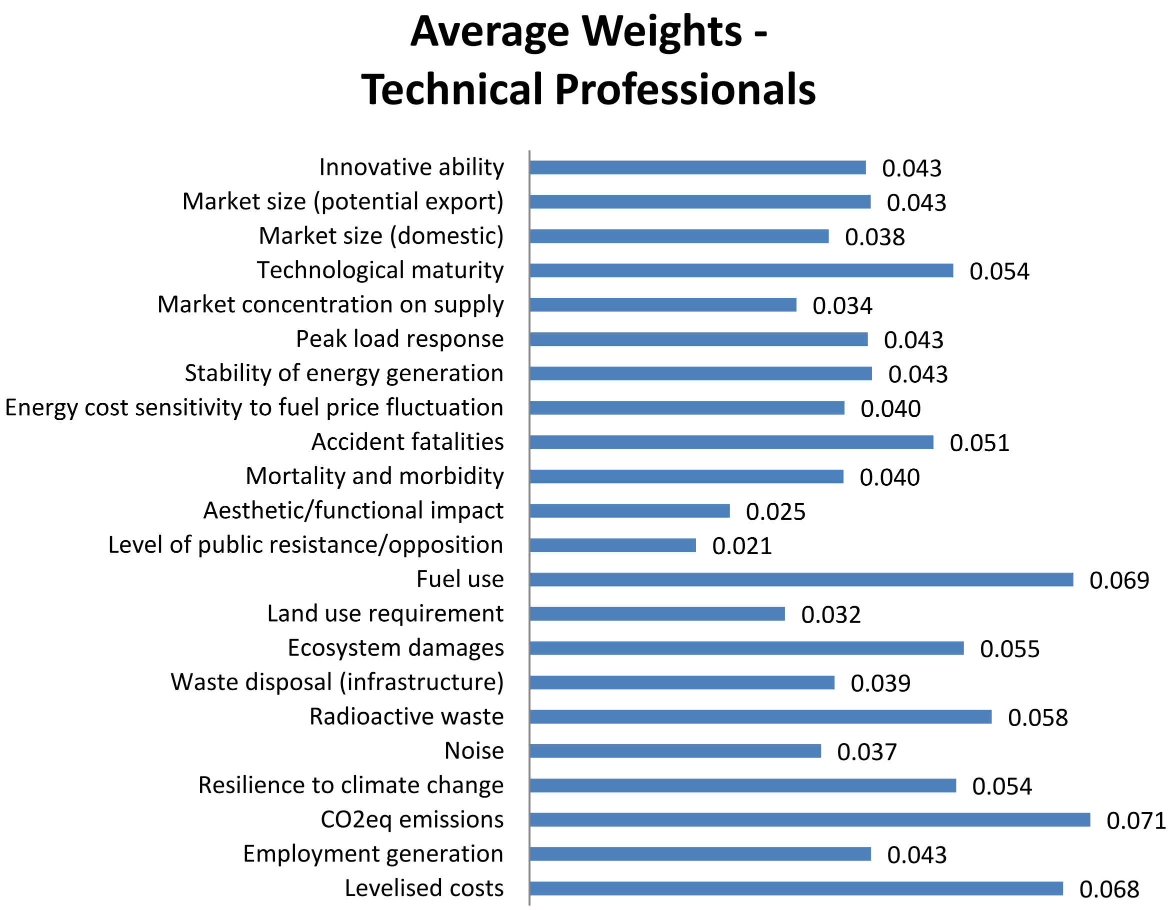


Figure 17. Average weights of the evaluation criteria and indicators based on the preferences of technical professionals.

4.2.4.4. Overall Evaluation

All three groups of local stakeholders expressed high preferences for CO2eq emissions, levelised costs, ecosystem damages, resilience to climate change. CO2eq emissions was the most preferred criterion by both energy industry actors and technical professionals, while this ranked 5th among public authorities.

From the distribution of weighting scores, it could be observed that public authorities gave more importance on ecosystem damages which ranked 2nd in the list. Moreover, public authorities expressed high preferences for social criteria. Mortality and morbidity was considered as the number one criterion, while accident fatalities ranked 3rd.

Energy industry experts also showed high preference for mortality and morbidity. However, this criterion was not given much importance by technical professionals. Accident fatalities, however, was ranked 8th among technical professionals and 12th among energy industry actors.

Meanwhile, technical professionals had expressed high preferences for fuel use which ranked 2nd among this stakeholder group. It could also be observed that compared to public authorities and energy industry experts, technical professionals expressed more preference for certain energy and technological criteria. Technological maturity and market size - both domestic and potential export, for example, received more weights from technical professionals compared to what the other stakeholder group have provided.

It could also be observed that public authorities, compared to the weights provided by energy industry experts and technical professionals, provided relatively low weights to certain energy and technological criteria, such as market size - domestic and potential export, stability of energy generation and peak load response.

Also, although energy public professionals and technical professionals provided the same weights to radioactive waste, energy industry experts gave a relatively lower weight to this criterion. Technical professionals also provided relatively lower weights to social criteria, such as mortality and morbidity and accident fatalities, compared to the other two stakeholder groups. Interestingly, energy and industry actors gave relatively higher weights to level of public resistance/opposition and aesthetic/functional impact compared to the other groups.

Figure 18 shows the convergence and divergence of preferences among the three different local stakeholder groups.

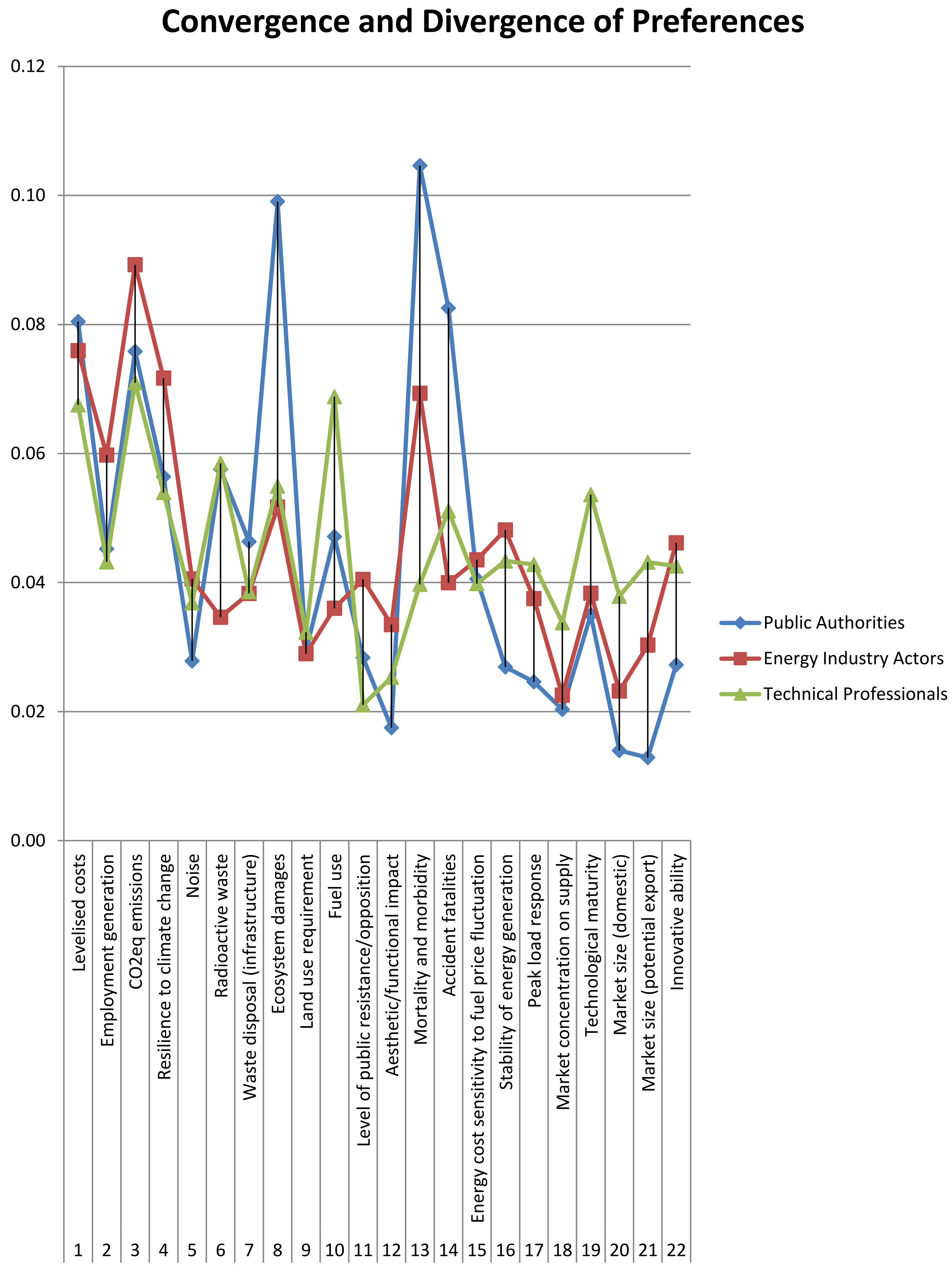


Figure 18. Distribution of weights for all criteria among stakeholder groups.

4.3. Evaluation of Low-Carbon Energy Technologies

Through the assessment of low-carbon energy technologies based on the weights derived from local stakeholders' preferences of the evaluation criteria and indicators, it was found that the highest ranked low-carbon energy technology is wind off-shore (0.79), followed by solar PVs (0.78), hydropower (0.74), wind on-shore (0.73), GTCC (0.58), GTCC with CCS (0.57), EPR (0.57), biomass (0.56), IGCC with CCS (0.53) and IGCC (0.45). Figure 19 shows the final scores of each low-carbon energy technology, including the contribution of each evaluation criteria.

The low-carbon energy technologies were also assessed based on equal weights. Figure 20 shows the final scores as well as contribution of each criterion for the technologies based on equal weights. The assessment shows that wind off-shore is still the highest ranked low-carbon energy technology with a score of 0.78. Wind off-shore is followed by solar PVs (0.77), wind on-shore (0.69), hydropower (0.67), GTCC (0.59), GTCC with CCS (0.54), biomass (0.53), IGCC with CCS (0.50), EPR (0.50), and IGCC (0.46).

Comparing the two set of assessments, it could be concluded that wind off-shore is the highest ranked low-carbon energy technology. Solar PVs, hydropower, wind on-shore, and GTCC are the top five technologies in both assessments. There was an inter-change in the ranking between wind on-shore and hydropower; also, the rankings for both criteria were relatively reduced based on equal weights.

IGCC remain as the lowest ranked low-carbon energy technology in both assessments. EPR, should equal weights be solely considered, would precede IGCC. However, should the preferences of local stakeholders will be considered, EPR would rank 7^{th} in the list, above biomass and IGCC with CCS. Figure 20 shows the final scores of each low-carbon energy technology based on equal weights.

It could also be observed that renewable energy technologies (e.g. solar, wind, and hydropower) outrank other groups of technologies, such as fossil-fuel based ones (e.g. IGCC, GTCC) and nuclear technology.

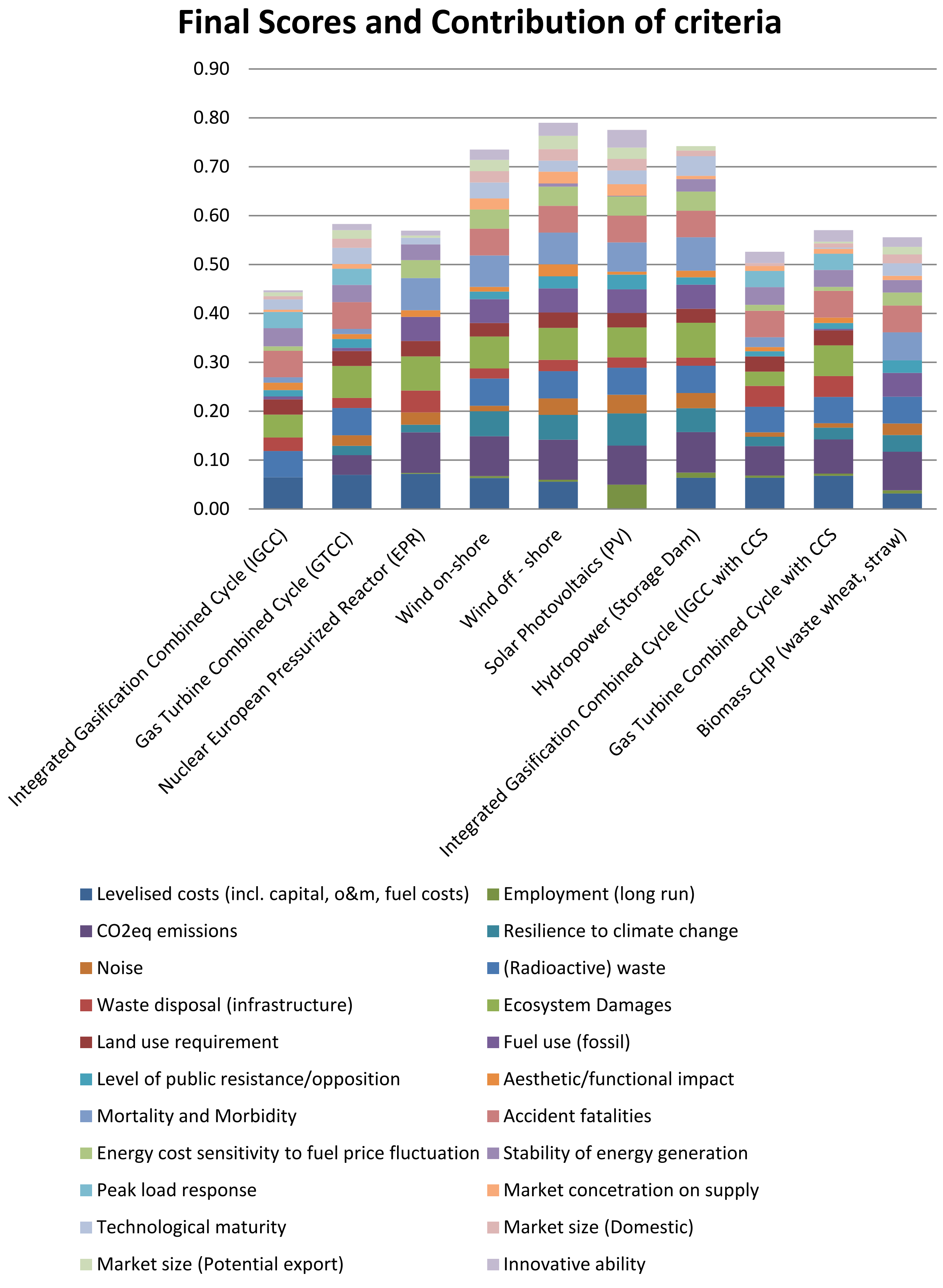


Figure 19.The final scores of the low-carbon energy technologies and the contribution of all criteria based on local stakeholders' perspectives.

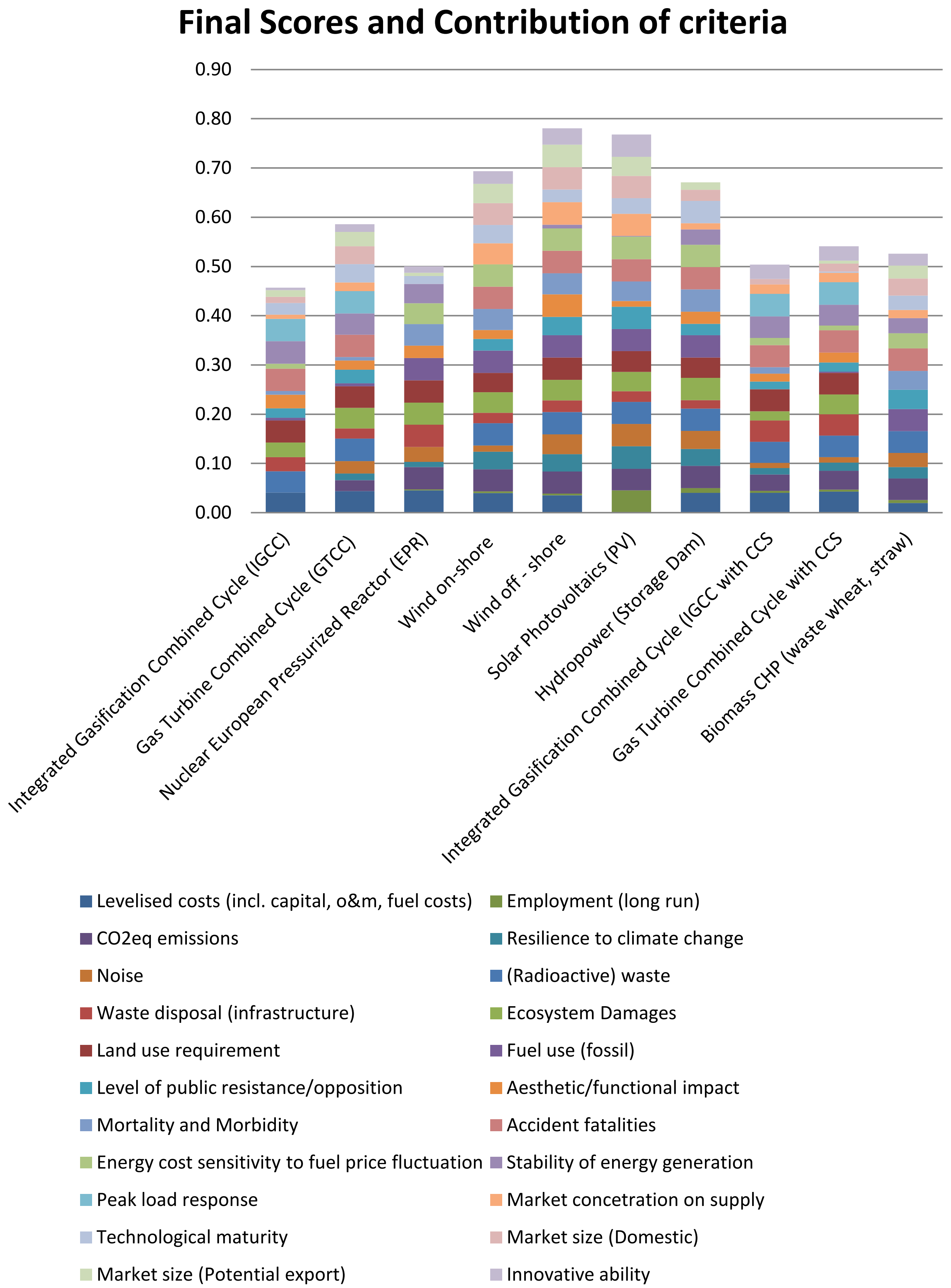


Figure 20.The final scores of the low-carbon energy technologies and the contribution of all criteria based on equal weights.

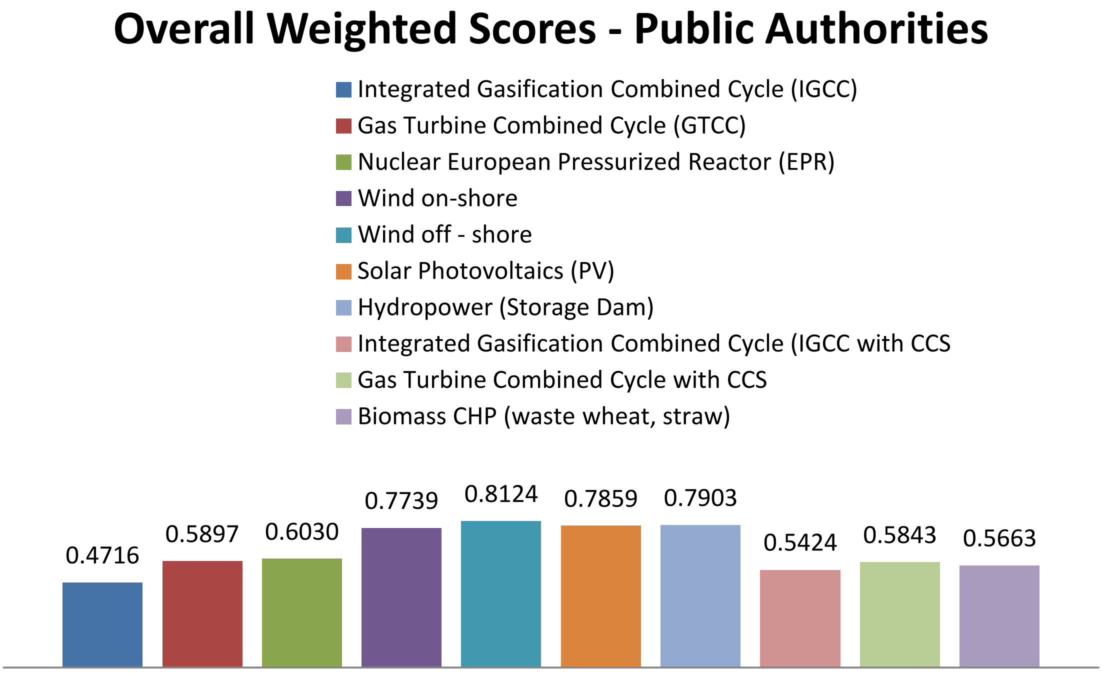


Figure 21. The scores of public authorities for the low-carbon energy technologies.

For public authorities, wind-off shore is the highest ranked low-carbon energy technology, followed by hydropower, solar photovoltaics, wind on-shore, EPR, GTCC, GTCC with CCS, biomass, IGCC with CCS, and IGCC. Wind off-shore received the highest scores with 0.8124, followed closely by hydropower with 0.7903. IGCC received the lowest scores with 0.4716, while IGCC with CCS got 0.5424.

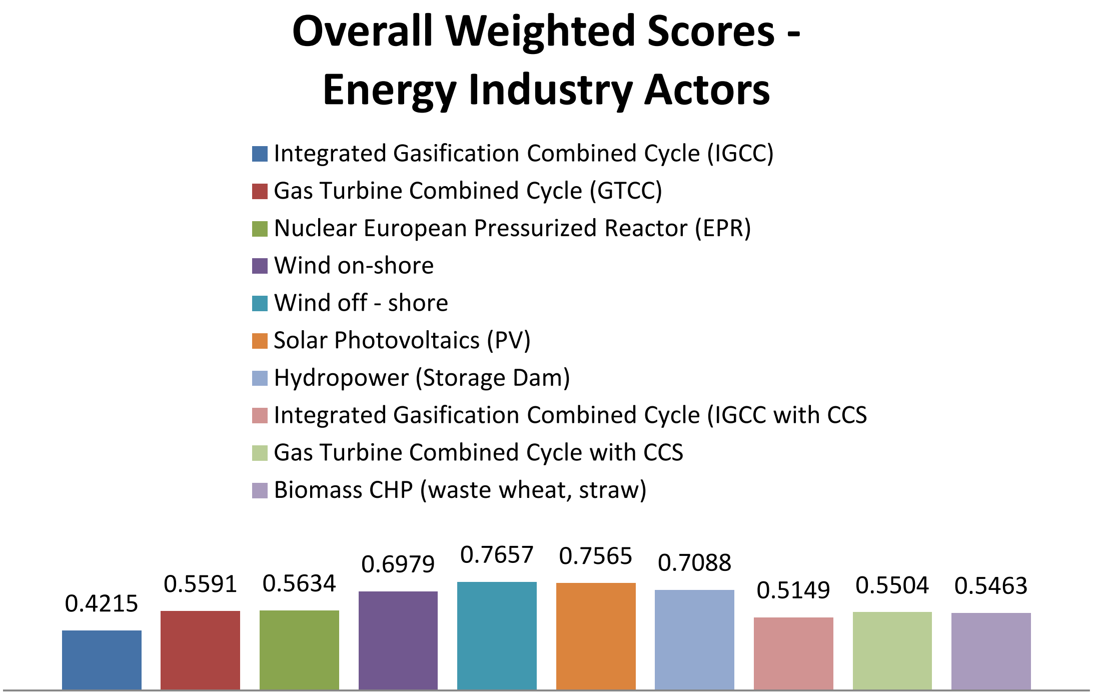


Figure 22. The scores of energy industry actors for the low-carbon energy technologies.

Wind off-shore is also the highest ranked low-carbon energy technology among energy industry actors. Wind off-shore received a score of 0.7657, followed closely by solar PV with 0.7565. Hydropower, wind on-shore, EPR, GTCC, GTCC with CCS, biomass, IGCC with CCS, and IGCC rounded off the list.

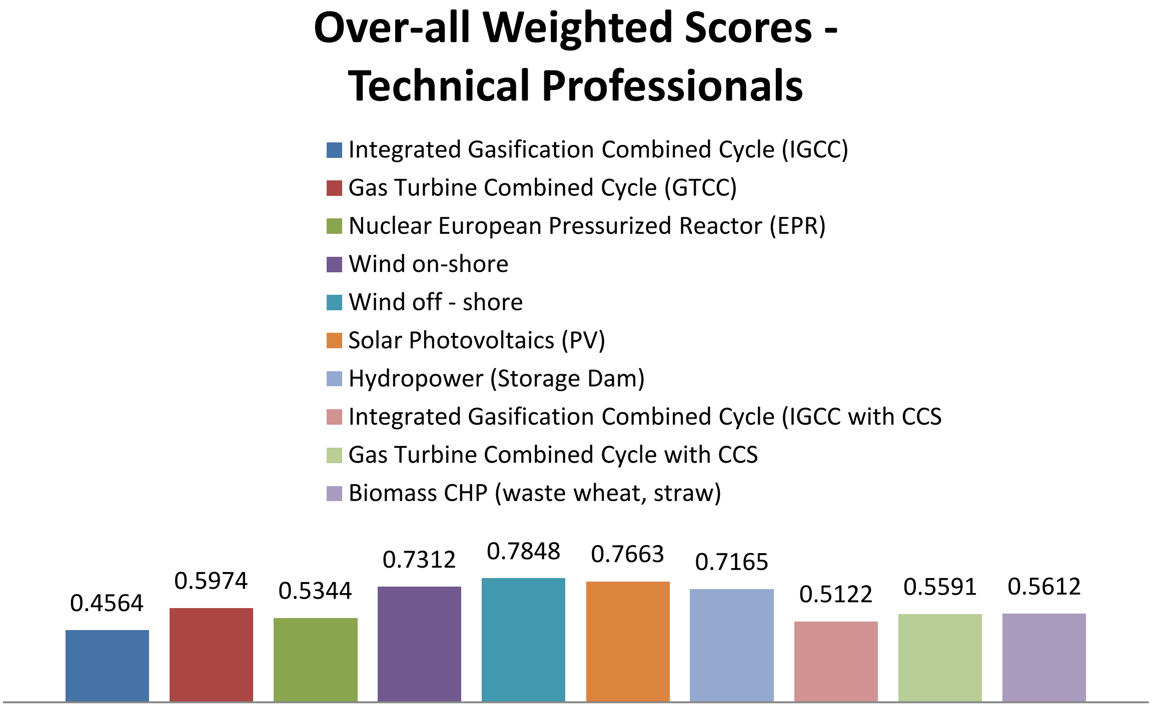


Figure 23. The scores of technical professionals for the low-carbon energy technologies.

The assessment results in Figure 14 show that among technical professionals, the highest ranked low-carbon energy technology is also wind off-shore with a score of 0.7848. This is followed by solar PV, wind on-shore, hydropower, GTCC, biomass, GTCC with CCS, EPR, IGCC with CCS, and IGCC.

Table 10.Ranking of the low-carbon energy technologies, including the distribution of scores, among the different local stakeholder groups.

Technology	Rank	Public Authorities	Rank	Energy Industry Actors	Rank	Technical Professionals
IGCC	10	0.4716	10	0.4215	10	0.4564
GTCC	6	0.5897	6	0.5591	5	0.5974
EPR	**5**	**0.6030**	**5**	**0.5634**	**8**	**0.5344**
Wind on-shore	4	0.7739	4	0.6979	3	0.7312
Wind off-shore	1	0.8124	1	0.7657	1	0.7848
Solar PV	3	0.7859	2	0.7565	2	0.7663
Hydropower	**2**	**0.7903**	**3**	**0.7088**	**4**	**0.7165**
IGCC with CCS	9	0.5424	9	0.5149	9	0.5122
GTCC with CCS	7	0.5843	7	0.5504	7	0.5591
Biomass	**8**	**0.5663**	**8**	**0.5463**	**6**	**0.5612**

It could be observed that among the three stakeholder groups, wind off-shore is the highest ranked low-carbon energy technology. Wind off-shore and wind on-shore are the two primary market sectors under wind energy. Differences between the two rest on working environment, difficulty of installation, and facility of access for installation and maintenance. However, wind off-shore generates higher electricity production, while wind on-shore necessitates for further technological improvements (European Commission, 2011b).

Solar PV is the 2^{nd} ranked technology for energy industry actors and technical professionals, while public authorities favoured hydropower. Solar PV is the 3^{rd} ranked technology among public authorities, while energy industry actors favoured hydropower. Meanwhile, wind on-shore is the 3^{rd} ranked technology among technical professionals, while public authorities and energy industry actors ranked it 4^{th}.

EPR is the 5^{th} ranked technology among public authorities and energy industry actors. This is followed by GTCC, GTCC with CCS, biomass, IGCC with CCS and IGCC for both stakeholder groups. Among technical professionals, hydropower is the 4^{th} ranked technology, followed by GTCC, biomass, GTCC with CCS, EPR, IGCC with CCS, and IGCC. Technical professionals, compared with the two other stakeholder groups, have low preferences for EPR based on its ranking.

IGCC with CCS and IGCC were the least significant low-carbon energy technologies among all three stakeholder groups.

Again, it could be observed from the rankings among the three local stakeholder groups that renewable energy technologies outrank other groups, such as fossil-fuel based ones (e.g. IGCC and GTCC) and nuclear technology (EPR).

4.4. Results of Weighting Survey Evaluation

Forty-four (44%) of the survey respondents had moderate satisfaction with regards to the ease in filling out the questionnaire. Thirty-three percent (33%) had high satisfaction, while 11%t deemed to have low satisfaction. Eleven percent (11%) of the respondents failed to provide their answers.

Thirty-nine percent (39%) of the respondents had moderate as well as high satisfaction with regards to the provision of the background information. Eleven percent (11%) had low satisfaction, while 11% did not answer.

As for the correspondence between the obtained weights and your actual preferences, 39% expressed moderate satisfaction; 22% conveyed low satisfaction; 11% said high satisfaction, while 28% did not provide their answers.

As for the speed of introducing and processing the required information, 39% expressed moderate satisfaction; 22% conveyed high satisfaction; 11% had low satisfaction, while 28% did not provide their responses.

The respondents took between 10 minutes (minimum) to 2 hours (maximum) to complete the survey tool. The respondents took an hour (mode) to finish answering the questionnaires.

Half (50%) of the survey respondents expressed that they did not have difficulty answering the weighting survey tool. Twenty-two percent (22%) said that they had difficulty with the survey method, while 28% did not provide their answers.

According to the respondents who had difficulty with the weighting survey tool, they had issues regarding the pairs of criteria for comparison, the correlation between the pair-wise comparison and the allocated score, and the provision of more detailed instructions as well as background information e.g. definition of each evaluation criteria and indicator.

As for the additional comments and suggestions, one respondent suggested that “when establishing evaluation criteria and indicators it would be necessary to start by defining the objectives to be accomplished case by case, an [sic] universal ranking would not be often applicable (land use requirement has a different weight if evaluating a technology for India than for Russia, peak load response will have a different value in the US than in a developing country deeded of base-load)".

Chapter 5: Conclusions and Recommendations

In this chapter, conclusions were drawn from the research findings and the methodological process.

5.1 Research Findings

5.1.1. Selection of Indicator Set

Majority of the respondents agreed with the retention of the pre-selected list of evaluation criteria and indicators that was based on literature review. As such, it could be concluded that the selected indicator set used for this study applied to the intended goal of evaluating low-carbon energy technologies. Moreover, the indicator set fulfilled basic requirements, such as relevance, comprehensiveness, and non-redundancy.

5.1.2. Preferences of Local Stakeholders

Local stakeholders, in general, expressed high preferences for CO2eq emissions, levelised costs, ecosystem damages, employment generation, resilience to climate change, fuel use, and waste disposal (infrastructure) which show implied responsibility towards local benefits and negative externalities.

Mortality and morbidity, accident fatalities as well as radioactive waste also achieved high preferences from the respondents which show how local stakeholders value the welfare of the public, including workers, during project installation and operation. The potential impacts of low-carbon energy technologies on human health and safety are considered a priority.

This research study also concludes that local stakeholders, as a whole, have relatively high preferences for economic, environmental and social criteria than energy or technological criteria. Among local stakeholders, low-carbon energy technologies have to fulfil certain economic, environmental, and social requirements that directly or indirectly impact the communities in the short-term and/or for the long haul.

Public authorities prioritize public health protection and safety as proven by their high preferences for mortality and morbidity and accident fatalities. Public authorities also give significant priority to ecosystem damages, CO2eq emissions as well as levelised costs which reflect their concern for local environmental protection as well as economic outlays.

Although sharing similar preferences with public authorities and energy industry experts, technical professionals have a unique high preference for fuel use. This research study also concludes that technical professionals, when compared to the weights provided by other stakeholder groups, have higher preferences for certain energy and technological criteria.

On the other hand, public authorities provide least priority to certain energy and technological criteria, while technical professionals have provided least preferences for social criteria.

As for the policy implications of this research study, it can be concluded that based on the overall preferences of stakeholders, there could be focus on policies or measures enabling or facilitating technologies that reflect the most preferred evaluation criteria and indicators, such as CO2 emissions, levelised costs, ecosystem damages, and employment generation.

Moreover, key differences with regards to local stakeholder preferences could be highlighted during local energy planning and decision making. Within the decision making context, relevant stakeholders and decision makers would have informed opinions about the value judgments of local stakeholders which need to be taken into account in the process. Also, knowledge about these key differences could be a topic for knowledge sharing, awareness raising and information dissemination, among other strategies.

As this research study enabled the mapping – albeit limited - of local stakeholder' preference, it is recommended that future studies should focus on a wider scale and on in-depth analysis. This research study mapped only three broad categories, namely public authorities, energy industry actors, and technical professionals. It would be substantive to map the preferences of distinct local stakeholder groups that apply within the urban energy context.

5.1.3. Ranking of Low-Carbon Energy Technologies

This research concludes that wind off-shore, solar PV, hydropower, wind-onshore, and GTCC are the low-carbon energy technologies that best reflect the preferences of local stakeholders based on their priorities for evaluation criteria and indicators. On the other hand, IGCC with CCS and IGCC were the least significant low-carbon energy technologies among all three stakeholder groups.

The highest ranked low-carbon energy technologies based on the preferences of local stakeholders were also comparable to the results of the assessment which considered equal weights. IGCC remains as the lowest ranked technology in both assessments. One key difference lies in the ranking of EPR. Based on equal weights, EPR would have a relatively low ranking compared with the results that considered local stakeholders' preferences.

While the results for public authorities and energy industry actors show preference for EPR, which has achieved relatively high rankings for both stakeholder groups, technical professional do not hold the same preference. On the other hand, technical professionals have relatively higher preferences for biomass compared to the weighting results achieved by the other stakeholder groups.

The five highest ranked low-carbon energy technologies, with the exception of GTCC, are technologically mature. Low-carbon energy technologies have their corresponding advantages and disadvantages. Certain technologies are technologically mature and have undergone market implementation, among other attributes, while there are others that are still being developed and demonstrated.

It could also be concluded that renewable energy technologies outrank the other groups of technologies e.g. fossil-fuel based ones and nuclear technology based on the over-all assessment as well as on the ranking for each local stakeholder group.

Technologies, such as solar PVs, wind, and hydropower, have progressed in terms of efficiency and reliability. Moreover, among the low-carbon energy technologies, wind onshore and hydropower are considered the least costly for emission reduction in the power sector. However, it is acknowledged that once these technologies are fully exploited, CCS, for example, which has not yet reached full maturity, would become very competitive.

Local stakeholders usually express their views about low-carbon energy technologies especially when it directly or indirectly impacts their own territories. However, through this methodology, local stakeholders explicitly expressed what their preferences are in an integrated manner. The process allowed for the identification of the best or the most preferred technologies based on local stakeholders' preferences.

This research study concludes that there is no one-size-fits-all-option when it comes to low-carbon energy technologies. The relative importance of the different evaluation criteria and indicators as conveyed by the weights provided by the survey respondents show differences in the over-all rankings among the local stakeholder groups identified. Lastly, this study begs the question: “Given the preferences of local stakeholders, what are the chances of objective-based results in the development of low-carbon energy technologies?”.

5.2. Discussions

The integrated weighting methodology used for this study allowed the respondents to provide their subjective judgments about the evaluation criteria and indicators under investigation. Through the initial ranking, the respondents were able to rank the criteria in a holistic manner, while the pair-wise comparisons enabled them to provide their preferences verbally, numerically, and graphically.

The methodology for this research study displayed how objective and subjective data can be integrated. Scores of performance were assigned to each of the low-carbon energy technology when assessed against the different evaluation criteria and indicators, while the survey respondents provided their subjective preferences through the weighting elicitation process via the two approaches, namely initial ranking and pair-wise comparisons.

It is important to note, however, that more than half (56%) of the respondents achieved low consistencies between their initial and final rankings. As the initial rankings provided the base for the consistency check, the results of the pair-wise comparisons could be unreliable. Borcherding, et al. (1991) in Grafakos, et al (2010) conveyed that the difference in consistency between weighting methods could be related to the large number of criteria for comparison.

This research study involved 22 pairs of criteria for comparison which could have entailed cognitive burden to the respondents. Hence, with the number of pairs for comparison, consistencies inevitably arose. The respondents were asked to modify their preferences should their weighting scores did not reach the consistency threshold value. However, having to repeat the pair-wise comparisons could have been a challenge.

Also, in this study, majority (67%) of the respondents thought that the initial rankings reflected their preferences more accurately rather than the results of the pair-wise comparisons. It could be observed that due to the cognitive demands as well as time constraints, the respondents were more comfortable with assigning numbers directly to a list of criteria than selecting a criterion for each pair-wise comparison.

In Grafakos, et al (2010), a sample of individual stakeholders and experts in the climate and energy field has expressed satisfaction as well as approval for both approaches in evaluating energy and climate policy interactions. The study showed that the initial ranking has facilitated a gradual approach to the evaluation problem. The pair-wise comparison, on the other hand, enabled a more accurate expression of the respondents’ preferences.

5.3. Limitations and Further Research

However, like Grafakos, et al. (2010), this research study merited a small number of respondents. This research study had to contend with low response rate for the weight elicitation process. As such, there could be a need for further application of this integrated weighting methodology with the involvement of a large number of respondents. Future respondents could also be stratified based on certain local stakeholders groups for comparison purposes.

It is important to point out that as this study aimed for a large number of respondents associated with local stakeholder groups, ranging from government to academe, there could have been differences in compatibility between the evaluation criteria and indicators and their expert knowledge, level of expertise, or analytical skills. At least one individual stakeholder begged out of the survey as the task at hand was out of the respondent's technical capacity.

Moreover, there could be further development in terms of maximizing the ease in filling out the questionnaire, the provision of background information, the correspondence between obtained weights and actual preferences, and the speed of introducing and processing the required information. Although half of the respondents stated that they did not have difficulty with the survey tool, it is important to maximize its manageability and performance.

Also, an introduction of the integrated weighting methodology in a different format could be convenient. For example, there could be the possibility of utilizing a web-based application rather than a computer-based (spreadsheet format) one for the survey tool. A web-based survey tool could maximize interactivity for the benefit of the respondents.

The integrated weighting methodology for this study could also be applied in a group decision context wherein local stakeholders and decision makers meet face-to-face e.g. workshop, consultation meetings. Furthermore, this integrated weighting methodology could be carried out through an online context e.g. webinar.

Moreover, different weighting methods could be tested to observe and compare any differences and similarities in the results. Through this approach, the reliability of the results could be guaranteed.

Lastly, in situations wherein decision makers have to discuss the development of low-carbon energy technologies, this methodology could be applied to evoke a democratic process in which value judgments are solicited transparently. Also, through this method, local stakeholders preferences are mapped out which is crucial in the identification of potential conflicts and resolution of actual ones.

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Annexes

Annex 1. Prerequisites of MCA Techniques for RES planning (Polatidis, et al., 2006, p. 185)

Prerequisites	Justification
Weights elicitation	To provide preference information between the evaluation criteria
Critical threshold values, veto	To operationalize the assimilative capacity of the environmental, economic, resource and social base
Comparability	To perform an integrated comparison between the different actions
Qualitative and quantitative information	To handle the mixed information usually present in problems of RES decision-making
Rigidity	To give robust results
Group decision-making	To include a diverse audience of stakeholders
Graphical representation	To render the outcome understandable
Ease of use	To familiarize the Decision Makers (DMs) with the decision-making process
Sensitivity analysis	To enhance the transparency of the procedure
Variety of alternatives	To incorporate all possible courses of action
Large number of evaluation criteria	To embrace all different aspects
Consensus seeking procedures	To reach up a global compromise
Incorporation of intangible aspects	To be capable of taking into account “hidden” dimensions of the problem
Incommensurability	To keep the decision criteria in their original units and provide a better decomposition of the issue
Treatment of uncertainty	To explicitly treat the imperfect data (uncertain, imprecise, missing, erroneous, etc.)
Partial compensation	To operationalize a strong sustainability conception
Hierarchy of scale	To decrease the ambiguities and provide for explicit consistency
Concrete meaning for parameters used	To improve the reliability of the process
Learning dimension	To acknowledge and accept new information revealed during the evolution of the procedure
Temporal aspects	To consider the emergency of the situation and clarify long-and short-term concerns

Annex 2. Comparison of multi-criteria techniques in the context of renewable energy problems (Polatidis, et al., 2006, p. 191).

Attributes	Modelling decision makers' preferences Weight as trade-offs Weights as importance coefficients	Strong-weak sustainability concept Compensability	Theoretical and technical features Input capabilities Interaction with the method Hierarchy consideration	Uncertainty treatment Probability distributions Fuzzy sets Thresholds	Practical requirements Ease of use Number of parameters to be estimated Interpretation of parameters Support a large number of decision makers Support a large number of alternatives, criteria Time and resources needed
MCDA Techniques					
MAUT	---	---	++	+	++
ELECTRE I	+++	+	+	--	++
ELECTRE II	+	++	+	+	+
ELECTRE III	+	++	+	++	++
ELECTRE IV	-	++	+	+	+++
ELECTRE TRI	+	++	+	+	++
PROMETHEE I	+	+	+	++	++
PROMETHEE II	+	+	+	+	+++
Regime Method	+	+	+	++	++
AHP	---	-	++	+	+
NAIADE	-	+	+	+++	++
Flag Model	-	++	+	+	+++
SMAA	-	-	++	+	++
SMART	---	-	+	+	++
LEXICOGRAPHIC	-	--	++	-	+++

The scale "+++/---"is ordinal in nature (+++ is more desirable than +; --- is less desirable than -).

Annex 3. Fundamental requirements for indicators (Burgherr, P. and Paul Scherrer Institut, 2005, p. 10)

Fundamental Requirements		
Scientific	Measurable and quantifiable	Adequately reflect the phenomenon intended to measure
	Meaningful	Appropriate to the needs of the user
	Clear in value	Distinct indication which direction is good and which is bad
	Clear in content	Measured in understandable units that make sense
	Appropriate in scale	Not over or under aggregated
	No redundancy or double counting	Indicators are not overlapping in what they measure
	Robust and reproducible	Indicator measurement is methodologically sound, fits the intended purpose and is repeatable
	Sensitive and specific	Indicators must be sensitive to changes in the system under study, and ideally respond relatively quickly and noticeably
	Verifiable	It is possible to verify an indicator by external persons or groups
	Hierarchical	To allow a user to understand the level of detail necessary
Functional	Relevant	For all stakeholders involved
	Compelling	Interesting, exciting and suggestive of effective action
	Leading	So that they can provide information to act on
	Possible to influence	Indicators must measure parameters that are possible to change
	Comparable	If the same indicators are used in several systems, they should be comparable
	Comprehensive	The indicator set should sufficiently describe all essential aspects of the system under study
Pragmatic	Manageable	Not too many to handle; also important in view of interactions with users and stakeholders
	Understandable	Possible to understand by stakeholders
	Feasible	Measurable at reasonable effort and cost
	Timely	Compilable without long delays
	Coverage of the different aspects of sustainability	Indicators address economic, environmental and social dimensions
	Allowing international comparison	To the extent necessary, i.e. in according with specific study objectives

Annex 4. The assessment criteria of renewable energy sources (Y.-C. Shen, et al, 2010, pp. 4608)

Policy Goal	Criteria	Description	Sources
Energy Goal	Energy price stability	The price of final product generated from renewable energy sources is not easily fluctuated.	Mamlook et al.(2001), Komor and Bazilian(2005), Liposcak et al. (2006), Begic and Afgan(2007), Bureau of Energy of Ministry of Economic Affairs(2007), Wang etal.(2009a,2009b), Jovanovic´ et al. (2009)
	Security for energy supply	The consistent availability of sufficient dependent on secure supplies of energy	Komor and Bazilian (2005), Burton and Hubacek (2007), Lund (2007), Cai et al. (2009a, 2009b)
	Low energy prices	The price of final product generated from renewable energy sources is acceptable	Komor and Bazilian(2005), Shaw andPeteves(2008)
	Stability for energy generation	The output generated by renewable energy sources is not easily fluctuated	Gross (2004), Taljan and Gubina(2009), Georgilakis and Katsigiannis (2009)
Environmental Goal	Carbon emissions reduction	The extents to which renewable energy sources diminish the emission of CO2.	Diakoulaki and Karangelis(2007), Burton and Hubacek(2007), Chatzimouratidis and Pilavachi(2007), Chatzimouratidis and Pilavachi (2008a), Chatzimouratidis and Pilavachi(2008b), Wang et al.(2008), Wang et al.(2009a,2009b), Jovanovic´ et al.(2009), Løken et al.(2009), Beccali et al.(2003), Komor and Bazilian(2005)
	SOx and NOx emissions redictions	The extents to which renewable energy sources diminish the emission of SOx and NOx	Diakoulaki and Karangelis(2007), Begic andAfgan(2007), Chatzimouratidis and Pilavachi(2007), Chatzimouratidis and Pilavachi (2008a), Chatzimouratidis and Pilavachi(2008b), Jovanovic´ et al. (2009), Komor and Bazilian(2005)
	Environmental sustainability	The development meets the needs of the present without compromising the ability of future generations to meet their own needs	World Commission of Environment and Development(1987), Komor and Bazilian(2005)
	Low land requirement	The power plants utilizing renewable energy sources will not occupy large land	Afgan and Carvalho(2002), Beccali et al.(2003), Wang et al.(2008), Chatzimouratidis and Pilavachi(2008a), Chatzimouratidis and Pilavachi (2008b), Wang et al.(2009a,2009b)
Economic Goal	Local economic development	The extents to which renewable energy source can stimulate the domestic economic development	Komor and Bazilian(2005), Williams et al.(2008), Sastresa et al.(2010)
	Increasing employment	The extents to which renewable energy source can create jobs	Haralambopoulos and Polatidis(2003), Beccali et al.(2003), Komor and Bazilian (2005), Erdo˘gmus- et al.(2006), Madlener et al.(2007), Doukas et al.(2007), Begic and Afgan(2007), Chatzimouratidis and Pilavachi (2008a), Chatzimouratidis andPilavachi(2008b)

	Technical maturity	The extents to which application of renewable energy sources is technically mature	Beccali et al.(2003), Wang et al.(2008), Huang et al.(2008), Wang et al. (2009a, 2009b)
	Potential for commercialization	The potential of successful commercialization based on assessed renewable energy resources	Lee et al.(2007), Lee et al.(2009)
	Market size	The demand of final products (electricity, gas, fuel, etc.) generated by renewable energy sources	Lee et al.(2007), Lewis and Wiser(2007), Lund (2009)
	Reasonableness for investment cost	The investment cost of renewable energy system is acceptable	Mamlook et al.(2001), Afgan and Carvalho(2002), Liposcak et al. (2006), Diakoulaki and Karangelis(2007), Madlener et al.(2007), Begic and Afgan(2007), Doukas et al.(2007), Jovanovic´ et al.(2009), Wang et al.(2009a,2009b), Chatzimouratidis and Pilavachi(2009a)

Annex 5. Sustainability indicators for urban energy systems (Kierstead, 2007)

Theme	Sub-theme	Indicator
Drivers	Demographics	Population
		Number of households
	Economic structure	Energy prices (by fuel)
		Employment
		Competition in electricity and gas markets
		Household weekly income and expenditure
	Local environment	Sunshine hours
		Wind speed
		Area
		Longitude and latitude
		Temperature
		Rainfall
	Infrastructure	Investment in energy industry (R&D capital stock)
		Car ownership (% households owning at least one)
		Road length
		Rail infrastructure (rail length, number of stations)
		% of houses meeting ‘decent’ housing standard
		Office space
Activities	Domestic	Delivered energy demand (by function – space heating, water heating, lights and appliances)
		Delivered energy demand (by fuel)
		Weekly household energy expenditure (by fuel)
		Total delivered domestic energy demand (electricity, other fuels)
	Transport	Daily average trips (by mode)
		Freight volumes (at airport and by road)
		Airport passenger volumes
		Total delivered transport energy demand (electricity, other fuels)
	Commercial	Total commercial turnover
		Total delivered commercial energy demand (electricity, other fuels)
	Industrial	Total delivered industrial energy demand (electricity other fuels)
Stocks and flows	Energy	Total energy production
		Total energy imports
		Total energy exports
		Total primary demand
Impacts	Social	Quality of life
		Road accidents
		Fuel poverty
	Economic	Economic output
		Energy intensity
		Labour productivity
	Environmental	Greenhouse gas emissions
		Acid rain precursor emissions
		SO2 and NO2 emissions

Annex 6. Sustainability assessment criteria in identifying and evaluating RES and energy efficiency projects (SF Energy Invest, 2010)

No.	Criterion	Category	Variable (proposal) [1]
1	Energy & water use and savings	Environment	% of energy/water saved
2	Raw materials use and savings	Environment	In tons
3	Greenhouse gas emission balance	Environment	CO2 emissions (equivalents)
4	Air pollution	Environment	Emissions of NOx , SO2, particulate matter
5	Water pollution and use	Environment	BOD, COD
6	Soil pollution and degradation	Environment	
7	Waste creation & disposal (incl. Hazardous waste)	Environment	In tons and description of disposal
8	Impact on biodiversity	Environment	
9	Impact on landscapes and land use	Environment	
10	Noise	Environment	In dB
11	Cost efficiency	Economic	Costs per tCO2 emission reduction
12	Employment creation and (local) income generation	Economic	
13	Financial/economic feasibility	Economic	NPV, IRR, Cash Flow
14	Health issues (mortality and morbidity)	Social	
15	Safety issues (e.g. accident rates)	Social	
16	Influence on food security	Social	
17	Education component/capacity building/awareness raising	Social	
18	Equal opportunities	Social	
19	Minimum energy efficiency for technology	Energy	
20	Compliance with laws and regulations	Legal	
21	Replication potential of a project	Economic	
22	Good management practices	Economic	
23	Human and labour rights	Social	
24	Participation of local stakeholders	Social	
25	Specific energy consumption	Building	kWh/m2 per year
26	Specific CO2 emission	Building	Kg/m2 per year

[1] If no measurable unit is available, then a form of relative scoring could be used, for example a scoring from -3 to +3. A scale of -3 and +3 gives the possibility to distinguish substantially the impact. The meaning would be the following: +3 – very positive, +2 –positive, +1 – slightly positive, 0 – neutral / no impact, -1 – slightly negative, -2 – negative, -3 – very negative. A more detailed variation (e.g. between -5 and +5) would make the choice less clear.

Annex 7. Commonly used evaluation criteria in RES applications (European Commission, 2003

Energy
• Tons of oil equivalent saved per year (Goumas et al, 1999) • Security of supply – qualitative (Siskos, Hubert, 1983) • Production diversification (Logan et al, 1995). *A diverse mix of generation resources can reduce exposure to risks from political regulatory and fuel price changes.* Can be measured by the Shannon – Weiner index of fuel diversity (DTI, 2003) • Fuel resource indicator (the amount of fuel consumed in tons divided by the energy produced in lifetime – Kg / kWh) (Afgan et al, 2000) • Availability of fuel (Mamlook et al, 2001) • Energy conversion efficiency (Mamlook et al, 2001) • Energy pay back ratio: the ratio of energy produced during the plant's normal life span divided by the energy required to build, maintain and fuel the generation (Gagnon et al, 2002) • Non-renewable energy supply – non renewable primary energy supply / total primary energy supply (Georgopoulou et al, 1998)
Economic
• Regional economic benefits(2% for the Greek case) (Polatidis, Haralambopoulos, 2002) • Maximize contribution to economic development (Keeney, 1996) • Diversification of economic base – economic diversity (Gregory and Keeney, 1994) • Taxes (Gregory and Keeney, 1994) • Multiplier effects (Gregory and Keeney, 1994) • Minimize economic production cost (Mills et al, 1996) • Operating, maintenance cost, capital cost, revenue, economic risk (Mills et al, 1996) • Net present value of the investment (Mills et al, 1996) • The amount of capital per kWh in lifetime – Euro / kWh (Afgan et al, 2000) • Community economic indicator (gain of GNP of the community per kWh – Euro / kWh) (Afgab et al, 2000) • Investment cost (Gungor and Arikan, 2000) • Return on investment (yr^{-1}) (Goumas et al, 1999) • Fraction of investment cost paid in foreign currency (Georgopoulou et al, 1998) • Cost of imports on fossil fuels (Georgopoulou et al, 1998) • Cost of electricity generation – Euro / kWh (Georgopoulou et al, 1998; Afgan, Carvalho, 2002) • Market potential (Hokkanen and Salminen, 1997) • Provide tax revenue to the province (Keeny and McDaniels, 1999) • Have stable returns over time (Keeny and McDaniels, 1999) • Cost benefit ratio, internal rate of return, payback period, present value (Coletsis et al, 2003; Karlis et al, 2002)
Social
• Employment creation (Siskos, Hubert, 1983) • Social cohesion and stability (Lahdelma et al, 2000) • Migration effects and mitigating rural depopulation (Beccali et al, 1998) • Regional infrastructure development (Lahdelma et al, 2000) • Act consistently with the public's environmental values (Keeney, 1996) • Minimize detrimental health and safety impacts to the public (Keeney, 1996) • Minimize detrimental health and safety impacts to the employees (Keeney, 1996) • Equitable compensation for concentrated local impacts (Keeney, 1996) • Be recognized as public service oriented (Keeney, 1996) • Employee health and safety – minimize number of days lost from work (Keeney, 1996; Keeney, McDaniels, 1990) • Cultural impacts (Gregory and Keeney, 1994) • Standard of living – social and cultural opportunities (Gregory and Keeney, 1994) • Relation with neighbouring areas (Gregory and Keeney, 1994) • Foreign control of resources (Gregory and Keeney, 1994) • Human resources development and training (Gregory and Keeney, 1994) • Displaced people (Gregory and Keeney, 1994) • Confront with requirements of regulatory authorities (Mills et al, 1994)

• New job indicator (the amount of paid hours per kWh in lifetime – hours / kWh) (Afgan et al, 2000) • Potential for social conflict creation (Tonn et al, 2000) • Creation of jobs (man days/year) (Goumas et al, 1999) • Cohesion to local activities (Georgopoulou et al, 1997) • Implementation of EU environmental policy (Georgopoulou et al, 1997; Coletsis et al, 2003) • Public acceptance (Hokkanen and Salminen, 1997; Coletsis et al, 2003) • Minimize adverse effects on lifestyle (Kenny and McDaniels, 1999) • Minimize property damage (Kenny and McDaniels, 1999) • Ensure an appropriate allocation of societal benefits (Kenny and McDaniels, 1999) • Equity considerations (Barron and Gordon, 1996) • Improve attitudes and education (Halkowicz et al, 2000) • Compatibility with political, legislative and administrative situation – qualitative (Beccali et al, 1998) • Appropriateness of the implementing organizations (Coletsis et al, 2003)
Environmental
• CO2 reduction potential (Goumas et al, 1999) • Other emissions reduction potential (S02, N02, Tropospheric Ozone, particulates, smoke, CO, VOC (Bond and Brooks, 1997) • Noise – dB(A) added x population affected (10^{-3}) (Georgopoulou et al, 1997) • Land use (km^2/TWh) (Gagnon et al, 2002; Afgan Carvalho, 2002) • Aesthetics – scenic beauty disturbance, wilderness (Gregory and Keeney, 1994) • Impacts to local flora and fauna (Gregory and Keeney, 1994) • Biodiversity loss – ecological integrity (Gregory and Keeney, 1994) • Water quality and demand (Gregory and Keeney, 1994) • Waste generation and disposal (Gregory and Keeney, 1994) • Land degradation (Gregory and Keeney, 1994) • Special areas of conservation (Bond and Brooks, 1997) • Amenity use of designated sites (Bond and Brooks, 1997) • The amount of emissions produced by the plant in tons divided by the energy produced in lifetime (Kg/kWh) (Afgan et al, 2000) • Acid rain: formation of sulphuric and nitric acid (Gagnon et al, 2002) • Photochemical smog creation: formation of ozone and other toxic pollutants (Gagnon et al, 2002) • Direct land requirements (Km^2/kWh) • Minimize odors (Keeny and McDaniels, 1999) • Provision of access roads (Alvarez – Farizon and Hanley, 2002)
Technical
• Maturity of the technology used – qualitative (Beccali et al, 1998) • Consistence of installation and maintenance requirements with local technical know-how – qualitative (Beccali et al, 1998) • Expertise of people regarding operation and maintenance (Beccali et al, 1998) • Maximize quality of service (Keeney, 1996) • Reliability (Mills et al, 1996) • Reliability and safety (Gungor and Arikan, 2000) • Safety in covering peak demand - % of peak demand exceeded by the maximum available power (Georgopoulou et al, 1997) • Stability of the network (Georgopoulou et al, 1997) • Potential for future development (Hokkanen and Salminen, 1997) • Maximize service cost (Keeny and McDaniels, 1999) • Promptly respond to service requests (Keeny and McDaniels, 1999) • Ease of implementation (Barron and Gordon, 1996) • Uninterrupted process (Hokkanen and Salminen, 1997)
Risk
• Health risk (Siskos, Hubert, 1983) • Technical risk – operational risk (Bardouille and Koubsky, 2000) • Environmental risk (Siskos, Hubert, 1983) • Entrepreneurial risk (Haralambopoylos, Polatidis, 2003)

- Risk of climate change - % increase of CO_2 emitted compared with 1990 (Georgopoulou et al, 1997; 1998)
- Risk diversification (Logan et al, 1995)

Annex 8. Survey Tool for Refinement and Validation of Evaluation Criteria and Indicators.

IHS
Making cities work

Survey on Refinement of Criteria

Answers marked with a * are required.

1. Survey Introduction

Dear Sir/Madam:

You are kindly invited to participate in a survey that seeks to refine and validate a list of criteria and indicators for evaluating low-carbon energy technologies in Europe from a local perspective. Your inputs are crucial in finalizing the evaluation criteria and indicators which will be used in eliciting local stakeholder group preferences. This study is supported by the ICLEI - Local Governments for Sustainability, European Secretariat (ICLEI Europe) and the Intelligent Energy Europe (IEE) project, Covenant capaCITY.

The survey shall not take much of your precious time. We estimate that it will not take you more than 15 minutes to complete the survey. We will highly appreciate it if you could complete the survey by **July 1, 2013 (Monday)**. Once the survey is completed, the aggregated results will be available in written reports which we could share with you. Rest assured that your responses will be kept completely confidential.

As mentioned, the finalized evaluation criteria and indicators will be used in eliciting local stakeholder group preferences. We will invite you by July 2, 2013 to participate in the online elicitation of preferences for the different evaluation criteria for low-carbon energy technologies under investigation. Both parts are significant in the research process. Hence, we encourage you to take part in both surveys.

Additionally, a local stakeholders' webinar will be carried out within the framework of Covenant CapaCITY project for further validation and more in depth understanding of local stakeholders' preferences regarding multiple evaluation criteria of energy technologies. Representatives of different local stakeholder groups in Europe will participate in an interactive preferences' elicitation process. The webinar aims to map stakeholders' preferences which would lead to further understanding of local priorities with regard to the evaluation criteria of low carbon energy technologies and systems.

Should you experience any technical difficulty or have any survey-related question, please feel free to contact us through this email address:*lenay.ensenado@gmail.com*.

Thank you very much in advance for your participation in this survey.

Sincerely,

Elena Marie Enseñado and Stelios Grafakos
Institute for Housing and Urban Development Studies
14th Building, T Building
Erasmus University Rotterdam
3062 PA, Rotterdam, the Netherlands

1 / 10 | 10%

Exit | Next

2. Background and Objective of the Study

This survey is part of a three-phase research study that aims to evaluate low-carbon energy technologies in Europe.

Phase 1: Selection of Evaluation Criteria and Indicators (Completed)

The evaluation criteria and indicators have been identified through a comprehensive literature review and validation of stakeholders and experts in energy technologies in Europe at national level.

Phase 2: Experts' Judgment Impact Assessment Survey

Energy experts are being consulted on the impact assessment of climate change mitigation technologies in the electricity sector using selected sustainability criteria and indicators.

Phase 3: Weighting of Criteria by Eliciting Stakeholders' Preferences

This phase intends to determine the evaluation criteria weights which will be undertaken through the following steps:

1. **Refinement of a list of criteria and indicators by local stakeholders in Europe**;
2. E-survey of local European stakeholders' preferences for electricity low-carbon technologies evaluation criteria; and
3. Conduct of a local stakeholders' webinar for an interactive preferences' elicitation process.

Objective of the Current Survey

The objective of this survey is to **refine and validate the list of evaluation criteria and indicators** selected for the research study. This list of evaluation criteria and indicators were made available through a comprehensive literature review and validation from various stakeholders and experts in energy technologies in Europe at the national level.

Based on your local context, we encourage you to improve the selected evaluation criteria and indicators, if you feel that this is deemed necessary. You can add, remove, or adjust on the criteria and indicators based on your knowledge, expertise, and experience.

The refinement of criteria precedes the elicitation of weighting preferences, and the the validated set of criteria and indicators will be used in the elicitation of preferences. The results of this survey are significant in the process of evaluating low-carbon energy technologies for selection and introduction at the European level.

2 / 10 | 20%

Exit | Back | Next

3. Low-Carbon Energy Technologies

The list of criteria and indicators will be used in evaluating the following low-carbon energy technologies.

Technology	Description
Integrated Gasification Combined Cycle (IGCC) coal	Future reference technology for 2030 is an IGCC power plant. IGCC technology is an emerging advanced power generation system having the potential to generate electricity from coal with high efficiency and lower air pollution ($NO_{x,}$ SO2, CO and PM10) than other current coal-based technologies.
IGCC coal with Carbon Capture and Storage (CCS)	IGCC technology lends itself very well to CCS due to the higher pressure of the gas stream and the possibility to achieve the highly concentrated formation of CO2 prior to combustion. For this to be possible then after having been cleaned of particulates the syngas enters a shift reaction unit in which the methane is reacted with steam to produce hydrogen and CO2. The preferred technique for CO2 separation in applications at higher pressure (i.e. IGCC) is currently physical absorption using solvents commonly used in commercial processes. Once captured, the CO2 can then be treated in the same way as for the other technologies incorporating CCS. The resulting power plant net efficiency for this technology scenario is 48.5%. CO2 transport and storage is modelled in the same way as for Pulverized Coal power plants.
Gas Turbine Combined Cycle (GTCC)	GTCC power plant involves the direct combustion of natural gas in a gas turbine generator. The waste heat generated by this process is then used to create steam for use in a steam generator, in a similar manor to that of IGCC technologies. In this combined cycle power plant around two-thirds of the overall plant capacity is provided by the gas turbine. Reference technology for large natural gas power plants is a 500 MW Combined Cycle (CC) unit. The analysis focuses on a base load power plant. Technology development until 2030 is taken into account with higher power plant efficiencies.
GTCC with CCS	The electricity generation aspect of this technology is exactly the same as the GTCC without CCS. The flue gas from the GTCC then enters the same CO2 separation, stripping, drying, transportation and sequestration process to that used for coal and lignite CO2 capture.
Nuclear European Pressure Water Reactor (EPR)	This ‘Generation III’ design of nuclear reactor uses either uranium oxide enriched to 4.9% fissile material (uranium-235) or a mix of uranium-235 and mixed uranium plutonium oxide (MOX), with pressurized water as the moderator and cooling agent. The heat from the reaction is used to produce steam to drive a steam turbine generator. It features not only superior reliability and safety over its current ‘Generation II’ counterparts but also higher efficiency. This results in less high-level radioactive waste per unit of electricity generated that requires either reprocessing or long term storage in geological repositories.
Wind onshore	The exploitation of wind energy has increased exponentially during the last decades, and there is still large unexploited wind energy potential in many parts of the world – both onshore and offshore. However, the success story of onshore wind energy has led to a shortage of land sites in many parts of Europe, particular in north-western Europe. Vestas’ V80 2 MW turbine serves as current reference technology for onshore wind power in Germany The capacity factor for a generic optimal site near to the coast of the North Sea is assumed to be 0.29. Future wind turbines in 2030 with higher capacities are assumed to be located at the same or similar sites.
Wind offshore	The shortage of land sites for onshore wind energy has spurred the interest in exploiting offshore wind energy. Offshore wind farms consisting of multiple wind turbines all connected to a single transformer station are more financially viable than individual turbines. Offshore sites also enjoy the advantage of having significantly more stable and higher wind speeds than onshore sites and which leads to a longer turbine life. Future wind turbines in 2030 with higher capacities than the current ones are assumed to be located at the Danish part of the North Sea (HornsRev) or similar sites. The whole park is assumed to consist of eighty Vestas V80 turbines with monopile steel foundations.
Solar Photovoltaics (PVs) - crystalline silicon	The PV installation is small and integrated onto a new or existing building. At 420 kW, this is suited to the roof of a public or commercial building and is too large for most domestic residences. Photovoltaic (PV) reference technology for crystalline silicon is the laminated, integrated slanted-roof multicrystalline-Si module in, which is adapted to the electricity production of 850 kWh kWp. Not only efficiency increase for the PV-cells as such, but also reduced energy demand in the production steps of the PV chains are taken into account for the modeling of the future 2030 reference PV units.

Hydropower	The hydro plant Illanz/Panix (Switzerland) is used as the reference reservoir site. Lifetime of the dam is assumed to be 150 years.
Biogas	Biogas (SNG) from forest wood gasification is assumed to fuel CHP units. Basis for the production of SNG via wood gasification is the assessment of a 50 MW demonstration plant. A commercialized methanation unit with double capacity and increased efficiency, as well as improved CHP unit SNG combustion, reflect the expected technology development until 2030.

Disclaimer: ICLEI Europe, coordinator of the Covenant capaCITY project, does not perceive nuclear power as a low-carbon option. It considers this technology dangerous and unsustainable and therefore doesn't support its promotion and implementation in any way.

3 / 10 | 30%

Exit | Back | Next

4. Profile of Respondent

This survey is designed to seek your professional views on the evaluation criteria and indicators for low-carbon energy technologies. For this section, kindly provide your name, organization, country of residence as well as indicate the stakeholder group you belong to. We assure you that individual responses will be kept confidential and will only be used for this survey alone.

1. Name

2. Organization

3. Country of residence *

4. Please select the stakeholder group you belong to: *

- (•) Government (European level)
- ( ) Government (National level)
- ( ) Electricity and energy associations
- ( ) Electricity producers
- ( ) Electricity consumers
- ( ) Academic - Research
- ( ) Consultants - Advisors
- ( ) Regulators and network administrators
- ( ) Financial and trading sector
- ( ) Non-government organizations
- ( ) Other (Please Specify)

4 / 10		40%

Exit

Back Next

5. Refinement of Evaluation Criteria

This research study employs a list of evaluation criteria and indicators that will be used in assessing selected low-carbon energy technologies. There are five broad categories for the evaluation criteria and indicators, namely economic, environmental, social, energy and technologial. There are 23 indicators in total which fall under these five categories. Based on the local context and with your knowledge, expertise and experience, we request that you refine the evaluation criteria and indicators under investigation.

Economic Criteria

Please study the following criteria and indicators under the economic category and their corresponding descriptions.

Levelised costs	Levelised costs of energy (LCOE) refers to investment costs, operational and maintenance costs, capacity factor, efficiency, material use.
Employment (short run)	The extent to which the application of the technology can create jobs at the investment stage. Furthermore, the criterion of employment reflects partly the extent of the impact that the technology has to the local economic development by providing jobs and generating income.
Employment (long run)	The extent to which the application of the technology can create jobs at the operation and maintenance stage.

1. Tick the option that best applies to each indicator. *

	Retain	Remove	Adjust
Levelised costs	◉	○	○
Employment (short run)	◉	○	○
Employment (long run)	◉	○	○

2. Should the indicators need to be removed or adjusted, please provide your justification.

Levelised costs	
Employment (short run)	
Employment (long run)	

3. Should you like to suggest any additional indicators to be included in this criteria category, please add them below:

1	
2	
3	
4	
5	

5 / 10		50%

Exit

Back Next

6. Refinement of Environmental Criteria

Please study the following criteria and indicators under the environmental category and their corresponding descriptions.

CO_{2eq} emissions	The indicator reflects the potential impacts of global climate change caused by emissions of GHGs for the production of 1 kwh.
Climate resilience	The degree of resilience of the energy technology to the future climactic changes and extreme weather events.
Noise pollution	Part of population feeling highly affected by the noise caused due to the function of the energy facility. This indicator is case sensitive and could have been measured as a factor of the noise generation by the energy technology estimated in dB multiplied by the number of people affected by the noise. However, since we are investigating different energy technologies and systems at a European scale we cannot measure precisely this indicator and therefore we will use an ordinal relevant scale to measure the perceived noise.
(Radioactive) waste	The amount of (radioactive) waste generated by the plant divided by energy produced.
Waste disposal (infrastructure)	Waste generation during the life cycle of the fuel and technology or availability of waste disposal infrastructure.
Ecosystem damages	This criterion quantifies the impacts of flora and fauna due to acidification and eutrophication caused by pollution from the production of 1 kWh electricity by the energy system and technology.
Land use requirement	The land required by each power plant and technology to be installed
Fuel use	The amount of fuel use per kWh of final electricity consumption.

1. Tick the option that best applies to each indicator. *

	Retain	Remove	Adjust
CO2eq emissions	◉	○	○
Climate resilience	◉	○	○
Noise pollution	◉	○	○
(Radioactive) waste	◉	○	○
Waste disposal (infrastructure)	◉	○	○

Ecosystem damages	(•)	( )	( )
Land use requirement	(•)	( )	( )
Fuel use	(•)	( )	( )

2. Should the indicators need to be removed or adjusted, please provide your justification.

CO2eq emissions	
Climate resilience	
Noise pollution	
(Radioactive) waste	
Waste disposal (infrastructure)	
Ecosystem damages	
Land use requirement	
Fuel use	

3. Should you like to suggest any additional indicators to be included in this criteria category, please add them below:

1	
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Exit

Back Next

7. Refinement of Social Criteria

Please study the following criteria and indicators under the social category and their corresponding descriptions.

Level of public resistance/opposition	Energy system induced conflicts that may endanger the cohesion of society (e.g. nuclear, wind, CCS). Opposition might occur due to the perceptions of people regarding the catastrophic potential or other environmental impacts (aesthetic, odor, noise) of the energy technology/system. This indicator also integrates the aspect of participatory requirement for the application of the technology. The higher the public opposition, the higher the participatory requirement is.
Aesthetic/functional impact	Part of population that perceives a functional or aesthetic impairment of the landscape area caused by the energy system. The aesthetic impairment is judged subjectively and therefore this criterion fits in the social category than the environmental one. In addition this is also a very location specific indicator and therefore an average metric will be determined measured in relative ordinal scale.
Mortality and morbidity	Mortality and morbidity due to air pollution caused by normal operation of the technology. This indicator is considered as an impact and composite indicator since it integrates all human health impacts caused from air pollution emissions as NOx, SO2, and PM.
Accidents and fatalities	Loss of lives of workers and public during installation and operation. Surrogate for risk aversion. This criterion partly integrates the catastrophic potential of the energy system/technology.

1. Tick the option that best applies to each indicator. *

	Retain	Remove	Adjust
Level of public resistance/opposition	◉	○	○
Aesthetic/functional impact	◉	○	○
Mortality and morbidity	◉	○	○
Accidents and fatalities	◉	○	○

2. Should the indicators need to be removed or adjusted, please provide your justification.

Level of public resistance/opposition	
Aesthetic/functional impact	

Mortality and morbidity	
Accidents and fatalities	

3. Should you like to suggest any additional indicators to be included in this criteria category, please add them below:

1	
2	
3	
4	
5	

7 / 10		70%

Exit

Back Next

8. Refinement of Energy Criteria

Please study the following criteria and indicators under the energy category and their corresponding descriptions.

Energy cost stability/sensitivity to fuel price fluctuation	The sensitivity of technology costs of electricity generation to energy and fuels prices fluctuations. The fraction of fuel cost to the overall electricity generation cost.
Stability of energy generation	Stability of output of electric power generated depending on the technology used. This reflects whether the energy supply is being interrupted. The presence of these interruptions impacts the electricity network stability. This criterion reflects whether the energy supply faces any interruptions due to the type of energy technology. This criterion reflects whether the energy supply faces any interruptions due to the type of energy technology.
Peak load response	Technology specific ability to respond swiftly to large variation of demand in time/% representing the possibility to satisfy the required load.
Market concentration on supply	The market concentration on the supply of primary sources of energy that could lead to disruption due to economic or political reasons.

1. Tick the option that best applies to each indicator. *

	Retain	Remove	Adjust
Energy cost stability/sensitivity to fuel price fluctuation	○	○	○
Stability of energy generation	○	○	○
Peak load response	○	○	○
Market concentration on supply	○	○	○

2. Should the indicators need to be removed or adjusted, please provide your justification.

Energy cost stability/sensitivity to fuel price fluctuation	
Stability of energy generation	
Peak load response	
Market concentration on supply	

3. Should you like to suggest any additional indicators to be included in this criteria category, please add them below:

1	
2	
3	
4	
5	

8 / 10 80%

Exit Back Next

9. Refinement of Technological Criteria

Please study the following criteria and indicators under the technological category and their corresponding descriptions.

Technological maturity	The extent to which the technology is technically mature. The criterion refers to the level of technology's technological development and furthermore the spread of the technology at the market.
Market size (domestic)	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.
Market size (potential export)	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.
Innovative ability	Flexibility and potential of the technology to integrate technological innovations.

1. Tick the option that best applies to each indicator. *

	Retain	Remove	Adjust
Technological maturity	○	○	○
Market size (domestic)	○	○	○
Market size (potential export)	○	○	○
Innovative ability	○	○	○

2. Should the indicators need to be removed or adjusted, please provide your justification.

Technological maturity	
Market size (domestic)	
Market size (potential export)	
Innovative ability	

3. Should you like to suggest any additional indicators to be included in this criteria category, please add them below:

1	
2	

3	
4	
5	

9 / 10		90%

Exit

Back Next

10. End of Survey

You have reached the end of the survey. As mentioned, the aggregated results will be available in written reports which we could share with you.

1. Would you like to receive the results of the study?

- ○ Yes
- ○ No

2. If yes, please provide us your email address.

Thank you very much for your participation in the survey. Your inputs are highly valuable in our research study. Please expect an email from us by July 2, 2013 regarding the elicitation of preferences for the different evaluation criteria of low-carbon energy technologies in Europe.

Sincerely,

Elena Marie Enseñado and Stelios Grafakos
Institute for Housing and Urban Development Studies
14th Building, T Building
Erasmus University Rotterdam
3062 PA, Rotterdam, the Netherlands

10 / 10		100%

Exit

Back Submit

Annex 9. Survey tool for the elicitation of weighting preferences of local stakeholders.

ELICITATION OF LOCAL STAKEHOLDERS' PREFERENCES FOR THE EVALUATION CRITERIA OF LOW-CARBON ENERGY TECHNOLOGIES

OBJECTIVE OF THE STUDY: The objective of this survey is to elicit local European stakeholders' preferences for the evaluation criteria of low-carbon energy technologies. The results of this survey are significant in the process of evaluating low-carbon energy technologies for selection and introduction at the European level. Also, this survey shall provide a better understanding of how local stakeholders value the selected evaluation criteria and low-carbon energy technologies. The results will highlight discrepancies on local stakeholders' preferences and values and could indicate areas of potential conflict during local energy planning and implementation of low-carbon energy technologies. The following are the selected low-carbon energy technologies and their corresponding descriptions.

Low-Carbon Energy Technologies		Descriptions
1	**Integrated Gasification Combined Cycle (IGCC) coal**	Future reference technology for 2030 is an IGCC power plant. IGCC technology is an emerging advanced power generation system having the potential to generate electricity from coal with high efficiency and lower air pollution (NO x, SO2, CO and PM10) than other current coal-based technologies.
2	**IGCC coal with Carbon Capture and Storage (CCS)**	IGCC technology lends itself very well to CCS due to the higher pressure of the gas stream and the possibility to achieve the highly concentrated formation of CO2 prior to combustion. For this to be possible then after having been cleaned of particulates the syngas enters a shift reaction unit in which the methane is reacted with steam to produce hydrogen and CO2. The preferred technique for CO2 separation in applications at higher pressure (i.e. IGCC) is currently physical absorption using solvents commonly used in commercial processes. Once captured, the CO2 can then be treated in the same way as for the other technologies incorporating CCS. The resulting power plant net efficiency for this technology scenario is 48.5%. CO2 transport and storage is modelled in the same way as for Pulverized Coal power plants.
3	**Gas Turbine Combined Cycle (GTCC)**	GTCC power plant involves the direct combustion of natural gas in a gas turbine generator. The waste heat generated by this process is then used to create steam for use in a steam generator, in a similar manor to that of IGCC technologies. In this combined cycle power plant around two-thirds of the overall plant capacity is provided by the gas turbine. Reference technology for large natural gas power plants is a 500 MW Combined Cycle (CC) unit. The analysis focuses on a base load power plant. Technology development until 2030 is taken into account with higher power plant efficiencies.
4	**GTCC with CCS**	The electricity generation aspect of this technology is exactly the same as the GTCC without CCS. The flue gas from the GTCC then enters the same CO2 separation, stripping, drying, transportation and sequestration process to that used for coal and lignite CO2 capture.
5	**Nuclear European Pressure Water Reactor (EPR)**	This 'Generation III' design of nuclear reactor uses either uranium oxide enriched to 4.9% fissile material (uranium-235) or a mix of uranium-235 and mixed uranium plutonium oxide (MOX), with pressurized water as the moderator and cooling agent. The heat from the reaction is used to produce steam to drive a steam turbine generator. It features not only superior reliability and safety over its current 'Generation II' counterparts but also higher efficiency. This results in less high-level radioactive waste per unit of electricity generated that requires either reprocessing or long term storage in geological repositories.

6	**Wind onshore**	The exploitation of wind energy has increased exponentially during the last decades, and there is still large unexploited wind energy potential in many parts of the world – both onshore and offshore. However, the success story of onshore wind energy has led to a shortage of land sites in many parts of Europe, particular in north-western Europe. Vestas' V80 2 MW turbine serves as current reference technology for onshore wind power in Germany The capacity factor for a generic optimal site near to the coast of the North Sea is assumed to be 0.29. Future wind turbines in 2030 with higher capacities are assumed to be located at the same or similar sites.
7	**Wind offshore**	The shortage of land sites for onshore wind energy has spurred the interest in exploiting offshore wind energy. Offshore wind farms consisting of multiple wind turbines all connected to a single transformer station are more financially viable than individual turbines. Offshore sites also enjoy the advantage of having significantly more stable and higher wind speeds than onshore sites and which leads to a longer turbine life. Future wind turbines in 2030 with higher capacities than the current ones are assumed to be located at the Danish part of the North Sea (HornsRev) or similar sites. The whole park is assumed to consist of eighty Vestas V80 turbines with monopile steel foundations.
8	**Solar Photovoltaics (PVs) - crystalline silicon**	The PV installation is small and integrated onto a new or existing building. At 420 kW, this is suited to the roof of a public or commercial building and is too large for most domestic residences. Photovoltaic (PV) reference technology for crystalline silicon is the laminated, integrated slanted-roof multicrystalline-Si module in, which is adapted to the electricity production of 850 kWh kWp. Not only efficiency increase for the PV-cells as such, but also reduced energy demand in the production steps of the PV chains are taken into account for the modeling of the future 2030 reference PV units.
9	**Hydropower**	The hydro plant Illanz/Panix (Switzerland) is used as the reference reservoir site. Lifetime of the dam is assumed to be 150 years.
10	**Biogas CHP**	Biogas (SNG) from forest wood gasification is assumed to fuel CHP units. Basis for the production of SNG via wood gasification is the assessment of a 50 MW demonstration plant. A commercialized methanation unit with double capacity and increased efficiency, as well as improved CHP unit SNG combustion, reflect the expected technology development until 2030.

Disclaimer: ICLEI Europe, coordinator of the Covenant capaCITY project, does not perceive nuclear power as a low-carbon option. It considers this technology dangerous and unsustainable and therefore doesn't support its promotion and implementation in any way.

Proceed to the list of instructions. >>>

INSTRUCTIONS ON HOW TO USE THE PAIRWISE WEIGHTING TOOL:

This survey on elicitation of preferences consists of six steps. The following instructions, which includes visual representations, will guide you in answering the survey . Take your time in ranking the different evaluation criteria and indicators. Feel free to go back and forth the different steps to achieve consistency as well as satisfaction with the results.

[Step 1] Study the descriptions of the different evaluation criteria and indicators for assessing selected low-carbon energy technologies.
[Step 2] Check how the low-carbon energy technologies perform against the evaluation criteria and indicators through the *Impact Matrix*.
[Step 3] Based on your preferences, classify the 23 evaluation criteria according to their levels of importance - whether high, moderate, or low.

List of Criteria	Min Score	Max Score	Level of Importance
Levelised costs (incl. capital, o&m, fuel costs)			
Employment (short run)			

Low
Moderate
High

Once you have ranked all 23 evaluation criteria, these will be automatically grouped together according to their level of importance. You will - again - rank them based on their specific grouping (high moderate, and low). Assign the number 1 for the most important criterion, 2 for the second most important, 3 for the third most important, and so on. Note: Do not enter a number that is previously selected, and assign rankings specific ONLY to each of the three criteria groupings: high, moderate, and low-importance criteria.

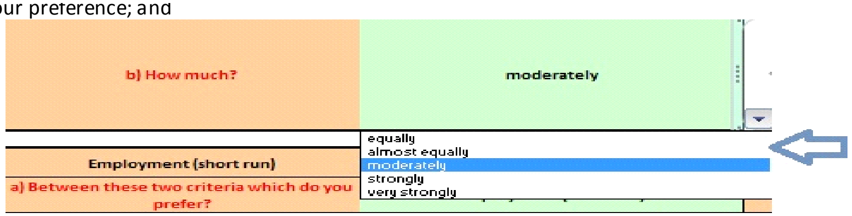
High Importance Criteria		Rank High Importance Criteria
Levelised costs (incl. capital, o&m, fuel costs)	0	1
Employment (short run)	0	3

[Step 3a] Rank the evaluation criteria and indicators that are considered of high-importance.
[Step 3b] This is specifically for the evaluation criteria and indicators with moderate-importance.
[Step 3c] Lastly, rank those evaluation criteria and indicators that are classified as of low-importance.
[Step 3d] Review the results once you complete the ranking of evaluation criteria and indicators for each level of importance.

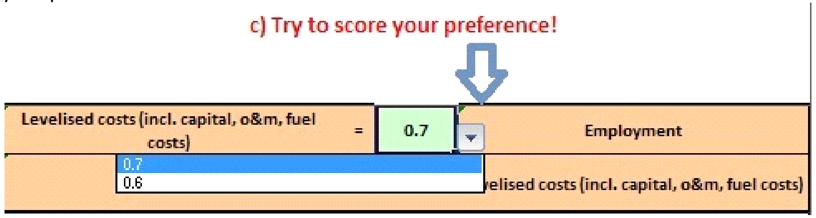
[Step 4] Carry out a series of pairwise comparisons between different criteria. This involves the following actions:

a. Select the criterion you prefer between a pair;

b. Indicate verbally the level of your preference; and



c. Specify numerically the level of your preference.



[Step 5] Once you complete the series of pairwise comparisons, observe the over-all results based on your preferences.

[Step 6] Check the consistency index. If there is inconsistency, go back to either Step 3 or Step 4 and modify your inputs.

If you have any questions or clarifications, please do not hesitate to contact us through our email addresses: **lenay.ensenado@gmail.com** and **s.grafakos@ihs.nl.** Once you have completed this survey, send us your final version of this excel sheet through this email address: lenay.ensenado@gmail.com.

Click here to start with the weighting tool. >>>

Profile of Respondent

Kindly provide your name, organization, country of residence as well as indicate the stakeholder group you belong to. We assure you that individual responses will be kept confidential and will only be used for this research study alone.

Name (optional): ______________________________

Organization (optional): ______________________________

Country of Residence: ______________________________

Select the the stakeholder group you belong to by putting an X sign:

a. Government (EU level) ________

b. Government (National level) ________

b. Government (Local level) ________

d. Electricity and energy associations ________

e. Electricity producers ________

f. Electricity consumers ________

g. Academic - Research ________

h. Consultants - Advisors ________

i. Regulators and network administrators ________

j. Financial and trading sector ________

k. Non-government organizations ________

l. Other (Please specify) ________

Kindly proceed to the list of criteria. >>>

LIST OF EVALUATION CRITERIA AND INDICATORS

	Criteria	Category	Units of Measurement
1	Levelised costs (incl. capital, o&m, fuel costs)	Economic	euros/Mwh
2	Employment generation	Economic	Jobs - year/GWh
3	CO2eq emissions	Environmental	g/kwh
4	Resilience to climate change	Environmental	"1-5"
5	Noise	Environmental	"1-5"
6	Radioactive waste	Environmental	m3/kwh
7	Waste disposal (infrastructure)	Environmental	kg/kwh
8	Ecosystem Damages	Environmental	PDF*m2*a/kWh
9	Land use requirement	Environmental	km2/TWh-year
10	Fuel use	Environmental	Mj/kwh
11	Level of public resistance/opposition	Social	"1-5"
12	Aesthetic/functional impact	Social	"1-5"
13	Mortality and Morbidity	Social	YoLL/kWh
14	Accident fatalities	Social	deaths
15	Energy cost sensitivity to fuel price fluctuation	Energy	%
16	Stability of energy generation	Energy	"1-5"
17	Peak load response	Energy	%
18	Market concetration on supply	Energy	"1-5"
19	Technological maturity	Technology	"1-5"
20	Market size (Domestic)	Technology	"1-5"
21	Market size (Potential export)	Technology	"1-5"
22	Innovative ability	Technology	"1-5"

Kindly proceed to Step 1. >>>

STEP 1: Study the Different Evaluation Criteria and Indicators.

This research study employs a list of evaluation criteria and indicators for assessing selected low-carbon energy technologies. There are five broad categories, namely economic, environmental, social, energy and technologial. There are 22 indicators in total which fall under these five categories. Please study the following criteria and indicators and their corresponding descriptions.

Criterion			Descriptions	Measurement Unit
Economic	1	**Levelised costs (incl. capital, o&m, fuel costs)**	Levelised costs of energy (LCOE) refers to investment costs, operational and maintenance costs, capacity factor, efficiency, material use.	euros/Mwh
	2	**Employment generation**	The extent to which the application of the technology can create jobs at the investment, operation and maintenance stage. Furthermore, the criterion of employment reflects partly the extent of the impact that the technology has to the local economic development by providing jobs and generating income.	Jobs - year/GWh
Environmental	3	**CO2eq emissions**	The indicator reflects the potential impacts of global climate change caused by emissions of GHGs for the production of 1 kwh.	g/kwh
	4	**Resilience to climate change**	The degree of resilience of the energy technology to the future climactic changes and extreme weather events.	"1-5"
	5	**Noise**	Part of population feeling highly affected by the noise caused due to the function of the energy facility. This indicator is case sensitive and could have been measured as a factor of the noise generation by the energy technology estimated in dB multiplied by the number of people affected by the noise. However, since we are investigating different energy technologies and systems at a European scale we cannot measure precisely this indicator and therefore we will use an ordinal relevant scale to measure the perceived noise.	"1-5"
	6	**Radioactive waste**	The amount of (radioactive) waste generated by the plant divided by energy produced.	m3/kwh
	7	**Waste disposal (infrastructure)**	Waste generation during the life cycle of the fuel and technology or availability of waste disposal infrastructure.	kg/kwh
	8	**Ecosystem Damages**	This criterion quantifies the impacts of flora and fauna due to acidification and eutrophication caused by pollution from the production of 1 kWh electricity by the energy system and technology.	PDF*m2*a/kWh
	9	**Land use requirement**	The land required by each power plant and technology to be installed.	km2/TWh-year
	10	**Fuel use**	The amount of (fossil) fuel use per kWh of final electricity consumption.	Mj/kwh

Social	11	**Level of public resistance/opposition**	Energy system induced conflicts that may endanger the cohesion of society (e.g. nuclear, wind, CCS). Opposition might occur due to the perceptions of people regarding the catastrophic potential or other environmental impacts (aesthetic, odor, noise) of the energy technology/system. This indicator also integrates the aspect of participatory requirement for the application of the technology. The higher the public opposition, the higher the participatory requirement is.	"1-5"
	12	**Aesthetic/functional impact**	Part of population that perceives a functional or aesthetic impairment of the landscape area caused by the energy system. The aesthetic impairment is judged subjectively and therefore this criterion fits in the social category than the environmental one. In addition this is also a very location specific indicator and therefore an average metric will be determined measured in relative ordinal scale.	"1-5"
	13	**Mortality and Morbidity**	Mortality and morbidity due to air pollution caused by normal operation of the technology. This indicator is considered as an impact and composite indicator since it integrates all human health impacts caused from air pollution emissions as NOx, SO2, and PM.	YoLL/kWh
	14	**Accident fatalities**	Loss of lives of workers and public during installation and operation. Surrogate for risk aversion. This criterion partly integrates the catastrophic potential of the energy system/technology.	deaths
Energy	15	**Energy cost sensitivity to fuel price fluctuation**	The sensitivity of technology costs of electricity generation to energy and fuels prices fluctuations. The fraction of fuel cost to the overall electricity generation cost.	%
	16	**Stability of energy generation**	Stability of output of electric power generated depending on the technology used.This criterion reflects whether the energy supply faces any interruptions due to the type of energy technology. The presence of these interruptions impacts the electricity network stability.	"1-5"
	17	**Peak load response**	Technology specific ability to respond swiftly to large variation of demand in time/% representing the possibility to satisfy the required load.	%
	18	**Market concetration on supply**	The market concentration on the supply of primary sources of energy that could lead to disruption due to economic or political reasons.	"1-5"

Technological	19	**Technological maturity**	The extent to which the technology is technically mature. The criterion refers to the level of technology's technological development and furthermore the spread of the technology at the market.	"1-5"
	20	**Market size (Domestic)**	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.	"1-5"
	21	**Market size (Potential export)**	Demand for final products (of energy technologies) and potential market size domestically. The potential market size plays an important role to establish industrial competitiveness and stimulate economic growth.	"1-5"
	22	**Innovative ability**	Flexibility and potential of the technology to integrate technological innovations.	"1-5"

Go to the next step and observe the impact matrix. >>>

Step 2: Check the performance of low-carbon energy technologies.

The selected low-carbon energy technologies under investigation perform differently when assessed against the different evaluation criteria and indicators. Check how the low-carbon energy technologies perform through the impact matrix below. This step can help you out in assessing your own preferences.

		Economic Category		Environmental category								Social Category				Energy Category				Technological Category			
	Criteria / Technologies	Levelised costs (1)	Employment (long-term) (2)	CO_2eq emissions (3)	Climate resilience (4)	Noise pollution (3)	Radioactive waste (3)	Waste disposal (infrastructure) (3)	Ecosystem damages (3)	Land use requirement (5)	Fuel use (3)	Level of public resistance/opposition (4)	Aesthetic/functional impact (3)	Mortality and morbidity (3)	Accidents and fatalities (3)	Energy cost sensitivity to fuel price fluctuation (3)	Stability of energy generation (4)	Peak load response (6)	Market concentration on supply (4)	Technological maturity (4)	Market size (domestic) (4)	Market size (potential export) (4)	Innovative ability (4)
	Measurement Unit	euros/Mwh	Jobs - year/GWh	g/kwh	"1-5"	"1-5"	m3/kwh	kg/kwh	PDF*m2*a/kWh	km2/TWh-year	Mj/kwh	"1-5"	"1-5"	YoLL/kWh	deaths	%	"1-5"	%	"1-5"	"1-5"	"1-5"	"1-5"	"1-5"
1	Integrated Gasification Combined Cycle (IGCC)	99.9	0.11	753	2.8	3.2	1.1E-09	2.3	0.013	9.7	6.90	3.4	3.7	7E-08	434	53	1.8	70	3.3	3.8	2.8	3.0	2.3
2	Gas Turbine Combined Cycle (GTCC)	78.9	0.11	388	3.1	2.1	3.5E-11	1.7	0.0033	18.6	6.79	2.9	3.0	7E-08	109	69	1.9	70	3.2	4.4	3.7	3.5	2.9
3	Nuclear European Pressurized Reactor	69.3	0.1	4.0	3.0	1.9	0.0	3.6	0.0	2.4	0.07	4.6	3.5	0.0	50000	4.5	2.1	10	3.4	3.4	2.2	2.8	2.7
4	Wind on-shore	107.2	0.17	16	3.5	2.7	8.4E-11	1.7	0.0034	72.1	0.06	3.1	3.0	7E-09	5	0	3.8	10	2.9	4.4	4.1	3.8	3.4
5	Wind off - shore	140.1	0.17	10	3.5	1.4	6.3E-11	1.9	0.0034	0	0.05	2.3	5.0	6E-09	10	0	3.5	10	2.9	3.9	4.1	4.0	3.8
6	Solar Photovoltaics (PV)	381.5	0.87	30	3.8	1.2	2.7E-10	1.7	0.0054	37	0.14	1.8	2.5	1E-08	10	0	3.8	10	2.9	4.2	4.1	3.8	4.4
7	Hydropower (Storage Dam)	104.8	0.27	4	3.5	1.6	4E-11	1.4	0.0003	54	0.00	3.2	3.5	1E-09	285	0	2.4	10	3.3	4.8	3.2	3.1	2.1
8	Integrated Gasification Combined Cycle (IGCC with CCS	105.5	0.18	205	3.1	2.8	1.4E-09	3.5	0.022	9.7	7.87	3.6	2.9	6E-08	434	47	1.9	70	3.2	2.7	2.7	2.6	3.6
9	Gas Turbine Combined Cycle with CCS	87.8	0.18	120	3.1	2.8	8.6E-10	3.5	0.0045	18.6	7.44	3.5	3.2	9E-08	109	55	1.9	70	3.2	2.9	2.9	2.8	3.6
10	Biomass CHP (waste wheat, straw)	244.9	0.2	37.0	3.3	1.9	0.0	0.0	0.0	543.0	0.11	2.2	1.7	0.0	5	22.0	2.5	10	3.2	4.0	3.7	3.4	3.3

Rank the different evaluation criteria based on their importance. >>>

Sources

1: IEA, 2010
2: Wei et al., 2010
3: NEEDS project, 2009
4: Grafakos, 2013
5: McDonald et al., 2009
6: Streimiekene, 2009

Step 3: Rank all evaluation criteria and indicators based on their importance.

This initial ranking is a major step in the weight elicitation process. This step will allow you to be familiarized with the ranking process as well as in how to compare the different evaluation criteria. Start by clicking the first green cell under the column 'level of importance'. Using the dropdown menu, rank the first evaluation criteria as to whether it is of high, moderate, or low importance. Continue the ranking process until you reach the last evaluation criteria.

	List of Criteria	Unit	Min Score	Max Score	Importance
1	Levelised costs (incl. capital, o&m, fuel costs)	euros/Mwh	69.3	381.5	Moderate
2	Employment generation	Jobs - year/GWh	0.11	0.87	Moderate
3	CO2eq emissions	g/kwh	4.0	753	High
4	Resilience to climate change	"1-5"	2.8	3.8	High
5	Noise	"1-5"	1.16	3.24	Low
6	Radioactive waste	m3/kwh	3.5E-11	2.3E-08	High
7	Waste disposal (infrastructure)	kg/kwh	0.037	3.64	Moderate
8	Ecosystem Damages	PDF*m2*a/kWh	0.00031	0.037	High
9	Land use requirement	km2/TWh-year	0.00	543	Low
10	Fuel use	Mj/kwh	0.00	7.87	Moderate
11	Level of public resistance/opposition	"1-5"	1.8	4.6	Moderate
12	Aesthetic/functional impact	"1-5"	1.7	5	Low
13	Mortality and Morbidity	YoLL/kWh	1.4E-09	8.7E-08	High
14	Accident fatalities	deaths	5	50000	High
15	Energy cost sensitivity to fuel price fluctuation	%	0	69	Moderate
16	Stability of energy generation	"1-5"	1.8	3.825	Moderate
17	Peak load response	%	10	70	Moderate
18	Market concetration on supply	"1-5"	2.87	3.39	Low
19	Technological maturity	"1-5"	2.73	4.75	Moderate
20	Market size (Domestic)	"1-5"	2.23	4.11	Moderate
21	Market size (Potential export)	"1-5"	2.6	4.0	Moderate
22	Innovative ability	"1-5"	2.1	4.4	Moderate

Rank the high-importance criteria. >>>

Step 3a: Rank the evaluation criteria that are considered of high-importance.

After ranking all 22 evaluation criteria and indicators, these will be grouped together according to their level of importance - whether high, medium, or low. For this sub-step, check the list of the high-importance criteria below, and assign their rankings specific to this grouping. Start by looking under the green column labelled 'rank high importance criteria'. Assign numbers, with 1 as the most important criterion, 2 as the second most important, 3 as the third most important, and so on. Note: Do not enter a number that is previously selected, and assign rankings specific **ONLY** to high-importance criteria.

	List of Criteria	Min Score	Max Score	Level of Importance
1	Levelised costs (incl. capital, o&m, fuel costs)	69.3	381.5	Moderate
2	Employment generation	0.1	0.9	Moderate
3	CO2eq emissions	4.0	753.0	High
4	Resilience to climate change	2.8	3.8	High
5	Noise	1.2	3.2	Low
6	Radioactive waste	0.0	0.0	High
7	Waste disposal (infrastructure)	0.0	3.6	Moderate
8	Ecosystem Damages	0.0	0.0	High
9	Land use requirement	0.0	543.0	Low
10	Fuel use	0.0	7.9	Moderate

High Importance Criteria	Select HIGH from the Droplist	Rank HIGH Importance Criteria
Levelised costs (incl. capital, o&m, fuel costs)	Moderate	
Employment generation	Moderate	
CO2eq emissions	High	6
Resilience to climate change	High	5
Noise	Low	
Radioactive waste	High	3
Waste disposal (infrastructure)	Moderate	
Ecosystem Damages	High	1
Land use requirement	Low	
Fuel use	Moderate	

11	Level of public resistance/opposition	1.8	4.6	Moderate
12	Aesthetic/functional impact	1.7	5.0	Low
13	Mortality and Morbidity	0.0	0.0	High
14	Accident fatalities	5.0	50000.0	High
15	Energy cost sensitivity to fuel price fluctuation	0.0	69.0	Moderate
16	Stability of energy generation	1.8	3.8	Moderate
17	Peak load response	10.0	70.0	Moderate
18	Market concetration on supply	2.9	3.4	Low
19	Technological maturity	2.7	4.8	Moderate
20	Market size (Domestic)	2.2	4.1	Moderate
21	Market size (Potential export)	2.6	4.0	Moderate
22	Innovative ability	2.1	4.4	Moderate

Level of public resistance/opposition	Moderate	
Aesthetic/functional impact	Low	
Mortality and Morbidity	High	2
Accident fatalities	High	4
Energy cost sensitivity to fuel price fluctuation	Moderate	
Stability of energy generation	Moderate	
Peak load response	Moderate	
Market concetration on supply	Low	
Technological maturity	Moderate	
Market size (Domestic)	Moderate	
Market size (Potential export)	Moderate	
Innovative ability	Moderate	

Rank the moderate-importance criteria. .>>>

Step 3b: Rank the evaluation criteria that are considered of moderate-importance.

Check the list of the moderate-importance criteria below, and assign their rankings specific to this grouping. Start by looking under the column 'rank moderate importance criteria'. Assign numbers, with 1 as the most important criterion, 2 as the second most important, 3 as the third most important. Note: Do not enter a number that is previously selected, and assign rankings **ONLY** to moderate-importance criteria.

	List of Criteria	Min Score	Max Score	Level of Importance	Moderate Importance Criteria	Select Moderate from the Droplist	Rank Moderate Importance Criteria
1	Levelised costs (incl. capital, o&m, fuel costs)	69.3	381.5	Moderate	Levelised costs (incl. capital, o&m, fuel costs)	Moderate	1
2	Employment generation	0.1	0.9	Moderate	Employment generation	Moderate	5
3	CO2eq emissions	4.0	753.0	High	CO2eq emissions	High	
4	Resilience to climate change	2.8	3.8	High	Resilience to climate change	High	
5	Noise	1.2	3.2	Low	Noise	Low	
6	Radioactive waste	0.0	0.0	High	Radioactive waste	High	
7	Waste disposal (infrastructure)	0.0	3.6	Moderate	Waste disposal (infrastructure)	Moderate	2
8	Ecosystem Damages	0.0	0.0	High	Ecosystem Damages	High	
9	Land use requirement	0.0	543.0	Low	Land use requirement	Low	
10	Fuel use	0.0	7.9	Moderate	Fuel use	Moderate	3

11	Level of public resistance/opposition	1.8	4.6	Moderate
12	Aesthetic/functional impact	1.7	5.0	Low
13	Mortality and Morbidity	0.0	0.0	High
14	Accident fatalities	5.0	50000.0	High
15	Energy cost sensitivity to fuel price fluctuation	0.0	69.0	Moderate
16	Stability of energy generation	1.8	3.8	Moderate
17	Peak load response	10.0	70.0	Moderate
18	Market concetration on supply	2.9	3.4	Low
19	Technological maturity	2.7	4.8	Moderate
20	Market size (Domestic)	2.2	4.1	Moderate
21	Market size (Potential export)	2.6	4.0	Moderate
22	Innovative ability	2.1	4.4	Moderate

Level of public resistance/opposition	Moderate	12
Aesthetic/functional impact	Low	
Mortality and Morbidity	High	
Accident fatalities	High	
Energy cost sensitivity to fuel price fluctuation	Moderate	4
Stability of energy generation	Moderate	9
Peak load response	Moderate	11
Market concetration on supply	Low	
Technological maturity	Moderate	6
Market size (Domestic)	Moderate	7
Market size (Potential export)	Moderate	8
Innovative ability	Moderate	10

Rank the low-importance criteria. >>>

Step 3c: Rank the evaluation criteria that are considered of low-importance.

Check the list of the low-importance criteria below, and assign their rankings specific to this grouping. Start by looking under the column 'rank low importance criteria'. Assign numbers, with 1 as the most important criterion, 2 as the second most important, 3 as the third most important. Note: Do not enter a number that is previously selected, and assign rankings **ONLY** to low-importance criteria.

	List of Criteria	Min Score	Max Score	Level of Importance
1	Levelised costs (incl. capital, o&m, fuel costs)	69.3	381.5	Moderate
2	Employment generation	0.1	0.9	Moderate
3	CO2eq emissions	4.0	753.0	High
4	Resilience to climate change	2.8	3.8	High
5	Noise	1.2	3.2	Low
6	Radioactive waste	0.0	0.0	High
7	Waste disposal (infrastructure)	0.0	3.6	Moderate
8	Ecosystem Damages	0.0	0.0	High
9	Land use requirement	0.0	543.0	Low
10	Fuel use	0.0	7.9	Moderate

Low Importance Criteria	Select LOW from the droplist	Rank LOW Importance Criteria
Levelised costs (incl. capital, o&m, fuel costs)	Moderate	
Employment generation	Moderate	
CO2eq emissions	High	
Resilience to climate change	High	
Noise	Low	3
Radioactive waste	High	
Waste disposal (infrastructure)	Moderate	
Ecosystem Damages	High	
Land use requirement	Low	2
Fuel use	Moderate	

11	Level of public resistance/opposition	1.8	4.6	Moderate
12	Aesthetic/functional impact	1.7	5.0	Low
13	Mortality and Morbidity	0.0	0.0	High
14	Accident fatalities	5.0	50000.0	High
15	Energy cost sensitivity to fuel price fluctuation	0.0	69.0	Moderate
16	Stability of energy generation	1.8	3.8	Moderate
17	Peak load response	10.0	70.0	Moderate
18	Market concetration on supply	2.9	3.4	Low
19	Technological maturity	2.7	4.8	Moderate
20	Market size (Domestic)	2.2	4.1	Moderate
21	Market size (Potential export)	2.6	4.0	Moderate
22	Innovative ability	2.1	4.4	Moderate

Level of public resistance/opposition	Moderate	
Aesthetic/functional impact	Low	4
Mortality and Morbidity	High	
Accident fatalities	High	
Energy cost sensitivity to fuel price fluctuation	Moderate	
Stability of energy generation	Moderate	
Peak load response	Moderate	
Market concetration on supply	Low	1
Technological maturity	Moderate	
Market size (Domestic)	Moderate	
Market size (Potential export)	Moderate	
Innovative ability	Moderate	

Observe the initial results. >>>

Step 3d. Check the over-all results of the initial ranking.

The outcome of the previous sub-steps, Step 3d provides you with the over-all results of the initial ranking in the weight elicitation process. Check the ranking below to check whether the results match your preferences. You can go back to the previous sub-steps to modify your preferences in order to achieve consistency as well as satisfaction with the results.

	List of Criteria	Min Score	Max Score	Level of Importance
1	Levelised costs (incl. capital, o&m, fuel costs)	69.3	381.5	Moderate
2	Employment generation	0.1	0.9	Moderate
3	CO2eq emissions	4.0	753.0	High
4	Resilience to climate change	2.8	3.8	High
5	Noise	1.2	3.2	Low
6	Radioactive waste	0.0	0.0	High
7	Waste disposal (infrastructure)	0.0	3.6	Moderate
8	Ecosystem Damages	0.0	0.0	High
9	Land use requirement	0.0	543.0	Low
10	Fuel use	0.0	7.9	Moderate

Criteria	OVERALL INITIAL RANKING OF CRITERIA
Levelised costs (incl. capital, o&m, fuel costs)	6
Employment generation	11
CO2eq emissions	6
Resilience to climate change	5
Noise	21
Radioactive waste	3
Waste disposal (infrastructure)	8
Ecosystem Damages	1
Land use requirement	20
Fuel use	9

11	Level of public resistance/opposition	1.8	4.6	Moderate
12	Aesthetic/functional impact	1.7	5.0	Low
13	Mortality and Morbidity	0.0	0.0	High
14	Accident fatalities	5.0	50000.0	High
15	Energy cost sensitivity to fuel price fluctuation	0.0	69.0	Moderate
16	Stability of energy generation	1.8	3.8	Moderate
17	Peak load response	10.0	70.0	Moderate
18	Market concetration on supply	2.9	3.4	Low
19	Technological maturity	2.7	4.8	Moderate
20	Market size (Domestic)	2.2	4.1	Moderate
21	Market size (Potential export)	2.6	4.0	Moderate
22	Innovative ability	2.1	4.4	Moderate

Level of public resistance/opposition	18
Aesthetic/functional impact	22
Mortality and Morbidity	2
Accident fatalities	4
Energy cost sensitivity to fuel price fluctuation	10
Stability of energy generation	15
Peak load response	17
Market concetration on supply	19
Technological maturity	12
Market size (Domestic)	13
Market size (Potential export)	14
Innovative ability	16

Carry out a series of pairwise comparisons. >>>

Step 4: Carry out a series of pair-wise comparisons.

At this step of the weight elicitation process, specify which criterion you prefer at each pair-wise comparison (1, 2, 3, etc.). Also, indicate verbally as well as numerically the level of your preference.
The blue horizontal bar in each pairwise comparison shows a graphical representation of your preference.

This step involves three tasks:

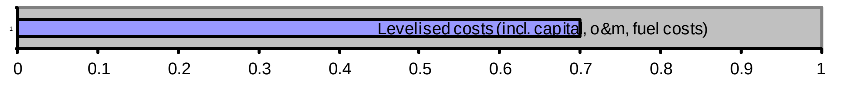
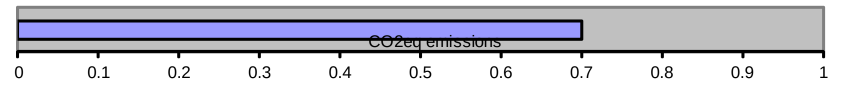
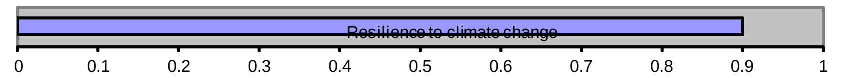
(a) Select the criterion you prefer betwen two criteria (**"Between these two criteria, which do you prefer?"**)

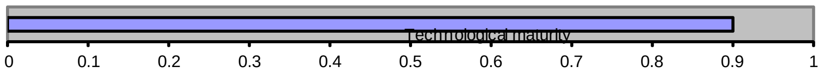
(b) Indicate *verbally* the level of your preference (**"How much?"**)

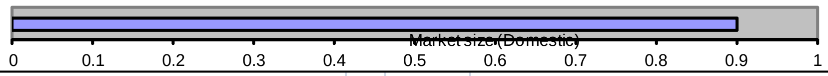
(c) Specify *numerically* the level of your preference (**"Try to score your preference!"**)

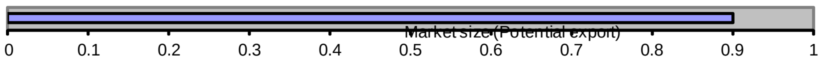
Oncer you are finished, observe the over-all results in the next sheet [Step 5].

Note: All light green cells below represent the above-mentioned tasks. Click each cell, and a dropdown menu appears. Tick the option that best suits your preference.

Order	Select the preferred criterion and indicate the level of your preference.		Try to score your preference!			
1	Levelised costs (incl. capital, o&m, fuel costs)	Employment generation	Employment generation	=	0.7	Levelised costs (incl. capital, o&m, fuel costs)
	a) Between these two criteria which do you prefer?	Levelised costs (incl. capital, o&m, fuel costs)	Levelised costs (incl. capital, o&m, fuel costs)	=	1.4	Employment generation
	b) How much?	moderately				
2	Employment generation	CO2eq emissions	Employment generation	=	0.7	CO2eq emissions
	a) Between these two criteria which do you prefer?	CO2eq emissions	CO2eq emissions	=	1.4	Employment generation
	b) How much?	moderately				
3	CO2eq emissions	Resilience to climate change	CO2eq emissions	=	0.9	Resilience to climate change
	a) Between these two criteria which do you prefer?	Resilience to climate change	Resilience to climate change	=	1.1	CO2eq emissions
	b) How much?	almost equally				

19	Technological maturity	Market size (Domestic)	Market size (Domestic)	=	0.9	Technological maturity
	a) Between these two criteria which do you prefer?	Technological maturity	Technological maturity	=	1.1	Market size (Domestic)
	b) How much?	almost equally				

20	Market size (Domestic)	Market size (Potential export)	Market size (Potential export)	=	0.9	Market size (Domestic)
	a) Between these two criteria which do you prefer?	Market size (Domestic)	Market size (Domestic)	=	1.1	Market size (Potential export)
	b) How much?	almost equally				

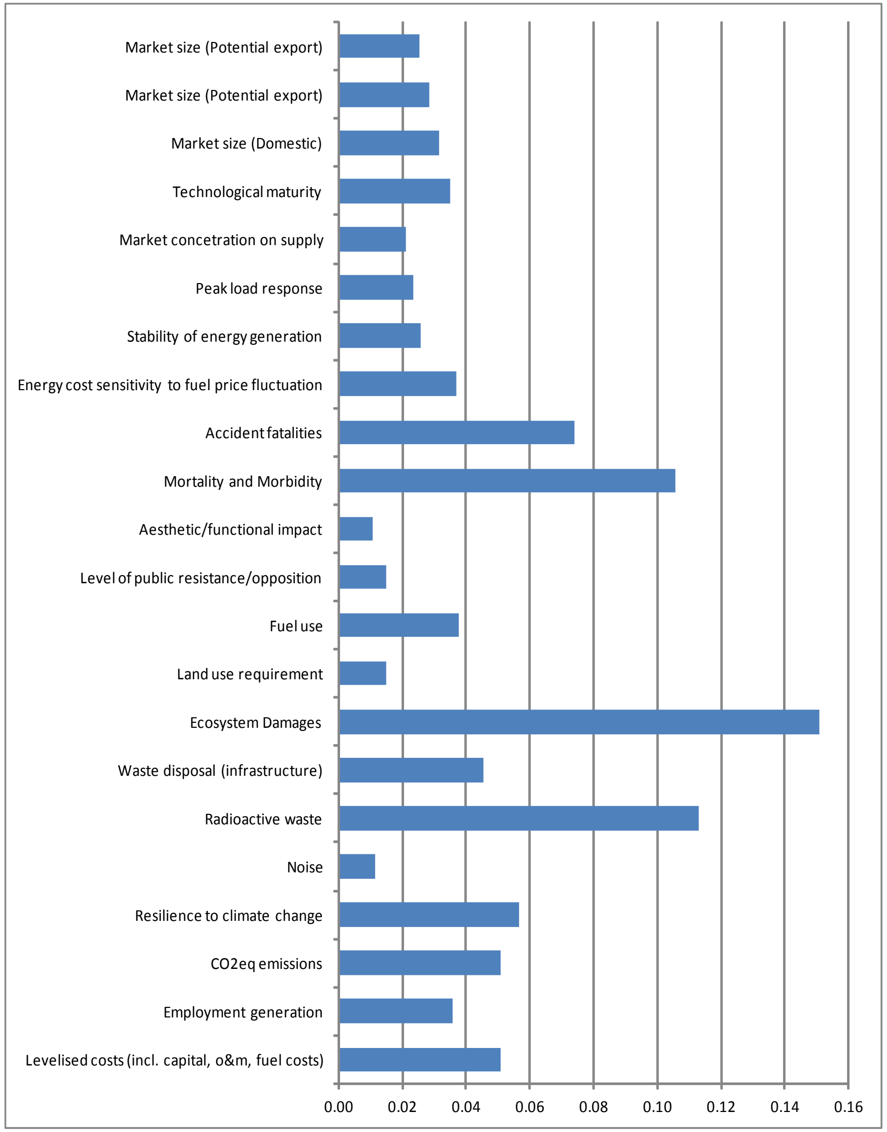
21	Market size (Potential export)	Innovative ability	Innovative ability	=	0.9	Market size (Potential export)
	a) Between these two criteria which do you prefer?	Market size (Potential export)	Market size (Potential export)	=	1.1	Innovative ability
	b) How much?	almost equally				

Observe the overall results. >>>

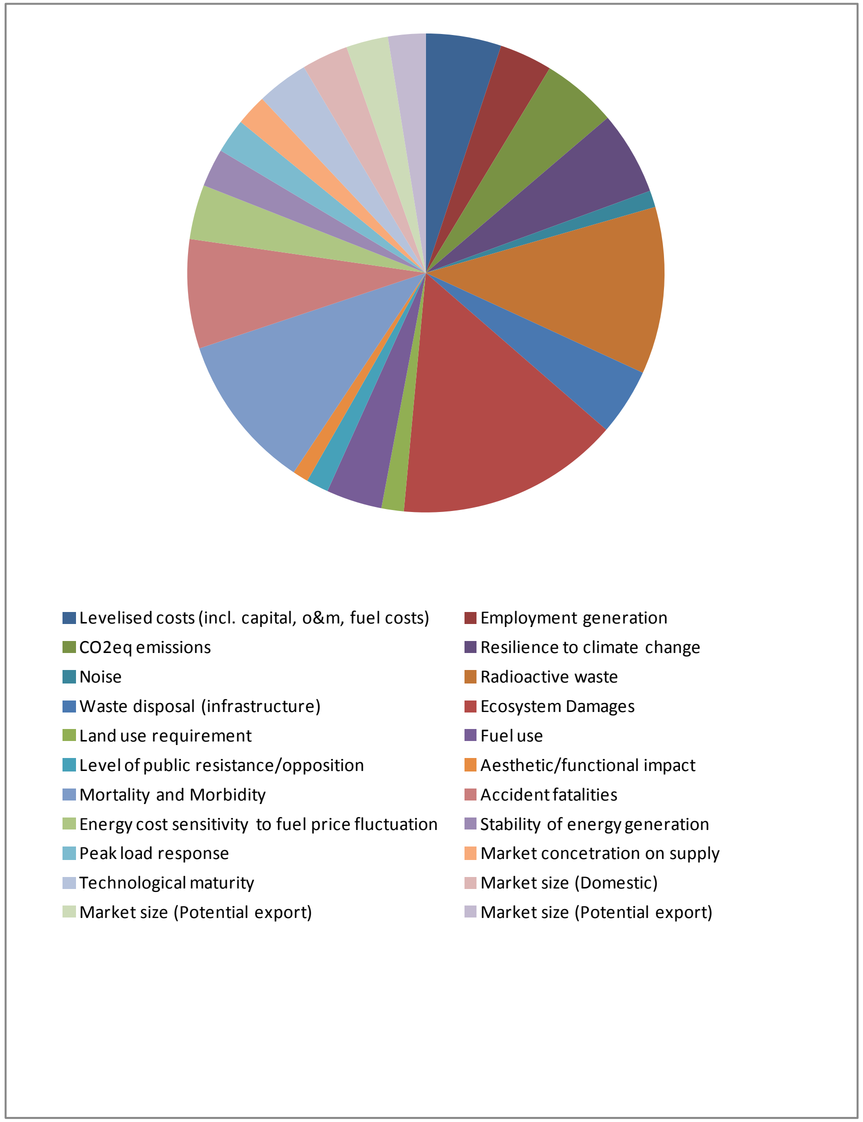
Step 5: Observe the over-all results based on your preferences.

Observe the over-all rankings, including the weighting factors, of the different evaluation criteria under investigation. Also, check the graphic representation of the criteria weights.

	Criteria	Relative Scores	Weighting Factors	RANK (based on pairwise comparisons)
1	Levelised costs (incl. capital, o&m, fuel costs)	1	0.05	6
2	Employment generation	0.7	0.04	11
3	CO2eq emissions	1.0	0.05	6
4	Resilience to climate change	1.1	0.06	5
5	Noise	0.2	0.01	21
6	Radioactive waste	2.2	0.11	2
7	Waste disposal (infrastructure)	0.9	0.05	8
8	Ecosystem Damages	3.0	0.15	1
9	Land use requirement	0.3	0.02	19
10	Fuel use	0.7	0.04	9
11	Level of public resistance/opposition	0.3	0.02	19
12	Aesthetic/functional impact	0.2	0.01	22
13	Mortality and Morbidity	2.1	0.11	3
14	Accident fatalities	1.5	0.07	4
15	Energy cost sensitivity to fuel price fluctuation	0.7	0.04	10



15	**Energy cost sensitivity to fuel price fluctuation**		0.7		**0.04**	**10**
16	**Stability of energy generation**		0.5		**0.03**	**15**
17	**Peak load response**		0.5		**0.02**	**17**
18	**Market concetration on supply**		0.4		**0.02**	**18**
19	**Technological maturity**		0.7		**0.03**	**12**
20	**Market size (Domestic)**		0.6		**0.03**	**13**
21	**Market size (Potential export)**		0.6		**0.03**	**14**
22	**Market size (Potential export)**		0.5		**0.03**	**16**



Go to the next sheet "OVERALL RESULTS"

Step 6: Check the Consistency Index

Study the index below to to check the consistency of your preferences. A remark at the bottom of the table would indicate whether you need to modify your preferences to achieve consistency or not. If you find inconsisteny, go back to either Step 3 or Step 4 and modify your preferences. Should you have any questions about the consistency index, please do not hesitate to contact us through our email addresses.

Constistency Check

Criteria	Initial Rank	Final Rank
Levelised costs (incl. capital, o&m, fuel costs)	6	6
Employment generation	11	11
CO2eq emissions	6	6
Resilience to climate change	5	5
Noise	21	21
Radioactive waste	3	2
Waste disposal (infrastructure)	8	8
Ecosystem Damages	1	1
Land use requirement	20	19
Fuel use	9	9
Level of public resistance/opposition	18	19
Aesthetic/functional impact	22	22
Mortality and Morbidity	2	3
Accident fatalities	4	4
Energy cost sensitivity to fuel price fluctuation	10	10
Stability of energy generation	15	16
Peak load response	17	17
Market concetration on supply	19	18
Technological maturity	12	12
Market size (Domestic)	13	13
Market size (Potential export)	14	15
Innovative ability	16	13

Ranking Consistency Index		
0.992	High consistency	Go to the next step

Go to the last page of the survey. >>>

Survey Evaluation

THANK YOU very much for your participation in this survey.

Once this survey is completed, we could share with you the **results**.

Should you wish to receive **written reports of the study**, please provide your **email address** below:

____

Lastly, we will highly appreciate it if you could provide us with **feedback** regarding our survey.

Evaluation questions			CLICK on the cells of this column for your answers
Question No 1	:	**Which method do you think that displays more accurately your preferences, initial ranking or pairwise comparisons?**	**initial ranking**
Question No 2	:	**Which is the level of your satisfaction by the use of this weighting method concerning:**	
a)	:	**the provision of the background information**	**moderate**
b)	:	**the ease of filling in the questionnaire**	**moderate**
c)	:	**the correspondence between the obtained weights and your actual preferences**	**high**
d)	:	**the speed of introducing and processing the required information**	**low**

Comments	:	
Question No 3	: Please, indicate how much time (minutes) you needed to complete all steps of the weighting method:	
Question No 4	: Did you face any difficulties by using this method?	
	If YES, indicate at which part (s):	
Other comments	:	

THANK YOU very much for your time and participation!

Sincerely,

Elena Marie Enseñado and Stelios Grafakos
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Annex 10: Assessment tool for the low-carbon energy technologies

Impact Assessment Matrix

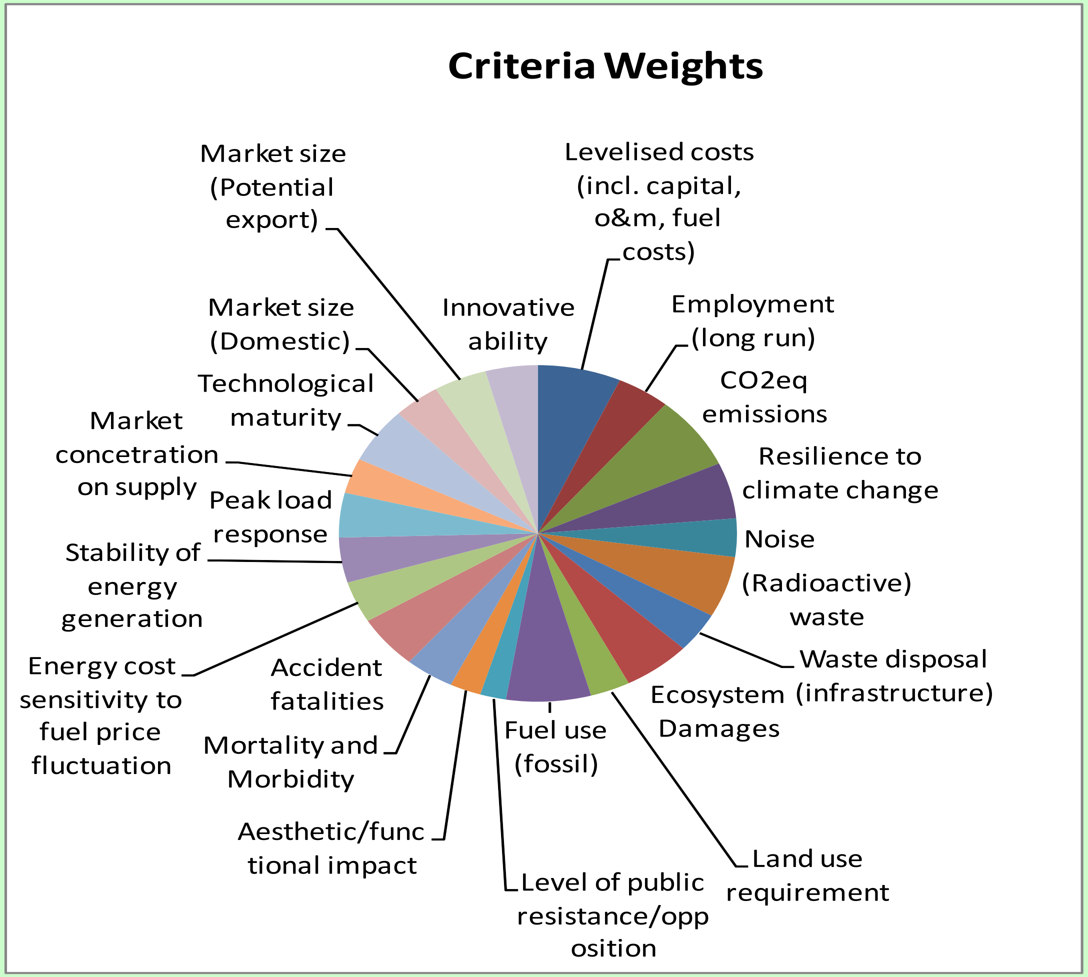
Options/Criteria	Levelised costs (incl. capital, o&m, fuel costs)	Employment (long run)	CO2eq emissions	Resilience to climate change	Noise	(Radioactive) waste	Waste disposal (infrastructure)	Ecosystem Damages	Land use requirement	Fuel use (fossil)	Level of public resistance/opposition	Aesthetic/functional impact	Mortality and Morbidity	Accident fatalities	Energy cost sensitivity to fuel price fluctuation	Stability of energy generation	Peak load response	Market concetration on supply	Technological maturity	Market size (Domestic)	Market size (Potential export)	Innovative ability
Scale units	euros/Mwh	Jobs -	g/kwh	"1-5"	"1-5"	m3/kwh	"1 - 5"	PDF*m2*a/	km2/TW	Mj/kwh	"1-5"	"1-5"	YoLL/kWh	deaths	%	"1-5"	%	"1-5"	"1-5"	"1-5"	"1-5"	"1-5"
	-1	1	-1	1	-1	-1	1	-1	-1	-1	-1	1	-1	-1	-1	-1	1	-1	1	1	1	1
	Min	Max	Min	Max	Min	Min	Max	Min	Min	Min	Min	Max	Min	Min	Min	Min	Max	Min	Max	Max	Max	Max
Integrated Gasification Combined Cycle (IGCC)	-100	0.110	-753	2.8	-3.2	0.00000	2.3	0	-9.7	-6.90	-3.41	3.70	0.00	-434	-53	-1.80	70.00	-3.29	3.78	2.75	3.00	2.33
Gas Turbine Combined Cycle (GTCC)	-79	0.110	-388	3.1	-2.1	0.00000	1.7	0	-18.6	-6.79	-2.88	3.03	0.00	-109	-69	-1.90	70.00	-3.19	4.40	3.72	3.50	2.85
Nuclear European Pressurized Reactor (EPR)	-69	0.140	-4	3.0	-1.9	0.00000	3.6	0	-2.4	-0.07	-4.61	3.54	0.00	-50000	-5	-2.08	10.00	-3.39	3.43	2.23	2.80	2.71
Wind on-shore	-107	0.170	-16	3.5	-2.7	0.00000	1.7	0	-72.1	-0.06	-3.14	3.00	0.00	-5	0	-3.83	10.00	-2.90	4.38	4.06	3.81	3.39
Wind off - shore	-140	0.170	-10	3.5	-1.4	0.00000	1.9	0	0.0	-0.05	-2.27	5.00	0.00	-10	0	-3.48	10.00	-2.87	3.88	4.11	4.00	3.76
Solar Photovoltaics (PV)	-382	0.870	-30	3.8	-1.2	0.00000	1.7	0	-37.0	-0.14	-1.78	2.53	0.00	-10	0	-3.75	10.00	-2.88	4.15	4.11	3.78	4.39
Hydropower (Storage Dam)	-105	0.270	-4	3.5	-1.6	0.00000	1.4	0	-54.0	0.00	-3.18	3.50	0.00	-285	0	-2.44	10.00	-3.25	4.75	3.17	3.06	2.06
Integrated Gasification	-105	0.180	-205	3.1	-2.8	0.00000	3.5	0	-9.7	-7.87	-3.63	2.85	0.00	-434	-47	-1.88	70.00	-3.17	2.73	2.69	2.58	3.56
Gas Turbine Combined Cyc	-88	0.180	-120	3.1	-2.8	0.00000	3.5	0	-18.6	-7.44	-3.45	3.18	0.00	-109	-55	-1.93	70.00	-3.17	2.85	2.89	2.77	3.56
Biomass CHP (waste wheat,	-245	0.210	-37	3.3	-1.9	0.00000	0.0	0	-543.0	-0.11	-2.16	1.70	0.00	-5	-22	-2.45	10.00	-3.20	4.03	3.67	3.39	3.30

Normalized Scores

Options	Levelised costs (incl. capital, o&m, fuel	Employment (long run)	CO2eq emissions	Resilience to climate change	Noise	(Radioactive) waste	Waste disposal (infrastructure)	Ecosystem Damages	Land use requirement	Fuel use (fossil)	Level of public resistance/opposit	Aesthetic/functional impact	Mortality and Morbidity	Accident fatalities	Energy cost sensitivity to fuel	Stability of energy generati	Peak load response	Market concetration on supply	Technological maturity	Market size (Domestic)	Market size (Potential export)	Innovative ability
Integrated Gasification Combined Cycle (IGCC)	0.902	0.00	0.00	0.00	1.00	0.95	0.63	0.65	0.98	0.12	0.58	0.61	0.16	0.99	0.23	0.00	1.00	0.81	0.52	0.28	0.29	0.12
Gas Turbine Combined Cycle (GTCC)	0.969	0.00	0.49	0.29	0.44	1.00	0.45	0.92	0.97	0.14	0.39	0.40	0.15	1.00	0.00	0.05	1.00	0.62	0.83	0.79	0.65	0.34
Nuclear European Pressurized Reactor (EPR)	1.000	0.04	1.00	0.24	0.34	0.00	1.00	0.99	1.00	0.99	1.00	0.56	0.96	0.00	0.93	0.14	0.00	1.00	0.35	0.00	0.15	0.28
Wind on-shore	0.879	0.08	0.98	0.78	0.72	1.00	0.46	0.92	0.87	0.99	0.48	0.39	0.94	1.00	1.00	1.00	0.00	0.06	0.81	0.97	0.86	0.57
Wind off - shore	0.773	0.08	0.99	0.77	0.12	1.00	0.52	0.92	1.00	0.99	0.17	1.00	0.95	1.00	1.00	0.83	0.00	0.00	0.57	1.00	1.00	0.73
Solar Photovoltaics (PV)	0.000	1.00	0.97	1.00	0.00	0.99	0.47	0.86	0.93	0.98	0.00	0.25	0.88	1.00	1.00	0.96	0.00	0.02	0.70	1.00	0.84	1.00
Hydropower (Storage Dam)	0.886	0.21	1.00	0.75	0.19	1.00	0.37	1.00	0.90	1.00	0.49	0.55	1.00	0.99	1.00	0.31	0.00	0.73	1.00	0.50	0.33	0.00
Integrated Gasification Combined Cycle (IGCC with CCS	0.884	0.09	0.73	0.29	0.76	0.94	0.95	0.41	0.98	0.00	0.65	0.35	0.29	0.99	0.32	0.04	1.00	0.58	0.00	0.24	0.00	0.64
Gas Turbine Combin	0.941	0.09	0.85	0.36	0.76	0.96	0.95	0.89	0.97	0.05	0.59	0.45	0.00	1.00	0.20	0.06	1.00	0.58	0.06	0.35	0.13	0.64
Biomass CHP (waste	0.438	0.13	0.96	0.52	0.37	0.97	0.00	0.00	0.00	0.99	0.14	0.00	0.84	1.00	0.68	0.32	0.00	0.63	0.64	0.76	0.57	0.53

Criteria Weighting

Category of Criteria	Criteria	Weights
Economic	Levelised costs (incl. capital, o&m, fuel costs)	6.8%
Economic	Employment (long run)	4.3%
Environmental	CO2eq emissions	7.1%
Environmental	Resilience to climate change	5.4%
Environmental	Noise	3.7%
Environmental	(Radioactive) waste	5.8%
Environmental	Waste disposal (infrastructure)	3.9%
Environmental	Ecosystem Damages	5.5%
Environmental	Land use requirement	3.2%
Environmental	Fuel use (fossil)	6.9%
Social	Level of public resistance/opposition	2.1%
Social	Aesthetic/functional impact	2.5%
Social	Mortality and Morbidity	4.0%
Social	Accident fatalities	5.1%
Energy	Energy cost sensitivity to fuel price fluctuation	4.0%
Energy	Stability of energy generation	4.3%
Energy	Peak load response	4.3%
Energy	Market concetration on supply	3.4%
Technology	Technological maturity	5.4%
Technology	Market size (Domestic)	3.8%
Technology	Market size (Potential export)	4.3%
Technology	Innovative ability	4.3%



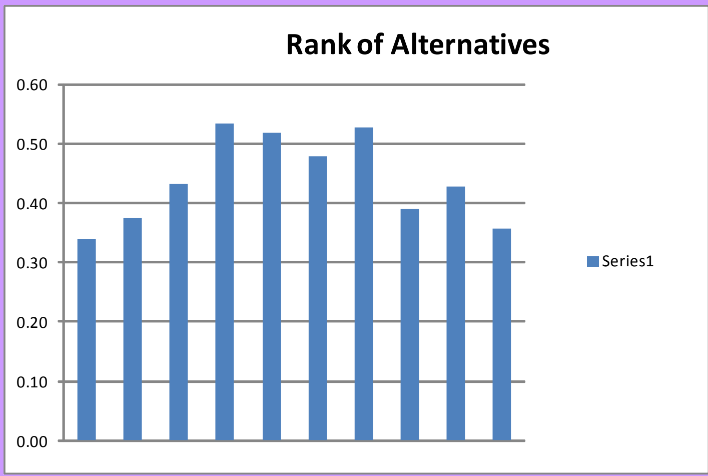
Weighted Scores

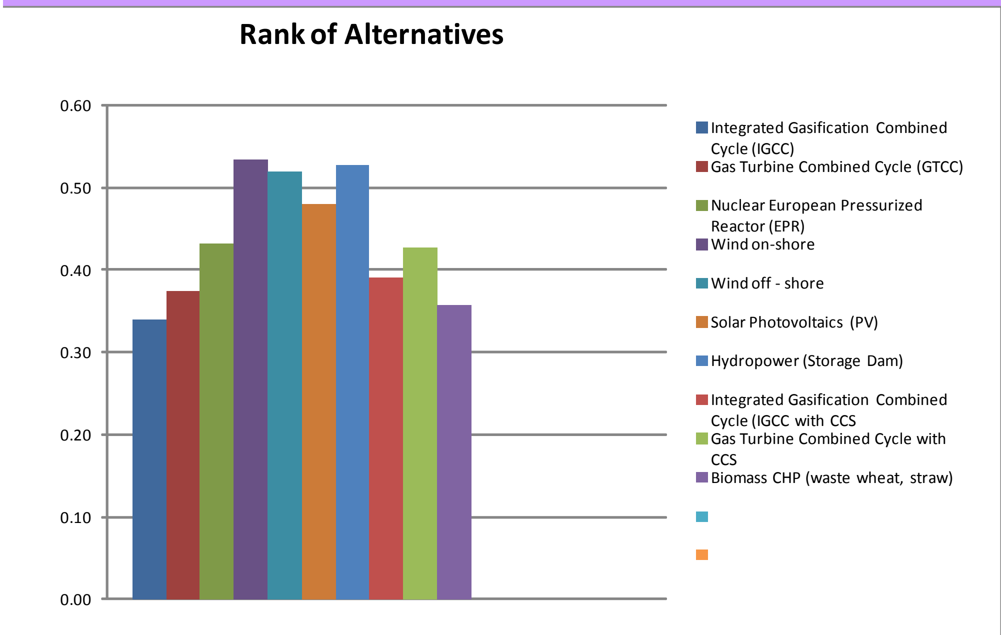
Final Score	Technologies	Levelised costs (incl. capital, o&m, fuel costs)	Employment (long run)	CO2eq emissions	Resilience to climate change	Noise	(Radioactive) waste	Waste disposal (infrastructure)	Ecosystem Damages	Land use requirement	Fuel use (fossil)	Level of public resistance/ opposition	Aesthetic /functional impact	Mortality and Morbidity	Accident fatalities	Energy cost sensitivity to fuel price	Stability of energy generation	Peak load response	Market concetration on supply	Technological maturity	Market size (Domestic)	Market size (Potential export)	Innovative ability
	Weights	6.8%	4.3%	7.1%	5.4%	3.7%	5.8%	3.9%	5.5%	3.2%	6.9%	2.1%	2.5%	4.0%	5.1%	4.0%	4.3%	4.3%	3.4%	5.4%	3.8%	4.3%	4.3%
0.34	Integrated Gasificatio	0.06	0.00	0.00	0.00	0.04	0.06	0.02	0.04	0.03	0.01	0.01	0.02	0.01	0.05	0.01	0.00	0.04	0.03	0.03	0.01	0.01	0.00
0.37	Gas Turbine Combin	0.07	0.00	0.03	0.02	0.02	0.06	0.02	0.05	0.03	0.01	0.01	0.01	0.01	0.05	0.00	0.00	0.04	0.02	0.04	0.03	0.03	0.01
0.43	Nuclear European Pr	0.07	0.00	0.07	0.01	0.01	0.00	0.04	0.05	0.03	0.07	0.02	0.01	0.04	0.00	0.04	0.01	0.00	0.03	0.02	0.00	0.01	0.01
0.53	Wind on-shore	0.06	0.00	0.07	0.04	0.03	0.06	0.02	0.05	0.03	0.07	0.01	0.01	0.04	0.05	0.04	0.04	0.00	0.00	0.04	0.04	0.04	0.02
0.52	Wind off - shore	0.05	0.00	0.07	0.04	0.00	0.06	0.02	0.05	0.03	0.07	0.00	0.03	0.04	0.05	0.04	0.04	0.00	0.00	0.03	0.04	0.04	0.03
0.48	Solar Photovoltaics (	0.00	0.04	0.07	0.05	0.00	0.06	0.02	0.05	0.03	0.07	0.00	0.01	0.03	0.05	0.04	0.04	0.00	0.00	0.04	0.04	0.04	0.04
0.53	Hydropower (Storage	0.06	0.01	0.07	0.04	0.01	0.06	0.01	0.05	0.03	0.07	0.01	0.01	0.04	0.05	0.04	0.01	0.00	0.02	0.05	0.02	0.01	0.00
0.39	Integrated Gasificatio	0.06	0.00	0.05	0.02	0.03	0.06	0.04	0.02	0.03	0.00	0.01	0.01	0.01	0.05	0.01	0.00	0.04	0.02	0.00	0.01	0.00	0.03
0.43	Gas Turbine Combin	0.06	0.00	0.06	0.02	0.03	0.06	0.04	0.05	0.03	0.00	0.01	0.01	0.00	0.05	0.01	0.00	0.04	0.02	0.00	0.01	0.01	0.03
0.36	Biomass CHP (waste	0.03	0.01	0.07	0.03	0.01	0.06	0.00	0.00	0.00	0.07	0.00	0.00	0.03	0.05	0.03	0.01	0.00	0.02	0.03	0.03	0.02	0.02

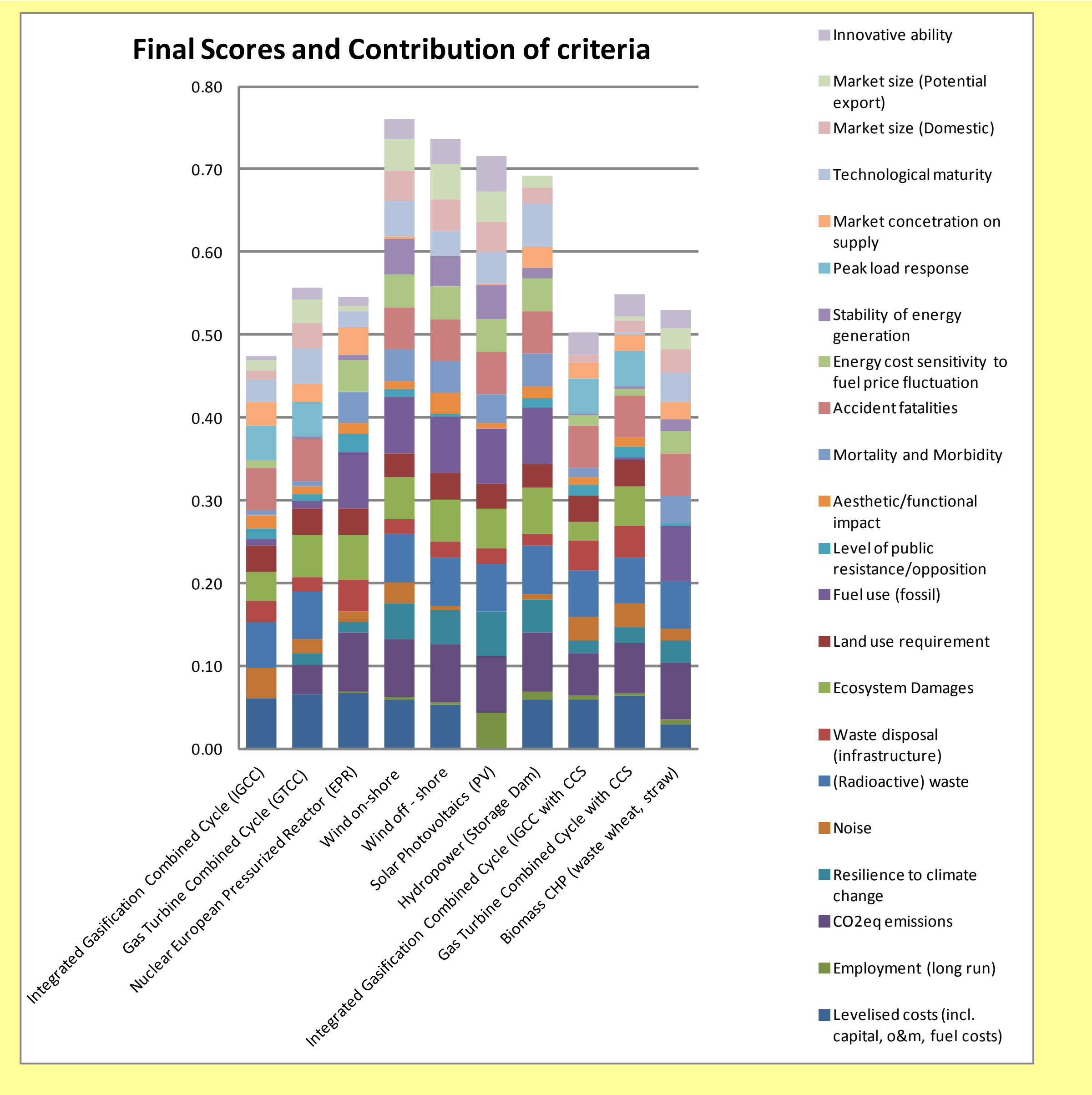
Equal weights results

Options	Score	Rank
Integrated Gasification Comb	0.34	10
Gas Turbine Combined Cycle	0.37	8
Nuclear European Pressurize	0.43	5
Wind on-shore	0.53	1
Wind off - shore	0.52	3
Solar Photovoltaics (PV)	0.48	4
Hydropower (Storage Dam)	0.53	2
Integrated Gasification Comb	0.39	7
Gas Turbine Combined Cycle	0.43	6
Biomass CHP (waste wheat,	0.36	9

CLEAR






Final Scores and Contribution of criteria
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Integrated Gasification Combined Cycle (IGCC)
Gas Turbine Combined Cycle (GTCC)
Nuclear European Pressurized Reactor (EPR)
Wind on-shore
Wind off - shore
Solar Photovoltaics (PV)
Hydropower (Storage Dam)
Integrated Gasification Combined Cycle (IGCC with CCS
Gas Turbine Combined Cycle with CCS
Biomass CHP (waste wheat, straw)
Innovative ability
Market size (Potential export)
Market size (Domestic)
Technological maturity
Market concetration on supply
Peak load response
Stability of energy generation
Energy cost sensitivity to fuel price fluctuation
Accident fatalities
Mortality and Morbidity
Aesthetic/functional impact
Level of public resistance/opposition
Fuel use (fossil)
Land use requirement
Ecosystem Damages
Waste disposal (infrastructure)
(Radioactive) waste
Noise
Resilience to climate change
CO2eq emissions
Employment (long run)
Levelised costs (incl. capital, o&m, fuel costs)

Schedule

Activities	Time Frame
1. Conduct of desk study	June 11 – July 22, 2013
2. Preparation of draft questionnaire (Refinement of Criteria)	June 11 - 20, 2013
3. Distribution of survey questionnaire (Refinement of Criteria)	June 21, 2013
4. Completion of survey (Refinement of Criteria)	July 1, 2013
5. Adjustment of criteria and indicators	July 2 – 4, 2013
6. Preparation of draft questionnaire (Elicitation of Preference)	June 21 – July 4, 2013
7. Distribution of survey questionnaire (Elicitation of Preference)	July 5, 2013
8. Completion of survey (Elicitation of Preference)	July 22, 2013