ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Technology Assessment of Two Energy Portfolios Using with a Hierarchical Decision Model

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Abstract

Nations take great interest in their energy policy as it ensures the quality of life for its people and also has a major impact on their economy. Within the context of the European Union, many benchmarks have been set in terms of increasing the use of renewable energy sources, but this alone is not adequate in providing base-load electricity supply. Member nations have chosen to go in different directions in addressing this issue based on factors such as political, economic and technological issues. Two nations that represent the vast extremes of national energy mix are France and Germany. France, due to low fossil fuel reserves, has chosen to develop and rely on nuclear energy as its primary source. Germany, on the other hand, has gone the way of renewable sources but still relies heavily on coal.

The search for a technical assessment regarding these countries and their energy mix proved unsuccessful, but developing a Hierarchical Decision Model could prove to be beneficial for energy departments. It was thought a model could be built using the available information regarding the various energy mixes of the countries. Using the technologies as alternatives, and determining the criteria which each satisfied, a model was developed to show what each nation weighted as high importance.

The study showed a couple results. First was that social/political factors were overwhelmingly low importance. It was also found to not completely reflect the countries' portfolios, suggesting more research must be done to refine and extend the model. Also, experts need to be consulted and areas such as public opinion need to be quantified. Ultimately, the model developed could help nations around the globe assess their needs and develop an energy mix suited to those needs.

Introduction

The research goal of this project was to identify the selection criteria of energy technologies for countries in the European Union. The work focused on technologies used to generate electrical energy. Other energy needs for transportation, heating, and manufacturing were not evaluated in this effort.

Countries within the EU have a mix of energy types including base-load and intermittent generation. The entire mix for a country or region is creates an energy portfolio. Often countries establish specific targets within their portfolios to emphasize societal goals. One common target is the percentage of renewable energies in a portfolio.

The countries of France and Germany have vastly different energy portfolios and have also developed different core competencies within the energy sector. In this paper we will use France and Germany to highlight what planning and assessment was used to create their unique portfolios.

Technology assessments offer insight about costs and benefits of individual technologies. These assessments become key inputs to selection of specific technologies and defining appropriate implementation strategies. This research has identified that Germany and France don't have multi-perspective assessments readily available. Lacking other evidence to measure and evaluate energy technology, a methodology was developed using a Hierarchal Decision Model. This is described in detail in the "building a model" portion of this document.

Energy portfolios

An energy portfolio is simply the breakdown of energy by source for a given country (or region). The portfolio may contain several energy technologies including renewable and non-renewable. It is the specific breakdown of technologies within the portfolio that is the topic of this paper and will be discussed further. An energy portfolio is filled or modified based on the goals of the individual country. Several factors are used to measure the cost versus benefits of selecting a particular energy source. Trade offs should be identified before making final determination of portfolio targets.

Base-load Energy -These are power plants dedicated to supplying a majority of a region's needs. Base-load plants have predictable outputs and low cost production compared with other energy sources [1].

Intermittent Energy - Energy sources that have significant deviations in the level of power produced. Most often these use renewable resources such as wind, sun, waves, etc. The fluctuations in output can cause premature wear and tear on the adjacent transmission elements used to control voltage. Many renewable energy sources produce intermittent power.

Energy Technologies

Energy portfolios can contain many types of technologies. For the sake of this review only established technologies are considered. Those include "conventional" coal, natural gas, nuclear, geothermal, hydro, solar and wind energy.

Coal

These generation plants use burning coal to create steam to turn a turbine which turns a generator. This type of generation is a form of base-load, thermal generation. The fuel is harvested from mines and transported to the generation site. Coal tends to be one of the least expensive fuels, but the air emissions present challenges with filtration [2].

Natural Gas

These are base load thermal plants that burn natural gas to turn a combustion turbine (CT). Relative to the coal plants emissions the CTs are much cleaner. Plants tend to be located near main gas lines, and are very exposed to resource availability leading to price volatility. Some versions of these plants are considered combined cycle plants that have one or two gas turbines feeding the still hot exhaust into a steam turbine. This captures heat that would otherwise just be vented to the atmosphere [3].

Nuclear
Nuclear power is considered any energy created from a controlled atomic reaction. Currently the only form of nuclear energy available is nuclear fission (splitting of atoms). Basic reactor design involves using a fissile material (usually uranium) in the form of pellets stacked in rods, to be lowered into a liquid medium. The medium will absorb heat from the reaction. This is a closed loop process with heat transferred to a steam turbine. The airborne emissions from nuclear power plants are very low compared with other base-load power plants. Nuclear waste is the result of spent fuel in the plant. This technology is affected more by social perceptions than by facts [4].

Geothermal
This technology uses the heat from the earth to create electricity. The heat can come from hot water or rock within the earth's crust. Geothermal is a renewable energy with minimal environmental impacts. Unfortunately, because of the cost for this technology, the number of quality geothermal sites is limited [5].

Hydropower
Water channeled through pipes turns electric turbans. The water source is typically held behind dams that increase the height of the water column, thereby increasing the force the water has on the turban blades. Hydropower is a renewable, mature technology, but requires a free flowing water source. Additionally the net change to the environment (from project sitting) is difficult to quantify. This can be used as base load generation or load following. The cost electricity from this technology is relatively cheap, but depending upon the location fuel can become limited in drought conditions. Additional constraints limit the use of this technology including: biological impacts, recreational needs of water supply, river flow requirements, and treaty issues if the water supply spans international borders [6].

Solar
Photovoltaic (PV) energy uses light from the sun to generate electricity. Applications vary from residential roof tops (1kW to 10kW) to utility applications that are greater than 1 MW. This is a renewable energy source, but can be affected by changes in lighting conditions. This can cause the output of the units to be intermittent. Another form of solar energy is the use of solar concentrators. This uses light to concentrate on a point where water is then heated. This becomes a modern steam turbine. Solar is relatively expensive compared to other energy sources, and currently needs subsidies to become cost competitive [7].

Wind
Windmills have been used to grind grain, pump water, charge batteries and generate electricity. This represents one of the cheapest renewable energies, but must be located on sites where the wind has some level of consistency. Often the best wind sites are located in remote portions of the electric system and can only connect to the lower voltage facilities. This can play havoc with voltage regulators and voltage sensitive industries. Wind has also been subsidized, but because of the maturity of the technology it has become more cost effective than in the past [8].

Energy policy

The following section provides an overview of the energy policies of France and Germany. While these two countries each have their own policies and goals because both countries are in the European Union (EU) it is useful to consider the overall policy of the region. The European energy policy is introduced, providing the framework for both countries' approach. The European Union itself follows specific rules and directions when dealing with energy, which are stated and explained. Furthermore, each country is discussed individually, identifying critical issues that impact energy decisions.

The European Union

Today around the world there is growing concern about climate change associated with increased greenhouse gas (GHG) emissions. Some have argued that recent weather events such as Hurricane Katrina, the heat wave in Europe, and the droughts and wildfires in Australia are signs of the climate change [9, 10]. There are also those who argue that the climate change is caused by the release of GHG emissions. This theory was testified by James Hansen, who is a NASA scientist, in 1988 [11]. Due to concerns about GHG's, the EU is focusing in energy technologies that reduce. To emphasize this direction many industrialized countries including the EU's member states signed the Kyoto Protocol, the international environment law, in Kyoto, Japan on December 11, 1997. The critical features of the Kyoto Protocol are to prevent climate change, reduce greenhouse gas (GHG) emissions and accelerate using renewable energies [9, 11].

Energy security is also an important concern for all countries. The susceptibility of the energy market to volatile imported fuel prices is concerning. A recent example of this type of issue occurred in January 2009 when Russia shut off one of its gas pipelines into Europe. The line was shut off because of dispute with Ukraine however it raised concerns in countries including Germany and France regarding the reliability of energy supply [12]. The EU and its member countries have to consider energy security when setting energy policy.

The EU has established several strategies to lead their member state countries towards the goal of reduced emissions. Energy from renewable technologies is encouraged because they reduce the emissions of GHG's and because they lessen the reliance fuels with volatile prices. Moreover, these technologies can help to create the new jobs and improve the economy [13].

The commission of the European communities has laid out a vision with four major components to achieve the strategies of energy security and sustainability for energy future. First, the efficient conversion and use of energy is very important in all sectors, which are electricity, heating and cooling, transport. Second, the multiple types of energy resources can increase energy security. Third, to use diversified fuels for the transport system will reduce greenhouse gas (GHG) emissions. Finally, the mutuality and flexibility of energy system can help to provide efficient service network [14].
According to the road map of the European Council (EC), they set up a prolonged goal to accept the strategic goal for Renewable Sources of Energy (RSE) at 20% of energy for final consumption by 2020. Also, it took a target to reduce fossil energy such as oil

and coal which can make greenhouse gas (GHG) by 20% under planned levels by 2020. The purposes of the European Commission are that all member states should try hard to achieve certain level for renewable energy resources. Also, the EC suggested a goal for renewable energy which is connected final energy consumption. Biofuels will be one of the renewable energy resources to use for transportation more than 10% increasing of the total fuel consumption of petrol and diesel by 2020 [15, 16, 17].

1. The strategies of renewable energies

For the purpose of the increasing security of supply and reducing greenhouse gas (GHG) emission, the European Union encouraged using the renewable energies to the member states. And they established several important principles for the future renewable energy policy.

- To set up the required and stabilized long term goals.
- To make flexible goals to deal with the state of reality.
- To be understanding heating and cooling.
- To keep up to develop the renewable energy technology.
- To take into deliberation environmental and social view
- To guarantee producing optimum results for the expenditure of policies
- To be capable of existing in harmony with the internal energy market

The main policy of the renewable energies in the overall EU is reducing greenhouse gas (GHG) emission since the 1990s. The EU has tried to promote using renewable energy with specific policies or technology programs such as the consumption of renewable energies would increase a 12% by 2020 from 1997 or under sector-specific legislation like the biofuels and renewable electricity directives [12].

2. The two critical support systems

In the all EU member states, there are two major support systems that is the feed-in tariff (FiT) system and the tradable green certificate (TGC) system for urging to use renewable energies. First, the feed-in tariff (FiT) system which is adopted by many countries in the EU can support sellers who have any kind of generator of renewable electricity to sell their product at a fixed tariff for a specified time period with several conditions relying on place and technology. The producer for the reward of producing of the renewable energy electricity can receive a determined price to follow the electricity market price. The representative countries are Germany, Spain and Denmark.
On the other hand, the tradable green certificate (TGC) is very useful support system in United Kingdom, Italy, Belgium and Poland. It designs to set out a fixed minimum quantity of certificates that originate per MWh of renewable energy electricity generated each year between generator and consumer. Furthermore, in the quota system, the renewable energy producer can get extra financial benefit from the electricity market. This means that the goal of renewable energy in the TGC system is set by the government and the certificate price is determined by the market [15].

3. Assessment of the influence of achieving the goal for renewable energies

There are several elements of the influence assessment such as impact on greenhouse gas (GHG) emissions, environment impacts, energy supply security and cost.

- Greenhouse gas emission and other environment impacts

In March 10, 2005, the European Council decided that the overall EU member states should have to reduce greenhouse gas (GHG) emissions under 15-30% compared to the 1990 by the Kyoto Protocol. Therefore, the EU set out the target to increase renewable energies which can make low or zero greenhouse gas (GHG) emission. Furthermore, reducing fossil fuels can make decreasing CO_2 and air pollution which are positive effects for the environment of the Earth [12].

- Energy supply security

Most of member states in the EU depend on the imported energy resources. That's why the security of energy supply is the most important item of assessment because it strongly affects the price of energy and political stability. Renewable energy helps to reduce the risk of the security of energy supply by raising the quantitative produced energy, diversifying the fuel type, diversifying the imported energy sources and possessing energy from political stable countries [12].

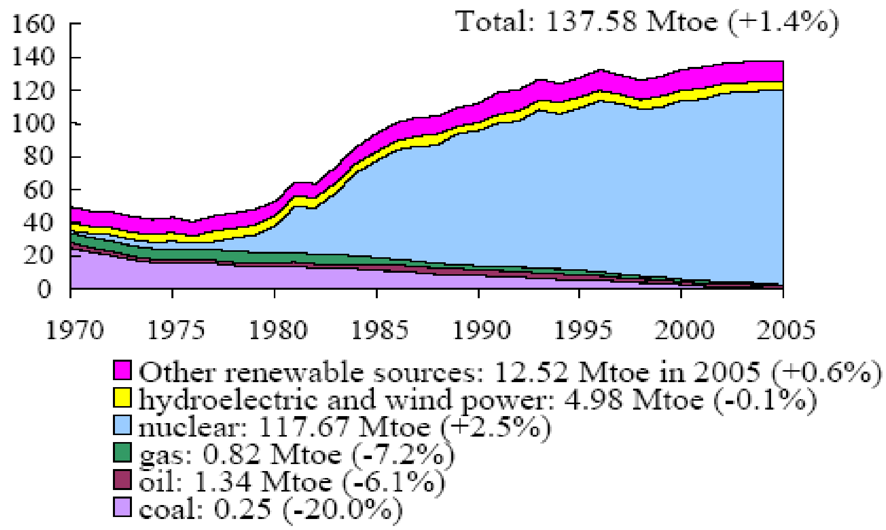
- Cost

Over the last 20 years, the cost of renewable energy is reducing rather than conventional energy sources. For instance, the price of wind energy has decreased by 50% over the last 15 years and solar photovoltaics are cheaper than their cost in 1990 more than 60%. However, the cost of renewable energies is still expensive more than the conventional energy sources and alters by the resources base and technologies [12].

France

A wide range of energy technologies exist in the European nation, and member nations have vastly different energy portfolios. This vast extreme is represented well when comparing France and Germany. France's portfolio is heavily dependant on nuclear reactors for electricity, and has also incorporated renewable sources such as hydroelectric and wood energy [18]. In the early to mid-seventies, France relied heavily on external sources for oil, which was a large part of their electricity source. This was at the time of a worldwide oil shortage, and prompted a change in the government's approach to energy policy. It was decided at that time the country could not be dependant on external sources for electricity, and maintaining electrical independence was essential to ensuring economic security.

The problem of gaining security was compounded by the lack of fossil fuels within the countries boarders, especially when compared to its European neighbors. France consumes 2.5% of the world's supplies (275 Mtoe), but rank near the last in fossil fuel reserves with 0.01% (23 Mtoe) [18]. Due to this lack of natural resources, and with the evolving technology of nuclear power, government officials chose to go in this direction. Over the next 10 years, the electricity output from nuclear rapidly increased, and by 1985 had reached 90% of France's total electricity output.



Source: Observatoire de l'énergie

Figure 1: France's domestic primary energy output (millions of toe) [19]

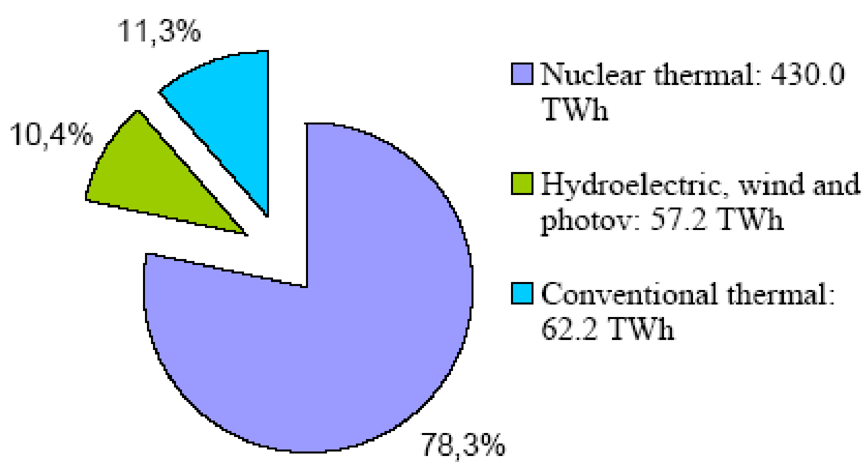


Figure 2: France's Net power generation in 2005 (549.4 TWh) [19]

In 2005, France passed the Energy Act defining four major objectives regarding its energy policy [18]:

- To contribute to national energy independence and guarantee security of supply,
- To ensure competitive energy prices,
- To protect human health and the environment, in particular by fighting against climate change,
- To guarantee social and territorial cohesion by ensuring energy access for all.

In order to reach these objectives, four principle areas of action were identified in the Act [18]:

- To control energy demand,
- To diversify sources of energy,
- To increase research,
- To provide methods of transporting and storing energy.

To provide a framework for these decisions, the following objectives were laid down [18]:

- A quartering of CO_2 emissions by 2050,
- Average reduction of final energy intensity of at least 2% per year to 2015, and of 2.5% from 2015 to 2030,
- Production of 10% of energy needs from renewable energy sources by 2010
- Incorporation of bio-fuels and other fuels of renewable origin to a level of 2% in 2006, 5.75% by the end of 2008 and 7% by the end of 2010.

France has managed to remain independent in terms of electricity, and the surplus produced has been a valuable export contributing to 2.3% of the national GDP in 2005 after peaking at 5% in the mid 1980's. This trade in electricity has helped keep electricity rates in France low [19].

Germany

Germany traditionally has a very diverse energy portfolio with coal still being a major contributor, despite its technological inferiority [20]. It also commited itself to reduce its amount of carbon dioxode to 40% less than the value of 1990 by 2020.

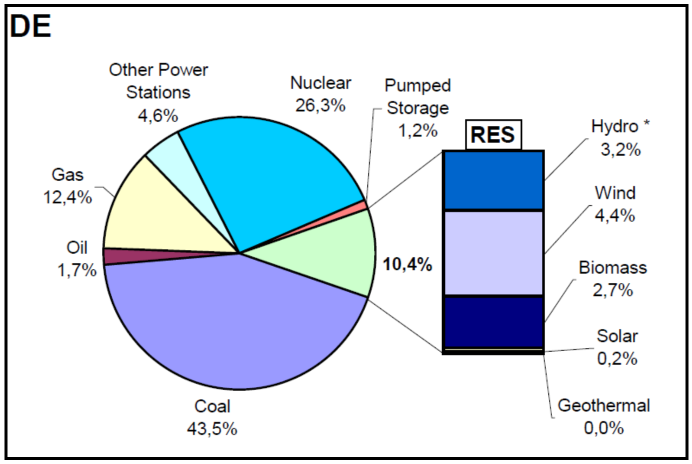


Figure 3: Germany's energy portfolio

When deciding issues related to energy, the German government follows the following strategic goals [21]:

- *Energy efficiency*
  Creating competition leads to higher efficiency, liberalization of the electric and gas market is essential to ensure competitive prices
- *Security of supply*
  Germany is dependent on energy import and therefore needs to have access to sufficient energy resources at any time. A diverse energy mix furthermore contributes to the country's independence
- *Environmental compatibility*
  Effective protection of the environment is essential in today's world. Furthermore, a reasonable use of natural resources has to be ensured

Since Chernobyl in 1986, nuclear energy has continued to suffer from negative public opinion. This is so much the case that under chancellor Schroeder, the German government decided to abandon nuclear technology by 2020. However, since it makes up a large portion of the current energy portfolio it must be replaced by an alternate energy technology. It is interesting to note that in many cases the likely replacement for nuclear energy is coal-burning plants [22]. This course of action is obviously counter to both Germany's and the EU's goal of reducing GHG emissions.

As Germany moves away from nuclear energy it has invested heavily in renewable energy technologies. Germany has become the world-wide leader in introducing renewable energy generation sources. By heavily subsidizing solar and wind energy (a certain selling price per kWh was assured, which was higher than the markets average), Germany and its respective companies in these fields were able to create far superior technology, making Germany the most progressive country using renewable energy sources. This expertise is also exportable, generating a lot of orders from all over the world for German companies [23].

Despite the use of renewable energy technologies Germany also finds itself relying natural gas energy with fuel supplied by outside countries such as Russia. With Russia currently supplying over 40% of Germany's total gas needs, this number will rise to 70%, as soon as all nuclear reactors are finally taken offline [24].

Building a Model

Technology Assessment

Review of literature and both French and German government web sites found no evidence of a formal technology assessment (TA) that might have been used to determine the mix of energy sources in each country's portfolio. Due to the myriad of emerging energy technologies and the far reaching social, political and economic impacts of energy it seems that this assessment should be important. In the United States between 1972 and 1995 the Office of Technology Assessment performed various assessments of technologies that were deemed to be important [25]. The focus of the OTA was to use a formal and systematic approach to technology assessment to help provide useful (understandable) information to policy makers on how different technologies compare [26]. The OTA performed many assessments in the area of energy a small sampling includes:

- Studies of the Environmental Costs of Electricity [27]
- Energy Technology Choices: Shaping Our Future [28]
- Renewing Our Energy Future [29]
- Energy in Developing Countries [30]
- Fueling Reform: Energy Technologies for Former Easter Bloc [31]
- New Electric Power Technologies [32]

Regrettably literature searches reveal no similar entity in either France or Germany. It should be noted that despite the useful analysis the OTA performed it was dissolved in 1995 during governmental budget cuts [27, 28].

Technology assessments such as those performed by the OTA can be long and complex. To be truly valuable they need to look at the technology alternatives from different perspectives. Linestone introduces the idea of technology assessment from multiple perspectives in his book. He proposes using what he calls a TOP assessment in which a technological, organizational, and personal perspective is used to compare alternatives [33]. When reviewing technologies such as energy which have broad societal, political, and economic impacts using this type of multiple perspective analysis as a framework for comparison would seem appropriate. It is this multiple perspective assessment framework which this paper aims to develop further.

Hierarchy Decision Model (HDM)

If the multiple perspective analysis is used as a framework it is then possible to develop a hierarchal decision model (HDM) with the perspectives as the main criteria and a series of sub criteria to be selected. An HDM uses priorities at each level of the hierarchy to show the relative contribution of each project to a goal [34]. Chatzimouratidis and Pilavachi have written several papers in which they use hierarchy decision processes to evaluate different aspects of energy. They used the technical to analysis the power plants in terms of technological, economic and sustainability [35]. The same authors used the same technique to evaluate power plant impact on the living standard [36, 37]. Additionally, the same method was employed to analyze non-radioactive emissions using objective and subjective evaluations [38]. This series of papers uses hierarchical models establish the relative contribution of criteria and sub-criteria to an overall goal. The construction of the models is similar to that proposed in this paper however the model that is being developed here uses a multiple perspective TA as the frame work.

HDM Criteria

Figure 4 shows the first level of the proposed TA HDM. The TOP perspectives proposed by Linestone [34] have been replaced by Technology, Social/Political, and Economic. The choice of technology as a criterion is obvious and need not be explained. The social/political perspective is meant to capture the contribution of the public perception (represented by societal views and politician position). The final perspective is economic which is important because all technologies will live or die by their financial success.

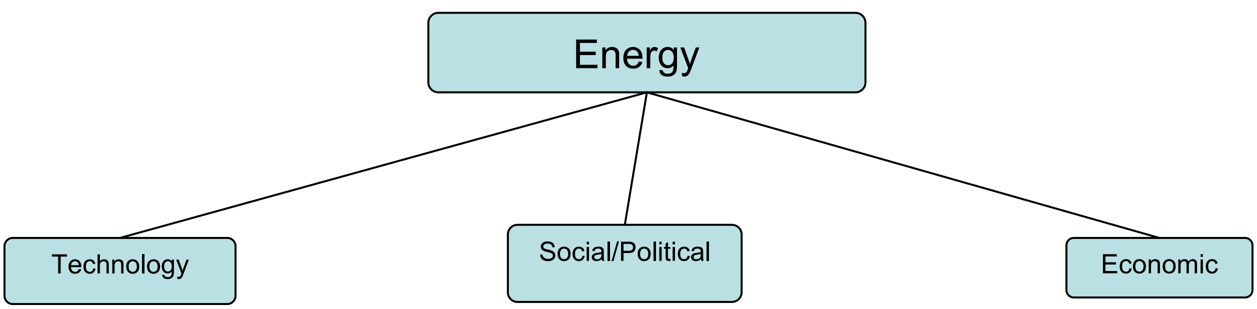


Figure 4: First level criteria in multiple perspective HDM for TA

The second level or sub-criteria in the proposed model is shown in figure 5. The technology criterion (perspective) is supported by the sub-criteria capacity, efficiency and availability. Capacity is a measure of the output of a given energy technology. The efficiency is the measure of energy in versus energy out for each technology. Finally availability of technology refers to the “up-time” or available running time of a technology. Each of these sub-criteria is measureable and are measures of the quality or capability of a given technology to produce power.

The social/political criterion has four main sub-criteria below. “EU goals” is a measure of whether the attributes of the technology are aligned with the larger goals of the region (for example nuclear energy supports the EU goal of green house gas reduction). The jobs sub-criterion is a measure of how many jobs might be created by a given technology. This criterion could also be part of the economic perspective but in this context it is mean to measure the political weight that is given to a technology because it creates jobs rather than economic weight. With controversial technologies such as coal and nuclear energy public opinion is an important criterion and that is why it is included as a sub-criteria. The final sub-criterion is the environment. This criterion, which itself is composed of two sub-criteria is a measure of environmental impact both local (non-radioactive: air, ground water etc.) and legacy (radioactive).

The third perspective in the HDM is economic. This criterion is supported by financially measurable sub-criteria cost per megawatt, capital cost to build power the power plant and fuel costs. The economic perspective is also supported by the environmental impact measure which can be evaluated in terms of financial impact.

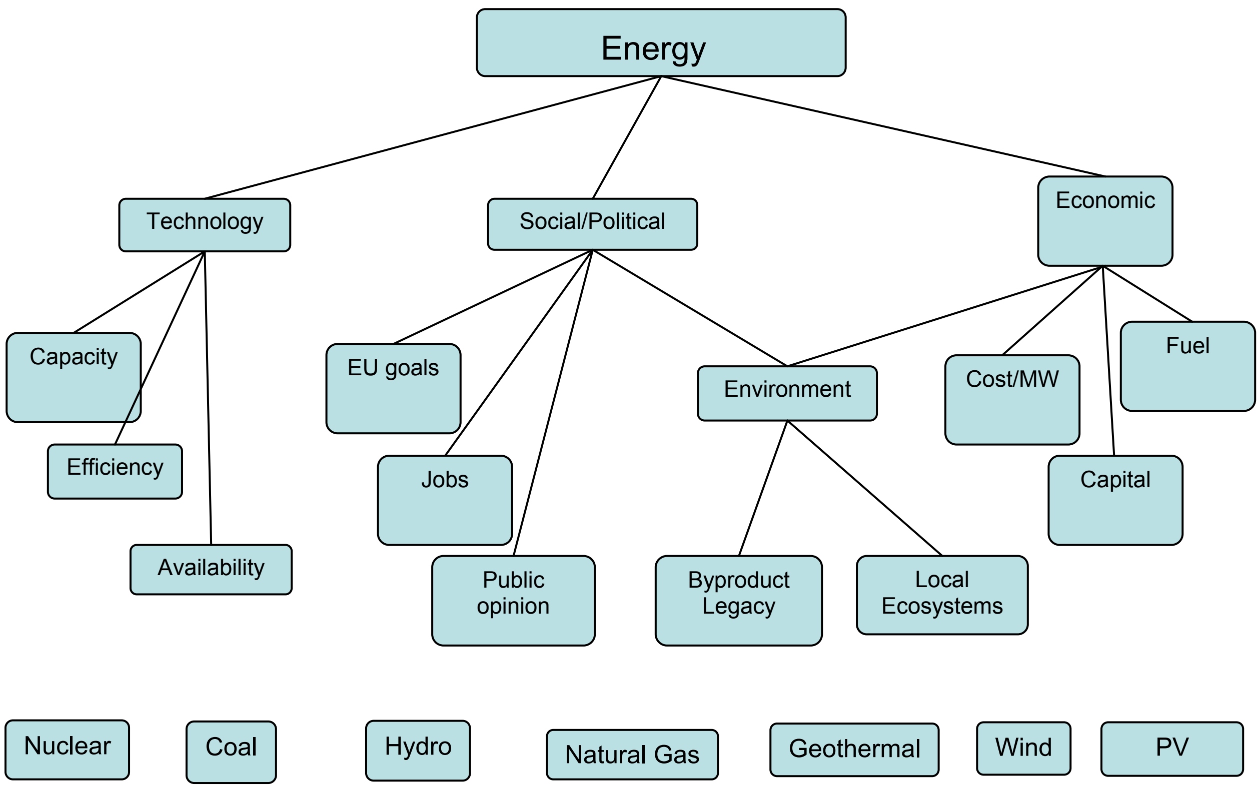


Figure 5: Multiple Perspectives HDM for TA

The final layer of the HDM model shown in figure 5 contains the alternative energies. These energy types were selected because they are mature technologies and are contained in France and Germany's portfolios.

Defining criteria measures

Using literature research, measures for all criteria except “EU goals” and “Public opinion” were found. The following chapter elaborates on these measures, explaining how each criterion is quantified.

Capacity

Capacity is defined as the amount of electricity, which the plant produces, divided by the amount of electricity it could have produced if it had run at full power over that period [35].

Table 3
Average capacity for the ten types of power plant (International Atomic Energy Agency (IAEA), 2002; US Department of Energy/Energy Information Administration (US DOE/EIA), 2006).

Type of power plant	Capacity (%)
Coal/lignite	70.8
Oil	26.2
Natural gas turbine	16.6
Natural gas combined cycle	38.2
Nuclear	90.5
Hydro	29.6
Wind	32.1
Photovoltaic	22.4
Biomass	70
Geothermal	82.5

Figure 6: Data input - capacity

Efficiency

Efficiency is defined as the ratio of the output energy to the input energy, indicating “how much useful energy we can get from an energy source” [35].

Table 1
Average efficiency coefficient for the ten types of power plant (International Atomic Energy Agency (IAEA), 2002).

Type of power plant	Efficiency coefficient (%)
Coal/lignite	39.4
Oil	37.5
Natural gas turbine	39
Natural gas combined cycle	54.8
Nuclear	33.5
Hydro	80
Wind	35
Photovoltaic	9.4
Biomass	28
Geothermal	6

Figure 7: Data input - efficiency

Availability

Availability is defined as the amount of time the plant is able to produce over a certain period by the amount of time in the period [35].

Table 2
Average availability for the ten types of power plant (International Atomic Energy Agency (IAEA), 2002).

Type of power plant	Availability (%)
Coal/lignite	85.4
Oil	92
Natural gas turbine	91
Natural gas combined cycle	91
Nuclear	96
Hydro	50
Wind	38
Photovoltaic	20
Biomass	80
Geothermal	95

Figure 8: Data input - Availability

Jobs

Figure 9 shows the average job creation for a power plant of 500MW [37].

Table 5
Average job creation for a power plant of 500 MW in the Unites States (Energy Power Research Institute (EPRI), 2001; Renewable Energy Policy Project (REPP), 2001; US Department of Energy (USDOE), 1997)

Type of power plant	Job creation (new employees/500 MW)
Coal/lignite	2500
Oil	2500
Natural gas turbine	2460
Natural gas combined cycle	2460
Nuclear	2500
Hydro	2500
Wind	5635
Photovoltaic	5370
Biomass	36,055
Geothermal	27,050

Figure 9: Data input - Jobs

Byproduct legacy

This criterion evaluates the amount of radioactivity generated by the different power plant. Figure 10 shows the amount of radioactivity of 1000MW power plants [37].

Table 3
Radioactivity from operation of 1000 MWe power plants in the United States (National Council on Radiation Protection and Measurements (NCRP), 1987a, b)

Type of power plant	Radioactivity (person-rem/year (1000 MWe power plant))
Coal/lignite	490
Oil	0
Natural gas turbine	0
Natural gas combined cycle	0
Nuclear	4.8
Hydro	0
Wind	0
Photovoltaic	0
Biomass	0
Geothermal	0

Figure 10: Data input - byproduct legacy

Local ecosystem

Besides radioactive emission, non-radioactive emissions like CO2 or NOx also pollute the air affect the climate as well as human beings. Figure 9 gives an overview of each plant's emission [37].

Table 2

Non-radioactive emissions from power plants based on global data (European Environment Agency (EEA), 2006; Intergovernmental Panel on Climate Change (IPCC), 2006; Koch, 2000; Meyer, 2002)

Type of power plant	Non-radioactive life cycle emissions (mg/kWh)				
	NMVOCs	CO_2-eq	NO_x	SO_2	Particulate matter
Coal/lignite	24	986,000	2986	16,511	347
Oil	18	1,131,178	5253	81,590	128
Natural gas turbine	118	560,000	1477	152	34
Natural gas combined cycle	118	450,000	756	152	6
Nuclear	0	21,435	51	27	2
Hydro	0	22,696	23	33	5
Wind	0	17,652	32	54	20
Photovoltaic	70	49,174	178	257	101
Biomass	80	58,000	1325	76	269
Geothermal	0	18,913	280	20	0

Figure 11: Data input - local ecosystem

Cost / MW [35]

Table 11

Average external costs for the ten types of power plant (Organisation for Economic Co-operation and Development (OECD), 2003).

Type of power plant	External costs (€cents/KWh)
Coal/lignite	8.40
Oil	6.75
Natural gas turbine	2.00
Natural gas combined cycle	1.33
Nuclear	0.49
Hydro	0.56
Wind	0.16
Photovoltaic	0.24
Biomass	2.65
Geothermal	0.20

Figure 12: Data input - Cost/MW

Capital [35]

Table 7
Average capital costs for the ten types of power plant (International Atomic Energy Agency (IAEA), 2002).

Type of power plant	Capital costs (€/kW)
Coal/lignite	975
Oil	483
Natural gas turbine	612
Natural gas combined cycle	587
Nuclear	1590
Hydro	2417
Wind	1250
Photovoltaic	4167
Biomass	1667
Geothermal	2158

Figure 13: Capital costs

Fuel [35]

Table 10
Average fuel costs for the ten types of power plant (Tarjanne and Luostarinen, 2003; US Department of Energy/Energy Information Administration (US DOE/EIA), 2005).

Type of power plant	Fuel costs (€cent/kWh)
Coal/lignite	1.31
Oil	1.84
Natural gas turbine	2.34
Natural gas combined cycle	2.34
Nuclear	0.27
Hydro	0
Wind	0
Photovoltaic	0
Biomass	2.05
Geothermal	0

Figure 15: Data input - fuel costs

Utility functions

Due to the lack of appropriate experts, it was not possible to generate meaningful utility functions. Instead, all value sets were normalized in order to end up with values only within the range between 0 and 100 (the highest value was set to 100, and all other values were calculated respectively).

Optimization process

Unfortunately, no experts were available to generate weights for the criteria and sub-criteria. Therefore another approach was used, which is summed up in the following objective:

Given a certain energy mix (for France/Germany), does a specific set of weights exist, which could lead to exactly this energy mix?

Operations research techniques were used to optimize the weights and, by implementing weak constraints (using deviations) finding the optimal solution [OR]. Furthermore, the two criteria "EU goals" and "Public opinion" were excluded, as there are no objective measures available. Instead, a country's public opinion might reveal itself within the set of weights, which is calculated during the optimization process.

OR-model

The following chapter gives on overview of the non-linear OR-model that was used.

1. **HDM-Model**

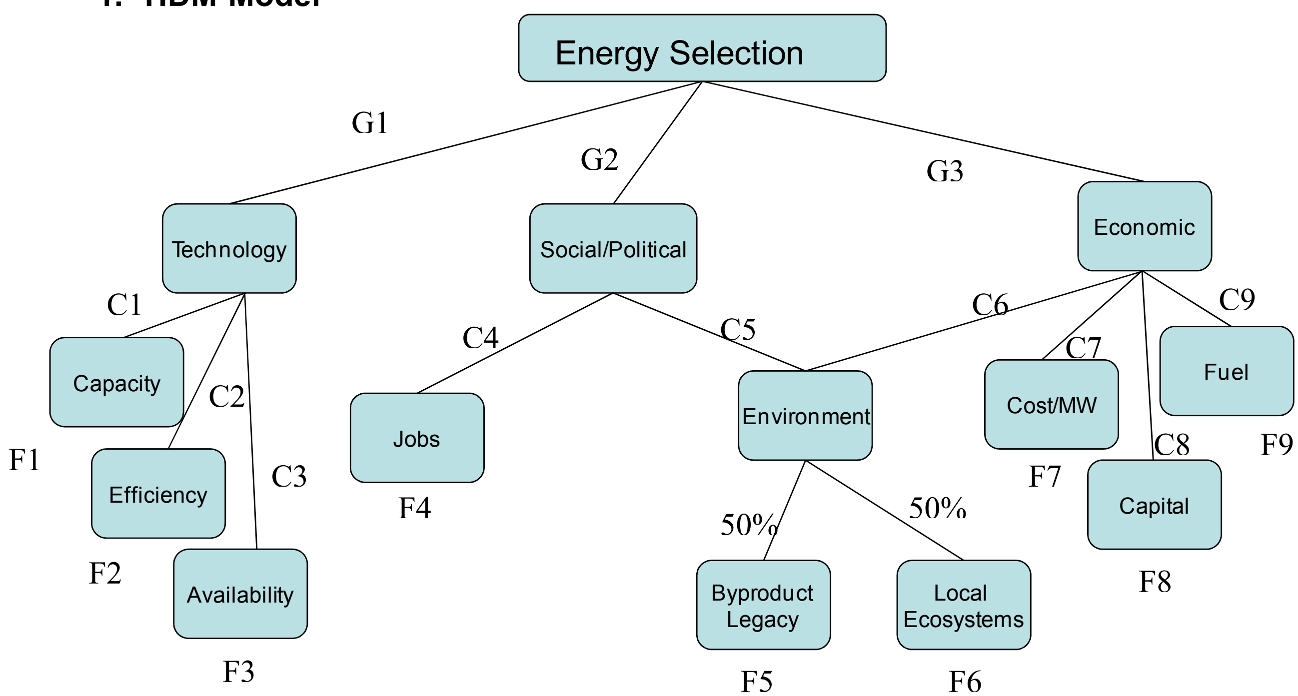


Figure 16: HDM Model

2. **List of Alternatives**
   Nuclear
   Coal
   Hydro
   Natural Gas
   Geothermal
   Wind
   Solar/PV

3. Calculating Final weights for each criteria (F_j)

F1 = C1 * G1
F2 = C2 * G1
F3 = C3 * G1
F4 = C4 * G2
F5 = 0.5*C5*G2 + 0.5*C6*G3
F6 = 0.5*C5*G2 + 0.5*C6*G3
F7 = C7 * G3
F8 = C8 * G3
F9 = C9 * G3

4. Data input

$$Da_{i,j} = \begin{matrix} Da_{1,1} & \cdots & Da_{n,1} \\ \vdots & \ddots & \vdots \\ Da_{1,n} & \cdots & Da_{n,n} \end{matrix}$$

i = Alternatives
j = Criterion values

	Nuclear	Coal	Hydro	Natural Gas	Geothermal	Wind	Solar/PV
Capacity	90.5	70.8	29.6	16.6	82.5	32.1	22.4
Efficiency	33.5	39.4	80	39	6	35	9.4
Availability/ Techn. Readiness	96	85.4	50	91	95	38	20
Jobs	9.2421442	9.2421442	9.2421442	9.0942699	100	20.831793	19.852126
Cost/MW	94.17	0	93.33	76.19	97.62	98.1	97.14
Capital	61.8	76.6	42	85.31	48.21	70	0
Fuel	99.73	98.69	100	97.66	100	100	100
Byproduct legacy	4.8	0	100	100	100	100	100
Local Ecosystem	13.34	3.41	13.3	9.86	13.29	13.04	10.77

Figure 17: Data Input

$$\forall\, i\ (Alternatives): \sum_j F_j * Da_{i,j} = RE_i$$

5. Portfolio results

$PO_i \ \forall\, i\ (Alternatives)$

2 sets of results (percentages of the current energy portfolio mix)

Germany [39] :

Nuclear	Coal	Hydro	Natural Gas	Geothermal	Wind	Solar/PV
26.3	43.5	3.2	12.4	0	4.4	0.2

France [19]:

Nuclear	Coal	Hydro	Natural Gas	Geothermal	Wind	Solar/PV
41	5	2	15	0	0	0

6. Objective

$$MIN \sum_i D_i^+ + D_i^-$$

7. Decision Variables

G1, G2, G3: Weights (goals)
C1 – C8: Weights (criteria)

Deviation variables
$D_i^+ \ \forall\, i\ (Alternatives)$
$D_i^- \ \forall\, i\ (Alternatives)$

8. Constraints

Non-negativity

Non-zero (zero was leading to errors → G1, G2, G3, C1-C8 > 0,01)

$\forall\, i\ (Alternative): RE_i + D_i^- - D_i^+ = PO_i$

G1 + G2 + G3 = 1
C1 + C2 + C3 = 1
C4 + C5 = 1
C6 + C7 + C8 + C9 = 1

Results

First run

In a first run the model lead to the following results.

Germany

The first run model results for Germany are shown in figures 18 and 19.

Sum of total deviations = 159.38

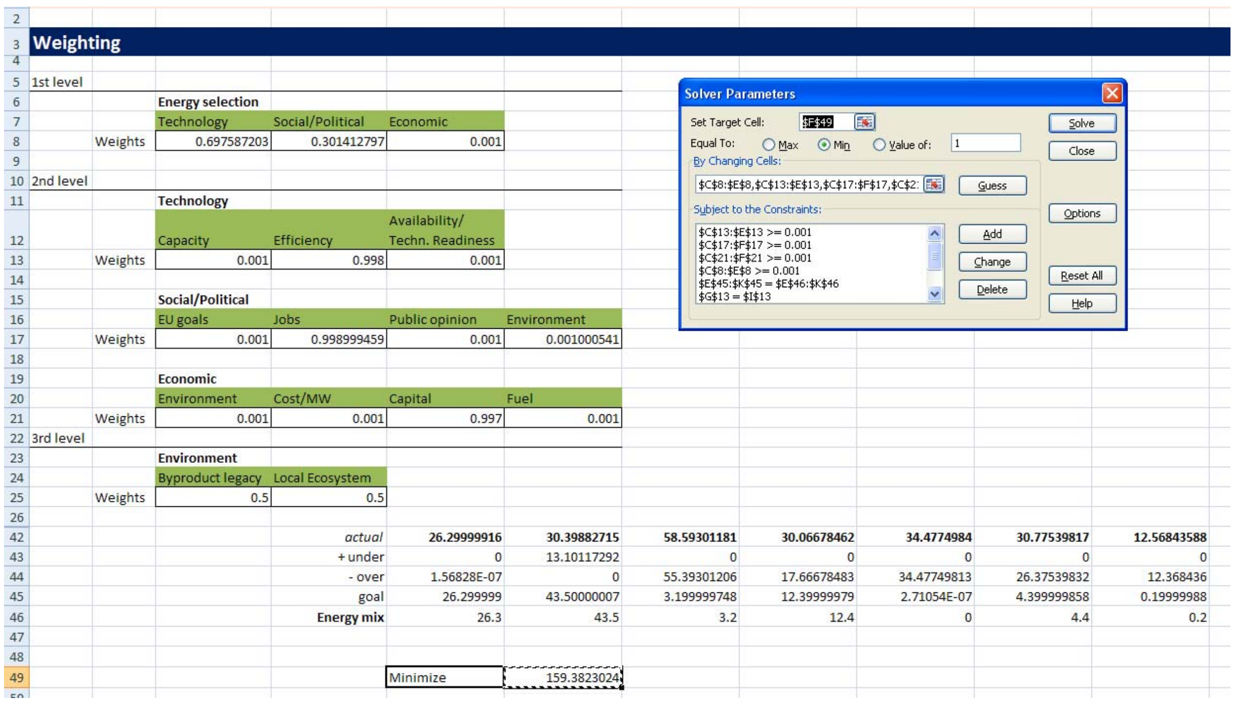


Figure 18: Germany - 1st results

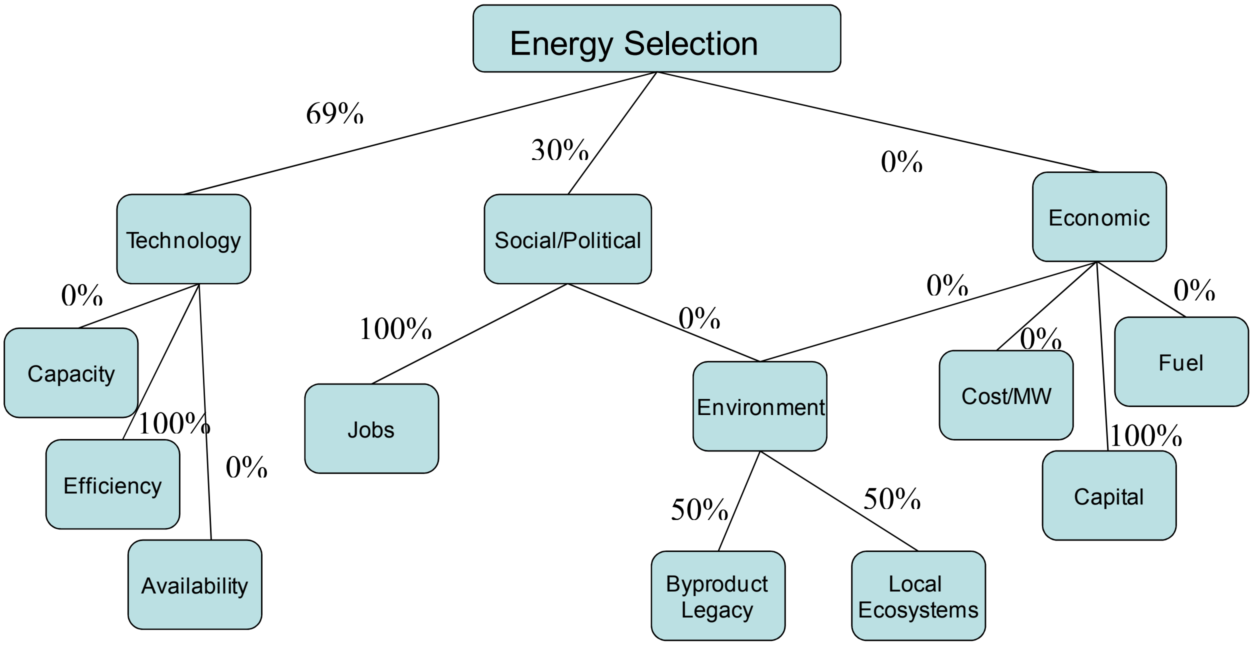
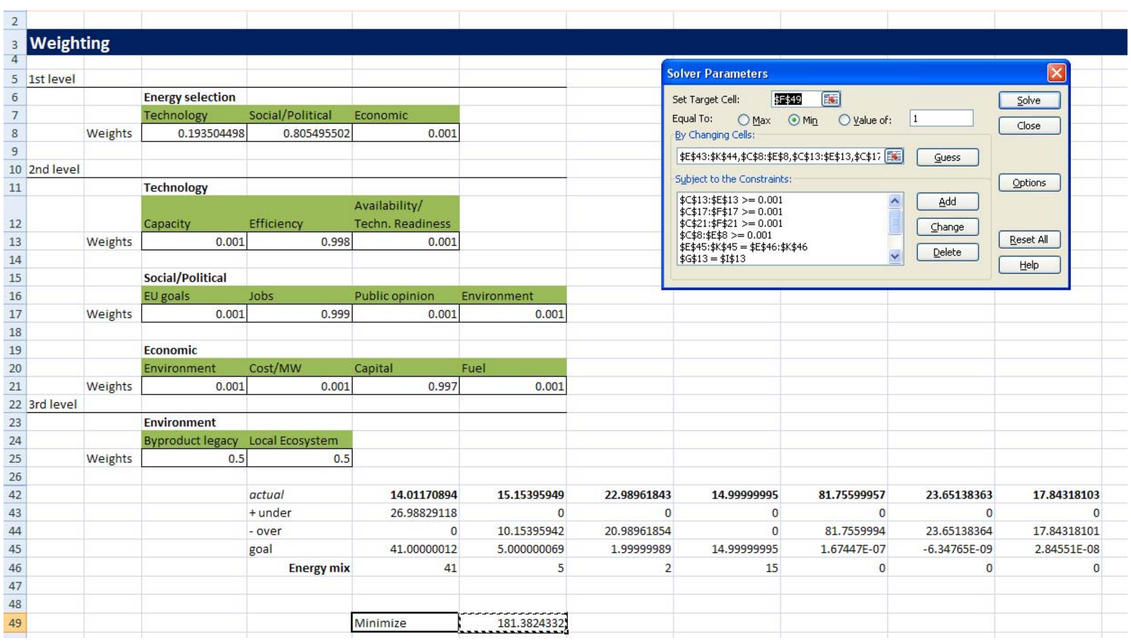


Figure 29: Germany - first weights

France

The results from the first run model for France are shown in figures 20 and 21.

Sum of total deviations = 181.38



2											
3	**Weighting**										
4											
5	1st level										
6			**Energy selection**								
7			Technology	Social/Political	Economic						
8		Weights	0.193504498	0.805495502	0.001						
9											
10	2nd level										
11			**Technology**								
12			Capacity	Efficiency	Availability/ Techn. Readiness						
13		Weights	0.001	0.998	0.001						
14											
15			**Social/Political**								
16			EU goals	Jobs	Public opinion	Environment					
17		Weights	0.001	0.999	0.001	0.001					
18											
19			**Economic**								
20			Environment	Cost/MW	Capital	Fuel					
21		Weights	0.001	0.001	0.997	0.001					
22	3rd level										
23			**Environment**								
24			Byproduct legacy	Local Ecosystem							
25		Weights	0.5	0.5							
26											
42				*actual*	**14.01170894**	**15.15395949**	**22.98961843**	**14.99999995**	**81.75599957**	**23.65138363**	**17.84318103**
43				+ under	26.98829118	0	0	0	0	0	0
44				- over	0	10.15395942	20.98961854	0	81.7559994	23.65138364	17.84318101
45				goal	41.00000012	5.000000069	1.99999989	14.99999995	1.67447E-07	-6.34765E-09	2.84551E-08
46				**Energy mix**	41	5	2	15	0	0	0
47											
48											
49					Minimize	181.3824332					

Figure 20: France - 1st results

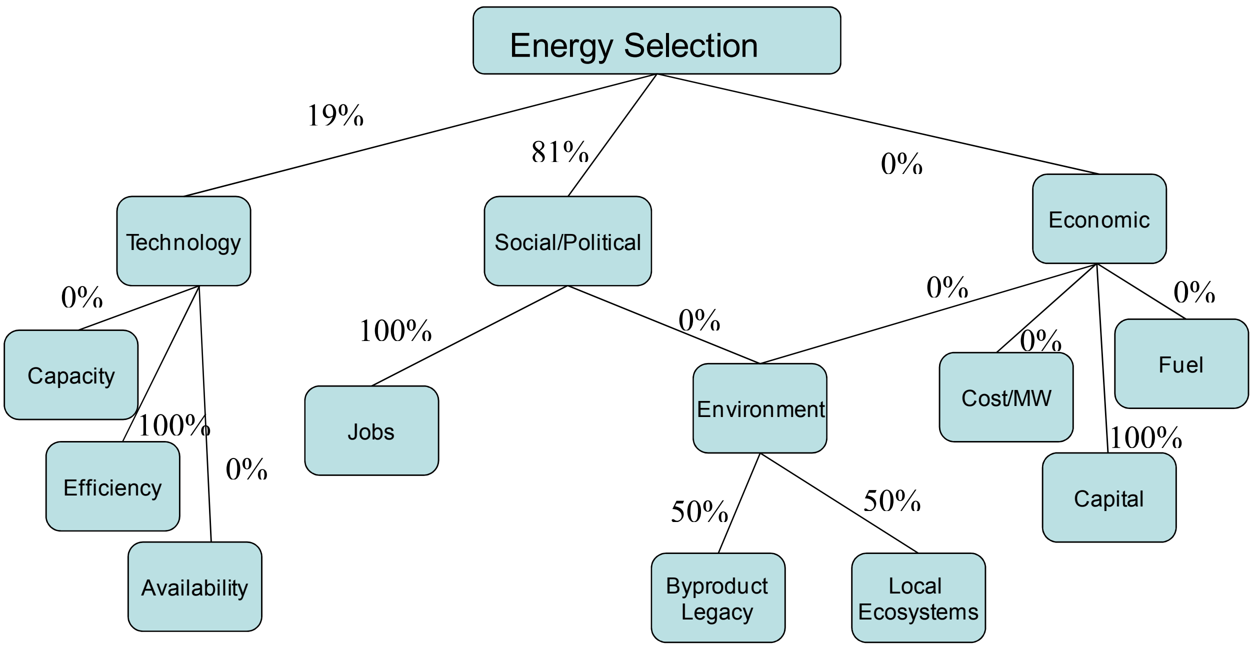


Figure 21: France - 1st weights

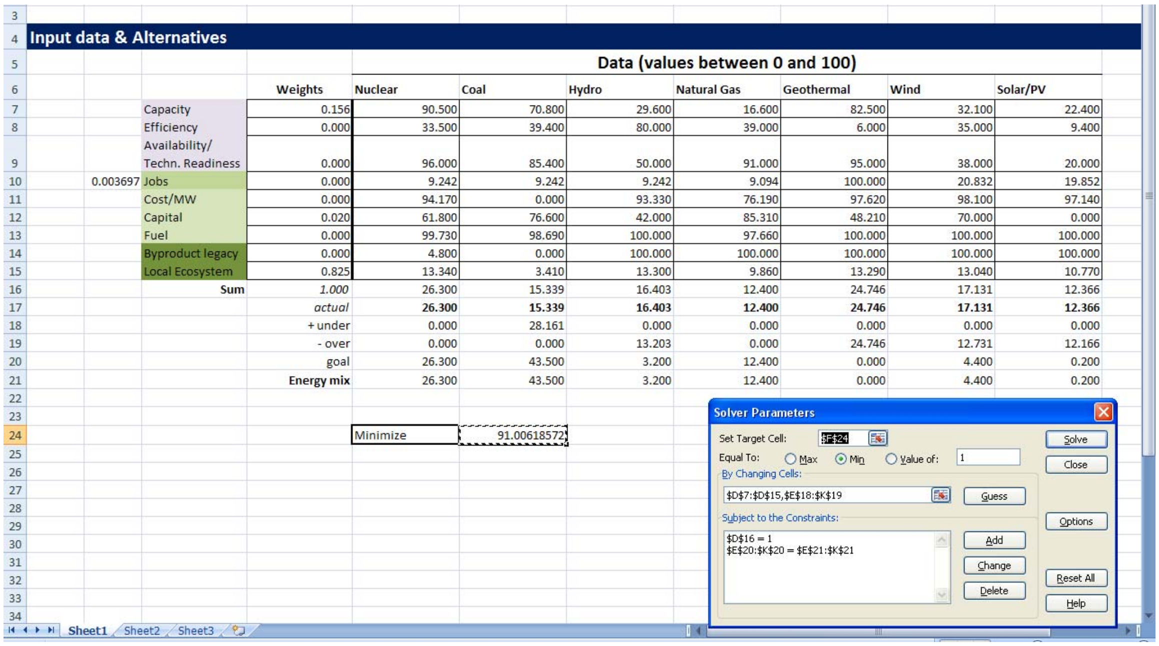
Second run

In order to come up with more consistent data, changes were made to make the model linear. Instead of using all weights of the criteria and sub-criteria as decision variables, the final weights (F1 – F9) are chosen to be varied. Eventually this reduces the amount of decision variables and constraints, increasing the probability of a better solution Changes made lead to the following result:

Germany:

Figure 22 and 23 show the tabulated results from the second run of the model.

Sum of total deviations = 91



Input data & Alternatives

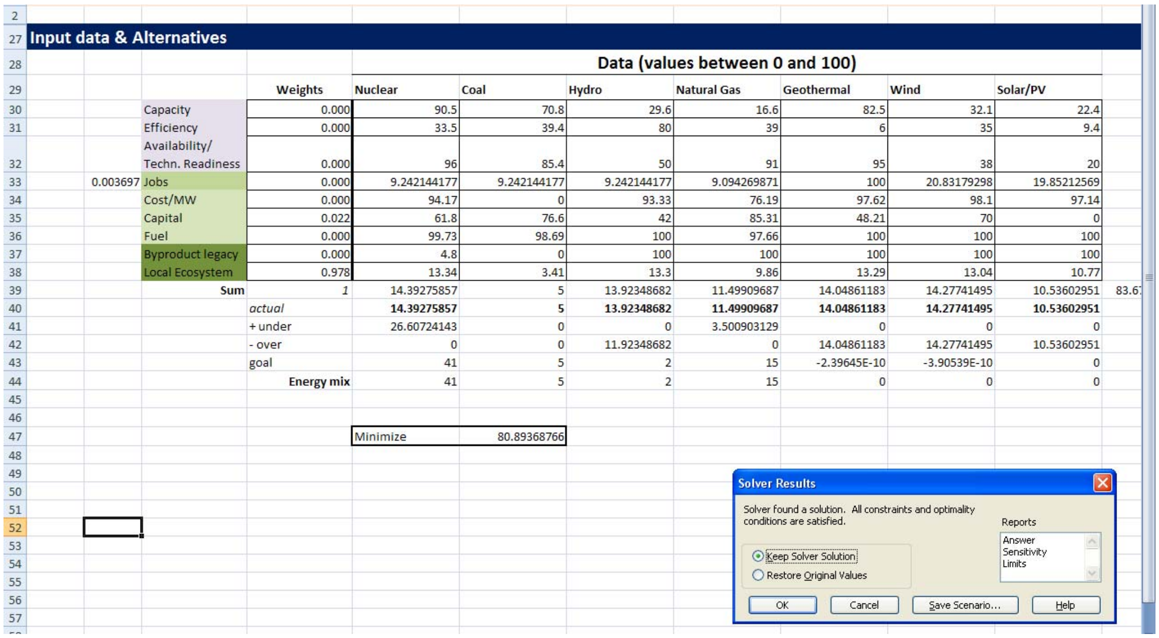
		Weights	Nuclear	Coal	Hydro	Natural Gas	Geothermal	Wind	Solar/PV
			Data (values between 0 and 100)						
	Capacity	0.156	90.500	70.800	29.600	16.600	82.500	32.100	22.400
	Efficiency	0.000	33.500	39.400	80.000	39.000	6.000	35.000	9.400
	Availability/ Techn. Readiness	0.000	96.000	85.400	50.000	91.000	95.000	38.000	20.000
0.003697	Jobs	0.000	9.242	9.242	9.242	9.094	100.000	20.832	19.852
	Cost/MW	0.000	94.170	0.000	93.330	76.190	97.620	98.100	97.140
	Capital	0.020	61.800	76.600	42.000	85.310	48.210	70.000	0.000
	Fuel	0.000	99.730	98.690	100.000	97.660	100.000	100.000	100.000
	Byproduct legacy	0.000	4.800	0.000	100.000	100.000	100.000	100.000	100.000
	Local Ecosystem	0.825	13.340	3.410	13.300	9.860	13.290	13.040	10.770
	Sum	*1.000*	26.300	15.339	16.403	12.400	24.746	17.131	12.366
		actual	**26.300**	**15.339**	**16.403**	**12.400**	**24.746**	**17.131**	**12.366**
		+ under	0.000	28.161	0.000	0.000	0.000	0.000	0.000
		- over	0.000	0.000	13.203	0.000	24.746	12.731	12.166
		goal	26.300	43.500	3.200	12.400	0.000	4.400	0.200
		Energy mix	26.300	43.500	3.200	12.400	0.000	4.400	0.200
			Minimize	91.00618572					

Figure 22: Germany - 2nd results

F1	Capacity	0.156
F2	Efficiency	0.000
F3	Availability/ Techn. Readiness	0.000
F4	Jobs	0.000
F5	Cost/MW	0.000
F6	Capital	0.020
F7	Fuel	0.000
F8	Byproduct legacy	0.000
F9	Local Ecosystem	0.825

Figure 23: Germany - 2nd weights

France:
Figures 24 and 25 summarize the results from the second run of the model for France.



Input data & Alternatives

			Data (values between 0 and 100)							
		Weights	Nuclear	Coal	Hydro	Natural Gas	Geothermal	Wind	Solar/PV	
	Capacity	0.000	90.5	70.8	29.6	16.6	82.5	32.1	22.4	
	Efficiency	0.000	33.5	39.4	80	39	6	35	9.4	
	Availability/ Techn. Readiness	0.000	96	85.4	50	91	95	38	20	
0.003697	Jobs	0.000	9.242144177	9.242144177	9.242144177	9.094269871	100	20.83179298	19.85212569	
	Cost/MW	0.000	94.17	0	93.33	76.19	97.62	98.1	97.14	
	Capital	0.022	61.8	76.6	42	85.31	48.21	70	0	
	Fuel	0.000	99.73	98.69	100	97.66	100	100	100	
	Byproduct legacy	0.000	4.8	0	100	100	100	100	100	
	Local Ecosystem	0.978	13.34	3.41	13.3	9.86	13.29	13.04	10.77	
	Sum	*1*	14.39275857	5	13.92348682	11.49909687	14.04861183	14.27741495	10.53602951	83.6
		actual	**14.39275857**	**5**	**13.92348682**	**11.49909687**	**14.04861183**	**14.27741495**	**10.53602951**	
		+ under	26.60724143	0	0	3.500903129	0	0	0	
		- over	0	0	11.92348682	0	14.04861183	14.27741495	10.53602951	
		goal	41	5	2	15	-2.39645E-10	-3.90539E-10	0	
		Energy mix	41	5	2	15	0	0	0	
			Minimize	80.89368766						

Figure 24: France - 2nd results

F1	Capacity	0.000
F2	Efficiency	0.000
F3	Availability/ Techn. Readiness	0.000
F4	Jobs	0.000
F5	Cost/MW	0.000
F6	Capital	0.022
F7	Fuel	0.000
F8	Byproduct legacy	0.000
F9	Local Ecosystem	0.978

Figure 25: France - 2nd weights

Discussion

From the results of the first model run it can be seen that the model was unable to find realistic values for the criteria and sub-criteria that would result in energy portfolios such as those of Germany and France. In trying to match the German energy portfolio the model found the optimum weights for the first level criteria to be 69% Technology, 30% Social/Political, and 0% Economic. However, the sum of deviations for the model is well in excess of 100 suggesting the model does cannot be made to fit. Similarly, the results for the French energy mix were found to be 19% Technology and 81% Social/Political with no weight on the Economic criteria. Again, the sum of deviations for the model for France is above 100 indicating a lack of fit. When the model was re-run as a linear model and the constraints were relaxed a similar result occurred. The sum of deviations for both Germany and France were above 100 suggesting the model does not fit the energy mix.

These results can be interpreted in different ways. The lack of fit of the model could indicate that an important criterion is missing or that one of the sub-criteria has been scored incorrectly. An alternate possibility for the lack of fit is that no such technology assessment was performed to choose technologies for the energy portfolios and other factors (public or political opinion) were used to make the decision.

Conclusions

From the literature it is evident that formal technology assessments of potential energy technologies to be included in national energy portfolios in Europe are lacking. Using a multiple perspective technology assessment model as framework and HDM as the evaluation methodology a complete technology assessment model was proposed. The technology portfolios of both France and Germany were used to check the model validity using operational research techniques. It was found that the model does not fit the portfolio mixes of either country. From this lack of fit there are a couple of possible conclusions. First, the model has not included or not correctly evaluated an important criterion resulting in incorrect values in the model. Alternatively, the lack of fit could be explained if no technology assessment was performed to select energy technologies for the portfolios and the technology was selected arbitrarily or by public or political opinion only. Due to the general lack of literature in the area of technology assessment at the governmental level in both Germany and France, certainly in regards to energy technologies, it seems the alternate conclusion is likely the correct conclusion.

Resources

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Appendix

Table 2 Share of primary energy from renewables—policy targets and scenarios[a]

Region/ country	2004 actual[b]	2010 policy targets[c]	2020 policy targets or scenarios[d]	Up to 2050 scenarios[e]	References for scenarios
World	3.8% or 8.2% or 13.0% or 16.5%	—	5%–15% low/reference	10%–15% low/reference	19–22, 32, 73, 87, 142
			15%–20% medium	25%–30% medium	22, 29, 30, 32, 33, 73, 87
			25% high	40%–50% high	19, 25, 28–30, 31, 33, 35, 36
Europe (EU25)	6.5%	12%	10% reference/ carbon constrained	15%–20% reference (by 2030)/carbon constrained	20, 21, 46, 47
			20% target	30%–40% policies (by 2030)	37–40, 43, 46–48
			23% revolution	50% revolution	45
United States	4.2%	—	7% reference	8% reference	21, 51, 52, 54, 55
			20% revolution	50% revolution	19
Japan	1.2%[f]	3%[f]	—	6% (2030) reference 17%/22% (2030) 25%/50% (2050) high/community	21, 56, 57
China	7.5%	10%	16% target	20%–30% policies	19, 58–62
Brazil	41%	—	30% high	—	63
India	39%	—	30%–35% policies	15%–30% policies	21, 65
Mexico	10%	—	20%–30% high	—	64
Thailand	6%	8%	—	—	
Germany	3.9%	4%	10% target	50% advanced	83
Netherlands	2%	—	—	80% policies	84
Poland	4.7%	7.5%	14% target	—	99
Spain	6.2%	12.1%	—	—	

[a]Policy targets and 2004 actual are from International Energy Agency (IEA), REN21 Renewable Energy Policy Network for the 21st Century, and European Commission publications (2–4, 12, 63, 88, 93–94), supplemented by data from scenarios cited. Most targets and scenarios count (or are presumed to count) renewable electricity according to the IEA method (see text); but the numbers would be higher if the BP method were applied. Targets or scenarios may not specify which method is used. Most global scenarios include traditional biomass, but some country targets and scenarios do not (e.g., the numbers shown for Thailand and China exclude traditional biomass). "Policies" means policy-intensive; "reference" also means "baseline."

[b]World actual 2004 depends on the accounting method used; see **Table 1** and the text. For comparison with most targets and scenarios, the 13% actual (IEA method with traditional biomass) should be used. Estimates for Europe actual 2004 vary from 5.6% to 7.5%.

[c]Thailand target for 2011.

[d]No world policy targets exist; the Mexico scenario is for 2025.

[e]Most scenarios in this column are for 2050, except the world (29) for 2040; and the following are for 2030: world (21), Europe (21, 38–40, 43), United States (21, 51), and Japan (21, 56).

[f]Japan's 1.2% share in 2004 and 3% target in 2010 exclude large hydro and geothermal. The share in 2004 including those sources has been reported as either 3.4% or 5.2%.

[14]

Table 3 Share of electricity from renewables—policy targets and scenarios[a]

Region/ country	2005 actual[b]	2010 policy targets	2020 scenarios or policy targets[c]	Up to 2050 scenarios[d]	References for scenarios
World	19%	—	15%–20% low/reference	15%–25% low/reference	19, 22
			20%–25% medium	30%–40% medium	20, 22, 23
			35%–40% high	50%–80% high	19, 25, 29
Europe[e] (EU25)	14%	21%	15%–20% reference	20%–25% reference (by 2030)	20, 21, 38–40, 43, 47
			25% carbon constrained	30% carbon constrained	20
			30% policies	45%–60% high (by 2030)	20, 25, 38–40, 43, 46, 47
			35% revolution	70% revolution	45
United States[f]	8%	5%–30% state targets	5%–33% state targets	9%–11% reference 11%–15% alternative (by 2030)	21, 51
			20% advanced and blueprint	50% high[g]	25, 49, 52, 53, 55
			30% revolution	80% revolution	50
Japan[a]	0.4% actual + 10% large hydro	1.35% target + large hydro	11% reference	11% (2030) reference 33%/41% (2030) high/community	21, 56
				50% high	25
China	16%	—	15%–25% reference	15% reference (by 2030)	21, 60
			35% policies	20%–40% policies advanced/alternative	21, 25, 58–62
			—	50% revolution	19
Asia-Pacific region[h]	16%	—	17% reference 39% accelerated	17% reference 50% accelerated	67
Latin America region	—	—	—	33% reference 90% revolution	19
Brazil[a]	5%	—	22% high	—	63
India[i]	11%	5%–10% state targets	18% reference 27% policies	12%–25% reference 40% high mitigation (by 2035)	21, 61, 66, 67
Mexico	16%	—	15% high	—	63
Germany	10%	12.5%	20% target	—	—
South Korea	1%	7%	—	—	—

[a]Policy targets and 2005 actual figures are from International Energy Agency (IEA), REN21 Renewable Energy Policy Network for the 21st Century (REN21), and European Commission (EC) publications (2–4, 12, 63, 88, 93, 94), supplemented by data from scenarios cited. Most targets and scenarios include large hydro, but some may not. The scenarios for Brazil and Japan's target of 1.35% by 2010 exclude large hydro.
[b]The Europe actual is for 2004. The Asia-Pacific region actual is for 2000. Figures are rounded to nearest whole percent.
[c]The Asia-Pacific region scenario is for 2025.
[d]Most scenarios are for 2050, except world (29) for 2040, and the following are for 2030: Europe (21, 38–40, 43), United States (21, 51), and Japan (21, 56).
[e]The EC in 2006 anticipated an actual 18% share of electricity by 2010.
[f]Policy targets are given equivalent to state-level renewable portfolio standards (RPS) policies in most U.S. states; no national-level target exists. California in 2005 proposed 33% share by 2020, up from 20% RPS by 2017 (**http://www.newrules.org**, viewed 1/31/07).
[g]The World Business Council for Sustainable Development (25) scenario for 2050 of 50% is for Canada and United States combined.
[h]Asia-Pacific region includes Australia, Brunei Darussalam, Canada, Chile, China, Chinese Taipei, Hong Kong, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, Papua New Guinea, Peru, Philippines, Russia, Singapore, Thailand, United States, and Vietnam.
[i]India has national policy targets of 10% of new capacity added from 2003 to 2010, 15% of total capacity by 2032, plus RPS policies in several states that serve as state targets.

[14]

Table 4 Share of transport energy from renewables (biofuels)—policy targets and scenarios

Region/country	2008–2015 policy targets[a]	Up to 2050 scenarios with references in parentheses
World	—	3% low (22) 15% med (22, 25) 25% high (22)
Europe (EU25)	5.75% energy share	6%–7% by 2030 reference (40, 43) 14%–26% by 2030 alternative (40, 43) 21% by 2050 (25)
France	10% energy share	—
Germany	E2	—
United States[b]	E10 in 3 states	25% (25)
Brazil	E25	
China	E10 in 9 provinces	
India	E10 in 13 states/territories	
Philippines	E10 (proposed)	
Thailand	E10	

[a]Source for policy targets: Renewable Energy Policy Network for the 21st Century (REN21) (3–4). E2, E10, and E25 refer to a blending mandate for blending all gasoline with 2%, 10%, or 25%, respectively, ethanol, which would result in a smaller share of transport fuels, taking into account other fuels not affected by the mandate, such as diesel and aviation fuel. Data on transport energy shares of biofuels implied by these blending requirements are often not readily available. Blending requirements for biodiesel are also appearing in several countries, typically B2 or B5; see REN21 (3–4).
[b]2050 scenario is for the United States and Canada combined.

[14]