# Determinants of the Sustainable Energy of the Future

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A Research Report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Business Administration.

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# ABSTRACT

The production of electricity is not always aligned with the future demands of society and, unfortunately, it comes with drawbacks, especially in developing countries. Based on a review of the relevant literature, a predictive qualitative model was formulated to explore the effects of the influencing factors of the energy fields on the choice of a sustainable energy for the future. The model is based on a layered framework of all the identified drivers for the choice of a means of generating electricity.

Scenarios tested against the theoretical model yield a set of results that comply with many of the observations expressed in the literature or even in the real word. These scenarios gave rise to propositions that were tested empirically.

The accuracy of the selection of the best means of generating energy for any country depends on the accuracy of the assessment carried out on the global situation of that country concerning the influencing drivers. The model proposed here uses such assessments as its starting point.

Key Words: Sustainable energy, electricity-generating means, natural resources, geographical locations, environmental issues, external drivers, fuzzy cognitive mapping.

# DECLARATION

I, Dr. Lilian Simon, declare that this research report is my own, unaided work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degrees or examination in this or any other university.

Dr. Lilian Simon

1st February 2007

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Yo deseo agredecer tambien a mi esposa, Sonia, por todas las cosas buenas que ella hace por mi.

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## Annexe

# 1. INTRODUCTION

Jacques Chirac, French President, addressing World Summit on Sustainable Development, Johannesburg

*Our house is burning and we look elsewhere. Nature, mutilated and over-exploited, can no longer reconstitutes itself and we refuse to admit it. Humanity is suffering. It is suffering from poor development, in the North as in the South, and we are indifferent. The Earth and humanity are in peril and we are all responsible. It is time now to open our eyes.* (Le Figaro, Wednesday 4th September 2002)

Thomas Friedman, journalist

*It's high time that energy efficiency, conservation and renewable ceased to be a fringe-issue for greenies, tree-huggers and enviros. A sustainable energy future is about a sustainable economy, about creating high-paying jobs in innovation and technology, about clean skies and healthy cities, about national security, about avoiding quagmires like Iraq. Sometimes I feel like renewable, efficiency and conservation make so much sense, and it just makes me sick that more is not being done...* (Thomas Friedman's blog, Friday 6th January 2006)

These two quotes are expressing very strongly the necessity of my following research study on the determinants of the sustainable energy of the future.

## 1.1. Purpose of the Study

The first part of the study explores the factors, which may influence the choice of a particular type of energy for a country. More specifically, the intent is to identify, analyse and interpret these influencing factors with the view towards finding the most commonly chosen sustainable energy of the future. The purpose of this study is to build a qualitative model that will predict the effect that the influencing factors will have on the choice of the sustainable energy of the future. For the sake of simplicity, only the factors that are considered to have the most influence will be listed and referred to in this study. Even after this simplification, the interaction between all the elements remains complex and difficult to quantify and, therefore fuzzy cognitive mapping (FCM) will be used to generate the qualitative model of the interactions between all the factors.

FCM is a modelling technique that has been found to be useful in modelling organisational or social-economic scenarios, which are dynamic and convoluted in nature (Kosko, 1993; Kardaras & Mentzas, 1997; and Aguilar, 2003). FCM can also be applied successfully to this study, as the different scenarios presented in this report will be dynamic and convoluted as well.

The sustainable energy of the future will have to take into account factors such as:

- Affordability for the biggest part of the population;
- Environmental harmlessness/friendliness for the entire population; and
- Representing a long-term solution for any country under scrutiny.

To emphasis those three previous points, sustainable energy is about using natural resources wisely and using electricity generated from clean sources and clean technologies.

## 1.2. Context of the Study

Energy development is the ongoing effort to provide abundant and accessible energy, through knowledge, skills and constructions. When harnessing energy from primary energy sources and converting them into ever more convenient secondary energy forms, such as electrical energy, both quantity (harnessing more primary energy) and quality (more efficient conversion to secondary energy) are important (Bilgen & Kaygusuz, 2004).

Future energy development faces great challenges because of an increasing world population, demands for higher standards of living, demands for less pollution, and the much-discussed end to fossil fuels. Without energy, the world's entire industrialised infrastructure would collapse, and so would agriculture, transportation, waste collection, information technology, communications and many of prerequisites that a developed nation takes for granted.

Thomas F. (Mack) McLarty, Former White House Advisor

*When a Brazilian brews her morning coffee today, she is likely to use electricity from a power plant in Uruguay that runs on natural gas from Argentina provided by a Chilean company. She drives to work in a Ford fuelled with Venezuelan gasoline, and her Canadian-owned factory may soon be powered by a 2,000-mile natural gas pipeline from Bolivia.* (New York Times Friday 1st February 2002)

The message is clear, energy is not only a concern for a nation but it is a worldwide issue; the word "globalisation" takes all its meaning from this topic! Therefore, it is perhaps ironic that in an age where the pace of technological change is almost overwhelming, the world will remain dependent, for 2000-2020 at least, on essentially the same forms of energy - oil, coal, and natural gas - that fuelled the $20^{th}$ century.

Indeed, ever since Colonel Drake drilled the first true oil well in the state of Pennsylvania in 1859, the ability of oil and natural gas to power electric generation plants, transportation, homes and industry has created both immense economic advances and significant controversy (King, 2004). Many times, it has been assumed that the world would quickly run out of oil. In 1939, and again in 1951, the U.S. Department of the Interior warned that all of the Earth's oil reserves totalled only enough to fuel the world's nations for about 13 years (Darmstadter, Teitelbaum & Polach, 1971). In fact, rather than becoming scarcer over time, energy has become much more plentiful. Over most of the history of the energy industry, prices have generally become lower and lower on an inflation-adjusted basis, while a combination of advancing technologies, determined entrepreneurs and alternative sources have exponentially expanded the total amount of energy and global reserves available for consumption.

There have long been periods of major changes in prices for oil and natural gas. Today, energy consumers of all types, from residential consumers to transportation firms to industrial plants, are suffering the economic effects of recently increased energy costs. Today's rapidly growing global demand for energy, combined with political strife in many oil exporting nations, could easily lead to a long-term period of relatively high market prices, both for crude oil and natural gas. The price of Arabian light crude oil rose from about $1.85 per barrel in 1972 to about $40 in 1981. Adjusted for inflation, that $40 barrel of oil would be $80 to $85 in 2005 dollars, see figure 1 below. Thus, today's oil prices, in the high $50s to $60 in late 2005, are painful, but, relatively speaking, not as high as they have been in the past (Plunkett Research, 2005).

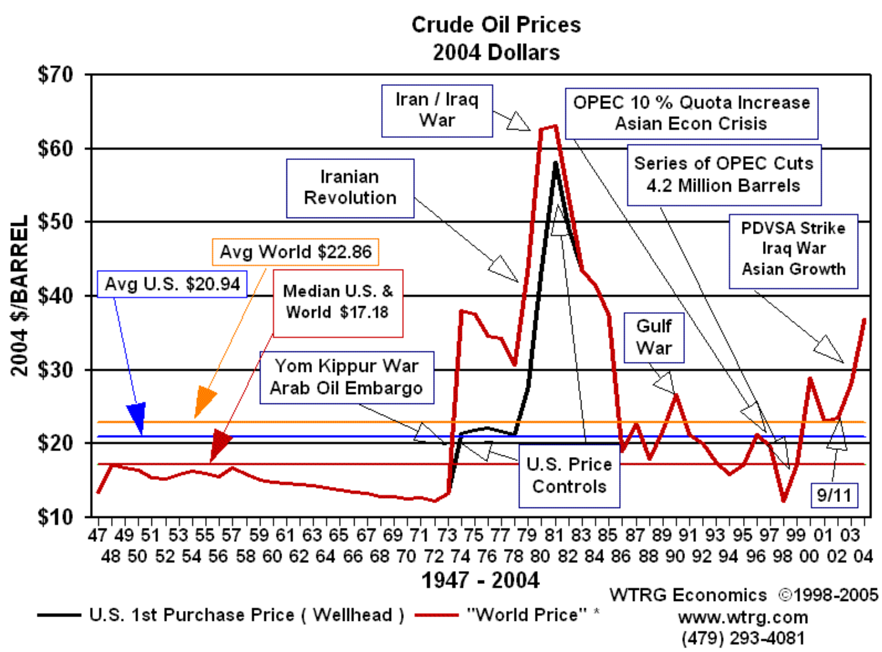



**Figure 1: History of the price of oil**

Source: Plunkett Research web site, (2005) This context of the study shows, on the basis of all these different points, that energy is one of the most important topics relating to the quality of our future standards of living.

## 1.3. Problem Statement

For clarity and simplicity, all the influencing factors that play a role in the choice of the sustainable energy of the future will be called drivers.

### *1.3.1. Main problem*

What is the effect of changing different drivers on the choice of the sustainable energy of the future?

### *1.3.2. Sub-problems*

<u>Sub-problem one:</u> Identifying the different drivers that may influence the choice of a particular type of energy.

<u>Sub-problem two:</u> Designing of a qualitative model that will take into account all the drivers and their inter-relationships.

<u>Sub-problem three:</u> Modelling of the different scenarios that show the effects of changing different drivers on the choice of the sustainable energy of the future.

## 1.4. Delimitations and Limitations

As the term "future" is too vague, a period must be defined. A time too close from nowadays will be of no use because the sources of energy are not going to change within the next 10 years, even though everybody sees the necessity to have better or at least other sources of energy quite soon, but most likely within a few decades from now (Hinrichsen & Robey, 2000). A time too distant from now will jeopardise our predictions. Therefore, according to the time needed to consider a switch from one source to another, the period considered under “future” will be 30-35 years from today (NAICS, 2002).

Another delimitation of this study is the utilisation of this new energy. The research is limited to the production of electricity, and does not consider: the specific research carried out in the transport field such as the use of bio fuels (ethanol or bio diesel) (USDA, 2005); research in the housing field such as the use of passive solar heating and day lighting; or research on geothermal direct use (producing heat directly from hot water within the earth) (Lienau, Lund & Culver, 1995) and geothermal heat pumps (using the shallow ground to heat and cool buildings) (Rafferty, 1999).

Lastly, the study will not involve the collection of primary data. All data will be secondary data sourced from academic (peer-reviewed) and/or reputable literature.

## 1.5. Significance of the Study

The significance of the study is twofold: first, for electricity providers such as Eskom in South Africa or EdF (Electricité de France) for France; second for the constructors of power plants or parts of power plants such as GE in the United States or SIEMENS in Germany.

The former category, indeed, does not wish to invest in billion dollar power plants, which could be useless in a few years time, for reasons such as natural resource shortages and new environmental laws, which prevent the use of environment damaging energy sources.

The latter category needs to know when the market is most likely to take a turn. Indeed, constructors of power plants have to invest in research and development in order to be able to propose new products to electricity providers. These constructors have to know several different important points in order to invest wisely, such as when they have to invest, in what kind of products and for how much.

This study, by providing information on the trends related to sustainable energy of the future, will help and guide the two players/categories of the energy field mentioned above to make the correct decisions for the way forward.

## 1.6. Assumptions

As mentioned above, the research findings are based only on what has been published thus far. Indeed, in a few years time if a researcher had to find something completely new, this discovery would have to be included in a new model. Therefore, the assumption that the sustainable energy for the year 2035 at least exists today has to be made. In other words, the reviewed literature will provide sufficient research findings in order for the outcome of the study to have a high degree of validity and reliability.

# 2. LITERATURE REVIEW

The literature review is set out in two sections; the first one gives some background on the different kinds of energy we can find nowadays. The second section focuses on the different drivers of the energy field and the trends in the decision-making mechanism for choosing a specific type of energy.

## 2.1. Different Energy Sources

As mentioned in the assumptions, the research will cover existing sources of energy or, at least, those that are currently under development.

Very often, not to say always, energy sources are split into two major groups: renewable and non-renewable. However, this classification is not without problems. Geothermal power and hydroelectric power are classified as renewable energy but geothermal sites eventually cool down and hydroelectric dams gradually become filled with silt, which may be very expensive to remove. It can be argued, though, that while a specific location may be depleted, the total amount of potential geothermal and hydroelectric power is not and a new power plant may sometimes be built in a different location. Nuclear power is not classified as a renewable source but the amount of uranium in the seas may continue to be replenished by rivers through erosion of underground resources for as long as the remaining life of the Sun (OMB, 1997).

In order to get better understandings of the current situation regarding different energy sources, hereafter is the split between these energies in the USA, which gives an accurate picture of the worldwide situation:

<u>Non-renewable:</u>

- 51% Coal;
- 20% Nuclear;

- 16% Natural Gas; and
- 3% Oil.

Renewable:

- 7% Hydro;
- 2% Biomass;
- less than 1% Geothermal;
- less than1% Solar; and
- less than 1% Wind.

These figures are given by the National Energy Education Development Project (NEEDP, 2004).

As seen in the USA example, most developed countries currently rely heavily on coal, oil, and natural gas for their energy. Fossil fuels are non-renewable; that is, they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. In contrast, renewable energy resources such as wind and solar energy are constantly replenished and will never run out.

Non-renewable and renewable energy sources are discussed respectively under sub-Sections 2.1.1 and 2.1.2, which follow.

### *2.1.1. Non-renewable*

Nowadays the majority of the power plants produce electricity by means of the "classic" generators. These generators are activated by turbines or motors, which use fossil fuels (oil, natural gas and coal) or atomic reactions (uranium) to work. Gas turbines and diesel motors produce the torque needed to activate the generator by using the fossil fuels (oil and natural gas) as a combustible. Steam turbines need one more step to have the same effect; indeed fossil fuels fired or atomic reactions are used as a heat source to boil water. The steam generated from the boiling water will rotate the large turbine that activates the generator that produces electricity.

**Table 1: Classification energy source versus power output**

| Power output | Oil | Natural gas | Coal | Uranium |
|---|---|---|---|---|
| 10 kW to 20 MW | Diesel motors | | | |
| 20 MW to 250 MW | Gas turbines (OC) Oil-fired | Gas turbines (OC) Gas-fired | Coal-fired | |
| 150 MW to 350 MW | Gas turbines (CC) Oil-fired | Gas turbines (CC) Gas-fired | Coal-fired | |
| 350 MW to 900 MW | | | Coal-fired | |
| 900 MW to 1800 MW | | | | Atomic reaction |

**OC**: Open cycle, the exhaust of the gas turbine goes directly to the atmosphere.

**CC**: Combined cycle, the exhaust of the gas turbine goes to a boiler to generate steam. This permits a much better yield for the same amount of natural resource burnt.

In Table 1 the power output is given per generator. A country such as South Africa can provide from its national company Eskom, 40,000 MW when all of the generators are operational and running simultaneously.

#### ***2.1.1.1. Fossil-fuel-fired power plant***

Introduction:

Coal, oil and gas are called "fossil fuels" because they are formed from the organic remains of prehistoric plants and animals.

Process of producing electricity by this means:

Coal is crushed to a fine dust and burnt. Oil and gas can be burnt directly.

**Burn Fuel → heat water to make steam → steam turns turbines → turbines turn generators → electrical power sent around country**

More details on this means:

Burning coal produces sulphur dioxide, an acidic gas that contributes to the formation of acid rain. Production of sulphur dioxide can be largely avoided by using "flue gas desulphurisation" to clean up the gases before they are released into the atmosphere. Crude oil (called "petroleum") is easier to get out of the ground than coal, as it can flow along pipes. This also makes it cheaper to transport. Natural gas provides around 20% of the world's consumption of energy, and, as well as being burnt in power stations, is used by many people to heat their homes. It is easy to transport along pipes, and gas power stations produce comparatively little pollution (Kirchgessner, 1997). Other fossil fuels are being investigated such as bituminous sands and oil shale. The difficulty is that they require expensive processing before they can be used; however, Canada has large reserves of “tar sands”, which provides economical production (Ebel, 2002).

Advantages of this means:

Very large amounts of electricity can be generated in one place using coal, cheaply. Transporting oil and gas to the power stations is easy. Gas-fired power stations are very efficient. In addition, a fossil-fuelled power station can be built almost anywhere, as long as large quantities of fuel are able to reach it (Ebel, 2002).

Disadvantages of this means:

The main drawback of fossil fuels is the air pollution it causes. Burning any fossil fuel produces carbon dioxide, which contributes to the "greenhouse effect". Burning coal produces more carbon dioxide than burning oil or gas. It also produces sulphur dioxide, a gas that contributes to acid rain.

Mining coal can be difficult and dangerous and strip mining destroys large areas of the landscape.

Coal-fired power stations need huge amounts of fuel, which means trainloads of coal almost constantly. In order to cope with changing demands for power, the station needs reserves, which necessitates covering a large area of countryside next to the power station with piles of coal (Best-Waldhober, Daamen & Faaij, 2006)

#### *2.1.1.2. Nuclear power plant*

<u>Introduction:</u>

Nuclear power is generated using uranium. Nuclear power produces around 11% of the world's energy needs, and produces huge amounts of energy from small amounts of fuel, without the pollution that results from burning fossil fuels (Gueorguiev & Spielberg, 2000).

<u>Process of producing electricity by this means:</u>

Nuclear power stations work similarly to fossil-fuel-burning stations, except that a "chain reaction" inside a nuclear reactor makes the heat instead. The reactor uses uranium rods as fuel, and the heat is generated by nuclear fission. Carbon dioxide gas is pumped through the reactor to remove the heat, and the hot gas then heats water to make steam.

**Nuclear fission makes heat** → **heat water to make steam** → **steam turns turbines** → **turbines turn generators** → **electrical power sent around country**

<u>More details on this means:</u>

Natural uranium is only 0.7% "uranium-235", which is the type of uranium that undergoes fission in this type of reactor. The rest is U-238, which just sits there getting in the way of the nuclear reaction. Modern reactors use "enriched" uranium fuel, which has a higher proportion of U-235.

Advantages of this means:

Nuclear Power does not produce smoke or carbon dioxide, so it does not contribute to the greenhouse effect. It produces huge amounts of energy from small amounts of fuel and produces small amounts of waste and nuclear power is reliable.

Disadvantages of this means:

Although not much waste is produced, this waste must be sealed up and buried for many millions of years to allow the radioactivity to die away.

Nuclear power is reliable, but a lot of money has to be spent on safety.

### *2.1.2. Renewable*

Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, and for hot water heating, solar cooling, and a variety of commercial and industrial uses (Tiwari, Padhyay & Rai, 1994). The sun's heat also drives the winds, whose energy is captured with wind turbines. The winds and the sun's heat cause water to evaporate. When this water vapour turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydroelectric power (Myers, Baird & Choate, 1990). Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called biomass energy (Volk, Kiernan, Fillhart, Abrhamson & White, 2001).

Hydrogen can be found in many organic compounds, as well as in water. It is the most abundant element on the Earth. Nevertheless, it does not occur naturally as a gas. It is always combined with other elements, such as with oxygen to make water.

Once separated from another element, hydrogen can be burned as a fuel or converted into electricity (Colson-Inam, 2003).

Not all renewable energy resources come from the sun. Geothermal energy taps into the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings (Kutscher, 2000). Moreover, the energy of the ocean's tides comes from the gravitational pull of the moon and the sun upon the Earth. In fact, ocean energy comes from a number of sources (Thorpe, 1998). In addition to tidal energy, there is the energy of the ocean's waves, which are driven by both the tides and the winds (Marine Foresight Panel, 1999). The sun also warms the surface of the ocean and warms up the water close to the ocean depths, creating a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity.

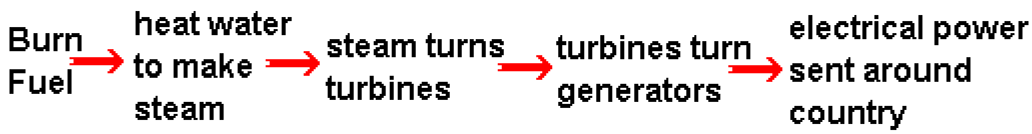
#### ***2.1.2.1. Biomass***

Introduction:

Wood was once our main fuel. We burned it to heat our homes and cook our food. Wood (FDR, 1995) still provides a small percentage of the energy we use, but its importance as an energy source is dwindling. Sugar cane is grown in some areas, and can be fermented to make alcohol, which can be burned to generate power in the same way as coal. Alternatively, the cane can be crushed and the pulp (called "bagasse") can be burned, to make steam to drive turbines. Other solid wastes, such as peat (Couch, 1993), can be burned to provide heat, or used to make steam for a power station. "Bioconversion" (Hall & Rosillo-Calle, 1998) uses plant and animal wastes to produce fuels such as methanol, natural gas, and oil. We can use rubbish, animal manure, woodchips, seaweed, corn stalks and other wastes as combustible.

Process of producing electricity by this means:

The fuel is burned, which heats water into steam, which turns turbines, which in turn drive generators, just like in a fossil-fuel power station.




Advantages of this means:

It makes sense to use waste materials where we can as:

- The fuel tends to be cheap.
- It is less demanding on the Earth's resources.
- It can permit to create new source of revenues for the farmers.

Disadvantages of this means:

Collecting the waste in sufficient quantities can be difficult and using fertilisers in order to improve yield can be harmful for the environment.

#### *2.1.2.2. Fuel cell*

Introduction:

A fuel cell is a device that generates electricity by a chemical reaction (EFCHP, 2004). Every fuel cell has two electrodes, one positive and one negative, called, respectively, “the cathode” and “the anode”. The reactions that produce electricity take place at the electrodes. Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes. Hydrogen is the basic fuel, but fuel cells also require oxygen.

One great appeal of fuel cells is that they generate electricity with very little pollution, and much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless by-product, namely water. One detail of terminology: a single fuel cell generates a tiny amount of direct current (DC) electricity. In practice, many fuel cells are usually assembled into a stack. Cell or stack, the principles are the same (Lloyd, 1999).

Process of producing electricity by this means:

The purpose of a fuel cell is to produce an electrical current that can be directed outside the cell to do work, such as powering an electric motor or illuminating a light bulb or a city. Because of the way electricity behaves, this current returns to the fuel cell, completing an electrical circuit. The chemical reactions that produce this current are the key to how a fuel cell works. There are several kinds of fuel cells, and each operates a bit differently. In general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionised," and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work. If alternating current (AC) is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter.

Oxygen enters the fuel cell at the cathode and, in some cell types; it there combines with electrons returning from the electrical circuit and hydrogen ions that have travelled through the electrolyte from the anode. In other cell types, the oxygen picks up electrons and then travels through the electrolyte to the anode, where it combines with hydrogen ions. The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction. Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity. Even better, since fuel cells create electricity chemically, rather than by combustion, they are not subject to the thermodynamic laws that limit a conventional power plant. Therefore, fuel cells are more efficient in extracting energy from a fuel. Waste heat from some cells can also be harnessed, boosting system efficiency still further (Jacoby, 1999).

More details on this means:

Even though, in the modern design, fossil fuels are consumed in the electrochemical reaction inside of a fuel cell, fuel cells do not do not produce the same unhealthy air pollution emissions that are generated by burning gasoline in cars or burning coal and other fossil fuels in power plants. With fuel cells, there is no combustion, so fewer gases are released into the environment. For example, almost no sulphur oxides ($SO_x$) or nitrogen oxides ($NO_x$) are emitted, and emissions do not include any particulate matter. The greenhouse gas carbon dioxide ($CO_2$) is a by-product, but because noxious air emissions are so low from fuel cell systems, certifications and permits are rarely needed to install commercial fuel cell systems. In addition, the high electrical efficiency of fuel cells provides much more electricity per unit of carbon released than conventional generators of similar size. If, in the end, fuel cells could use hydrogen produced by electrolysis powered by electricity generated from renewable sources, the environmental benefits would be even greater. In that case, the outputs of fuel cells would be electricity, heat, and water vapour (produced when the hydrogen and oxygen combine in the fuel cell) (Jacoby, 1999).

Advantages of this means:

They are clean. Fuelled by pure “clean” hydrogen, fuel cells produce only pure water as exhaust. They also have a high efficiency. Fuel cells extract more energy from a fuel due to the increase in efficiency of electrochemical conversion over combustion. There are no moving parts in a fuel cell stack itself so there are no mechanical inefficiencies.

Fuel cells are silent with no moving parts; fuel cells stack themselves and are vibration-free. The absence of combustion and moving parts means that fuel cell technologies are expected to provide much improved reliability over traditional combustion engines. Fuel cells can be responsive to changing electrical loads: more fuel is simply fed into the fuel cell stack. The speed of such a response is fast enough for many applications.

In term of power quality, fuel cells provide high quality DC power, perfect for modern electrical applications such as sensitive electronics or hospital equipment.

Disadvantages of this means:

Fuel cells are not the perfect solution to the world's energy needs. Several obstacles need to be overcome before widespread use of fuel cells occurs.

Firstly, they are too expensive. Although some fuel cell systems are in use today, very few are currently cost effective. For stationary fuel cells, typical capital costs for installed systems exceed $5,000 per kilowatt, well above the target capital cost of $1,000-$1,500 used by most energy generation developers. Secondly, early technology risks are associated with fuel cells. Fuel cells are still in a relatively early stage of development and even the few commercially available models have limited fleet-operating experience. This emerging technology requires risk-taking early adopters as end users in order to ultimately expose more consumers to the benefits of fuel cells. Thirdly is the problem of durability. In order to become widely accepted as a clean distributed generator, fuel cells must prove their adaptability for a variety of applications. In addition, certain fuel cell system components, like the cell stack which can require a costly replacement every one to five years depending on the model, must be developed to have a longer lifespan or be easily and cheaply replaced (Breeze, 1998).

#### *2.1.2.3. Geothermal*

Introduction:

The centre of the Earth is around 6,000 degrees Celsius. Even a few kilometres down, the temperature can be over 250 degrees Celsius. In general, the temperature rises one degree Celsius for every 36 metres you go down. In volcanic areas, molten rock can be very close to the surface. Geothermal (Huttrer, 2000) energy has been used for thousands of years in some countries for cooking and heating.

<u>Process of producing electricity by this means:</u>

Hot rocks underground heat water to produce steam. We drill holes down to the hot region; steam comes up, is purified and used to drive turbines, which drive electric generators. There may be natural "groundwater" in the hot rocks anyway, or we may need to drill more holes and pump water down to them. The first geothermal power station was built at Landrello, in Italy, and the second was at Wairekei in New Zealand. Others are in Iceland, Japan, the Philippines and the United States. In Iceland, geothermal heat is used to heat houses as well as for generating electricity. See Figure 2 below.

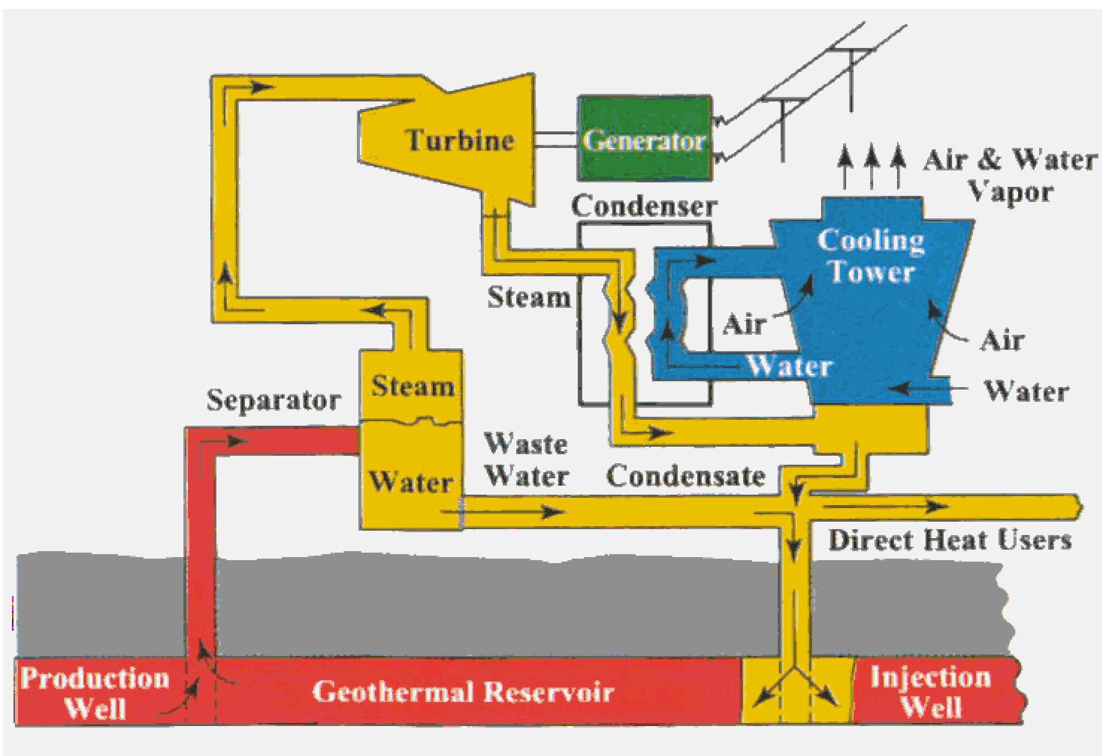



**Figure 2: Geothermal power plant**

Source: Geothermal Resources web site, (2006)

More details on this means:

Geothermal energy (Lund & Freeston, 2000) is an important resource in volcanically active places such as Iceland and New Zealand. How useful it is depends on how hot the water gets. This heat depends on how hot the rocks were to start with, and how much water we pump down to them. Water is pumped down an "injection well", filters through the cracks in the rocks in the hot region, and comes back up the "production well" under pressure. It "flashes" into steam when it reaches the surface. The steam may be used to drive a turbo-generator. The steam must be purified before it is used to drive a turbine, or the turbine blades will be "furred up".

Advantages of this means:

Geothermal energy does not produce any pollution, and does not contribute to the greenhouse effect. The power stations do not take up much room, so there is not much impact on the environment. No fuel is needed and once you have built a geothermal power station, the energy is almost free. A little energy might be needed to run a pump, but this can be taken from the energy being generated.

Disadvantages of this means:

The biggest problem with geothermal energy is that there are not many places where a geothermal power station can be built. Hot rocks of a suitable type are needed, at a depth where it can be drilled down to them. The type of rock above is also important; it must be of a type that it can easily be drilled through. In addition, a geothermal site may at times "run out of steam", perhaps for decades. Hazardous gases and minerals may come up from underground, and can be difficult to safely dispose of (Lippmann, 2002).

#### 2.1.2.4. *Normal hydro*

Introduction:

We have used running water as an energy source for thousands of years, initially to grind corn. Today there are many hydroelectric power stations (Egre, Gagnon & Milewki, 1999), providing around 20% of the world's electricity.

Process of producing electricity by this means:

A dam is built to trap water, usually in a valley where there is an existing lake. Water is allowed to flow through tunnels in the dam, to turn turbines and thus drive generators. Hydroelectric power stations can produce a great deal of power very cheaply. Although there are many suitable sites around the world, hydroelectric dams are very expensive to build. However, once the station is built, the water comes free of charge, and there is no waste or pollution. See Figure 3 below.

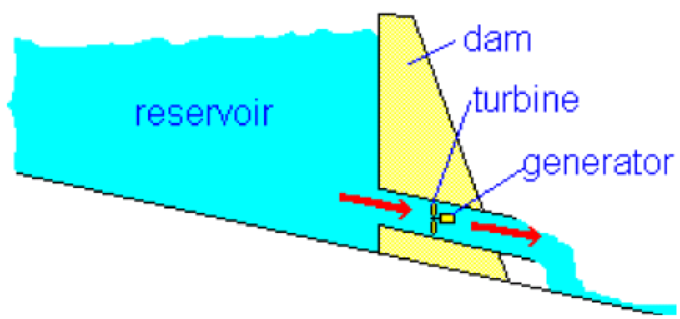



**Figure 3: Normal hydraulic power plant**

Source: Based on Henry, (1992)

More details on this means:

Gravitational potential energy is stored in the water above the dam. Because of the great height of the water, it will arrive at the turbines at high pressure, which means that a great deal of energy can be extracted from it. In mountainous countries such as Switzerland and New Zealand, hydroelectric power provides more than half of the country's energy needs. An alternative is to build the station next to a fast-flowing river. However, with this arrangement, the flow of the water cannot be controlled, and water cannot be stored for later use.

Advantages of this means:

Once the dam is built, the energy is virtually free and is much more reliable than wind, solar or wave power. No waste or pollution produced and water can be stored above the dam ready to cope with peaks in demand. Hydroelectric power stations can increase to full power very quickly, unlike other power stations.

Disadvantages of this means:

The dams are very expensive to build and building a large dam will flood a very large area upstream, causing problems for animals that used to live there. Water quality and quantity downstream can be affected, which can have an impact on plant life

Finding a suitable site can be difficult, and the impact on residents and the environment may be unacceptable.

#### ***2.1.2.5. Storage hydro***

Introduction:

Pumped storage reservoirs are not really a means of generating electrical power (Nixon, 2000). They are a way of storing energy so that it can be released quickly when it is needed. Demand for electrical power changes throughout the day. For example if a sudden peak in demand arises and if power stations do not generate more power immediately, there will be power cuts around the country. The problem is that most of our power is generated by fossil fuel power stations, which take half an hour or so to crank themselves up to full power. Nuclear power stations take much longer. We need something that can go from nothing to full power immediately, and keep us supplied for around half an hour until the other power stations catch up. Pumped storage reservoirs are the answer we have chosen.

Process of producing electricity by this means:

Water is pumped up to the top reservoir at night, when demand for power across the country is low. When there is a sudden demand for power, the "head-gates" (huge taps) are opened, and water rushes down the tunnels to drive the turbines, which drive the powerful generators. The water then collects in the bottom reservoir, ready to be pumped back up later. See Figure 4 below.

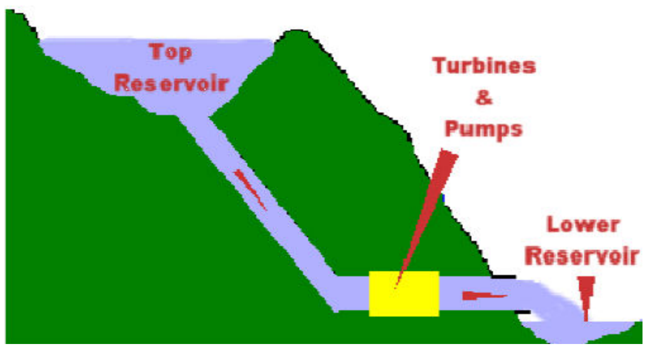



**Figure 4: Storage hydraulic power plant**

Source: Based on Henry, (1992)

Advantages of this means:

It is a good means of storing energy for quick release. There is a little effect on the landscape and there is no pollution or waste.

Disadvantages of this means:

This means is expensive to build. Once it is used, you cannot use it again until you have pumped the water back up.

### 2.1.2.6. Ocean thermal

Introduction:

Ocean Thermal Energy Conversion (OTEC) (Gauthier, 2000) is a means of converting into useful energy the temperature difference between the surface water of the oceans in tropical and sub-tropical areas and water at a depth of approximately 1,000 metres that comes from the Polar Regions. For OTEC a temperature difference of 20°C is adequate, which embraces very large ocean areas, and favours islands and many developing countries. The continuing increase in demand from this sector of the world (as indicated by World Energy Council figures) provides a major potential market (Vega, 1992)

Process of producing electricity with this means:

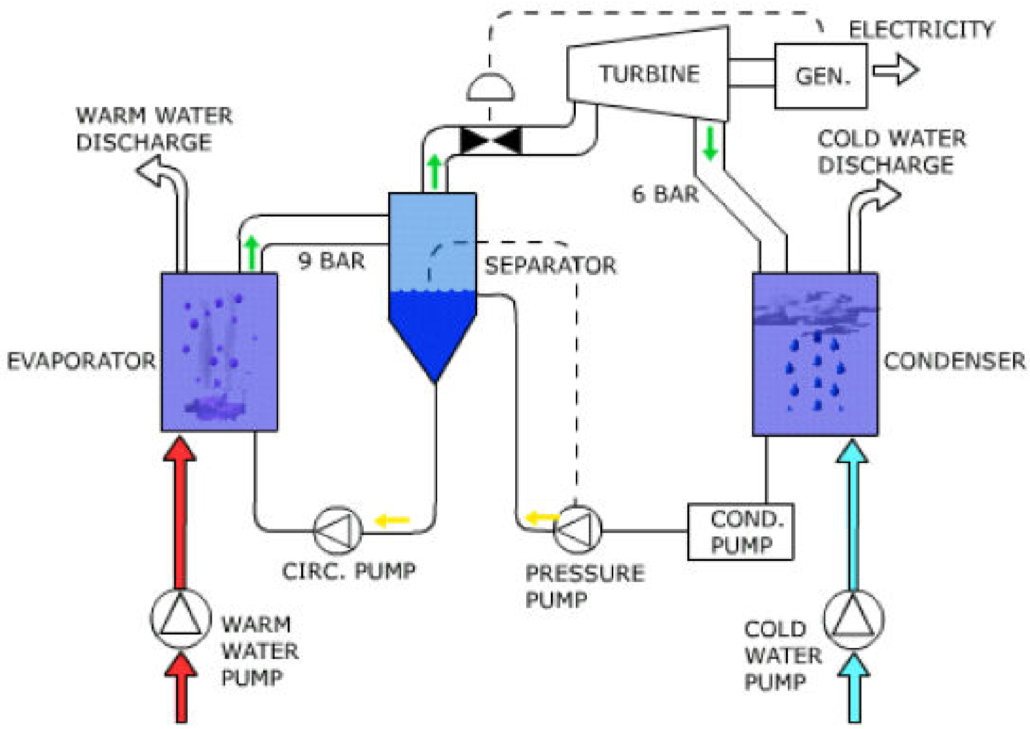



**Figure 5: Ocean thermal energy conversion**

Source: Based on Vega, (1992)

More details on this means:

Depending on the location of their cold and warm water supplies, OTEC plants can be land-based, floating, or, as a longer-term development, grazing. Floating plants have the advantage that the cold water pipe is shorter, reaching directly down to the cold resource, but the power generated has to be brought ashore, and moorings are likely to be in water depths of, typically, 2 000 metres.

Advantages of this means:

One advantage of OTEC is that electricity can be generated without any natural resources. A further benefit is that, unlike most renewable energies, it is base-load. The thermal resource of the ocean ensures the power source is available day or night, and with only modest variation from summer to winter. There is no pollution or environmental damages.

Disadvantages of this means:

The quantity of electricity produced by OTEC is very low. The transport of the electricity to the right place of use can be challenging due to the issue of mooring.

#### *2.1.2.7. Solar*

Introduction:

We have used the Sun for drying clothes and food for thousands of years, but only recently have we been able to use it for generating power. The Sun is 150 million kilometres away, and amazingly powerful. Just the tiny fraction of the Sun's energy that hits the Earth (around a hundredth of a millionth of a percent) is enough to meet all our power needs many times over. In fact, every minute, enough energy arrives at the Earth to meet our demands for a whole year, if only we could harness it properly (Tyner, Gregory, Geyer & Romero, 2001).

Process of producing electricity by these means:

**Solar cells** ("photovoltaic" or "photoelectric" cells) convert light directly into electricity. In a sunny climate, you can get enough power to run a 100W light bulb from just one square metre of a solar panel. This was originally developed in order to provide electricity for satellites, but these days many of us own calculators powered by solar cells. See Figure 6 below.

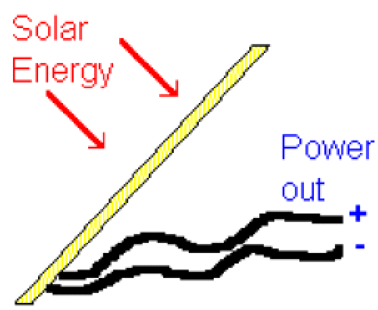



**Figure 6: Photovoltaic cell**

Source: Based on Tyner, Gregory, Geyer & Romero, (2001)

**Solar water heating** occurs when heat from the Sun is used to heat water in glass panels on roofs. Water is pumped through pipes in the panel. The pipes are painted black, so they become hot faster when the Sun shines on them. Solar heating is worthwhile in places like California and Australia, where you get lots of sunshine. See Figure 7 below.

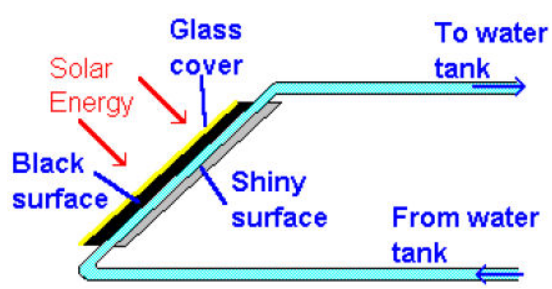



**Figure 7: Solar water heating**

Source: Based on Tyner, Gregory, Geyer & Romero, (2001)

**Solar Furnaces** use a huge array of mirrors to concentrate the Sun's energy into a small space and produce very high temperatures. A solar furnace at Odellio, in France, used for scientific experiments, can achieve temperatures up to 33,000 degrees Celsius. See Figure 8 below.

**Figure 8: Solar furnace**

Source: Solar Furnace web site, (2006)

**Solar towers** are a type of a big greenhouse, which is warmed by the Sun. In the middle of the greenhouse, you put a very tall tower. The hot air from the greenhouse will rise up this tower, fast and can drive turbines along the way. This could generate significant amounts of power, especially in countries where there is a lot of sunshine and a lot of room, such as Australia. See Figure 9 below.

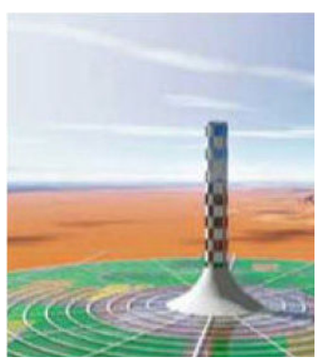


**Figure 9: Solar tower**

Source: Solar Tower web site, (2006)

In California, the Solar One power station uses the Sun's heat to make steam, and drive a generator to make electricity. The station looks a little like the Odellio solar furnace, except that the mirrors are arranged in circles around the "power tower". As the Sun moves across the sky, the mirrors turn to keep the rays focused on the tower, where oil is heated to 3,000 degrees Celsius and the heat from the oil is used to generate steam. This steam then drives a turbine, which in turn drives a generator capable of providing 10kW of electrical power.

Advantages of these means:

Solar energy is free, needs no fuel, and produces neither waste nor pollution. In sunny countries, solar power can be used where there is no easy way to get electricity to a remote place and it is handy for low-power uses, such as solar-powered garden lights and battery chargers.

Disadvantages of these means:

Solar energy does not work at night and solar cells cost a great deal compared to the amount of electricity they will produce in their lifetime. Solar energy can also be unreliable unless you are in a very sunny climate. In the United Kingdom, solar power is not much use except for low-power applications, as you need a very large area of solar panels to get a decent amount of power.

At this stage solar energy is still of very small benefit concerning the amount of energy we could get from the Sun.

#### ***2.1.2.8. Tidal***

Introduction:

The tide moves a huge amount of water twice each day, and harnessing it could provide a great deal of energy (Neuhoff, 2004). Although the energy supply is reliable and plentiful, converting it into useful electrical power is not easy. Only around 20 sites in the world have been identified as possible tidal power stations.

Process of producing electricity by this means:

These work rather like a hydroelectric scheme, except that the dam is much bigger. A huge dam is built across a river estuary. When the tide ebbs and flows, the water flows through tunnels in the dam. The ebb and flow of the tides can be used to turn a turbine, or to push air through a pipe, which then turns a turbine. Large lock gates, like the ones used on canals, allow ships to pass. See Figure 10 below.


**Figure 10: Onshore tidal energy**

Source: Based on Davies, Proctor & O'Neil, (1991)

Another option for tidal energy is to use offshore turbines, rather like an underwater wind farm. This has the advantage of being much cheaper to build, and does not have the environmental problems that a tidal barrage would bring. There are also many more suitable sites. See Figure 11 below.


**Figure 11: Offshore tidal energy**

Source: Tidal Energy web site, (2006)

More details on this means:

The largest tidal power station in the world (and the only one in Europe) is in the Rance estuary in northern France. It was built in 1966. A major drawback of tidal power stations is that they can only generate when the tide is flowing in or out; in other words, only for ten hours each day. However, tides are very predictable, so we can plan to have other power stations generating at those times when the tidal station is out of action.

Advantages of this means:

Once tidal station is built, tidal power is free. It produces no greenhouse gases or other waste, needs no fuel and produces electricity reliably. Tidal stations are not expensive to maintain and offshore turbines and vertical-axis turbines are not expensive to build and do not have a large environmental impact.

Disadvantages of this means:

A barrage across an estuary is very expensive to build, and affects a very wide area. Also the environment is changed for many miles upstream and downstream and there are only few suitable sites for tidal barrages. Tidal Stations only provide power for around ten hours each day, when the tide is actually moving in or out.

#### ***2.1.2.9. Wave***

Introduction:

Ocean waves are caused by the wind as it blows across the sea (Thorpe, 1998). Waves are a powerful source of energy. The problem is that it is not easy to harness this energy and convert it into electricity in large amounts. Thus, wave power stations are rare.

Process of producing electricity by this means:

There are several methods of getting energy from waves, but one of the most effective works like a swimming pool wave machine in reverse. At a swimming pool, air is blown in and out of a chamber beside the pool, which makes the water outside bob up and down, causing waves. At a wave power station, the waves arriving cause the water in the chamber to rise and fall, which means that air is forced in and out of the hole in the top of the chamber. See Figure 12 below.

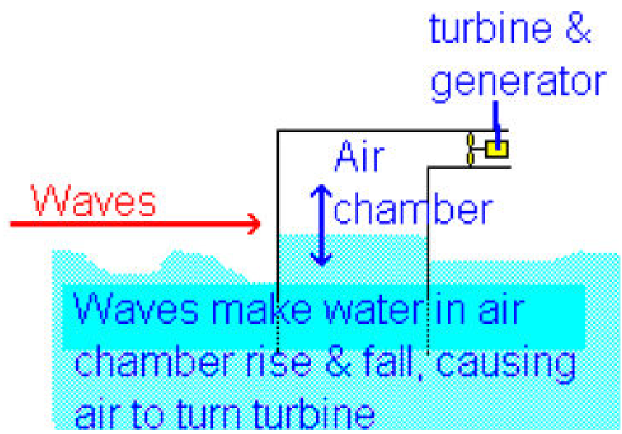



**Figure 12: Onshore wave energy**

Source: Based on Davies, Proctor & O'Neil, (1991)

The same principle can be used for the offshore material.

Advantages of this means:

The energy is free, no fuel needed, no waste produced. Wave stations are not expensive to operate and maintain and they can produce a great deal of energy.

Disadvantages of this means:

Depending on the waves, at times a lot of energy can be produced and sometimes nothing. Wave stations need suitable sites, where waves are consistently strong. Some tidal station designs can be very noisy.

#### *2.1.2.10. Wind*

Introduction:

We have used the wind as an energy source for a long time. The Babylonians and Chinese were using wind power to pump water for irrigating crops 4,000 years ago. Wind power was used in the Middle Ages, in Europe, to grind corn, which is where the term "windmill" comes from (Neuhoff & De Vries, 2004).

Process of producing electricity by this means:

We can use the energy in the wind by building a tall tower, with a large propeller at the top. The wind causes the propeller to rotate, which turns a generator to produce electricity. We tend to build many of these towers together, to make a "wind farm" and produce more electricity. It is only worth building wind farms in places that have strong, steady winds. See Figure 13 below.

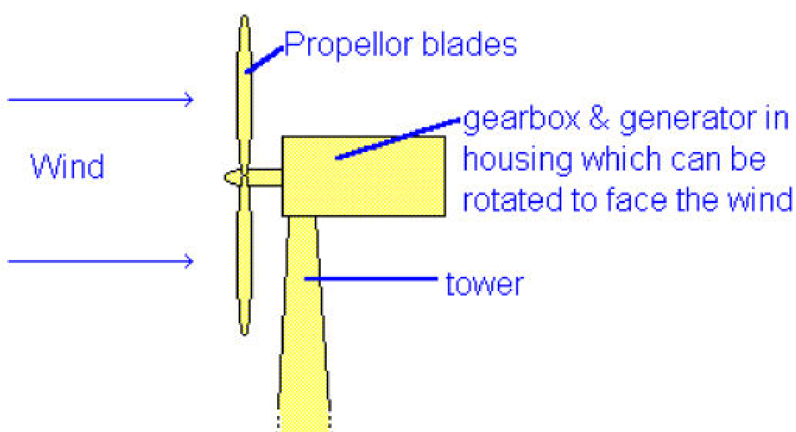



**Figure 13: Wind energy**

Source: Based on Murtagh, Basu & Broderick, (2005)

More details on this means:

The best places for wind farms are in coastal areas, at the tops of rounded hills, open plains and gaps in mountains, places where the wind is strong and reliable.

To be worthwhile, you need an average wind speed of around 25 km/h. The blades can be angled to "fine" or "coarse" pitch, to cope with varying wind speeds, and the generator and propeller can turn to face the wind wherever it comes from. Some designs use vertical turbines, which do not need to be turned to face the wind.

Advantages of this means:

Wind farms do not need fuel and produce neither waste nor greenhouse gases. The land beneath the propellers can usually still be used for farming. It is a good method of supplying energy to remote areas.

Disadvantages of this means:

The wind is not always predictable; some days there will be no wind. The most suitable areas for wind farms are often near the coast, where land is expensive. The propellers can be noisy. Wind generators have a reputation for making a constant, low, "swooshing" noise day and night. An entire wind farm makes quite a racket! Having said that aerodynamic designs have improved, modern wind farms are much quieter.

## 2.2. Drivers

The literature review makes it clear that there are four main constructs, within the drivers of the sub-problem 1, which can influence the type of energy that will become the sustainable energy of the future. These four constructs are the availability of natural resources, the geographical locations of the future plants, the environmental issues and the economical/ financial factors.

Proposition: The result of the absence of all the drivers in a simulation using the qualitative model will be investigated.

### 2.2.1. Construct 1: Natural resources/reserves

Renewable energy will not run out, ever. Other sources of energy are finite and will some day be depleted. Currently, fossil fuels represent almost 90% of total energy supply; oil is the main source of energy (40%), followed by coal (26%) and natural gas (21%) (WEC-CCR, 2003).

Proposition: The result of the presence of only drivers concerning the natural resources in a simulation using the qualitative model will be investigated.

#### 2.2.1.1. Oil

Conventional oil:

Since the oil supply disruptions of the early 1970s, the United States, for instance, has increased its dependence on foreign oil supplies instead of decreasing it (Adelman, 1995). Currently, the EU imports 50% of its energy and this will raise to 70% by 2030, with an increasing share for fossil fuels "unless bold measures are adopted." This increased dependence impacts more than just on the national energy policy. Conservative predictions are that conventional oil production will peak in 2007. Other less conservative predictions mention that the world conventional oil production will peak somewhere between 2020 and 2050, but that the output is likely to increase at a substantially slower rate after 2020 (Campbell, 2002).

Non-conventional oil:

Non-conventional types of production include tar sands, shale oil and bitumen. These resources are estimated to contain three times as much oil as the remaining conventional oil resources but few are economically recoverable with current technology, although this may change. Recovery of oil from tar sands is now economically viable, with billions of dollars being invested in new oil recovery plants (Quinn & Cleveland, 2005).

#### 2.2.1.2. Natural-gas

Conventional natural gas:

The worldwide natural-gas consumption is increasing, while oil consumption is decreasing. Indeed, usually the solution to cope with peaking electricity demand is to opt for gas turbines. Moreover, new natural gas fields have been discovered, especially in China, which can explain the sudden interest in this source of energy (EnCana Corporation, 2005). The equilibrium point of the demand for conventional natural gas will probably be somewhat later than for oil. The pessimists predict a peak for conventional gas production between 2010 and 2020.

Non-conventional natural gas:

There are large unconventional gas resources, like methane hydrate or geo-pressurised zones, which could increase the amount of gas by a factor of ten or more, if it is recoverable. Vast quantities of methane hydrate are inferred from the actual finds. Methane hydrate is a clathrate; a crystalline form in which methane molecules are trapped. The form is stable at low temperature and high pressure, conditions that exist at ocean depth of 500 meters or more, or under permafrost. Inferred quantities of methane hydrates exceed those of all other fossil fuels combined, including oil, conventional natural gas and coal. Technology for extracting methane gas from the hydrate deposits in commercial quantities has not yet been developed (Dillon, 2002).

#### 2.2.1.3. Coal

The difference between coal resources and coal reserves is essential to interpretation. Indeed, the commonly held distinction is that a coal resource is coal existing in the earth, whereas a coal reserve is that portion of the resource, which can be economically mined (Westman, Haycocks & Karnis, 1999). There are large but finite coal reserves, which may increasingly be used as an energy source during oil depletion. There are today 200 years of economically exploitable reserves at the current rate of consumption. Reserves have increased by over 50% in the last 22 years and are expected to continue to increase. Coal resources are estimated to be ten times larger (Scaroni, Miller& Pisupati, 2004). Large amounts of coal waste that has been produced during coal mining and stored near mines could become exploitable with new technology.

#### *2.2.1.4. Uranium*

Reserve and resource statistics are available for most commodities but those for uranium are noteworthy in that they reflect both the reliability of the estimate and the prospective extraction cost. The latter is unusual in the mining world, but is important as it is frequently claimed that much of the uranium reserve base is not economically viable as the anticipated mining costs lie in excess of the current market price of uranium (Mikhailov, 2001). Concern that uranium could eventually run out and threaten the future of nuclear power programmes led to substantial exploration programmes from the 1950s to the 1970s. These programmes achieved considerable successes. Many new mines were brought into operation, frequently financed by the collateral provided by long-term contracts with electricity utilities. The commercial uranium market has historically experienced roller coaster conditions, with successive booms and busts.

The trickiest part of harnessing nuclear power is enriching the uranium. The raw product dug out of the ground is about 0.7% of U-235. To make it usable in a standard reactor, it needs to be enriched to between three and four percent U-235. The largest viable uranium deposits are in Australia, Canada, Kazakhstan and South Africa, in that order. Combine the deposits in South Africa and Namibia (fifth on the list) and you have roughly the same amount as in Canada. Niger is currently a hot prospecting ground but while ore bodies there should be cheap to mine, total known deposits are relatively small.

Plenty of expansion is planned in the uranium-mining sector, but it still looks like supply will fall well short of demand. It is theoretically possible that a third of world's power will be supplied by nuclear generation by 2050. For that to happen, current uranium output would have to increase eight-fold. The same holds in the short term. The current 440 reactors and 66 firmly planned ones will need 80,000 tons to feed them by 2010. Current and firmly planned mines will fall about 10,000 tons short of this, and that is before demand doubles, as increasingly believable analysts are predicting (Maverick Magazine, 2006). Therefore, concerns about the long-term sustainability of nuclear power owing to an inadequate resource base will persist.

### ***2.2.2. Construct 2: Geographical locations***

Proposition: The result of the presence of only drivers relating to the geographical locations in a simulation using the qualitative model will be investigated.

This last construct has a bigger impact on the renewable energy sources than on the conventional ones. Indeed conventional power stations can be erected almost anywhere, as there is only need for a reliable transportation structure for "feeding" the station with the needed natural resource. On the other hand, geographical location is crucial for all renewable energy sources:

- For using biomass energy, the country must have a huge quantity of farming possibilities (land, weather, water, farmers) (Couch, 1993).
- For using geothermal energy, the country must be situated where the hot rocks of a suitable type are found at depths that make the rocks accessible (Huttrer, 2000).
- For using hydro energy, the country must have at least rivers and, even better, mountains where the dams can be built (Egre, Gagnon & Milewki, 1999).
- For using ocean thermal, tidal or wave energy, the country must be close to a sea or to an ocean (Gauthier, 2000; Neuhoff, 2004; Thorpe, 1998).

- For using solar energy, the country must be situated in sunny region where the sun is present very often throughout the year (Gould, Zavoico, Collier & Grimaldi, 2000).
- For using wind energy, the country must be situated in windy region where the wind is present very often throughout the year (Neuhoff & De Vries, 2004).

### *2.2.3. Construct 3: Environmental issues*

Proposition: The result of the presence of only drivers concerning the environmental issues in a simulation using the qualitative model will be investigated.

#### *2.2.3.1. Polluting emissions*

Climate change is one of the greatest environmental, economic and social threats facing the planet and is likely to be the dominant environmental issue of the 21st century. Indeed, when oil production begins to decline, humanity may increasingly turn to less environmentally friendly energy sources such as coal, of which significant reserves remain on Earth. This may exacerbate global warming, and health and developmental problems such as cancer and autism.

Since the late 19th century, the Earth's average surface temperature has risen by 0.3-0.6°C (Karoly, 2003). According to most scientific reports, this is predominantly due to human activities like burning fossil fuels and deforestation, which causes carbon dioxide ($CO_2$) and other greenhouse gas emissions (Hansen, Ruedy, Glascoe & Sato, 1999). In parallel, with global warming, fossil fuels contribute also to acid rains (Gerhard, Harrison & Hanson, 2001). However, natural gas is generally considered the least polluting of the fossil fuels, with coal being the most polluting.

Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies. They do not produce carbon dioxide ($CO_2$) gas emissions and would help compliance with the Kyoto commitments (UNFCCC, 2005).

In Europe, in 1997, a white paper on renewable energy wanted 3,000 MW of power to come from photovoltaic (PV) (Davidson & Komp, 1983) by 2010, but a market analysis conducted in 2005 shows that: the cumulated installed PV capacity in Europe is 1,000 MW; the prospects for market growth, mostly driven by Germany, remain positive; and the 3,000 MW target for 2010 appears within reach but at which cost? Indeed, this "green" policy lies heavily on the German economy and even the new government says:

Angela Merkel, German Chancellor, addressing Energy Conference, Berlin

*We are still against the $CO_2$ gas emissions and the greenhouse gas emissions, the nuclear solution complies with that and could be cheaper for the time being!* (Der Spegel, Friday 14th October 2005)

#### *2.2.3.2. Nuclear waste*

As mentioned in the previous section, a new age of pro-nuclear energy is rising, and standards of safety are increasing in order to justify the use of nuclear plants, especially following on from Greenpeace's statements that the proposals for new safety are misleading. While ostensibly designed to increase nuclear safety, the pro-nuclear defenders hide their true purpose, which is to revitalise the nuclear industry. Greenpeace urges the EU not to subsidise the ailing industry, but to use taxpayers' money for clean energy instead.

The long-term radioactive waste storage problems of nuclear power have not been fully solved (Hill & Gunton, 2001). Several countries have considered using underground repositories. Nuclear waste takes up little space compared to wastes from the chemical industries, which remain toxic indefinitely. Spent fuel rods are now stored in concrete casks close to the nuclear reactors. The amounts of waste can be reduced in several ways. Both nuclear reprocessing and fast breeder reactors can reduce the amounts of waste. Sub-critical reactors or fusion reactors could greatly reduce the time the waste has to be stored (OECD/NEA, 1988).

Advocates of nuclear power argue that nuclear power is cost-competitive and an environmentally friendly way to produce energy versus fossil fuels, when externality associated with both forms of energy production is taken into account. In addition, nuclear power has a high-energy return on energy investment (EROI). Using life cycle analysis, it takes 4-5 months of energy production from the nuclear plant to fully pay back the initial energy investment.

#### *2.2.3.3. Natural environment*

Not only are the non-renewable ways of producing electricity harmful to the environment; certain renewable manners can be damaging too. The most known is the hydro, which can be unfriendly to the natural environment - upstream with the building of large dams and downstream with the modification of the river flows (Egre, Gagnon & Milewki, 1999). Indeed, the largest dams in the world have had big impacts on the wild and human lives; for instance, in China, the Three Gorges hydro project forced more than several millions of people re-locate as well as animals. Downstream, the well-known example of the Nile illustrates the harmful effects a hydroelectric dam can have on the natural environment.

Other renewable projects can also have some environmental drawbacks; biomass can force farmers to rely extensively on fertilisers, which can be very dangerous for our rivers (Couch, 1993). Geothermal can retrieve from the Earth gases that are more damaging than the $CO_2$ of the coal-fired power stations (Huttrer, 2000). Wind farms (Neuhoff, 2004) and wave walls (Thorpe, 1998) can be so noisy that it becomes very difficult to stay close to them the entire day.

### *2.2.4. Construct 4: Economical/financial factors*

<u>Proposition:</u> The result of the presence of only drivers concerning the economical/financial factors in a simulation using the qualitative model will be investigated.

#### *2.2.4.1. Demand/supply of electricity*

The world demand for electricity is growing steadily around 1.9% a year and this should continue on the same basis until 2030; this figure is based on assumptions about economic and population growth, as well as developments in energy intensity. But, in certain developing countries such as South Africa and India or in a booming country such as China, the growth rate can easily break the 10% a year figure (EMP, 2005). Indeed, industrial countries will experience a slowdown in their energy demand, but demand in developing countries will grow rapidly; by 2030, over half of the world's energy demand is expected to come from developing countries (compared to 40% today). Therefore, the supply has to increase even more to avoid disruption of the supply chain. Generally, the response to cope with this soaring demand of electricity is the use of more conventional sources of energy with all their drawbacks.

By using renewable energy and better yet energy-efficient technologies in the household, the general demand for electricity might decrease, which will help the environment and typically save money for users in the end. Indeed, in the near future, the prospect of increase competition in the electricity industry, particularly retail wheeling, will threaten to make the traditional concept of a retail monopoly franchise for the provision of electric service outdated. If such is the case, consumers will be able to choose freely among suppliers of different kinds of energy sources. Consumers' choices will reveal the appropriate balance between supply and demand and the nature of the resource.

#### *2.2.4.2. Cost*

The cost, in the decision-making process for the choice of a particular type of way of generating electricity, is certainly one of the most important points but it is also one of the most difficult to assess. Several studies have been carried out by a group of experts such as electrical engineers, financial advisors, natural resource specialists who have been appointed by electricity suppliers such as EdF in France or Eskom in South Africa in order to define the cheapest way of producing electricity. Throughout the literature, the most relevant studies are based on a method called the "levelised" lifetime cost approach (Morgan, Granger & Tierney, 2002). In the different studies and using this approach, the experts included as many factors as they could:

- The power output of a unit built;
- The lifetime expectancy of a unit built;
- The construction phase of a new power plant: i.e. duration of the construction and specific construction costs.
- The sum needed to finance the construction, the interest rate: financial implications;
- The maintenance cost;
- The cost of the combustible, and its price inflation for the forthcoming years; and
- The down time of a unit (for maintenance, for instance, but as well due to a lack of wind for a wind farm, a lack of Sun for a solar plant, or a lack of water for a hydro).

On the other hand, certain costs have not been taken into account:

- Electricity generation costs calculated are busbar costs, at the station, and do not include transmission and distribution costs.
- The costs associated with residual emissions, including greenhouse gases, are not included in the costs provided below.

Two remarks about the set up of the following table:

- The classification of the coal-fired power plants begins with the most polluting one and proceeds to cleanest one; hence, it can be noticed that the price per kWh is increasing.
- The classification of the gas-fired power plants begins with the less efficient one and proceeds to complete with the most efficient; hence it can be noticed that the price per kWh is decreasing.

**Table 2: Levelised lifetime cost (cents per kWh) (Based on Winston, 2002)**

| Generating electricity type | Cost (cents per kWh) |
|---|---|
| Coal-Fired PF (Pulverised Fuel) | 3 |
| Coal-Fired CFB (Combustion Fluidised Bed) | 3.5 |
| Coal-Fired IGCC (Integrated Gasification Combustion Cycle) | 4 |
| Gas-Fired OCGT (Open Cycle Gas Turbine) | 3.5 |
| Gas-Fired CCGT (Combined Cycle Gas Turbine) | 2.5 |
| Oil-Fired | 5 |
| Nuclear | 2 |
| Biomass | 7 |
| Fuel Cell | 15 |
| Geothermal | 5 |
| Hydro | 7 |
| Offshore Wind Farm | 7 |
| Onshore Wind Farm | 5.5 |
| Solar | 10 |
| Offshore Waves & Marine | 8 |
| Onshore Waves & Marine | 6.5 |

#### 2.2.4.3. *Efficiency*

Energy efficiency means using less energy to accomplish the same task. The more efficient use of energy throughout an entire country results in less money spent on energy by homeowners, schools, government agencies, businesses, and industries. An energy-efficient economy can grow without using more energy. For instance from 1970 to 2000, U.S. energy consumption grew only 45% while the U.S. Gross Domestic Product (GDP) increased 160%. In other words, the amount of energy used per dollar of GDP decreased 44% from 1970 to 2000 (Schlegel, 2002)

An economy that uses less energy also produces less pollution, because the two are closely tied. By 1999, greenhouse gas emissions from energy use had risen 13% above 1990 levels. During that period, energy use increased 14.9% (Blumstein, Goldman & Barbose, 2003).

**Table 3: Efficiency (Based on Blumstein, 2003)**

| Generating electricity type | Efficiency today | Efficiency future |
|---|---|---|
| Coal-Fired PF | 38% | 40% |
| Coal-Fired CFB | 38% | 40% |
| Coal-Fired IGCC | 48% | 50% |
| Gas-Fired OCGT | 39% | 43% |
| Gas-Fired CCGT | 58% | 60% |
| Oil-Fired | 36% | 38% |
| Biomass | 24% | 25% |

For the most conventional means of generating electricity, it is possible to calculate efficiency by comparing the amount of natural resources these means are using with the quantity of electricity generated. For the renewable means, calculation is different; efficiency is linked more to the different losses, for instance mechanical losses that accumulate during the process of generating electricity. Indeed, as renewable means do not use natural resources, efficiency cannot be calculated in the way used for conventional power plants. Nevertheless, renewable power plants are much more efficient than conventional power plants; for instance, in general, hydropower plants have efficiency higher than 98%.

A remark needs to be made about biomass power plants. These plants are classified in the renewable power plants, but they have a very low efficiency, because they do not transform renewable resources directly into electricity. Biomass plants need one more step, which is the generation of steam for the steam turbine.

As mentioned above, economic efficiency is the most important measure of efficiency because it measures how a plant uses scarce resources and what the value of those resources is. Economic efficiency is measured using production cost. Production cost, which is different from the levelised lifetime cost, is the cost of operating the plant, including fuel, labour, materials, and services, to produce one kilowatt-hour (kWh) of electricity. In 2005, nuclear power had the lowest production cost of the major sources of electricity, with a production cost of 1.72 cents/kWh. Coal had a cost of 2.21 cents/kWh, natural gas 7.51 cents/kWh, and petroleum 8.09 cents/kWh. Hydro had a production cost of 0.83 cents/kWh, wind 0.04 cents/kWh, and solar 2.17 cents/kWh (Winston, 2002).

#### 2.2.4.4. Regulation incentive/penalty

Renewable energy production is a relatively young market compared with the conventional energies such as oil, gas, and coal or nuclear, and the correct political framework is needed to guarantee fair access to this market. Policy mechanisms to support renewable energy sources can include direct financial incentives, industry standards and boosting public acceptance, or can include indirect penalties on the polluting energy sources. Indeed, fossil fuels can be forced to be less damaging for the environment. In order to reduce the greenhouse emissions from burning fossil fuels, various techniques have been proposed for carbon sequestration. Such proposed solutions may increase the price of using fossil fuels, and therefore transform them into less cost-effective energy resource

(Borenstein & Bushnell, 2000). Furthermore, Greenpeace argues that national regulations governing the access of renewable electricity to the power grids are a key success factor and member states have to ensure that the regulations are adhered to by the operators. The national regulations may also provide for priority access to the grid system of renewable electricity. These prerogatives may help to reach the terms of the Kyoto Protocol (UNFCCC, 2005).

#### ***2.2.4.5. Employment***

Most renewable energy investments are spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within the same country, frequently in the same area, and often in the same town. This means your money stays home to create jobs and fuel local economies, rather than going overseas (GEJ, 2006).

There are also many agribusiness opportunities in renewable technologies. You can grow crops to make bio fuels. Moreover, some farmers and ranchers have the opportunity to lease land to utilise for the installation of large wind turbines.

#### ***2.2.4.6. Role of the big players***

As mentioned in the Section 1.5., the big players are the electricity providers and the constructors of power plants. They can influence the design, location, construction of future power plants as well as what the sustainable energy of the future will be. Indeed, if they prefer investing in a particular type of solution rather than another one, for whatever reason (economical, financial, political), this solution will be most likely to emerge for the future, even though this solution may not be the best one.

#### ***2.2.4.7. Availability of engineering***

As mentioned above the demand for electricity in developing countries will soar, in the near future, and in order to cope with this demand it is most likely that the use of more conventional sources of energy will be chosen. This choice is dependent on the availability of natural resources (e.g. natural gas in China and coal in South Africa) or the direct cost of building a new power plant. However, there is another factor to take into account; this is the availability of local engineering. Indeed, most of the renewable sources of energy installations or even nuclear power stations need much more engineering attention than coal- or natural-gas-fired power plants. Unfortunately, the need for highly skilled people cannot always be fulfilled by the local structure. Therefore, if newer ways of producing electricity are chosen in these countries, they will have to rely on engineering from overseas, which can be a burden or, at least, entail certain dependence.

## 2.3. Decision-Making Trends

### *2.3.1. Being independent: An example from France*

Proposition: The result of the example from France will be used in a simulation using the qualitative model for validating the model.

France has 59 nuclear reactors operated by Electricité de France (EdF) with a total capacity of over 63 GWe, supplying over 426 billion kWh per year of electricity, 78% of the total generated there (EdF, 2005). The present situation is due to the French government's decision in 1974, just after the first oil shock, to expand rapidly the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous energy resources. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense in minimising imports and achieving greater energy security. Because of the decision taken in 1974, France now claims a substantial level of energy independence and almost the lowest-cost electricity in Europe. Over 90% of its electricity is nuclear or hydro.

From being a net electricity importer through most of the 1970s, France now has a steadily growing net export of electricity, which amounted to 63 billion kWh and

€2.6 billion in 1999. France is the world's largest net electricity exporter, and electricity is France's fourth largest export. (Italy has no operating nuclear power plants and is Europe's largest importer of electricity, with most coming ultimately from France. The UK has also become a major customer for French electricity.)

Going against the trend found in most other European countries, France has plans to further grow its nuclear power industry. A report released by the French government in November 2003 called for a significant expansion of the industry, including the construction of a third-generation of nuclear reactors and the upgrading of existing plants. France has collaborated with Germany to develop the European Pressurized Reactor (EPR). The EPR is a third-generation reactor, designed to be safer, more efficient, and less susceptible to a terrorist attack. Each EPR reactor should produce around 1,600 megawatts (MW) of electricity, versus 900 MW for most second-generation reactors. EdF announced in November 2004 that it would build the world's first EPR at a site near Flamaville. EdF plans to complete the project by 2012, at a cost of $3.8 billion. EdF also plans to build an additional uranium-enrichment plant at its Tricastin site, in order to avoid dependence on fuel imports.

France has taken a leading role in the development of the International Thermonuclear Experimental Reactor (ITER). ITER, a consortium of the European Union, the United States, Japan, Russia, China, and South Korea, seeks to build a working fusion reactor by 2015.

### *2.3.2. Being environmental: An example from Germany*

<u>Proposition:</u> The result of the example from Germany will be used in a simulation using the qualitative model for validating the model.

Coal and nuclear power plants are still the pillars of Germany's power generation. Indeed, coal is the most important energy source, accounting for 50.6% of the country's gross electricity production in 2002 (brown coal 27.4% and hard coal 23.2%), according to government statistics. Nuclear power was the second most important energy source, providing 28.4% of total gross electricity production in 2002. Natural gas accounted for 9.3%, down slightly year-on-year. However, the biggest increase in generation came from wind, which jumped 60% year-on-year.

According to the country’s Renewable Energy Sources Act promulgated in October 2005, Germany aims to increase the share of power covered by renewable energy to 12.5% by 2010, and to 20% by 2020. The country’s long-term goal is to meet at least 50% of the country’s total primary energy consumption with renewable energy by 2050. Between 1991 and 2002, consumption of renewable electricity (not including hydro) more than quadrupled. In 2002, consumption of power generated from renewable energy reached 27 Bkwh, or approximately 5.3% of the country's total electricity consumption. Germany is currently the world leader in wind power, with more than a third of the world’s installed wind capacity. As of the July of 2004, Germany had 15,797 wind turbines in operation, with an installed capacity of 15.3 GW, according to Germany Association for Wind Energy in October 2005. With suitable locations on land now becoming scarce, the government aims to develop large wind parks offshore.

Besides wind power, Germany is home to some of the world’s largest solar energy facilities. In September 2004, Shell, along with partners GEOSAL and WestFonds, began operating a 5 MW solar power plant in Leipzig. City Solar AG reportedly is building a 7.4 MW solar power plant at Göttelborn, the world’s largest, according to City Solar.

In November 2003, geothermal was added to the country’s power generation mix, when Germany’s first geothermal power plant began operating at Neustadt-Glewe, Mecklenburg-Western Pommerania. There are currently two other geothermal projects being developed in Unterhaching and in Weinheim. There also are 34 major geothermal plants used for heat generation in Germany.

### 2.3.3. Being affordable: An example from South Africa

Proposition: The result of the example from South Africa will be used in a simulation using the qualitative model for validating the model.

South African electricity is the second cheapest in the world; there are two main reasons for this:

- South Africa has the world's seventh largest amount of recoverable coal reserves (54.6 billion short tons), approximately 5% of the world total. This allows the national company Eskom, one of the largest utilities in the world, to generate electricity at a very low cost.
- In the past few years, fears that electricity was becoming unaffordable for the poor forced the government to stop Eskom charging inflated electricity rates. In 2004, a tariff rate of 2.5% was set, below the rate of inflation to ensure affordable electricity for all.

### 2.3.4. Needing diversification: An example from Norway

Norway is highly dependent upon hydropower for its electricity needs; therefore, a diversification from the present energy source is critically required. In 2003, the country generated 104.5 Bkwh of hydropower, or 99% of total electricity generation. Norway's hydroelectric infrastructure consists of many small plants. The largest, Kvilldal, has an installed capacity of 1,240 megawatts (MW), or 4% of national installed capacity.

Norway's strategy to rely on hydropower leaves the country vulnerable to fluctuations, which requires imports to meet seasonal shortages, but also opens the possibility of exports during wetter conditions. Norway still has the potential to increase hydro-generated power, through refurbishing existing facilities, as well as constructing new hydropower plants. However, most of Norway's waterways have been developed and any new facilities would be likely to be small developments. In addition, many waterways are protected from further development because of environmental concerns.

As an alternative to hydroelectricity, the Norwegian government has tried to encourage the diversification of the country's power sector by granting permits for the construction of natural gas-fired power plants. Naturkraft, a joint venture of Norsk Hydro and Statkraft, plans to begin construction in late 2005 on a 400-MW gas-fired plant near the gas terminal at Karsto. The future of gas-fired generation capacity, however, is in doubt due to government regulations concerning carbon dioxide emissions and resistance from environmentalists (EIA, 2006).

Norway has also looked towards wind power as a way to supplement hydroelectric capacity. The country has a modest amount of installed wind capacity, which generated 0.22 Bkwh in 2003. Havgul, a consortium of Norwegian energy companies, has proposed building a 1,795-MW, offshore wind farm in More & Romsdal, western Norway. The project would consist of four wind parks and would be one of the largest such projects in the world.

In this chapter, some propositions, for investigation, have been made. These propositions have been represented in Table 4.

**Table 4: First list of propositions**

| Tests | Propositions | Drivers | Table |
|---|---|---|---|
| Checking scenarios | France in 70s | Drivers related to France in the 70s | 17 |
| | France in 80s | Drivers related to France in the 80s | 19 |
| | South Africa | Drivers related to South Africa | 22 |
| | Germany | Drivers related to Germany | 25 |
| Investigating scenarios | General scenarios | No drivers | 26 |
| | | All natural resources | 27 |
| | | All geographical locations | 28 |
| | | All external drivers | 29 |
| | | All natural resources/all geographical locations | 30 |
| | | All natural resources/all external drivers | 31 |
| | | All geographical locations/all external drivers | 32 |
| | | All drivers | 33 |

The remaining propositions include a mix of the different drivers (listed above) according to the case under scrutiny.

**Table 5: Second list of propositions**

| Tests | Propositions | Drivers | Table |
|---|---|---|---|
| Investigating scenarios | Farming countries | Drivers related to farming countries | 35 |
| | | First proposition plus oil available | 36 |
| | | First proposition plus coal available | 37 |
| | | First proposition plus gas available | 38 |
| | | First proposition plus enriched uranium available | 40 |
| | Evolving farming countries | First proposition plus demand/supply issue | 41 |
| | | Previous proposition plus constructors'/end users' influence | 42 |
| | | Previous proposition plus polluting emissions issue | 43 |
| | | Previous proposition plus levelised lifetime cost | 44 |
| | | Previous proposition plus waste issue | 45 |
| | Eastern countries | Drivers related to eastern countries condition 1 | 48 |
| | | Drivers related to eastern countries condition 2 | 50 |
| | | First proposition plus engineering available | 51 |
| | | Second proposition plus engineering available | 52 |
| | Middle east countries | Drivers related to middle east countries | 53 |
| | | First proposition plus external-condition drivers | 55 |

# 3. RESEARCH QUESTIONS

The answers to the following research questions will enable us to identify the different nodes (addressing Sub-problem 1) and links (addressing Sub-problem 2) of a qualitative model. This qualitative model will allow us to test different scenarios of the effect of changing different drivers on the choice of the sustainable energy of the future (addressing Sub-problem 3 and, therefore, the main problem).

Firstly, the key concepts are listed and then the causal relationships are explored. In the tables describing causal relationships, the source and destination attributes are listed, together with an indication of whether an increase in the strength of the attribute increases or decreases the consequential attribute (indicated by a plus or minus sign). So for example, “polluting emissions” is identified as a characteristic of environmental issues in Table 8 and then, reading from Table 12, it is suggested that, when environmental issues are taken into account, polluting emissions will increase the likelihood of nuclear energy as a sustainable source of energy and, on the other hand, will decrease the likelihood of the choice of oil-fired station as a sustainable source of energy.

## 3.1. Identification of the Drivers

What are the different drivers, which may influence the choice of a particular type of energy?

As seen in the literature review the drivers have been classified in four different categories, which are listed below.

### 3.1.1. Natural resources

The key natural resources, which might be considered for the qualitative model, are listed in Table 6.

**Table 6: Natural resources as drivers**

| Natural Resources | Reference |
|---|---|
| Conventional oil | Campbell (2002) |
| Non-conventional oil | Quinn (2005) |
| Conventional natural gas | EnCana Corporation (2005) |
| Non-conventional natural gas | Dillon (2002) |
| Coal | Wetman, Haycocks & Karnis (1999) |
| Uranium | Mikhailov (2001) |

### 3.1.2. Geographical locations

The key geographical-location aspects, which might be considered for the qualitative model, are listed in Table 7.

**Table 7: Geographical locations as drivers**

| Geographical Location | Reference |
|---|---|
| Farming possibilities | Couch (1993) |
| Geothermal possibilities | Huttrer (2000) |
| Presence of rivers | Egre, Gagnon & Milewki (1999) |
| Presences of mountains | Egre, Gagnon & Milewki (1999) |
| Close to sea/ocean | Gauthier (2000), Neuhoff (2004), Thorpe (1998) |
| Sunny region | Gould, Zavoico, Collier & Grimaldi (2000) |
| Windy region | Neuhoff & De Vries (2004) |

### *3.1.3. Environmental issues*

The key environmental issues, which might be considered for the qualitative model, are listed in Table 8.

**Table 8: Environmental issues as drivers**

| Environmental Issues | Reference |
|---|---|
| Polluting emissions: | |
| Global warming | Karoly (2003) |
| Greenhouse gases | Hansen, Ruedy, Glascoe & Sato (1999) |
| Acid rains | Gerhard, Harrison & Hanson (2001) |
| Nuclear waste | Hill & Gunton (2001) |
| Natural environment: | |
| Flooding | Egre, Gagnon & Milewki (1999) |
| Chemical pollution | Couch (1993) & Huttrer (2000) |
| Noise | Thorpe (1998) & Neuhoff (2004) |

### *3.1.4. Economical/financial*

The key economical and financial aspects, which might be considered for the qualitative model, are listed in Table 9.

**Table 9: Economical/financial aspects as drivers**

| Economical/Financial | Reference |
|---|---|
| Demand/Supply of Electricity | EMP (2005) |
| Cost | Morgan, Granger & Tierney (2002), Winston (2002) |
| Efficiency | Blumstein, Goldman & Barbose (2003) |
| Incentive/penalty | Borenstein & Bushnell (2000) |
| Employment | GEJ (2006) |
| Role of the big players | |

| | |
|---|---|
| Availability of engineering | |

## 3.2. Influence of the Drivers

What are the distinguishing roles or effects of the different drivers on the choice of the sustainable energy of the future?

### *3.2.1. Research questions: Natural resources*

- How will the present amounts of natural resources, such as conventional fossil fuels, influence the decision-making process for the choice of the sustainable energy of the future?
- How will the discovery of new replacing natural resources, such as non-conventional natural gas, influence the decision-making process for the choice of the sustainable energy of the future?
- How will the behaviour of the owners of large natural resources influence the decision-making process for the choice of the sustainable energy of the future?

These different questions and their influence on the type of power generation chosen are listed in Table 10. These different interpretations are obtained from the observations, which have been made throughout the literature.

**Table 10: Effects of natural resources**

| Attribute | Consequence | Effect | Comment |
|---|---|---|---|
| **Uranium** | | | |
| | Nuclear station | + | The presence of uranium will increase the likelihood of the use of a nuclear station. |
| | Coal-fired station | - | The presence of uranium may have some negative influence on the use of a coal station. |

| | | | |
|---|---|---|---|
| | Natural-gas-fired station | - | The presence of uranium may have some negative influence on the use of a natural gas station. |
| | Oil-fired station | - | The presence of uranium may have some negative influence on the use of an oil station. |
| | Renewable | 0 | The presence of uranium does not really influence on the use of renewable energy. |
| **Coal** | | | |
| | Nuclear station | - | The presence of coal has some negative influence on the use of a nuclear station. |
| | Coal-fired station | + | The presence of coal will increase the likelihood of the use of a coal station. |
| | Natural-gas-fired station | - | The presence of coal has some negative influence on the use of a natural gas station. |
| | Oil-fired station | - | The presence of coal has some negative influence on the use of an oil station. |
| | Renewable | 0 | The presence of coal does not really influence on the use of renewable energy. |
| **Natural gas** | | | |
| | Nuclear station | - | The presence of natural gas has some negative influence on the use of a nuclear station. |
| | Coal-fired station | - | The presence of natural gas has some negative influence on the use of a coal station. |
| | Natural-gas-fired station | + | The presence of natural gas will increase the likelihood of the use of a natural gas station. |
| | Oil-fired station | - | The presence of natural gas has some negative influence on |

| | | | |
|---|---|---|---|
| | | | the use of an oil station. |
| | Renewable | 0 | The presence of natural gas does not really influence on the use of renewable Energy. |
| **Oil** | | | |
| | Nuclear station | - | The presence of oil has some negative influence on the use of a nuclear station. |
| | Coal-fired station | - | The presence of oil has some negative influence on the use of a coal station. |
| | Natural-gas-fired station | - | The presence of oil has some negative influence on the use of a natural gas station. |
| | Oil-fired station | + | The presence of oil will increase the likelihood of the use of an oil station. |
| | Renewable | 0 | The presence of oil does not really influence on the use of renewable energy. |

The different influences mentioned in Table 10 can at times be more subjective than real; this above all for the uranium case. Indeed, in most of the industrialised or developed countries, nuclear energy is really present even though there is not much presence of uranium in the soil. This fact can be explained by two phenomena; the first one is that nuclear power stations do not need a lot of raw material to be able to produce electricity. Therefore, it is easy to get the needed fuel to the station from somewhere else, even very far away, because it is not difficult to transport. The second phenomenon is that the uranium has to be enriched anyway to be used in a nuclear power station; this implies the need of special installation and engineering. Most of the time, the availability of the raw material and the installations to enrich it, are not found together in the country where the uranium is available.

On the other hand, for the fossil fuels, the presence of one of them entails very often the presence of the power station using it. Indeed, fossil-fuel-fired stations need plenty of natural resources to be able to produce electricity. Therefore, it is always easier to transport electricity than to transport fossil fuels; generally, the power station is built close to the coalmine or to the natural gas well.

### 3.2.2. Research Question: Geographical locations

Only one question really matters: What influence will the location of the new power plant have on the choice of a possible technology?

As mentioned previously, the geographical location does not really influence the choice of a type of conventional power plant; we have observed the same phenomenon for the renewable plants as regards to the natural resources. The exception is, perhaps, a nuclear power plant, which has to be close to a river or an ocean from a safety point of view and also from a cooling-efficiency point of view.

**Table 11: Effects of geographical locations**

| Attribute | Consequence | Effect | Comment |
|---|---|---|---|
| **Farming possibility** | | | |
| | Conventional station | 0 | No special influence. |
| | Biomass station | + | Land to be able to farm. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | + | Water to be able to farm. |
| | Storage station | + | Water to be able to farm. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | + | Sun to be able to farm. |
| | Tidal station | - | Negative influence. |
| | Offshore wave station | - | Negative influence. |
| | Onshore wave station | - | Negative influence. |
| | Offshore wind station | - | Negative influence. |
| | Onshore wind station | + | Land to put wind turbines. |

| | | | |
|---|---|---|---|
| **Geothermal possibility** | | | |
| | Conventional station | 0 | No special influence. |
| | Biomass station | - | Negative influence. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | + | Site to produce steam easily. |
| | Hydro station | - | Negative influence. |
| | Storage station | - | Negative influence. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | - | Negative influence. |
| | Tidal station | - | Negative influence. |
| | Offshore wave station | - | Negative influence. |
| | Onshore wave station | - | Negative influence. |
| | Offshore wind station | - | Negative influence. |
| | Onshore wind station | - | Negative influence. |
| **Rivers** | | | |
| | Nuclear station | + | Safety and cooling. |
| | Conventional station | 0 | No special influence. |
| | Biomass station | + | Water to be able to farm. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | + | Availability of water to be used. |
| | Storage station | + | Availability of water to be used. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | - | Negative influence. |
| | Tidal station | - | Negative influence. |
| | Offshore wave station | - | Negative influence. |
| | Onshore wave station | - | Negative influence. |
| | Offshore wind station | - | Negative influence. |
| | Onshore wind station | - | Negative influence. |
| **Mountains** | | | |
| | Conventional station | 0 | No special influence. |

| | | | |
|---|---|---|---|
| | Biomass station | - | Negative influence. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | + | Possibility of building a dam. |
| | Storage station | + | Possibility of building a dam. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | - | Negative influence. |
| | Tidal station | - | Negative influence. |
| | Offshore wave station | - | Negative influence. |
| | Onshore wave station | - | Negative influence. |
| | Offshore wind station | - | Negative influence. |
| | Onshore wind station | + | Often windy in the mountains. |
| **Oceans** | | | |
| | Nuclear station | + | Safety and cooling. |
| | Conventional station | 0 | No special influence. |
| | Biomass station | - | Negative influence. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | - | Negative influence. |
| | Storage station | - | Negative influence. |
| | Thermal ocean station | + | The ocean is the source of the energy. |
| | Solar station | - | Negative influence. |
| | Tidal station | + | The ocean is the source of the energy. |
| | Offshore wave station | + | The ocean is the source of the energy. |
| | Onshore wave station | + | The ocean is the source of the energy. |
| | Offshore wind station | + | The wind turbines are situated in the ocean. |
| | Onshore wind station | - | Negative influence. |

| | | | |
|---|---|---|---|
| **Sun** | | | |
| | Conventional station | 0 | No special influence. |
| | Biomass station | + | Sun to be able to farm. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | - | Negative influence. |
| | Storage station | - | Negative influence. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | + | The sun is the source of the energy. |
| | Tidal station | - | Negative influence. |
| | Offshore wave station | - | Negative influence. |
| | Onshore wave station | - | Negative influence. |
| | Offshore wind station | - | Negative influence. |
| | Onshore wind station | - | Negative influence. |
| **Wind** | | | |
| | Conventional station | 0 | No special influence. |
| | Biomass station | - | Negative influence. |
| | Fuel cell station | - | Negative influence. |
| | Geothermal station | - | Negative influence. |
| | Hydro station | - | Negative influence. |
| | Storage station | - | Negative influence. |
| | Thermal ocean station | - | Negative influence. |
| | Solar station | - | Negative influence. |
| | Tidal station | + | More the wind is strong bigger is the tidal. |
| | Offshore wave station | + | More the wind is strong bigger are the waves. |
| | Onshore wave station | + | More the wind is strong bigger are the waves. |
| | Offshore wind station | + | The wind is the source of the energy. |

| | | | |
|---|---|---|---|
| | Onshore wind station | + | The wind is the source of the energy. |

### *3.2.3. Research questions: Environmental issues*

- How will the environmental laws influence the decision-making process for the choice of the sustainable energy of the future?
- How will the fears of living in an unhealthy world (in the public's opinion) influence the decision-making process for the choice of the sustainable energy of the future?

These different questions and their influence on the type of power generation chosen are listed in table 12. The symbols used under "effect" have to be further explained. In Table 12, the following conventions are used to indicate the influence of polluting emissions: (-) indicates that there is a bad influence which is difficult to live with; (0) indicates that there can be a bad influence but it can be avoided; and (+) indicates that there is no bad influence. On the topic of waste, the same conventions apply. The last topic, natural environment, takes into account nuisances such as noise, perturbation of the wild life, deterioration of the vegetation and so forth.

**Table 12: Effects of the environmental issues**

| Attribute | Consequence | Effect | Comment |
|---|---|---|---|
| **Polluting emissions** | | | |
| | Nuclear station | + | No presence of bad emissions. |
| | Coal-fired station PF | - | Very high level of greenhouse gas emissions. |
| | Coal-fired station CFB | - | High level of greenhouse gas emissions. |
| | Coal-fired station IGCC | 0 | With this technique, the emission of greenhouse gases is much reduced. |
| | Natural-gas-fired station | - | High level of greenhouse gas |

| | | | |
|---|---|---|---|
| | OCGT | | emissions. |
| | Natural-gas-fired station CCGT | - | High level of greenhouse gas emissions. |
| | Oil-fired station | - | Very high level of greenhouse gas emissions. |
| | Biomass station | - | High level of greenhouse gas emissions (burning peat or gases from fermentation). |
| | Fuel cell station | + | No emissions whatsoever. |
| | Geothermal station | 0 | Bad gases can be extracted with the steam from the earth. |
| | Hydro station | + | No emissions whatsoever. |
| | Storage station | + | No emissions whatsoever. |
| | Thermal ocean station | + | No emissions whatsoever. |
| | Solar station | + | No emissions whatsoever. |
| | Tidal station | + | No emissions whatsoever. |
| | Wave station | + | No emissions whatsoever. |
| | Wind station | + | No emissions whatsoever. |
| **Waste** | | | |
| | Nuclear station | - | The nuclear wastes have a very long lifespan. |
| | Coal-fired station | 0 | The ashes can be very cumbersome and difficult to store. |
| | Natural-gas-fired station | + | No waste whatsoever. |
| | Oil-fired station | + | No waste whatsoever. |
| | Biomass station | 0 | The same issue with the ashes. |
| | Fuel cell station | + | No waste whatsoever. |
| | Geothermal station | + | No waste whatsoever. |
| | Hydro station | + | No waste whatsoever. |
| | Storage station | + | No waste whatsoever. |
| | Thermal ocean station | + | No waste whatsoever. |
| | Solar station | + | No waste whatsoever. |

| | | | |
|---|---|---|---|
| | Tidal station | + | No waste whatsoever. |
| | Wave station | + | No waste whatsoever. |
| | Wind station | + | No waste whatsoever. |
| **Natural environment** | | | |
| | Nuclear station | + | No issues. |
| | Coal-fired station | + | No issues. |
| | Natural-gas-fired station | + | No issues. |
| | Oil-fired station | + | No issues. |
| | Biomass station | - | The fertilisers used can damage the environment. |
| | Fuel cell station | + | No issues. |
| | Geothermal station | + | No issues. |
| | Hydro station | - | Destruction of natural locations up and down to the dam. |
| | Storage station | - | Destruction of natural locations up and down to the dam. |
| | Thermal ocean station | + | No issues. |
| | Solar station | + | No issues. |
| | Tidal station | 0 | Perturbation of the estuary lives. |
| | Offshore wave station | + | No issues. |
| | Onshore wave station | 0 | Can be very noisy. |
| | Offshore wind station | + | No issues. |
| | Onshore wind station | 0 | Can be very noisy. |

### *3.2.4. Research questions: Economical/financial drivers*

- Will the increase in efficiency influence the switch from conventional sources of energy to a renewable source of energy?
- Will the increase in the electricity demand influence the switch from conventional sources of energy to a renewable source of energy?
- Will the overall costs for the renewable source of energy installations influence the use of cleaner energy sources?

- How will the regulation schemes, incentives for renewable energies or penalties for environmentally damaging energy sources influence the decision-making process for the choice of the sustainable energy of the future?
- How will employment factors influence the decision-making process for the choice of the sustainable energy of the future?
- What role will the electricity providers play in the decision-making process for the choice of the sustainable energy of the future?
- What role will the constructors of electrical facilities play in the decision-making process for the selection of the future sustainable energy source?

These different questions and their influence on the type of power generation chosen are listed in table 13. As seen in the literature review, the number of topics to take into account can be very large. Therefore, for the sake of keeping the future qualitative model easily usable, these topics are kept to six and, obviously, these six topics are the ones most often referred to the literature.

The same kind of conventions as used in the previous table is used here: (+) indicates a positive influence on the type of power station considered; (0) indicates no real influence can be determined; (-) indicates a negative influence on the type of power station considered.

**Table 13: Effects of the economical and financial drivers**

| Attribute | Consequence | Effect | Comment |
|---|---|---|---|
| **Demand/supply for electricity** | | | |
| | Nuclear station | + | Conventional energy is the first choice when demand is much higher than supply. |
| | Coal-fired station | + | Conventional energy is the first choice when demand is much higher than supply. |
| | Natural-gas-fired station | + | Conventional energy is the first |

| | | | |
|---|---|---|---|
| | | | choice when demand is much higher than supply. |
| | Oil-fired station | + | Conventional energy is the first choice when demand is much higher than supply. |
| | Biomass station | - | Cannot really cope with a huge increase in demand. |
| | Fuel cell station | - | Cannot really cope with a huge increase in demand. |
| | Geothermal station | 0 | Not the first choice when the demand increases. |
| | Hydro station | 0 | Not the first choice when the demand increases. |
| | Storage station | + | Can be part of the solution during peak demand. |
| | Thermal ocean station | - | Cannot really cope with a huge increase in demand. |
| | Solar station | - | Cannot really cope with a huge increase in demand. |
| | Tidal station | 0 | Not the first choice when the demand increases. |
| | Wave station | 0 | Not the first choice when the demand increases. |
| | Wind station | 0 | Not the first choice when the demand increases. |
| **New power plant levelised lifetime cost** | | | |
| | Nuclear station | + | One of the cheapest solutions nowadays for conventional energy generation. |
| | Coal-fired station PF | + | One of the cheapest solutions nowadays for conventional energy generation. |
| | Coal-fired station CFB | 0 | Neither cheap nor expensive solution for conventional energy generation. |
| | Coal-fired station IGCC | - | One of the most expensive solutions for conventional |

| | | | |
|---|---|---|---|
| | | | energy generation. |
| | Natural-gas-fired station OCGT | - | One of the most expensive solutions for conventional energy generation. |
| | Natural-gas-fired station CCGT | + | One of the cheapest solutions nowadays for conventional energy generation. |
| | Oil-fired station | - | One of the most expensive solutions for conventional energy generation. |
| | Biomass station | - | One of the most expensive solutions for renewable energy generation. |
| | Fuel cell station | - | One of the most expensive solutions for renewable energy generation. |
| | Geothermal station | 0 | Neither cheap nor expensive solution for renewable energy generation. |
| | Hydro station | - | One of the most expensive solutions for renewable energy generation. |
| | Storage station | - | One of the most expensive solutions for renewable energy generation. |
| | Thermal ocean station | - | One of the most expensive solutions for renewable energy generation. |
| | Solar station | - | One of the most expensive solutions for renewable energy generation. |
| | Tidal station | - | One of the most expensive solutions for renewable energy generation. |
| | Offshore wave station | 0 | Neither cheap nor expensive solution for renewable energy generation. |
| | Onshore wave station | + | One of the cheapest solutions nowadays for renewable |

| | | | |
|---|---|---|---|
| | | | energy generation. |
| | Offshore wind station | 0 | Neither cheap nor expensive solution for renewable energy generation. |
| | Onshore wind station | + | One of the cheapest solutions nowadays for renewable energy generation. |
| **Efficiency** | | | |
| | Nuclear station | + | The most efficient solution of the conventional energy generation. |
| | Coal-fired station PF | - | Very inefficient solution. |
| | Coal-fired station CFB | - | Very inefficient solution. |
| | Coal-fired station IGCC | 0 | Neither efficient nor inefficient solution. |
| | Natural-gas-fired station OCGT | - | Very inefficient solution. |
| | Natural-gas-fired station CCGT | + | The second most efficient solution of the conventional energy generation. |
| | Oil-fired station | - | Very inefficient solution. |
| | Biomass station | - | Very inefficient solution. |
| | Fuel cell station | + | Very efficient solution. |
| | Geothermal station | 0 | Neither efficient nor inefficient. |
| | Hydro station | + | Very efficient solution. |
| | Storage station | 0 | Neither efficient nor inefficient. |
| | Thermal ocean station | + | Very efficient solution. |
| | Solar station | + | Very efficient solution. |
| | Tidal station | + | Very efficient solution. |
| | Wave station | + | Very efficient solution. |
| | Wind station | + | Very efficient solution. |
| **Incentive/penalty laws** | | | |
| | Nuclear station | - | There is fear of the nuclear solution, but no laws against or in favour. But the international |

| | | | |
|---|---|---|---|
| | | | community prevents certain countries from using it. |
| | Coal-fired station PF | - | International penalties: too damaging for the environment. |
| | Coal-fired station CFB | 0 | Neither incentives nor penalties. |
| | Coal-fired station IGCC | + | International incentives: the less damaging coal fired solution. |
| | Natural-gas-fired station OCGT | - | International penalties: not the best natural gas fired solution. |
| | Natural-gas-fired station CCGT | + | International incentives: the best natural gas fired solution. |
| | Oil-fired station | - | International penalties: too damaging for the environment. |
| | Biomass station | + | National incentives to lower unemployment of farmers. |
| | Fuel cell station | + | International incentives for the renewable solutions. |
| | Geothermal station | + | International incentives for the renewable solutions. |
| | Hydro station | 0 | Neither incentives nor penalties. |
| | Storage station | 0 | Neither incentives nor penalties. |
| | Thermal ocean station | + | International incentives for renewable solutions. |
| | Solar station | + | International incentives for renewable solutions. |
| | Tidal station | + | International incentives for renewable solutions. |
| | Wave station | + | International incentives for renewable solutions. |
| | Wind station | + | International incentives for renewable solutions. |
| **Engineering availability** | | | |
| | Nuclear station | + | Sensible technology and the |

| | | | |
|---|---|---|---|
| | | | production of the needed enriched uranium. |
| | Coal-fired station | - | Common technology. |
| | Natural-gas-fired station | - | Common technology. |
| | Oil-fired station | - | Common technology. |
| | Biomass station | - | Common technology. |
| | Fuel cell station | + | State-of-the-art technology. |
| | Geothermal station | 0 | Neither common nor state-of-the-art technology. |
| | Hydro station | 0 | Neither common nor state-of-the-art technology. |
| | Storage station | 0 | Neither common nor state-of-the-art technology. |
| | Thermal ocean station | + | State-of-the-art technology. |
| | Solar station | + | State-of-the-art technology. |
| | Tidal station | 0 | Neither common nor state-of-the-art technology. |
| | Wave station | 0 | Neither common nor state-of-the-art technology. |
| | Wind station | - | Common technology. |
| **Constructors'/end users' influence** | | | |
| | Nuclear station | + | Preferences for the technologies which use large turbines and generators. |
| | Coal-fired station | + | Preferences for the technologies which use large turbines and generators. |
| | Natural-gas-fired station | + | Preferences for the technologies which use large turbines and generators. |
| | Oil-fired station | + | Preferences for the technologies which use large turbines and generators. |
| | Biomass station | 0 | Use of smaller turbines and generators. |

| | | | |
|---|---|---|---|
| | Fuel cell station | - | New technologies not really developed by the constructors and not really used by the end users. |
| | Geothermal station | + | Preferences for the technologies which use large turbines and generators. |
| | Hydro station | + | Preferences for the technologies which use large turbines and generators. |
| | Storage station | + | Preferences for the technologies which use large turbines and generators. |
| | Thermal ocean station | - | New technologies not really developed by the constructors and not really used by the end users. |
| | Solar station | - | New technologies not really developed by the constructors and not really used by the end users. |
| | Tidal station | 0 | Use of smaller turbines and generators. |
| | Wave station | 0 | Use of smaller turbines and generators. |
| | Wind station | 0 | Use of smaller turbines and generators. |

## 3.3. Simulations

What is the effect of changing different drivers on the choice of the sustainable energy of the future?

This question will be addressed through the analysis of different scenarios using a qualitative model. Of course, it will not be possible to test all the different existing scenarios, as mathematically speaking the number of the different combinations will be huge. The idea it is to test the most likely scenarios and most interesting ones.

# 4. RESEARCH METHODOLOGY

## 4.1. Method Selection

The research is based on a literature review, all relevant documents (articles, books, web sites) that have been published about energy topics and, more specifically, about energy sources.

Different publications in the literature were sourced to derive the four constructs that are mentioned again in the paragraphs that follow.

For construct 1, publications on natural resources were reviewed, not only on the status of the reserves but also on other topics such as the policy around the natural resources; strategy of the owners of oil fields; strategy of the dependents on oil and so forth.

Construct 2, is much straighter forward, because this construct has a direct and obvious effect on the technology chosen.

For construct 3, publications on environmental issues were reviewed, not only on the direct effects of the use of conventional energies but also on another topics such as the policy around environmental behaviour; the ways of using “green” energy; the different commitments for the future to preserve the planet Earth and so forth.

For construct 4, publications on the economical and financial factors of the energy (field such as cost/efficiency, demand/supply, employment and so forth) were reviewed.

Secondly, publications were reviewed where the drivers have led to decisions around energy sources in different contexts. This part of the review was useful for defining trends in decision-making mechanisms.

It is proposed to construct an exploratory model of the effects of the most influencing drivers. This qualitative model is constructed by combining all relevant information gained directly from the literature review. It has been judged that the amount of information the literature supplies would be enough to construct such a model. Another way of finding the relevant information could have been used to find the influencing drivers, i.e. undertaking a DELPHI study (Mitchell, 2005). The Model will then be used to generate a number of scenarios that could be checked in subsequent research or even approved by a panel of specialists.

Naturally, building a model that reflects all the interactions of the influencing drivers is not a simple undertaking and is difficult to implement in a deterministic fashion. Aguillar (2003) comments, that forming mathematical models of dynamic systems can be both difficult and costly. Furthermore, these systems may have significant feedback loops rendering the system non-linear and impossible to solve quantitatively. The use of fuzzy cognitive mapping (FCM) provides a suitable technique for exploring such systems and, once constructed, FCM allows qualitative simulation and experimentation with the system.

## 4.2. Fuzzy Cognitive Maps

Fuzzy cognitive mapping draws a causal map to represent the model and behaviour of a system in which the concepts interact according to imprecise rules, thereby simulating the functioning of complex systems (Stylios & Groumpos, 2000). The technique was originally introduced by Kosko (1993) as an evolution of cognitive mapping that incorporated both vagueness and feedback loops (Miao, Liu, Tao & Shen, 2002). These extensions allow the exploration of causal relationships between fuzzy concepts such policies, objectives, facts, processes and values. This tolerance of imprecise concepts has contributed to the successful use of FCM in modelling socio-economic scenarios that are ill structured, dynamic and convoluted in nature.

A fuzzy cognitive map is constructed by assembling a selection of nodes, which represent qualitative concepts, and edges, which are the causal links between nodes (Mohr, 1997). Nodes may be either bivalent (0 or 1) or trivalent (-1, 0 or 1) and in the simplistic version of FCM, edges may have a weight of one or minus one, corresponding to a causal increase or decrease respectively (Aguilar, 2003). An edge weight of zero would represent no causal link between the nodes.

The normalised value of each node is calculated by summing the weighted value of each of its contributing nodes and applying a non-linear function to the result. This equation for the trivalent system is represented in Equation 1 where A is the activation level of each node, E is the edge weight and T is the threshold value. For simplicity, the threshold value is commonly taken to be zero:

**Equation 1: New node value**

$$A_i^{new} = f(u_i) = \begin{cases} 1 & u_i > T_i \\ 0 & u_i = T_i \\ -1 & u_i < T_i \end{cases}$$

where

$$u_i = \sum_{j=1}^{n} A_i E_{ij}$$

Source: Miao, Liu, Tao & Shen, (2002)

Nodes that have no causal influences are referred to as policy nodes. These nodes provide the opportunity for the researcher to explore the model by turning them “on” and “off”, by explicitly setting the activation level. As the policy nodes are manipulated, the model will respond accordingly. Since FCM usually includes feedback, loops there are three possible states that a system can display (Rossouw, 2004):

- Fixed point;
- Limit cycle; and
- Chaotic behaviour.

In the fixed-point state, the system arrives at a single stable state where some nodes are on and the others off. When a consistent repeating pattern emerges, the system is said to have reached a limit cycle, where the system oscillates between predictable states. When the system fails to stabilise and no pattern is discernible, the system is said to display chaotic behaviour.

In order to test the effect of the change of influencing factors, the model should be allowed to reach equilibrium in the initial state prior to the new input state being implemented (Kosko, 1993).

## 4.3. Model Design

### *4.3.1. Overview*

Based on the review of the literature in Chapter 2 and the concepts and links identified in Chapter 3, a qualitative model of the effects of the energy-field drivers on the choice of the sustainable energy of the future is proposed, as illustrated in Figure 14. The sections that follow identify the nodes and edges of the fuzzy cognitive map that encodes the model.

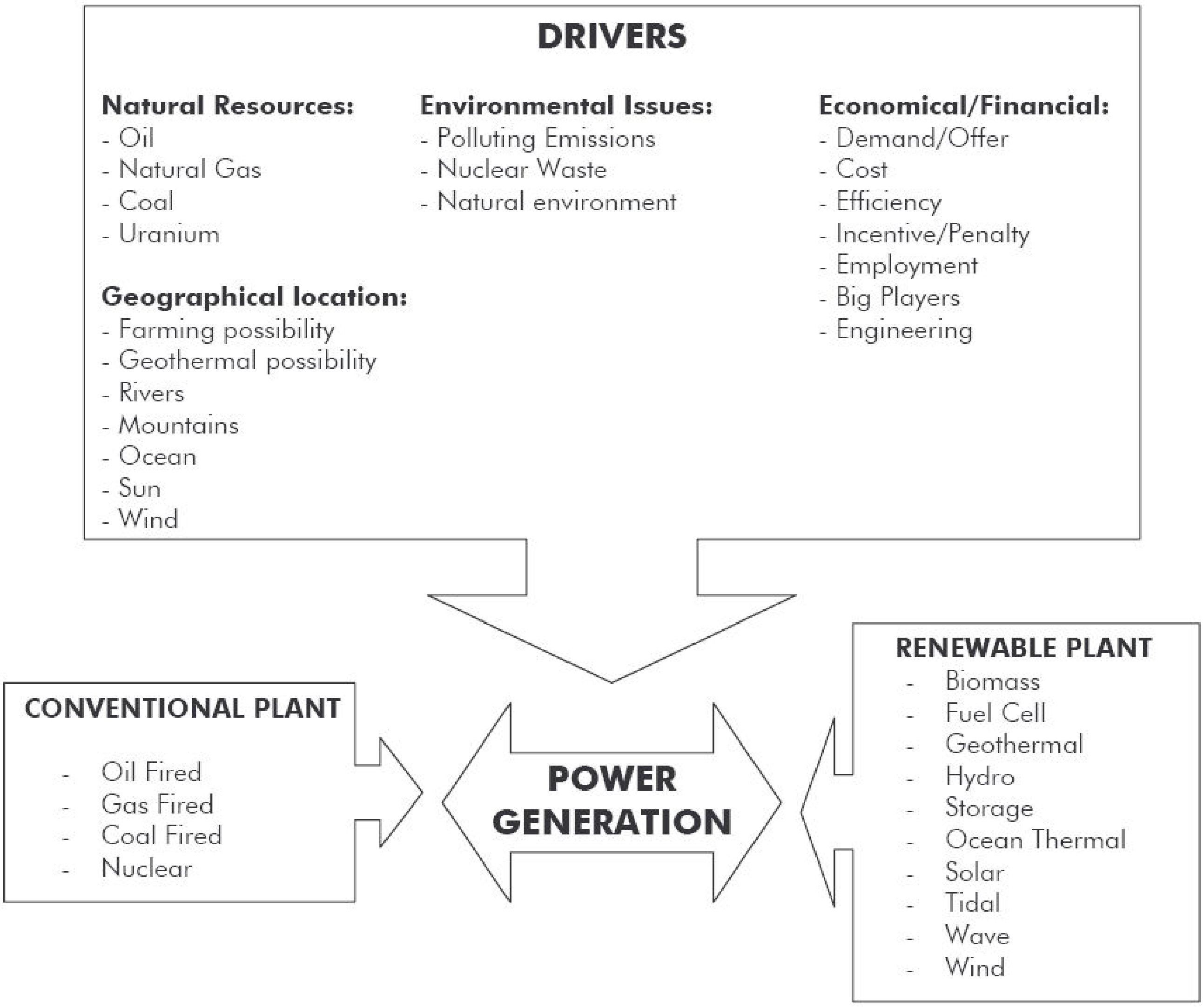



**Figure 14: Model overview**

### *4.3.2. Type of power nodes*

Based on a selection from the literature review, two different types of generating power exist, which represent 19 nodes:

<u>Non-renewable:</u>

- Nuclear power station;
- Coal-fired power station (PF, CFB and IGCC);

- Natural-gas-fired power station (OCGT and CCGT); and
- Oil-fired power station.

Renewable:

- Biomass;
- Fuel cell;
- Geothermal;
- Hydro;
- Storage;
- Ocean thermal;
- Solar;
- Tidal;
- Wave (offshore and onshore); and
- Wind (offshore and onshore).

These nodes are mostly trivalent; they can have a positive influence on the other nodes; and they can have no influence at all on the other nodes or a negative influence on the other nodes. For instance, quite often storage hydraulic power plants are associated with nuclear power plants; indeed, as it is difficult to shut down a power plant during the low demand hours, for instance during the night, the extra power is therefore consumed in the storage stations by using the turbines in pumps. Hence, we have a positive influence on the storage hydraulic power plants from the nuclear power plants. An example of no influence could be the presence of nuclear power plants that does not influence the presence of renewable power plants other than hydraulics. Lastly, an example of negative influence could be the presence of natural-gas-fired power stations that entails no presence of oil-fired power stations.

As shown in Table 14, when a conventional type of technology is chosen, the other types are very often avoided. The same phenomenon is visible for the renewable technologies.

### *4.3.3. Natural resource nodes*

Using the dimensions of the natural resources discussed in Section 3.2.1., the natural resources nodes to be implemented are:

- Oil;
- Natural-gas;
- Coal; and
- Uranium.

As seen before in Table 10, these nodes can be trivalent: i.e. high (1), neutral (0), or low (-1).

### *4.3.4. Geographical location nodes*

Using the dimensions of the geographical location discussed in Section 3.2.2., the geographical location nodes to be implemented are:

- Farming possibility;
- Geothermal possibility;
- Rivers;
- Mountains;
- Oceans;
- Sun; and
- Wind.

As seen before in the Table 11, these nodes can be trivalent: i.e. high (1), neutral (0), or low (-1).

### *4.3.5. Environmental issue nodes*

Using the dimensions of the environmental issues discussed in Section 3.2.3., the environmental issues nodes to be implemented are:

- Polluting Emissions;
- Waste; and
- Environmental Effect.

As seen before in Table 12, these nodes can be trivalent: i.e. high (1), neutral (0), or low (-1).

### *4.3.6. Economical/financial nodes*

Using the dimensions of the economical and financial drivers discussed in Section 3.2.4., the economical and financial nodes to be implemented are:

- Demand/supply issue;
- Levelised lifetime cost;
- Efficiency;
- Incentive/penalty laws;
- Engineering availability; and
- Constructors'/end users' influence.

As seen before in Table 13, these nodes can be trivalent: i.e. high (1), neutral (0), or low (-1).

### *4.3.7. Model formulation*

The matrix shown in Table 14 below represents the weightings of the causality links identified in the literature review. Each entry in the matrix represents an interaction between the concepts listed in the left-most rows and top-most columns of the matrix. Reading across a row yields the effect the node has on other nodes. For example, reading across the row representing nuclear station, it is suggested that the presence of a nuclear station will increase the presence of water-powered stations and decrease the presence of fire-powered stations and will have no influence on renewable stations. Reading down a column, on the other hand, gives the effects of the other nodes on the node of the column. Thus, the development of nuclear station will be decreased by the availability of coal, natural gas, and oil but will be increased by the availability of uranium, engineering and availability of water and will not change with the presence of a farming possibility or a geothermal possibility.

**Table 14: FCM edge weighting matrix**

Receptor

| Transmitter | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuclear Station | 1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal Fired Station PF | -1 | 1 | 1 | 1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal Fired Station CFB | -1 | 1 | 1 | 1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal Fired Station IGCC | -1 | 1 | 1 | 1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas Fired Station OCGT | -1 | -1 | -1 | -1 | 1 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas Fired Station CCGT | -1 | -1 | -1 | -1 | 1 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oil Fired Station | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Biomass Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Fuel Cell Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Geothermal Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Hydro Station | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Storage Station | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Ocean Thermal Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Solar Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 |
| Tidal Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 |
| Offshore Wave Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 | -1 | -1 |
| Onshore Wave Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 | -1 | -1 |
| Offshore Wind Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 |
| Onshore Wind Station | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 |
| Uranium | 1 | -1 | -1 | -1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal | -1 | 1 | 1 | 1 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas | -1 | -1 | -1 | -1 | 1 | 1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oil | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Farming Possibility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | -1 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | -1 | 1 |
| Geothermal Posibility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Rivers | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Mountains | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 |
| Oceans | 1 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | 1 | 1 | 1 | 1 | -1 |
| Sun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 |
| Wind | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 |
| Polluting Emissions | 1 | -1 | -1 | 0 | -1 | -1 | -1 | -1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Waste | -1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Environmental Effect | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| Demand/Offer Issue | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | 0 | 0 | 1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 |
| Levelised Lifetime Cost | 1 | 1 | 0 | -1 | -1 | 1 | -1 | -1 | -1 | 0 | -1 | -1 | -1 | -1 | -1 | 0 | 1 | 0 | 1 |
| Efficiency | 1 | -1 | -1 | 0 | -1 | 1 | -1 | -1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Incentive/Penalty Laws | -1 | -1 | 0 | 1 | -1 | 1 | -1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Engineering Availability | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | -1 | -1 |
| Constructors/End Users Influence | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | -1 | 1 | 1 | 1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 |

These links are illustrated graphically in Figure 15. In this representation, red lines indicate a negative link, blue lines indicate a positive link, and no lines indicate no link between nodes.

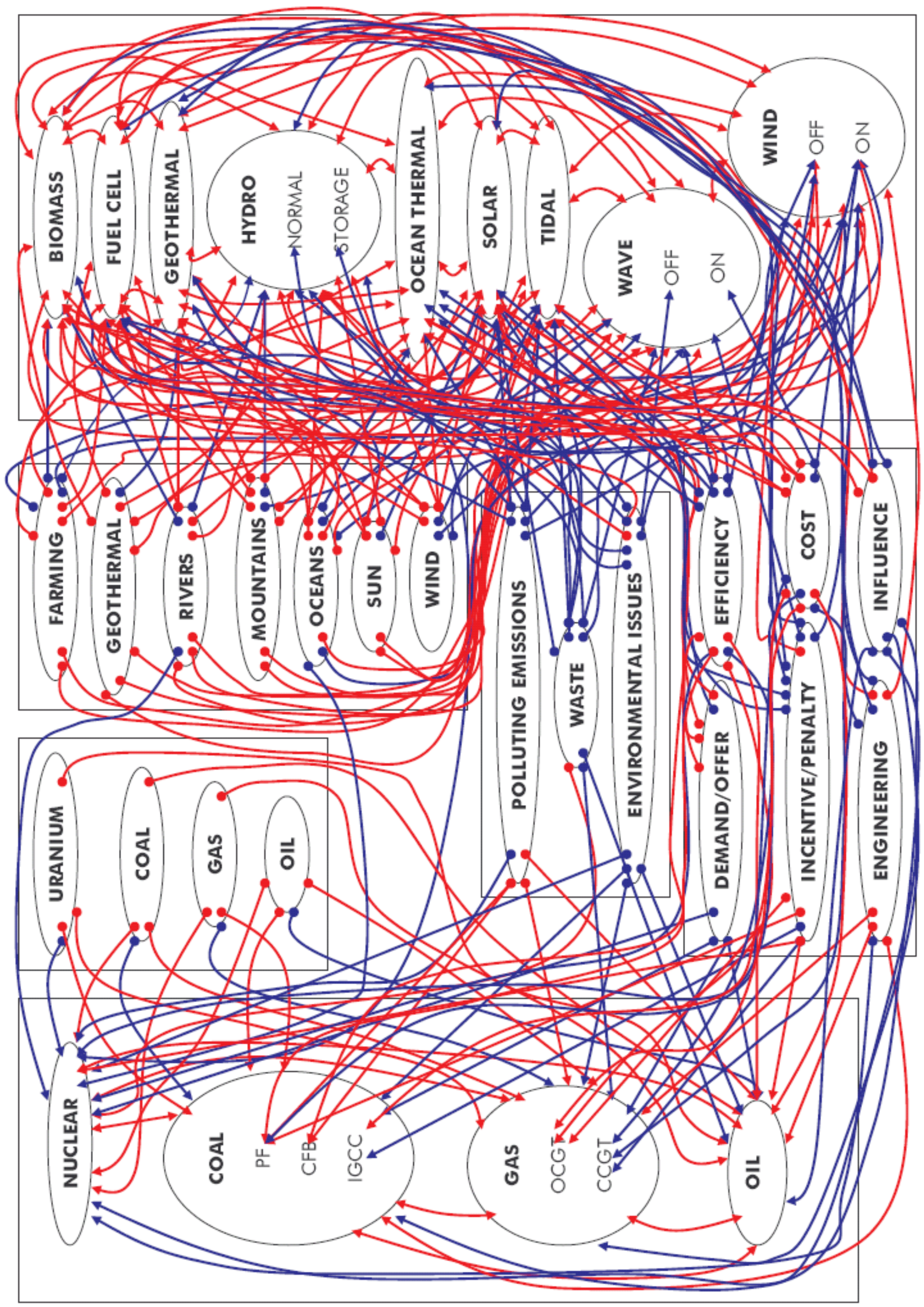



**Figure 15: Sustainable energy FCM**

## 4.4. Test Scenarios

In order to verify the predictions of the model and their accuracy, a range of checking scenarios will be implemented. These scenarios will be based on facts already known (first part of the propositions from Table 4). Later, in order to explore the predictions of the model, a range of chosen scenarios (it is technically unfeasible to test all the possible scenarios) is tested (second part of the propositions from Table 4 and the propositions from Table 5).

As shown in Table 14, the FCM edge weighting matrix will be identical for all the different scenarios; i.e. that the same effects should give the same results no matter where we are situated in the world. On the other hand, what is going to change between the different scenarios is what is called the "start up" position. In this start up position it will be necessary to define the present situation regarding the means of generating electricity (in this model 19 different means) and also to take into account the different drivers (in this model, 20 different determinants).

### *4.4.1. The example from France*

The model was tested against the energetic situation in France in the 70s and then in the 80s, when the politicians during these times had to make decisions about the future of the means of generating electricity for France.

**Table 15: Initial electricity generating means in France in the 70s**

| Generating means | Status | Comment |
|---|---|---|
| Nuclear station | 0 | At the beginning of the 70s France did not have any nuclear station, but thought of having few. |
| Coal-fired station PF | 1 | In the 70s France relied heavily on coal-fired station of the 1st generation, coal was available at that time. |
| Coal-fired station CFB | 0 | Not yet. |

| | | |
|---|---|---|
| Coal-fired station IGCC | 0 | Not yet. |
| Gas-fired station OCGT | 1 | Few. |
| Gas-fired station CCGT | 0 | Not yet. |
| Oil-fired station | 1 | Few. |
| Hydro station | 1 | The second source of electricity for France at that time. |
| Storage station | 1 | One. |
| Tidal station | 1 | One. |
| Other renewable station | 0 | Not yet. |

**Table 16: Drivers taken into account in France in the 70s**

| Drivers | Status | Comment |
|---|---|---|
| Uranium | 0 | Not available locally at that time. |
| Coal | 1 | The only natural resource available. |
| Natural-gas | 0 | Not available locally. |
| Oil | 0 | Not available locally. |
| Farming possibility | 1 | Huge possibility. |
| Geothermal possibility | 0 | Not much possibility. |
| Rivers | 1 | Present. |
| Mountains | 1 | Present. |
| Oceans | 1 | Present. |
| Sun | 0 | Not much present throughout the year. |
| Wind | 1 | There are spots, where the wind can be quite strong. |
| Polluting emissions | 0 | Not much a concern at that time. |
| Waste | 1 | Fear about the nuclear wastes. |
| Environmental effects | 0 | Not much a concern at that time. |
| Demand/supply issue | 0 | The offer can match easily the demand. |
| Levelised lifetime cost | 1 | The cost was always a concern. |
| Efficiency | 0 | Not much a concern at that time. |
| Incentive/penalty laws | 0 | Not much a concern at that time. |

| | | |
|---|---|---|
| Engineering availability | 1 | Present. |
| Constructors'/end users' influence | 1 | Big lobbying from the constructors on the end users. |

**Table 17: Result of the simulation for France in the 70s**

| | Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Startup | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | 4 | | | | | | | | | | | | | | | | | | | |
| | 5 | | | | | | | | | | | | | | | | | | | |
| | 6 | | | | | | | | | | | | | | | | | | | |
| | 7 | | | | | | | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | | | | | | |
| | 9 | | | | | | | | | | | | | | | | | | | |
| Cycle | 10 | | | | | | | | | | | | | | | | | | | |
| | 11 | | | | | | | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | | | | | | |

| | Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Startup | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 4 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 5 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 6 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 7 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 8 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 9 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| Cycle | 10 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 11 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| | 12 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |

The simulation shows very interesting results, first and foremost because the model reached equilibrium, which is not always the case, as we will see in the following scenarios. Secondly, in terms of the important point that the result shows, France should opt for nuclear power even though there is no uranium available locally and fear exists regarding nuclear waste. Nuclear power was exactly what, the politicians decided at that time, with the launch of France's nuclear programme in the middle of the 70s. We can now update the model by taking into account the effects of this decision and launch again a simulation, which will show what occurred in the 80s.

In Table 15, the only alteration to be made is the presence of nuclear stations. For Table 16 there are different points to up date as a result of the political decision taken and also as a result of the change in France's situation regarding natural resources.

**Table 18: Drivers taken into account in France in the 80s**

| Drivers | Status | Comment |
|---|---|---|
| Uranium | 1 | As the decision was taken to go nuclear, France built state-of-the-art facilities to enrich the uranium. |
| Coal | 0 | At the beginning of the 80s the reserves of coal started depleting and the remaining coal was of poor quality. |
| Natural-gas | 0 | Not available locally. |
| Oil | 0 | Not available locally. |
| Farming possibility | 1 | Huge possibility. |
| Geothermal possibility | 0 | Not much possibility. |
| Rivers | 1 | Present. |
| Mountains | 1 | Present. |
| Oceans | 1 | Present. |
| Sun | 0 | Not much present throughout the year. |
| Wind | 1 | There are spots, where the wind can be quite strong. |
| Polluting emissions | 1 | The international community started to be aware of the damage caused by the $CO_2$ emissions. |
| Waste | 0 | France built the best places to store the waste safely. Therefore, there was much less concern in the public opinion. |
| Environmental effects | 1 | All the environmental issues started to be taken into account. |
| Demand/supply issue | 1 | The demand was rising above the available offer. |
| Levelised lifetime cost | 1 | The cost was always a concern. |
| Efficiency | 1 | The efficiency started to be taken into account, due to the oil crisis; the idea was to create the same amount of electricity with less natural resources. |
| Incentive/penalty laws | 1 | The first laws regarding the conservation |

| | | |
|---|---|---|
| | | of the environment were stated. |
| Engineering availability | 1 | Present. |
| Constructors'/end users' influence | 1 | Big lobbying from the constructors on the end users. |

**Table 19: Result of the simulation for France in the 80s**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

This time the model did not reach equilibrium but is in a limit cycle. The model switches between two different statuses. The first one of these statuses represents clearly France's situation in the 80s and 90s; i.e. the abandonment of the coal-fired stations for the nuclear stations as base load and the natural-gas stations (CCGT, because of improved efficiency) as peak load. The second one of these statuses could represent the choice, which France should take in the near future. Indeed, nowadays the drivers of the simulation of Table 18 are almost the same and we can see that France is beginning to think about renewable energy sources much more often than in the past. This is exactly what is shown in the second status.

#### *4.4.2. The example from South Africa*

The model was tested against the energetic present situation in South Africa and trends related to decision-making.

### Table 20: Initial electricity generating means in South Africa

| Generating means | Status | Comment |
|---|---|---|
| Nuclear station | 1 | South Africa has the only nuclear power plant on the African continent. |
| Coal-fired station PF | 1 | Since the 60s until today, more than 90% of the electricity available is generated by this means. |
| Coal-fired station CFB | 0 | Not yet. |
| Coal-fired station IGCC | 0 | Not yet. |
| Gas-fired station OCGT | 1 | Few. |
| Gas-fired station CCGT | 0 | Not yet. |
| Oil-fired station | 1 | Few. |
| Hydro station | 1 | Few. |
| Storage station | 0 | Not yet. |
| Other renewable station | 0 | Not yet. |

### Table 21: Drivers taken into account in South Africa

| Drivers | Status | Comment |
|---|---|---|
| Uranium | 1 | One of the biggest reserves in the world. The issue is to make it enriched at good price. |
| Coal | 1 | One of the biggest reserves in the world with quite a good quality. |
| Natural-gas | 0 | Not available locally. |
| Oil | 0 | Not available locally. |
| Farming possibility | 1 | Huge possibility. |
| Geothermal possibility | 0 | Not much possibility. |
| Rivers | 1 | Present. |
| Mountains | 1 | Present. |
| Oceans | 1 | Present. |
| Sun | 1 | Almost present every single day of the year. |
| Wind | 1 | There are spots/areas, where the wind |

| | | |
|---|---|---|
| | | can be quite strong. |
| Polluting emissions | 0 | Still not much of a concern. |
| Waste | 1 | Fear about the nuclear wastes. |
| Environmental effects | 0 | Still not much a concern. |
| Demand/supply issue | 1 | The demand soars; the available supply cannot cope with the increasing demand. |
| Levelised lifetime cost | 1 | The cost was always a concern and remains one. |
| Efficiency | 0 | Not much a concern as the level of natural resources is very high. |
| Incentive/Penalty Laws | 0 | Still not much a concern. |
| Engineering Availability | 0 | Shortage of skilled people. |
| Constructors'/end users' Influence | 0 | Not much of an influence. |

**Table 22: Result of the simulation for South Africa**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 10 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 11 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 12 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

The result can be analysed in two parts: the first one with regards to what is happening in South Africa at present; and the second one with regards to the possibilities that have not really been taken into account. Indeed, the model shows that South Africa has to invest in new coal-fired power plants, including new generation of power plants, which are cleaner and more efficient, even though these two points are not much of a concern nowadays in South Africa. The model shows also that South Africa has to develop its nuclear fleet. Those two choices are taken into account, as Eskom will build new coal-fired power plants in the North of Limpopo Province in the near future as well as in the Vaal Triangle, and new nuclear power plants in the region of Cape Town.

The model does not show the use of natural-gas-fired power plants, which Eskom is busy building now on the coast. There are two possible explanations for this. Firstly, the model is not referred enough and does not take into account all the drivers needed to arrive at the type of decision that Eskom took; or secondly, Eskom took a bad decision in building natural-gas-fired power plants. As an alternative of natural-gas-fired plants, the model shows two other possibilities; the first one is the use of biomass power plants, which could be a good idea to fight the unemployment and the poverty. Indeed, many more people would be needed on the farms to produce the raw material used in this kind of power station. The second one is the use of the wind power plants, which are quick to install and could be built in several locations in South Africa and offshore. For these reasons, natural-gas-fired stations would not be a sensible option for electricity generation for South Africa to choose.

### *4.4.3. The example from Germany*

The model was tested against the energetic present situation in Germany and trends related to decision-making. The German model is not as fixed as the French one; therefore, it is more complicated to simulate it. The starting line of the model for this simulation represents the situation in Germany in the 90s.

**Table 23: Initial electricity generating means in Germany**

| Generating means | Status | Comment |
|---|---|---|
| Nuclear station | 1 | Significant part of the production. |

| | | |
|---|---|---|
| Coal-fired station PF | 1 | Big part of the production. |
| Coal-fired station CFB | 1 | Big part of the production. |
| Coal-fired station IGCC | 0 | Not really yet available. |
| Natural-gas-fired station OCGT | 1 | Significant part of the production. |
| Natural-gas-fired station CCGT | 0 | Not really yet available. |
| Oil-fired station | 1 | Few. |
| Hydro station | 1 | Few. |
| Storage station | 1 | Few. |
| Other renewable station | 0 | Not really yet available. |

**Table 24: Drivers taken into account in Germany**

| Drivers | Status | Comment |
|---|---|---|
| Uranium | 0 | Not much uranium available and not many enrichment facilities. |
| Coal | 1 | There is still some coal available. |
| Natural-gas | 1 | Locally there is not much natural gas available, but Germany has exclusive contracts with Russia to get natural-gas at competitive prices. |
| Oil | 0 | Not available locally. |
| Farming possibility | 1 | Huge possibility. |
| Geothermal possibility | 1 | Possibilities, as Germany uses already geothermal to heat shopping centres and municipal buildings. |
| Rivers | 1 | Present. |
| Mountains | 0 | Not much present. |
| Oceans | 1 | Present. |
| Sun | 0 | Not much present throughout the year. |
| Wind | 1 | There are spots where the wind can be quite strong. |
| Polluting emissions | 1 | Big concern. |

| | | |
|---|---|---|
| Waste | 1 | Fear about the nuclear wastes. |
| Environmental effects | 1 | Big concern. |
| Demand/supply issue | 0 | The demand is still easily matched by the supply. |
| Levelised lifetime cost | 1 | The cost was always a concern and remains one. |
| Efficiency | 1 | The efficiency is taken into account. |
| Incentive/penalty laws | 1 | The incentive laws for renewable energies are very strong. |
| Engineering availability | 1 | Present. |
| Constructors'/end users' influence | 1 | Big lobbying from the constructors on the end users. |

**Table 25: Result of the simulation for Germany**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 3 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 9 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 11 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |

As the second simulation of the example from France, the model does not reach equilibrium but is in a limit cycle and switches between two different statuses. As stated in Table 24, the German laws are quite in favour of the renewable energies - in favour of cleaner ways of generating electricity and in favour of ways that are more efficient as well. This preference is clearly shown in the simulation; indeed, there is the presence of nuclear power, which is one the most efficient and one of the cleanest means of generating electricity regarding polluting emissions. The result of the simulation also shows the presence of the coal-fired power (but only the cleanest one IGCC), the presence of the natural-gas-fired power (but only the most efficient one CCGT), and at finally all kinds of renewable energies.

## 4.5. Analysis

The three examples of France, Germany and South Africa show that the model can be quite accurate and therefore can be used to influence the choice of the sustainable energy of the future.

Each of the simulated scenarios provokes a response in the model, which will then reach one of the three possible equilibrium states - fixed point, limit cycle or chaotic behaviour - as in the examples above. Once the model has reached equilibrium or a limit cycle, the state of the model nodes is interpreted with respect to the evolution of the energy field in the world. Where collaborating or contradictory observations exist in the literature, these observations are incorporated into the discussion to provide triangulation.

# 5. PRESENTATION/INTERPRETATION OF RESULTS

Chapter 5 addresses Sub-problem 3 by interpreting the results generated by applying the test conditions listed in Section 4.4 to the model described in Section 4.3.

None of the chaotic behaviour simulations will be presented in this chapter, as they are considered as irrelevant for the purpose of the research study.

## 5.1. General Scenarios

In this chapter, we analyse how the model reacts to certain conditions by applying certain general constraints. It will be observed that in most of the cases the model does not reach equilibrium but is in a limit cycle, which normally shows two statuses - the first one directly linked to the conventional ways of generating electricity, and the second one directly linked to the renewable ways of generating electricity. This specificity stems from the structure of the model, which, of course, is based on the reality of the electricity-generating field.

### *5.1.1. No drivers*

For the first scenario, the most basic of all, we do not introduce any drivers. Therefore, natural resources drivers, geographical-location drivers and external-condition drivers are at 0. This scenario would correspond to a country where there are no natural resources available, where the geographical locations do not foster any specific renewable energy and, finally, where no external-condition drivers are present either. We could argue that this scenario is unlikely to occur in the real world, but this scenario can deliver some general directions.

**Table 26: Result of the simulation with no drivers**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

As expected, the model does not reach equilibrium and keeps switching between two statuses. The status characterising the conventional ways of generating electricity has some selectivity; indeed, only the station based on coal and oil have been selected. These two means were the first methods used to generate electricity. On the other hand, the status characterising the renewable ways of generating electricity does not have any selectivity; indeed all the methods are present from the most basic to the most sophisticated.

### *5.1.2. Natural resource drivers*

For this scenario, we introduce only the natural resource drivers and do not introduce the others. Therefore, the natural resource drivers are at 1, geographical-location drivers and external-conditions drivers are at 0. This scenario would correspond to a country where all kinds of natural resources are available, but where the geographical locations do not foster any specific renewable energy and where no external-condition drivers are present either. This scenario has a higher likelihood to occur than the previous one.

**Table 27: Result of the simulation with natural resource drivers**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Once again, the model does not reach equilibrium and keeps switching between two statuses. As we introduced only drivers that are directly linked to conventional ways of generating electricity and not really linked to renewable energies, the conclusions drawn from this simulation are only relevant for the non-renewable energies. Therefore, if a country has all the natural resources available and does not have any external drivers that could influence its choices, this country would go for the easiest way, i.e. natural-gas-fired stations and oil-fired stations. Why easiest? Because these two kinds of stations are easy to erect, they are easy to run, and natural gas and oil are the two natural resources that are the easiest to transport and to store.

### *5.1.3. Geographical-location drivers*

For this scenario, we introduce only the geographical-location drivers and do not introduce the others. Therefore, the geographical-location drivers are at 1, natural resource drivers and external-condition drivers are at 0. This scenario would correspond to a country where there are all kinds of geographical locations available, but where no natural resources are available and where no external-condition drivers are present either.

**Table 28: Result of the simulation with geographical-locations drivers**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 6 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 8 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 10 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 12 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Once again, the model does not reach equilibrium and keeps switching between two statuses. As we introduced only drivers that are directly linked to the renewable ways of generating electricity and not really linked to the non-renewable energies, the conclusions drawn from this simulation are only relevant for the renewable energies. We can observe that only two renewable energy means have been left out - the fuel cell stations and the wave stations. What is really amazing is that these two are the last two means which are developed nowadays. Therefore, they are less commonly known.

With the previous simulation and this latest one, we can see that the model is capable of pretty good selectivity under conditions that are very easy to identify. Conditions such as the availability of natural resources or the specificity of the geographical features in the country that we want to analyse the present energetic situation in order to decide on the future of its energetic situation.

### 5.1.4. External-condition drivers

For this scenario, we introduce only the external-condition drivers and do not introduce the others. Therefore, the external-condition drivers are at 1, natural resources drivers and geographical-location drivers are at 0. This scenario would correspond to a country, where all the external conditions are applicable, but where there are no natural resources available and where the geographical locations do not foster any specific renewable energy either.

**Table 29: Result of the simulation with external-condition drivers**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

For this simulation, we can observe that the selectivity due to the external-condition drivers is not as accurate as that for the two previous types of drivers. Indeed, for either the conventional ways of generating electricity or the renewable energies we have almost all kinds of stations. Therefore, we can conclude that the model will be selective and accurate only by associating the external-condition drivers with the other drivers. In other words, the external-condition drivers alone do not give meaningful selectivity results for the model but when used in conjunction with the other divers they give the model selectivity.

### *5.1.5. Natural resource/geographical-location drivers*

For this scenario, we introduce natural resource drivers and the geographical-location drivers, and do not introduce the external-condition drivers. Therefore, the natural resource drivers and the geographical location drivers are at 1, and the external-condition drivers are at 0. This scenario would correspond to a country where there are all kinds of natural resources available and where the geographical locations can foster any specific renewable energy and where no external-condition drivers are present.

**Table 30: Result of the simulation with natural resource/geographical-location drivers**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The model has been designed in such a way that there is almost no interlink between the conventional energies and the renewable energies. (The only exception is the hydro stations with the nuclear stations). Therefore, as a result, we find the juxtaposition of the two results from the simulation done for the natural resource drivers and the simulation done for the geographical-location drivers individually. We cannot take this remark as a critic of the Model, because in the real world it is really done this way, there are no links between the conventional energies and the renewable energies.

### 5.1.6. Natural resource/external-condition drivers

For this scenario, we introduce the natural resource drivers and the external-condition drivers, and do not introduce the geographical-locations drivers. Therefore, the natural resource drivers and the external-condition drivers are at 1, and the geographical-location drivers are at 0. This scenario would correspond to a country where there are all kinds of natural resources available and where all the external-condition drivers are present and where the geographical locations do not foster any specific renewable energy.

**Table 31: Result of the simulation with natural resource/external-condition drivers**

| | Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 6 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 7 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 8 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 9 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle | 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 11 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

For this simulation, we introduced only drivers that are directly linked to the conventional ways of generating electricity and are not really linked to the renewable energies; the conclusions drawn from this simulation are only relevant for the non-renewable energies. If a country has all the natural resources available and all the external-condition drivers present, a very interesting result is produced. Indeed, the only two conventional means of generating electricity are the nuclear power stations and the natural-gas-fired stations using combined cycle. This interesting result will be further developed in the last section of this chapter.

### *5.1.7. Geographical-location/external-condition drivers*

For this scenario, we introduce the external-condition drivers and the geographical-location drivers, and do not introduce the natural resource drivers. Therefore, the external-condition drivers and the geographical-location drivers are at 1, and the natural resource drivers are at 0. This scenario would correspond to a country where all the external-condition drivers are present and where the geographical locations can foster any specific renewable energy and where no natural resources are available.

**Table 32: Result of the simulation with geographical-location/external-condition drivers**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

For this simulation, we introduced only drivers that are directly linked to the renewable ways of generating electricity and are not really linked to the non-renewable energies, which mean that the conclusions drawn from this simulation are only relevant for the renewable energies. The fact of using all the external-condition drivers and the geographical-location drivers in this simulation implies the presence of all renewable energies, even the ones that have been left out for the simulation based only on the geographical-location drivers. This situation shows that the external-condition drivers are in favour of all the renewable energies.

### *5.1.8. All drivers*

For the scenario in Table 33, we introduce all the drivers; i.e. natural resource drivers, geographical-location drivers and external-condition drivers are at 1. This scenario would correspond to a country where there are all kinds of natural resources available, where the geographical locations can foster any specific renewable energy and finally where all the external-condition drivers are present as well.

**Table 33: Result of the simulation with all drivers**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

As expected, the result of this simulation is the juxtaposition of the two previous results for the two previous simulations carried out individually. However, this simulation is very interesting. Where does one find a country where all the natural resources are available, where all the different kinds of geographical locations are present and where all the external-condition drivers should be taken into account?

Only at the scale of the world are all the natural resources present, all the geographical locations also, and the world should be concerned by all the external-condition drivers present in the simulation. These external-condition drivers are listed in the points follow:

- Polluting emissions: As seen in the literature review this is one of the main concern for the future as it can lead to the global warming of the Earth.
- Waste: Coal wastes such as ashes can be easily handled anywhere in the world. The concerns are more with nuclear-waste, which can be very well handled in countries like France but can be a challenging issue in other parts of the world.
- Environmental effects: People constantly want better places to live in. Therefore, there are more and more concerns regarding issues such as the noise, deterioration of the air, the wild life environment, and so forth.
- Demand/supply issue: The world is constantly developing and therefore the number of people who will require access to electricity will increase every year.
- Levelised lifetime cost: Overall, the world will look for the lowest levelised lifetime cost for fulfilling its needs in electricity.
- Efficiency: The more the electricity-generating efficiency capabilities increase, the longer will the world's natural reserves will last.
- Incentive/penalty laws: More frequently, laws from summits like Kyoto will be drafted and applied more severely.
- Engineering availability: With globalisation, skilled people will be available throughout the world.
- Constructors'/end users' influence: Again with globalisation, the influence of the main constructors will be spread throughout the world.

Therefore, for the sustainable energy of the future for the whole world, all renewable energies should be part of the solution, and for the conventional means of generation, the nuclear stations and the natural-gas-fired stations, which are the most efficient at present.

Before commenting any further, it would be useful to verify at this stage that the starting status regarding the different means of generating electricity does not influence the final result. Therefore, in this simulation using all the drivers, we will start the simulation with all the generating means at 1 instead of 0, such as in the other simulations.

**Table 34: Result of the simulation with all drivers and all generating means**

| Output | | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 7 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 9 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 11 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| Output | | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cycle | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

It is easy to see that, in this case, the starting status regarding the different means of generating electricity does not influence the final result. Indeed, the result of this simulation is exactly the same as that for the previous simulation. This is true in this particular case but, of course, cannot be generalised for all the cases.

In the two simulations, the same results were obtained. However, as explained in the limitations of the study, the results of the simulations represent a medium-term solution only. For the long-term solution, the natural gas reserves will be completely depleted, meaning that natural gas will no longer be part of the solution. On the other hand, the new generation of nuclear stations will be in place. These nuclear stations will be able to burn 90% of the natural uranium instead of the 0.7% at present. Therefore, these new nuclear stations will give us ten thousands of years of energy against the 70 years of today. These new nuclear stations will be cooled down with helium, which will also improve the efficiency drastically.

This new generation of nuclear stations should be at the price of the present generation of nuclear stations, around the year 2050; i.e. 3 billion Euros. As mentioned before, it will not be for another 50 years that these nuclear stations will be built, because they are too expensive and not reliable enough, to build today.

Unfortunately, it is not possible to contemplate the sustainable energy of the future on a world scale as if the world were completely unified. For a start, the developed countries do not have the same interests as the developing countries. The countries with natural resources available do not have the same constraints as the countries that are completely dependent on others to procure such natural resources. Therefore, at least for the medium term as proposed for this study, we would need to consider countries that have the same kind of constraints and the same kind of possibilities to foresee what would be their sustainable energy of the future. It is exactly what will be done in Section 5.2.

## 5.2. Specific Scenarios

Reality based scenarios will be analysed in this section; i.e. scenarios which are directly in line with what one could observe in different countries of the world. To start with, the situation of the most common type of country will be analysed - the farming countries. Indeed not so long ago in the year 60s, even present developed countries were farming countries.

After this generic scenario, other more specified scenarios will be simulated as well, such as the case of eastern countries and countries in the Middle East.

### *5.2.1. Farming countries*

It will be assumed that the farming country does not have any means of generating electricity available. Therefore, the first line of the model will contain only 0s. For the first simulation, it will be assumed as well that the farming country does not have any natural resources available, which is the case for many countries throughout the world. Finally, no external-condition drivers will be taken into account either, which can also be the case for many countries. Concerning the points taken into account, i.e. at 1 on the start-up line, there is the farming possibility (obvious), the presence of rivers (for water in case of necessity), the presence of mountains (to build even small dams), the presence of the sun (which is required for farming), and the presence of wind (in any country there is always wind).

**Table 35: Result of the simulation for the farming countries**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

We can see that the model can be very selective and can give very specific results for very specific initial conditions. Few of the outcomes of this simulation can be seen as very straight forward but with regards to the quite elaborate and quite complicated model, these straight forward results are reassuring of the accuracy of the model. Indeed, for the renewable energies, in the result obtained we could have expected the presence of the biomass stations and the hydro stations, but we could not have necessarily expected the presence of the storage, the solar and the onshore wind stations. The second interesting part of the result relates to conventional energies; the farming countries that do not have any natural resources should use coal- and oil-fired stations to fulfil their needs for electricity. This is exactly what it is observed in most of the poorest farming countries.

In the following simulations, and using the same initial conditions, the farming country will be considered to have some natural resources.

**Table 36: Result of the simulation for the farming countries with oil**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

For this simulation, the availability of oil has been added. We can observe that the result is exactly the same as for the previous simulation, with no oil available. This means that although the country has oil, it cannot rely only on oil-fired stations. The first reason is that the farming possibilities are still available and it would be foolish not to use them (employment of the people, for instance) and the second reason is that it is certainly better for a country to sell part of its oil (balance of payment) than to use all of it only to generate electricity.

**Table 37: Result of the simulation for the farming countries with coal**

| Output | | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | | | | | | | | | | | | | | | | | | | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

For this simulation, the availability of coal has been added. For the renewable energies, the outcome is unchanged, which is normal regarding the comment made before. On the other hand, for the part of the result regarding conventional energies, the outcome has changed slightly. The simulation shows that the country should choose only coal-fired stations to generate electricity. The first explanation for this is that the reserves of coal are generally greater than the reserves of oil; therefore, coal-fired stations should be able to last longer. As second reason is that the price of coal is much less than the price of oil. Therefore why buy expensive natural resources from other countries when the needed natural resources are available locally?

The result of the next simulation is interesting because, we add in the availability of a natural resource, but the means of generating electricity associated with this natural resource was not present in the result of the first simulation of Table 35.

**Table 38: Result of the simulation for the farming countries with natural gas**

Output

| | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Cycle

Once again, the part of the result regarding the renewable energies did not change as expected, but the part regarding the conventional energies switched from the use of coal-fired stations to the use of natural-gas-fired stations. This result is easy to analyse: first and foremost it is obvious to use natural resources available locally to generate electricity. However, it has been observed in the case of the availability of oil that it is still recommended to use the coal-fired stations. In the case of the availability of natural gas, this recommendation disappears. The reasons for this are: firstly, natural gas is cheaper than oil and therefore it is better to use it locally than to sell it to other countries; and, secondly that coal is not really easy to transport and, therefore, when natural-gas is available locally it does not make much sense to buy coal from other countries.

For the next simulation the availability of uranium will be added in but as already noted in previous simulation, the availability of uranium on its own does not determine the decision-making process. Let us see this fact with the two simulations set out below.

**Table 39: Result of the simulation for the farming countries with uranium**

| Output | | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

In the previous simulations adding in the availability of one of the natural resources gave some selectivity to the model; i.e. the model reached equilibrium and, most important in the result of these simulations, the generating means associated with the natural resource was present (for instance, natural-gas-fired stations when natural-gas is present). In this simulation the model does not reach equilibrium and keeps switching between two statuses: one with all the conventional energies and one with none of them; in other words the Model cannot really "decides" with the drivers present. What is missing in this simulation for it to exhibit the same kind of behaviour as the previous simulations is the fact that natural uranium cannot be used directly in a nuclear power station; it has to be enriched. To enrich uranium we need the presence of engineering skills, which is discussed in the following simulation.

**Table 40: Result of the simulation for the farming countries with enriched uranium**

| Output | Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 6 | | | | | | | | | | | | | | | | | | | |
| | 7 | | | | | | | | | | | | | | | | | | | |
| | 8 | | | | | | | | | | | | | | | | | | | |
| | 9 | | | | | | | | | | | | | | | | | | | |
| | 10 | | | | | | | | | | | | | | | | | | | |
| | 11 | | | | | | | | | | | | | | | | | | | |
| | 12 | | | | | | | | | | | | | | | | | | | |

| Output | Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 4 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 5 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 6 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 7 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 8 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 9 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 10 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 11 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | 12 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

With a natural source that can be used in a power station, i.e. the enriched uranium, it is obtained a clearer result. Indeed, the use of the coal-fired stations has been abandoned. The fact that the oil-fired stations are still present can be explained by the fear of the nuclear power. More external-condition drivers have to be added to the simulation to remove the presence of the oil-fired stations.

As a remark regarding the result of this simulation the fact of having added the availability of engineering in the start up line caused wind stations to drop out of the result. This phenomenon is explained by the fact that during the construction of the model it was considered that the solar stations needed more engineering than the wind stations.

In the energy field, in particular in the production of electricity, one of the most important transformations is the mutation of a farming country to a more industrialised country. This type of situation will be used in the following simulations.

Generally, the first sign of transformation in a developing country is the increase of the demand for electricity; therefore, it is the first external-condition driver to add to the model.

**Table 41: Result of the simulation for the farming countries with demand**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 4 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

An increase in the demand for electricity it has to be understood as a drastic increase, i.e. supply cannot match the demand. The result of the simulation shows that to be able to increase the electricity production quickly, natural-gas-fired stations (open cycle) must be added. This result is very interesting because this is exactly what is happening in countries such as Brazil. Indeed, in Brazil, the demand for electricity is soaring and the supply cannot really cope with this increase. Therefore, many open cycle gas turbine stations are built throughout the country, even though Brazil has to buy natural gas from its neighbours Argentina and Bolivia. The reason is that the quickest way of generating big amounts of electricity is by building open cycle gas turbine stations.

The fact of having added the demand/supply issue in the start-up line caused the drop out of the solar stations from the result. This behaviour of the model is explained by the fact that solar stations do not generate big amounts of electricity. Indeed this generating means can be used as a complement of electricity production but cannot be used as a "base load station". For the same quantity of electricity to be produced by a gas turbine, it is necessary to have a huge solar station.

**Table 42: Previous simulation plus constructors'/end users' influence**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 4 | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

When a country has a big demand for means of generating electricity; the constructors of such equipment start putting pressure on the end users to buy their products. Therefore, in the above simulation this external-condition driver has been added. The result of the simulation does not change from the previous one, but equilibrium is reached more quickly. Therefore, we can really see that the constructors have some influence on the end users even though the former is the supplier and the latter is the customer.

After the first rush of having a means of generating electricity up and running, the public opinion starts being concerned by the environmental issues such as those related to polluting emissions. Therefore, in the following simulation this external-condition driver will be taken into account as well.

**Table 43: Previous simulation plus polluting emissions**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

Once again, the final result is the same, but what are interesting are the different steps that the model takes. Indeed, in the previous simulation the model went almost directly to the result without considering too many options. In the current simulation, the model takes into account an additional condition regarding the environment. Therefore, it tries to include in the result some renewable energies but, unfortunately, the demand/supply issue is still the main driver and in the final result most of the renewable energies are left out.

The following point taken into account in the decision-making process is normally the cost of a new station. Indeed, after having addressed the problem of the demand as short-term concern, the electricity producers want to address as a long-term concern the cost of building and running a new station. Therefore, in the following simulation cost will be taken into account as additional external-condition driver as well.

**Table 44: Previous simulation plus levelised lifetime cost**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

For the renewable energies, the result does not change much; biomass, hydro, storage and onshore wind stations are still present, only offshore wind stations are added. For the conventional energies, there is a complete change; the natural-gas-fired and oil-fired stations have been left out of the result and the nuclear stations appear in the result. In this way, it can be seen that the levelised lifetime cost has a huge impact on the decision-making process, as shown in the literature review, the two cheapest kinds of stations are the nuclear stations and the coal-fired stations, and the two more expensive ones are the natural-gas-fired and the oil-fired stations.

However, what remains the biggest problem surrounding the nuclear plant is the issue regarding nuclear-waste. In order to complete these evolving simulations, a last one will be presented – relating to the concern about nuclear-waste. Indeed, if a country does not have the right facilities to handle nuclear-waste, it will have to consider the simulation represented in Table 45. If a country has in place the correct facilities and procedures to handle the nuclear-waste, it will have to consider the simulation shown in Table 44.

**Table 45: Previous simulation plus waste**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 |
| 6 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 7 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

There is not much of a surprise in the result: this time the nuclear solution has been abandoned and the result reinstates the natural-gas-fired and oil-fired stations, but this time with combined cycle gas turbine stations, which have a smaller levelised lifetime cost. Indeed, this is exactly one of the major decisions that has to be taken by a company that wants to lower the cost of a cleaner electricity base load production. As seen in the simulation in Table 44 one can opt for nuclear stations but facilities for the disposal of nuclear-waste have to be available (a choice made by France and other developed countries a few decades ago). If a country does not want to take on the burden of nuclear-waste, it can opt for the combined cycle gas turbine stations. This option entails the conversion of the open cycle gas turbine stations, which have been built to respond to the increasing demand, to combined cycle gas turbine stations (a choice made by a number of developing countries, such as Argentina).

With these two different kinds of simulations for the farming countries, the “static” simulations and, the “evolving” simulations that have been described in this section we can confirm that the model gives very accurate results and, therefore, this model can be used as a decision-making tool. It is referred as “static” simulations, the simulations done in the first part of this section where an attempt has been made to add in only natural resource drivers at the current energetic situation. It is referred as "evolving" simulations, the simulations done in the second part of this section where an attempt has been made to add in one new external-condition driver in every simulation.

### *5.2.2. Eastern countries*

The example of the eastern countries will be presented for two main reasons; the first being because this example can be linked to what happened in Russia, and the second being to show that the status of the starting line of the generating means can have a big influence on the final result of the simulation. Therefore, the status of the starting line of the drivers will be kept the same for the two following simulations in order to see the result produced by changing the generating means only.

**Table 46: First initial electricity generating means in eastern countries**

| Generating means | Status | Comment |
|---|---|---|
| Nuclear station | 0 | Eastern countries are cautious before they choose to go for nuclear stations. |
| Coal-fired station PF | 1 | Big part of the production. |
| Coal-fired station CFB | 0 | Not yet available at that time. |
| Coal-fired station IGCC | 0 | Not yet available at that time. |
| Natural-gas-fired station OCGT | 1 | Significant part of the production. |
| Natural-gas-fired station CCGT | 0 | Not really yet considered at that time. |
| Oil-fired Station | 1 | Significant part of the production. |
| Hydro station | 1 | Significant part of the production. |
| Storage station | 1 | Part of the production. |
| Other renewable station | 0 | Not yet considered at that time. |

An important point to note is that the simulation involving eastern countries considers them soon after industrialisation.

**Table 47: Drivers taken into account in eastern countries**

| Drivers | Status | Comment |
|---|---|---|
| Uranium | 1 | Uranium available. |
| Coal | 1 | Coal available in huge quantity. |
| Natural-gas | 1 | Natural-gas available in huge quantity. |
| Oil | 1 | Oil available in quantity. |
| Farming possibility | 1 | Huge possibility. |
| Geothermal possibility | 1 | Possibilities. |
| Rivers | 1 | Present. |
| Mountains | 1 | Present. |
| Oceans | 1 | Present. |
| Sun | 0 | Not much present throughout the year. |
| Wind | 1 | There are spots, where the wind can be quite strong. |
| Polluting emissions | 0 | Not a concern at that time. |
| Waste | 1 | No facilities to handle the nuclear waste at that time. |
| Environmental effects | 0 | Not a concern at that time. |
| Demand/supply issue | 1 | The demand started soaring when the countries started developing. |
| Levelised lifetime cost | 1 | The cost was always a concern. |
| Efficiency | 0 | The efficiency was not taken into account at that time. |
| Incentive/penalty laws | 0 | No laws existing at that time. |
| Engineering availability | 0 | Not much present at that time. |
| Constructors'/end users' influence | 1 | Big lobbying from the constructors of the end users, as they were many small constructors in eastern countries at that time. |

**Table 48: First result of the simulation for eastern countries**

| Output | Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 2 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 3 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 4 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 5 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 6 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 7 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 8 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 9 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 10 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 11 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| | 12 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| Output | Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

The result shows that for the conventional energies, eastern countries should add to their current fleet cleaner coal-fired stations (CFB) and more efficient natural-gas-fired stations (CCGT), almost entirely as a result of the demand driver. For the renewable energies, even more means are proposed to be added to the current fleet. Indeed, the first means being the biomass stations, this advice is logical regarding all the farming drivers, which are present in eastern countries. The second means being the geothermal stations, once again, this recommendation is logical as eastern countries have geothermal possibility as a driver. For the tidal station solution, which is the first time that this generating mean comes up on its own in the final result of a simulation when not all of the renewable energies are present, it is also normal because most of the eastern counties are surrounded by oceans. For onshore wave station solution, exactly the same comment as the tidal stations can be applied. Finally, the onshore and offshore wind stations are present in the final result because of presence of the drivers such as the presence of wind and oceans.

For the second simulation on the example of the Eastern Countries, we are going to re-look at these countries at a time they had already added nuclear stations to their energy-generating fleet. Therefore, the addition of nuclear stations will be the only change in the starting line of the second simulation.

**Table 49: Second initial electricity generating means in eastern countries**

| Generating means | Status | Comment |
|---|---|---|
| Nuclear station | 1 | Eastern countries are considered just after they had chosen to go for nuclear stations. |
| Coal-fired station PF | 1 | Big part of the production. |
| Coal-fired station CFB | 0 | Not yet available at that time. |
| Coal-fired station IGCC | 0 | Not yet available at that time. |
| Natural-gas-fired station OCGT | 1 | Significant part of the production. |
| Natural-gas-fired station CCGT | 0 | Not really yet considered at that time. |
| Oil-fired Station | 1 | Significant part of the production. |
| Hydro station | 1 | Significant part of the production. |
| Storage station | 1 | Part of the production. |
| Other renewable station | 0 | Not yet considered at that time. |

**Table 50: Second result of the simulation for eastern countries**

| Output / Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| 2 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 4 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 5 | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Output / Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

The final result is completely different from that for the previous simulation; indeed, eastern countries made a good decision for their choice of conventional energies because the final result regarding the conventional energies is identical to what appears in the starting line, i.e. the current fleet used by eastern countries. For renewable energies, the result of the simulation recommends only the addition of the wind stations to the current fleet.

With these two simulations, we have shown that by only changing one generating means in the starting line, we can change the final result completely. We can now show that by adding one more driver to the starting line, even with different generating means on this line we can reach the same final result.

For the example of the eastern countries, we left out the availability of engineering at the time of industrialisation. The fact of leaving out of the external-condition drivers the availability of engineering can be debatable. Indeed, we can argue that industrialisation entailed the availability of engineering or that the availability of engineering entailed the industrialisation. Therefore, in the following two simulations, which are the same as the two previous simulations, we will add in this driver onto the starting line.

**Table 51: First result of the simulation for eastern countries with engineering**

| Output | Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 8 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | 12 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |

The result of the simulation gives clear-cut results with regards to the conventional energies. One of these is the presence of nuclear stations even though this generating means was not on the starting line and the other is still the presence of oil-fired stations. For the renewable energies, the model does not reach equilibrium and keeps switching between two statuses. The first status characterises the current status of the eastern countries because it includes only the generating means of the starting line. The second status includes, in addition, biomass, geothermal, tidal, onshore wave and onshore wind stations. One amusing point is the presence of the onshore wave and the onshore wind station and not the offshore ones, despite the presence of oceans as a driver. This fact is certainly the result of the presence of the levelised lifetime cost driver and the absence of the environmental effect driver. Indeed, the former gives preference to the onshore stations, as they are cheaper than the offshore stations and, the latter gives preference to the offshore stations, as they do not produce heavy noise at the coast.

**Table 52: Second result of the simulation for eastern countries with engineering**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 8 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 10 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 12 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| Cycle 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 10 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 11 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |

This simulation proves that this model can reach the same result even when the starting lines are not the same for two simulations. This similarity is due to the presence of an extra driver, which is the engineering-availability driver.

### 5.2.3. Middle East countries

The example of the Middle East countries will be presented because it represents a typical example of countries, which have huge natural resources. This advantage of having these strategic natural resources abundantly available makes these countries to pay little attention to any other external drivers.

On the starting line is the presence of natural gas and of oil for the natural resource part and, for the geographical-location part, is the presence of the oceans, the sun and the wind. All other drivers are kept at 0.

**Table 53: Result of the simulation for Middle East countries**

| Output | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Output | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cycle 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The model with this simulation does not reach equilibrium, but only one status out of two really shows what happens in the Middle East countries, i.e. the status regarding the conventional energies. Indeed, in the Persian Gulf countries, the only means of generating electricity is open cycle gas turbine stations and oil-fired stations. The second status with all the renewable energies shows an alternative solution - which the Persian Gulf countries could look for a new means of generating electricity. However, without any other external-condition drivers this choice is left out.

These countries will at some stage have to take into account the other external-condition drivers.

In the following simulation, certain external-condition drivers are added to the starting line in order to see what is going to happen in the near future for these countries regarding their means of electricity generating.

**Table 54: External-condition drivers taken into account in Middle East countries**

| Drivers | Status | Comment |
|---|---|---|
| Polluting emissions | 1 | As the countries are using fired stations there are polluting emissions. |
| Waste | 1 | No facilities to handle the nuclear waste, as they do not really need nuclear stations yet. |
| Environmental effects | 1 | They have to take into account the environmental effects such as noise. |
| Demand/supply issue | 1 | The demand has started soaring as they are developing their countries for tourism and the need for desalinated water. |
| Levelised lifetime cost | 1 | It can be considered that the price of new power stations will be taken into account eventually. |
| Efficiency | 1 | The efficiency should be taken into account as well. Indeed, why use more natural resources to get the same amount of electricity. |
| Incentive/penalty laws | 1 | They will have to follow the Kyoto protocol as everybody else. |
| Engineering availability | 1 | They have the power to pay overseas engineers to stay in these countries. |
| Constructors'/end users' influence | 0 | Lobbying from the constructors can be left out. |

**Table 55: Result of the simulation for Middle East countries with external-condition drivers**

Output

| Cycle | Nuclear Station | Coal Fired Station PF | Coal Fired Station CFB | Coal Fired Station IGCC | Natural Gas Fired Station OCGT | Natural Gas Fired Station CCGT | Oil Fired Station | Biomass Station | Fuel Cell Station | Geothermal Station | Hydro Station | Storage Station | Ocean Thermal Station | Solar Station | Tidal Station | Offshore Wave Station | Onshore Wave Station | Offshore Wind Station | Onshore Wind Station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | |

| Cycle | Uranium | Coal | Natural Gas | Oil | Farming Possibility | Geothermal Posibility | Rivers | Mountains | Oceans | Sun | Wind | Polluting Emissions | Waste | Environmental Effect | Demand/Offer Issue | Levelised Lifetime Cost | Efficiency | Incentive/Penalty Laws | Engineering Availability | Constructors/End Users Influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Startup | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 2 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 4 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 5 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 6 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 7 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 8 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 9 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 10 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 11 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 12 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |

This time the model reaches equilibrium with a mix of conventional and renewable energies. As we can observe (from Table 55), the oil-fired stations have been left out of the solution, probably as a result of polluting emissions. On the other hand, the combined cycle gas turbine stations have been added to the solution, as a result of their affordable cost and their efficiency. The interesting point is that now the renewable energies are part of the solution and not an alternative solution, as shown in the previous simulation. Even very sophisticated means of generating electricity such as the fuel cell stations and the ocean thermal stations, are part of the renewable energies proposed. Of course, more classical means or it should be mentioned more expected means - such as solar and wind stations - are also part of the solution.

The purpose of the research was to build, check and use a model that permits the definition of the most likely sustainable energy of the future under certain constraints, and not to multiply forever the simulations. Therefore, it is assumed that all the objectives have been fulfilled.

# 6. CONCLUSION

## 6.1. Summary

### *6.1.1. Introduction*

The choice a country has to make of a particular type of means of generating electricity, which will be sustainable for the near future, is quite wide; the number of factors influencing this choice is even wider. This report therefore draws on the pertinent literature to build a qualitative theoretical model in order to explore the effects of various external drivers on the choice of the sustainable energy of the future. This chapter reviews the main findings and provides suggestions for future research in the same field.

### *6.1.2. Model formulation*

Overview:

As mentioned above, the qualitative theoretical model that helped to explore different scenarios had to integrate all the different means of generating electricity - the renewable ones and the non-renewable ones. This model, presented in Figure 16 below, is the conceptualisation of all the trends found in the literature regarding the generation of electricity in accordance with the external drivers found. This model does not pretend to represent every single external driver but does give a fair representation of most of him or her or at least the most important among them.

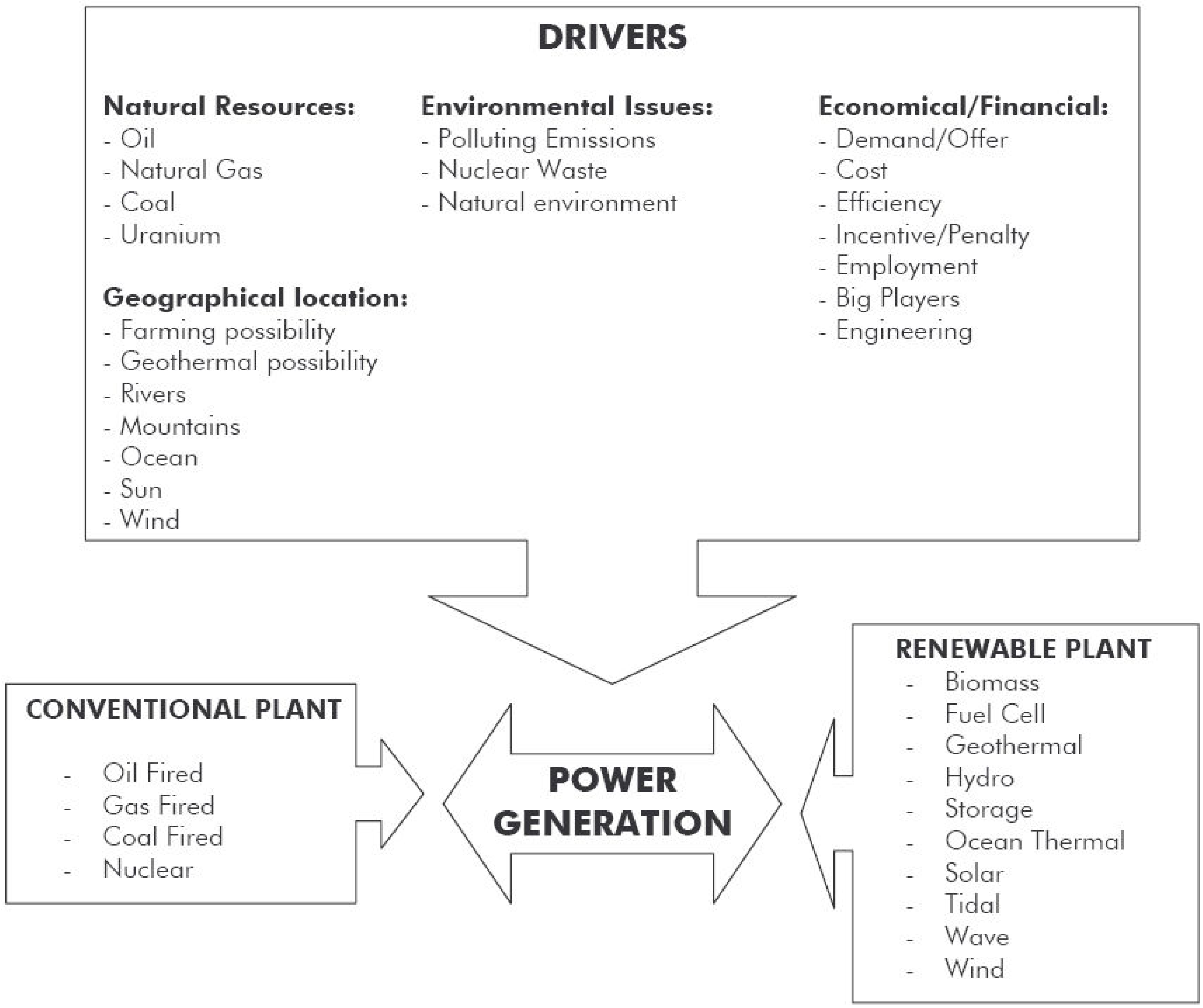



**Figure 16: Model overview**

Power Generation:

Energy sources are usually split into two major groups, even though this classification is not always without problems. Indeed, some overlapping could be seen between the renewable and the non-renewable energies. Therefore, in order to avoid this confusion we can split these two groups into conventional plants/stations and renewable plants/stations.

Conventional Plants:

Nowadays, the majority of the electricity is produced worldwide by these means. These conventional plants need to burn natural resources in order to produce the torque needed to activate large turbines or to produce steam from boiling water, which will rotate large steam turbines. Finally, the turbines rotate generators that produce electricity (Kirchgessner, 1997; Gueorguiev & Spielberg, 2000).

Renewable Plants:

They are plants, which use, directly or indirectly, resources, which can be replenished easily such as the sun, wind, water, hydrogen and so forth. The most developed and the most used throughout the world are the plants using water from rivers (dams) and oceans (tidal). Indeed, hydroelectricity power (Myers, Baird & Choate, 1970) was one of the first means of generating electricity, even before the conventional plants were built. The more recent renewable energies, which are being intensely developed nowadays, are the ones using the Sun (Tiwari, Padhyay & Rai, 1994), the wind on and offshore (Neuhoff & De Vries, 2004), and the waves on and offshore (Thorpe, 1998). Other renewable energies are developed in countries where it is possible to use them as base load; for instance geothermal (Huttrer, 2000) in Iceland or biomass (Couch, 1993; Hall & Rosillo-Calle, 1998) in the Ukraine. Finally, the ones which have to be further developed in order to reduce their running and manufacturing costs are the fuel cell (European Fuel Cell and Hydrogen Projects, 2004) and the ocean thermal (Gauthier, 2000).

Drivers:

The drivers are the influencing factors or constructs which can influence the choice of a specific means of generating electricity. These drivers can be split into two different kinds/types. The first kind is directly linked to the means of generating electricity - for instance for the conventional plants by burning natural resources and for the renewable plants by their geographical location. The second kind is directly linked to the effects that the generating means have on external factors or vice versa.

Natural resources:

Whereas other sources of energy are capable of being depleted, renewable energy will never run out. Currently, fossil fuels represent almost 90% of the total energy supply; with oil at 40%, coal at 26%, and natural gas at 21% (Executive Summaries of World Energy Conference Commission Report, 2003).

The difference between resources and reserves is essential to an interpretation of natural resources, particularly for coal and uranium. The commonly held distinction is that a resource is what exists in the earth of a particular commodity, whereas a reserve is that portion of the resource that can be economically mined (coal) (Westman, Haycocks & Karnis, 1999), or used (uranium) (The Uranium Institute, forthcoming).

Geographical locations:

The geographical location of the conventional power stations is almost irrelevant, apart from the need for a reliable transport structure for providing the station with the needed natural resource. For all the renewable energy sources, however, geographical location is of primary importance. For using geothermal energy, for example, the country must be situated where the hot rocks are at a depth where they can be reached (Huttrer, 2000). If hydro energy is to be generated, the country must have at least rivers and, even better, mountains for the building of dams (Egre, Gagnon & Milewki, 1999).

Environmental issues:

These drivers are associated with the damages that the considered electricity-generating means can create. The polluting emissions produced by the fossil-fuel-fired stations are the most important challenge to the protection of the environment.

These stations generate carbon dioxide and other greenhouse gases (Hansen, Ruedy, Glascoe & Sato, 1999), which lead to the phenomena of acid rain (Gerhad, Harrison & Hanson, 2001) and global warming (Karoly, 2003).

Nuclear waste (Hill & Gunton, 2001) needs to be handled with care, but with new facilities for re-treating these waste, the problem is lessening. Environmental issues are also associated with renewable energy sources as well: the hydro can be unfriendly to the natural environment, upstream and downstream (Egre, Gagnon & Milewki, 1999); biomass can force the farmers to rely extensively on fertilisers that can be dangerous for our rivers (Couch, 1993); and wind farms (Neuhoff, 2004) and wave walls (Thorpe, 1998) can be unbearably noisy.

Economical/financial factors:

These factors often come into play in developing countries, where the match between the demand and the supply of electricity can have a big impact. If the demand soars, the supply has to increase at an even faster rate. In such situations, the response is the use of more conventional sources of energy with all their drawbacks.

The levelised lifetime cost approach (Morgan, Granger & Tierney, 2002), captures in the price of a kWh for a specific electricity-generating means all the costs involved: the duration of the construction phase of a unit; the power output of the unit built; the lifetime of the unit built; the financing of the project; the maintenance costs; and the generating costs and others.

Energy efficiency is another driver in the economic/financial category, and refers to using less energy to accomplish the same task. Efficient use of energy throughout an entire country results in less money spent on energy and an energy-efficient economy can grow without using more energy and produces less pollution (Blumstein, Goldman & Barbose, 2003).

Incentive and penalty laws are the policy mechanisms to support the use of the younger renewable energy sources. The incentives include direct financial incentives and the boosting of public acceptance. Penalties include indirect penalties on the polluting energy sources (Borenstein & Bushnell, 2000).

The second last driver to be referred to here is the availability in the considered country of a particular energy source. Most renewable energy installations or even nuclear power stations need much more engineering than coal or natural gas-fired power plants, for their functioning and their maintenance. Unfortunately, the required highly skilled people cannot always be provided locally.

Finally, the most subjective of the drivers in this category is the role played by the constructors of new plants and the producers of electricity. If these two players prefer investing in a particular type of solution rather than another one, this preference might become the solution chosen whether it is the optimal one or not.

<u>Encoding:</u>

The frameworks representing the major components of the qualitative model and the links between the constituent elements are encoded using Fuzzy Cognitive Mapping, which has been found to be useful in modelling complex and ill-structured domain problems such as the interactions occurring in the determination of the sustainable energy of the future.

### *6.1.3. Exploring the Model*

<u>Test scenarios:</u>

In order to explore the behaviour of the qualitative model and, thus, the predicted effect of the various driver options, a range of test scenarios was selected. France, South Africa and Germany were chosen as an appropriate set of countries against which to test the model. After checking the accuracy of the model, defined scenarios have been tested in order to evaluate the main trends regarding the sustainable energy of the future. From these scenarios, the simulations gave interesting solutions, which can be taken as propositions.

Propositions:

An examination of the results generated by the model under the selected test scenarios suggests the following propositions:

1- No drivers are present in this proposition. The model does not reach equilibrium. The solution suggests that for conventional plants, only the use of coal- and oil-fired stations. For renewable plants the use of none of the generating methods listed or all of them, which is not really relevant at this point in time.

2- All the natural resources are available in this proposition. The model does not reach equilibrium. With regards to the nature of the inputs to the model, only the recommendations regarding the conventional plants can be seen as relevant. The only two generating means kept in the solution are the two more simple ones: the open cycle gas turbine and the oil-fired stations.

3- All the geographical locations are present in this proposition. The model does not reach equilibrium. With regards to the nature of the inputs of the model, only the recommendations regarding the renewable plants can be seen as relevant. Amazingly, enough, not all the generating means are kept in the solution. Indeed, fuel cell and wave stations, which are the newest methods, are not part of the solution.

4- All the external-condition drivers are present in this proposition. The model does not reach equilibrium. There is no real selectivity of the model with only the presence of the external-condition drivers as all the generating means (conventional and renewable) are present in the solution, except the open cycle gas turbine and the oil-fired stations, which are the two easiest solutions for producing electricity.

5- All the natural resources are available and all the geographical locations are present in this proposition: The solution is the juxtaposition of the two solutions from propositions 2 and 3.

6- All the natural resources are available and all the external-condition drivers are present in this proposition. The model does not reach equilibrium. With regards to the nature of the inputs to the model, only the recommendations regarding the conventional plants can be seen as relevant. The solution includes the two most sustainable generating means, i.e. nuclear and combined cycle gas turbine stations.

7- All the geographical locations and all the external-condition drivers are present in this proposition. The model does not reach equilibrium. With regards to the nature of the inputs to the model, only the recommendations regarding the renewable plants can be seen as relevant. With the presence of all the external-condition drivers this time the solution includes all the renewable energy means.

8- All the drivers are present in this proposition. The model does not reach equilibrium. This test scenario is the simulation of the world energy generation environment and the result of this proposition, which represents the solution of the sustainable energy of the future and includes only the nuclear and the CCGT stations for the conventional plants and all the means for renewable plants.

9- Farming countries. In this proposition all, the drivers concerning the farming countries are present. The model reaches equilibrium. For the conventional plants, the use of coal- (all the methods) and oil-fired stations is suggested, and for the renewable plants biomass, hydro, storage, solar, and onshore wind stations.

10- Farming countries plus oil available. In this proposition, the same drivers as for proposition 9 are present plus the driver regarding the availability of oil. No changes in the solution occur from the proposition 9.

11- Farming countries plus coal available. In this proposition, the same drivers as for proposition 9 are present plus the driver regarding the availability of coal. The model reaches equilibrium. For the conventional plants only the use of coal-fired stations (all the methods) is suggested, and for the renewable plants, the same as for proposition 9.

12- Farming countries plus gas available. In this proposition, the same drivers as for proposition 9 are present plus the driver regarding the availability of gas. The model reaches equilibrium. For the conventional plants the use of natural-gas- (both methods) and oil-fired stations is suggested, and for the renewable plants, the same as for proposition 9.

13- Farming countries plus enriched uranium available. In this proposition, the same drivers as for proposition 9 are present plus the driver regarding the availability of enriched uranium. The model reaches equilibrium. For the conventional plants the use of nuclear stations and oil-fired stations is suggested, and for the renewable plants biomass, hydro, storage, and solar stations.

14- Evolving farming countries:

a. Farming countries plus demand/supply issue. In this proposition, the same drivers as for proposition 9 are present plus the driver regarding the demand/supply issue. The model reaches equilibrium. For the conventional plants the use of coal- (all the methods), natural-gas- (only OCGT) and oil-fired stations is suggested, and for the renewable plants biomass, hydro, storage, and onshore wind stations.

b. Previous proposition plus constructors'/end users' influence. In this proposition, the same drivers as for proposition 14-a are present plus the driver regarding the constructors'/end users' influence. No changes in the solution occur from proposition 14-a.

c. Previous proposition plus polluting emissions issue. In this proposition, the same drivers as for proposition 14-b are present plus the driver regarding the polluting emissions issue. No changes in the solution occur from proposition 14-a.

d. Previous proposition plus levelised lifetime cost. In this proposition, the same drivers as for proposition 14-c are present plus the driver regarding the levelised lifetime cost. The model reaches equilibrium. For the conventional plants the use of nuclear stations and coal-fired stations (all the methods) is suggested, and for the renewable plants biomass, hydro, storage, offshore and onshore wind stations.

e. Previous proposition plus waste issue. In this proposition, the same drivers as for proposition 14-d are present plus the driver regarding the waste issue. The model reaches equilibrium. For the conventional plants the use of coal- (all the methods), natural-gas- (both methods) and oil-fired stations is suggested, and for the renewable plants the same as for proposition 14-e.

15- Eastern countries' first proposition. In this proposition, all the drivers concerning eastern countries, before the nuclear solution was implemented, are present. The model does not reach equilibrium. For the conventional energies, only one solution is suggested: the use of coal- (but only PF and CFB), natural-gas- (both methods) and oil-fired stations. For the renewable plants, the choice between two solutions is suggested: the first one is storage and onshore wind stations and the second one is biomass, geothermal, hydro, storage, tidal, onshore wave, offshore and onshore wind stations.

16- Eastern countries' second proposition. In this proposition, all the drivers concerning eastern countries, after the implementation of the nuclear solution, are present. The model reaches equilibrium. For the conventional plants, the use of nuclear stations, coal- (only PF), natural-gas- (only OCGT) and oil-fired stations is suggested, and for the renewable plants hydro, storage, offshore and onshore wind stations.

17- Eastern countries' first proposition plus engineering available. In this proposition, the same drivers as for proposition 15 are present plus the driver regarding the availability of engineering. The model does not reach equilibrium. For the conventional plants, only one solution is suggested: the use of nuclear stations and oil-fired stations. For the renewable plants, the choice between two solutions is suggested: the first one is hydro and storage stations and the second one is biomass, geothermal, hydro, storage, tidal, onshore wave and onshore wind stations.

18- Eastern countries' second proposition plus engineering available. In this proposition, the same drivers as for the proposition 16 are present, plus the driver regarding the availability of engineering. No changes in the solution occur from proposition 17.

19- Middle East countries. In this proposition, all the drivers concerning the Middle East countries are present. The model does not reach equilibrium. Only one realistic solution presents itself and this solution suggests the use of only the conventional plants in particular natural-gas- (only OCGT) and oil-fired stations.

20- Middle East countries plus external-condition drivers. In this proposition, the same drivers as for proposition 19 are present, plus all the external-condition drivers except the one regarding the constructors'/end users' influence. The model reaches equilibrium. For the conventional plants, only the use of the gas-fired stations (both methods) is suggested, and for the renewable plants fuel cell, ocean thermal, tidal, wave (both methods) and wind (both methods) stations.

## 6.2. Recommendations

Based on the concepts explored in this report, the following recommendations are presented:

- The elaborated qualitative model can be very useful for a country to determine the way forward with regards to its energy policy. The choice of the external drivers for consideration at the starting line is crucial for the simulation and, unfortunately, is not always straightforward to identify. Therefore, a lot of attention has to be paid at this stage of the simulation in order for an accurate result to be obtained.
- When the model reaches equilibrium during a simulation, the conclusions are easy to draw but when the model does not reach equilibrium and keeps switching between two solutions, some extra attention has to be paid in the analysis in order that the most suitable solution can be decided on.

## 6.3. Limitations

### *6.3.1. Simplification*

Any attempt to render complex interactions in a qualitative model must, by its very nature, be a simplification of the true interactions and this model is no exception. The results predicted by this model may, therefore, contain certain distortions and inaccuracies, but its true value lies in assisting any country to conceptualise the forces (drivers) at work by revealing the major themes (trends).

### 6.3.2. Verification

The concepts encapsulated in this model are drawn from a very diverse range of theories that have not been consolidated into one framework before. However, the model has been empirically validated through its application to diverse tests scenarios and the results of the simulations were quite accurate with the reality. The model does, therefore, provide a clear set of propositions that can be put to the test.

The contribution from the panel of specialists also permits the validation of the inputs of the model and, more importantly, its outcomes (Refer to the annexe).

### 6.3.3. Depth of research

Not all the components included in the model have been subjected to the same depth of research. This inconsistency in depth could receive some criticism and, perhaps, some further attention in other research. However, as already mentioned, the model had to be simplified in order to be easily usable. So, one of these simplifications has been made through lack of depth analyses in certain secondary topics.

### 6.3.4. Differentiation

As a modelling technique, FCM is not unduly sensitive to ill-defined entities. The better the entities are defined and understood, the better the model will perform. This trend has been observed in certain simulations, particularly with the renewable energies, where, sometimes, the model did not have much selectivity with regards to the different means. In order to improve selectivity, it is possible to better define the drivers or by adding new drivers.

### *6.3.5. Completeness*

Once again, in the interests of practicality, influencing factors have been left out of the model. In order to create a bigger and more fully inclusive model, these should be considered and included.

### *6.3.6. Strength of interactions*

For simplicity's sake, the weightings of edges in this model are all assumed to be one, zero, or minus one. However, it is certain that in reality, the different edges will have different weightings. Similarly, the model does not incorporate partial activation nodes; they are either on or off, which results in distinct state quantification. Allowing a continuous range of values would improve the accuracy of the model.

## 6.4. Future Research

### *6.4.1. Empirical validation*

A quantitative study could be conducted to verify and calibrate the predictions of the model. Such a study would involve the development of a suitable instrument to measure the different drivers in order to build a mathematical quantitative model.

### *6.4.2. Other drivers*

As mentioned before, in order to produce a more accurate, more selective and more reliable qualitative model, more external-condition drivers could be added.

### *6.4.3. Other means of generating electricity*

If this model is used, it will have to be updated with the addition of the new means of generating electricity available at the time.

## 6.5. Conclusion

Although the qualitative model presented in this report has been built from a layered framework based on findings from the literature and the real facts, it does not include all the possible divers. However, the model is quite accurate and gives relevant solutions to the question: "What will the sustainable energy of the future be?"

Even though the utopia of having a unique solution for the whole world would be the most satisfactory proposal, it is unfortunately not completely realistic. Indeed, every country has its own possibilities and constraints and a communal solution could only be easily proposed if the world started sharing its wealth and its ideal vision for a better future.

As seen in this report, the model includes only solutions known today or, at least, under development nowadays. For this reason, the model can provide solutions only for the near future. Indeed, for longer-term solutions we will have to wait for new generation of nuclear power stations, or new coal- and natural-gas-fired stations with no $CO_2$ emissions. Better yet, we might need to wait for new fuel cells with huge power outputs, using only $H_2$ and releasing only water. All of these solutions would be more efficient, safer, more reliable, and more environmentally oriented; in other words, the sustainable energies of the 22$^{nd}$ century.

# LIST OF REFERENCE


Adelman, M.A. (1995): The Genie out of the Bottle, *World Oil since 1970*, Cambridge, MIT Press.

Aguilar, J. (2003): A Survey about Fuzzy Cognitive Maps Papers, *International Journal of Computational*, 3(2), pp. 27-33.

Best-Waldhober, M., Daamen, D. & Faaij, A. (2006): *Informed Public Opinions on CO2-Capture and Storage Technologies,* presented at Leiden University, 7 September.

Bilgen, S. & Kaygusuz, K. (2004): Renewable Energy for a Clean and Sustainable Future, *Energy Sources,* 26, p. 1119.

Blumstein, C., Goldman, C. & Barbose, G. (2003): Who Should Administer Energy Efficiency Programs?, *Energy Sources*, 53, p. 597.

Borenstein, S. & Bushnell, J. B. (2000): *Electricity Restructuring: Deregulation or Re-regulation?*, revised version published in Regulation, 23(2), pp. 27-35.

Breeze, P. (1998): *Power Generation Technologies: Evaluating the Cost of Electricity*, first edition, London, Financial Times.

Campbell, C. J. (2002): *Global Petroleum Reserves-A View to the Future*, by Thomas S. Ahlbrandt and J.McCabe, United States Geological Survey, Published in Geotimes, November 2002.

Colson-Inam, S. (2003): Fuel Cells as a mean for Green power generation, *Boston University Emerging Technology and Best Industry Practice Seminar Series*, Boston, Boston University Publications.

Couch, G. R. (1993): Fuel Peat-World Resources and Utilisation, *IEA Coal Research*, London.

Darmstadter, J., Teitelbaum, P. D. & Polach, J. G. (1971): Energy in the World Economy, Statistical Review of Trends in Output, *Trade and Consumption since 1925,* London, McGraw-Hill Book Company.

Davidson, J. & Komp, R. J. (1983): The Solar Electric Home, *Ann Arbor,* Michigan: aatec publications.

Davies, A. M., Proctor, R. & O'Neil, M. (1991): Shallow Sea Hydrodynamic Models in Environmental Science, *Cray Channels*, 12 (4), pp. 15-17.

Der Spiegel (2002): German News Paper, Speech from Angela Merkel, Angela Merkel, addressing Energy Conference in Berlin, Friday 14th October 2005.

Dillon, W. (2002): Gas Methane Hydrates: A New Frontier, *U.S. Geological Survey,* 10 June, Tokyo, GSJ Symposium.

Ebel, R. (2002): Geopolitics of Energy into the 21st Century, *presented at Inter-Governmental Authority on Development (IGAD) Symposium,* 16 February, New York.

EdF (2005): Electricité de France, http://www.edf.fr/1i/Accueil.html, (accessed 29 October 2005).

EFCHP (2004): European Fuel Cell and Hydrogen Projects, Luxembourg, *Office for Official Publications of the European Communities.*

Egré, D., Gagnon, L. & Milewski, J.C. (1999): Are large hydro projects renewable and green? *International Journal on Hydropower & Dams*, First Issue, Lausane.

EIA (2005): Energy Information Administration, http://www.eia.doe.gov/emeu/cabs/norenv.htm, (accessed 15 September 2005).

EMP (2005): Electricity Markets and Policy web site: http://eetd.lbl.gov/EA/EMP/drlm-pubs.html, (accessed 12 October 2005).

EnCana Corporation (2005): *Operations: U.S. Rockies, Jonah*. Internet News Release, http://en.wikipedia.org/wiki/EnCana_Corporation, (accessed 29 October 2005).

FDR (1995): Forestry Department Report, Forests, fuels and the future, *Wood energy for sustainable development*. FAO Forestry Department Forestry Topics Report No. 5, Rome.

Friedman, T. (2006): Blog on a Sustainable Energy Future, *Green is the New Red White and Blue!*, http://www.watthead.blogspot.com/2006/01/thomas-friedman-on-sustainable-energy.html, (accessed 17 February 2006).

Gauthier et al. (2000): European Union Conference Ocean Thermal Energy Conversion (OTEC) and Deep Ocean Water Applications (DOWA), Market Opportunities for European Industry, *New and Renewable Technologies for Sustainable Development,* Madeira, Portugal.

GEJ (2006): Green Energy Jobs, http://www.greenenergyjobs.com, (accessed 16 February 2006).

Gerhard, L. C., Harrison, W. E. & Bernold, H. M. (2001): Geological Perspective on Global Climate Change. *AAPG Division of Environmental Geosciences*.

Gould, W., Zavoico, A., Collier, W. & Grimaldi, I. (2000): Energex 2000, *Proceedings of the eighth International Energy Forum*, Las Vegas, Nevada, July 23-28, 2000.

Gueorguiev, B. & Spiegelberg, R. (2000): Optimization on Nuclear Power Plant Performance and Service Life*, International Atomic Energy Agency*, New York, World Energy Council.

Hall, D. O. & Rosillo-Calle, F. (1998): World Energy Council, *Survey of Energy Resources*, Chapter 10: Biomass (other than Wood), pp. 227-241.

Hansen, J.R., Ruedy, R., Glascoe, J., Sato, M. (1999): GISS Analysis of Surface Temperature Change, *Journal of Geophysical Research,* 104, pp. 30997-31022.

Henry, P. (1992): Génie mécanique, Mécanique des fluides, *presse polytechniques et universitaires Romandes*, Lausane.

Hill, M. & Gunton, M. (2001): A Multi-Attribute Comparison of Indefinite Storage and Geological Disposal of Long-Lived Radioactive Wastes, *Rep.PTR-01-02*, Pangen, Baden, Switzerland.

Hinrichsen, D. & Robey, B. (2000): Population and Environment, *The Global Challenge,* first edition, Baltimore: published by John Hopkins School.

Huttrer, G. W. (2000): The status of world geothermal power generation, *Proceedings*, World Geothermal Congress, Japan, pp. 23-37.

Jacoby, A. (1999): New Fuel Cells Run Directly on Methane, *Chemical & Engineering News*, Washington.

Kardaras, D. & Mentazas, G. (1997): Using Fussy Cognitive Maps to Model and Analyse Business Performance Assessment, in J. Chen & Mital (eds.), *Advances in Industrial Engineering Applications and PracticeII*, pp. 63-68.

Karoly, D.J. (2003): Ozone and climate change, *Science* 302, pp. 236-237.

King, B. W. (2004): *The Ghost of Colonel Drake*, first edition, Whiskey & Gunpowder, Agora Publishing, Washington.

Kirchgessner, D. A., et al (1997): Estimate of Methane Emissions from the U.S. Natural Gas Industry, *Chemosphere*, 35(6), pp. 1365-1390.

Kosko, B. (1993): *Fuzzy Thinking: the New Science of Fuzzy Logic*, first edition, New York, Hyperion.

Kutscher, C. F. (2000): The Status and Future of Geothermal Electric Power, *presented at the American Solar Energy Society*, Madison Wisconsin.

Le Figaro (2002): French News Paper, Speech from Jacques Chirac, French President, addressing World Summit on Sustainable Development in Johannesburg, Wednesday 4th September 2002.

Lienau, P. J., Lund, J. W. & Culver, G. G. (1995): Geothermal Direct use in the United StatesUpdate: 1990-1994, *proceedings of the World Geothermal Congress*, International Geothermal Association, pp. 363-369.

Lippmann, M. J. (2002): Geothermal and the Electricity Market in Central America, *Geothermal Resources Council Transactions*, 26, pp. 399-404.

Lloyd, A. (1999): The Power Plant in Your Basement, *Scientific American*, p. 80.

Lund, J. W. & Freeston, D. H. (2000): World-wide direct uses of geothermal energy, *Proceedings World Geothermal Congress 2000*, Tokyo, pp. 1-22.

Marine Foresight Panel (1999): Energies from the Sea-Towards 2020, Publication 4064, 2, p. 99.

Mawerick (2006): a business magazine for proudly capitalist South Africans, *Uranium Rush*, South Africa, April, pp. 46-57.

Miao, Y., Liu, Z., Tao, X.H. & Shen, Z.Q. (2002): Simplification, Merging and Division of Fuzzy Cognitive Maps, *International Journal of Computational Intelligence and Applications*, 2(2), pp. 185-208.

Mikhailov, V. (2001): The Uranium Institute, Twenty-sixth Annual Symposium, 5-7 September, London.

Mitchell, J. (2005): Modeling the Effect of Incentive Schemes on Organisational Culture. *MBA report*. Johannesburg: University of the Witwatersrand.

Morgan, M., Tierney, G. & Tierney, S. F. (2002): Research Support for the Power Industry, *Issues in Science and Technology*, pp. 81-87.

Mohr, S.T. (1997): The Use and Interpretation of Fuzzy Cognitive Maps, Masters Dissertation, Rensselaer Polytechnic Institute, http://www.voicenet.com/~smorh/fcm_white.html, (accessed 20 October 2005).

Murtagh, P. J., Basu, B. & Broderick, B. (2005): Along wind response of wind turbine tower with blade coupling subjected to rotationally sampled wind loading, Engineering Structures, 27, pp. 1209-1219.

Myers, J. M., Baird, C. D. & Choate, R. E. (1990): Evaporation losses in sprinkler irrigation, Florida *Water Resources Research Center Publication No. 12,* University of Florida, Gainesville, 41, pp. 1970-1973.

NAICS (2002): North American Industry Classification System, http://www.bls.gov/lbs/naics.htm (accessed 4 October 2005).

NEEDP (2004): National Energy Education Development Project, http://www.eere.energy.gov/ (accessed 4 October 2005).

Neuhoff, K. (2004): Large Scale Deployment of Renewable for Electricity Generation, Paris.

Neuhoff, K. & De Vries, L. (2004): Insufficient Incentives for Investment in Electricity Generation, Utilities Policy, 12.

New York Times (2002): Speech from Thomas F. (Mack) McLarty, Former White House Advisor, Friday 1st February 2002.

Nixon, S. C., et al. (2000): Sustainable use of Europe's Water?: state, prospects and issues, Luxembourg, *Office for Official Publications of European Communities*, 2000, environmental assessment series, 7, p. 36.

OECD/NEA (1988): Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programmes, Report by an NEA Group of Experts, OECD/NEA, Paris, *Nuclear Waste Bulletin* (February 1988). Update on Waste Management Policies and Programmes, Issue No. 2, OECD/NEA, Paris.

OMB (1997): Office of Management and Budget, *North American Industry Classification System*, Washington, p. 105.

Plunkett Research (2005): *Plunkett's Oil & Natural Gas Exploration & Production Trends & Statistics 2005*, published by: Plunkett Research, Ltd, New York, 36 pages.

Quinn, T. J., Cleveland P. D. (2005): *Turning tar sands into oil*, first published, p. 22.

Rafferty, K. (1999): Scaling in Geothermal Heat Pump Systems, *Geo-Heat Centre*, Oregon Institute of Technology.

Rossouw, D. (2004): Modelling the impact of Regulatory Policy on the Banking System, *Unpublished MBA Dissertation*. Johannesburg: University of the Witwatersrand.

Scaroni, A. W.,Miller, B. G. and Pisupati, S. V. (2004): *Combustion Research at Penn State's Energy and Fuels Research Center*, Thirteenth Annual International Pittsburgh Coal Conference, University of Pittsburgh, September 3-7.

Schlegel, J. (2002): Energy Efficiency Options for the New England Demand Response Initiative, *Framing Paper No.4, Publication 5482*.

Solar Furnace (2006): http://www.wastech.com.hk/products/renewable-energy.htm, (accessed 9 June 2006).

Solar Tower (2006): http://www.wentworth.hsw.gov.au/solartower/, (accessed 9 June 2006).

Stylios, C. D. & Groumpos, P. P. (2000): Fuzzy Cognitive Maps in Modelling Supervisory Control Systems, *Journal of Intelligent Technology*, 3(1), pp. 43-47.

Thorpe, T. W. (1998): An Overview of Wave Energy Technologies, East Tennessee State University, Tennessee, 13-17 July, Proceedings of the Sixth Bi-Annual Energy Congress.

Tidal Energy (2006): http://www.bluenergy.com/tidal.html, (accessed 9 June 2006).

Tiwari, G. N., Ppadhyay, M. & Rai, A. N. (1994): A Comparison of Passive Cooling Techniques, *Building and Environment*, 29(1), p. 21.

Tyner, C. E., Gregory, K., Geyer, M. & Romero, M. (2001): Concentrating Solar Power in 2001, in *an IEA/Solar Paces Summary of Present Status and Future Prospects*.

UNFCCC (2005): United Nations Framework Convention on Climate Change, http://www.unfccc.int, for the legal texts of the UNFCCC and the Kyoto Protocol, (accessed 9 October 2005).

USDA (2005): United States Department of Agriculture, http://www.rurder.usda.org, (accessed 4 October 2005).

Vega, L. A. (1992): Ocean Thermal Energy Conversion *in Ocean Energy Recovery: The State of the Art*, New York, Popular Science.

Volk, T. A., Kiernan,B. D., Fillhart, R. C., Abrhamson, L. P. & White, E.H. (2001): Wood Biomass as an Alternative Farm Product: *2000 Annual Report*.

WEC-CCR (2003): Executive Summaries of World Energy Conference Commission Report*, World Energy Resources*, 1985-2020, IPC Science and Technology Press, Guildford, pp. 15-16 & pp. 46-47.

Westman, E. C., Haycocks, C. & Karnis, M. (1999): Accuracy analysis of GIS-based coal resource estimation, *Soc. Min. Eng.*, Preprint 4, pp. 84-99.

Winston, C. (2002): U.S. Industry Adjustment to Economic Deregulation, *Journal of Economic Perspectives,* 12(3).

# Annexe

## COMMENTS FROM A PANEL OF SPECIALISTS

As mentioned in Chapter 4. Section 4.1., the research, the different hypotheses, the different assumptions, and the different scenario starting lines conditions and of course the different scenario outcomes were scrutinised by a panel of specialists. The panel was as follows:

- Philippe Machard (French), ALSTOM Engineering Manager;
- Gert Coetzee (South African), Electrical Engineer ESKOM Consultant;
- Wikus Strydom (South African), Scheduling Manager for Primary and Secondary Supply Chain events related to bulk fuels at Engen Petroleum;
- Pr. Jean-Marie Génin (French), Professor of Material Science in the Laboratory of Physical Chemistry and Microbiology for the Environment, Henri Poincaré University (Nancy-France); and
- Hugh Kennedy (South African), Country Manager, ALSTOM Global Power Sales.

The questions put to Philippe and Gert were:

*Does the research study reflect what is observed in the real world in particular with regards to your field of expertise?*
*Does the research study take into account all the major points of the generating electricity field?*

The question put to Wikus and Jean-Marie was:

*Does the research study reflect what is observed in the real world in particular with regards to your field of expertise?*

The questions put to Hugh were:

*Does the research study reflect what is observed in the real world in particular with regards to your field of expertise?*
*Do the different studied scenarios give solutions, which can be part of the solution of the sustainable energy of the future?*

The responses given to these questions are set out in the section that follows under the names of the relevant member of the panel.

**Philippe Machard:**

It will be relevant to describe my background, experience and knowledge, briefly, in the Power Generating Sector.

I graduated from ENSAM (Ecole Nationale des Arts et Metiers) where I obtained my degree in Mechanical Engineering.

After having spent two years lecturing in Ivory Coast under National Service duties, I began my career with GEC Alsthom in 1989, specialising in turbo generator commissioning and analyses. Experience over five years was obtained in the commissioning of generators that were integrated in nuclear, coal fired, open gas and combined cycles as well as hydro power plants that were installed worldwide.

I then spent four years in South Africa dealing mainly with maintenance issues on Eskom's generator fleet.

Thereafter I joined the generator service engineering team back in Belfort France as the head of the engineering department.

On that basis, I think that Dr. Lilian Simon's work has developed a reasonable approach to study and to obtain a simplified and objective decision making model on a multi variable level to a complex problem, such a the choice of the sustainable energy of the future.

The model has been reasonably challenged with sensible results and drawbacks are clearly identified.

This FCM method was completely unknown to me, but as seen over the different simulations carried out this method can be a very powerful tool in the decision making process. As mentioned in the Dr. Lilian Simon's report conclusion, a weighted drivers approach could have been tried, as it is evident that some drivers may play a larger role than others in the decision-making process, even though the main driver could be the environmental aspect for the planet. This is not necessary always the key one for a country that is more focussed on economical aspects and short terms requirements. However, it is obvious that this new study could be very difficult to finalise and would be more of the format of a PhD report.

The growth requirements could lead to different levels of additional active power capability ranges to be obtained in a same period window based on country installed capacity, therefore this factor could influence the type of additional energy required.

Despite political and the public's opinion, it is not surprising to see that nuclear power could be considered as the sustainable energy of the future in the European western countries.

Concerning South Africa's present power situation and the present problems and shortages that Eskom is facing, the model will most definitely be of use. In my field of career, and in particular with regards to research and development, in the field of power generation, the study has shown to touch base on most different energy generating means for the near future.

There is a worldwide power crisis phenomenon being experienced now, especially in China, India and now Russia. This type of study is therefore exactly what is required in the power sector today. Indeed this model reflects on the present real world situation and can be used to supply advice for the different countries of the world, depending on their resources and external drivers, as depicted in the research report.

The work performed by Dr. Lilian Simon is well documented and takes into account all the industrial means to generate electricity and associated major points.

**Gert Coetzee:**

South Africa is blessed by its rich Coal and Uranium deposits and a resource that we could hopefully utilise more effectively in the future to the advantage of all South Africans.

The present shortage of generation in the short term, transmission restrictions o the Cape and the goal to support economic growth of 6% has perhaps been the main drivers that supported the decision to install open and combined cycle plants in the Cape Area. The challenge in the future would be to find innovative ways to sustain the usage of these assets.

Dr. Lilian Simon's work highlights some interesting points that are challenges for the Southern African Industry for the future. The work illustrates the usefulness and effectiveness of a modelling method that can be used for the decision-making, something to betaken note of.

The research work essentially addresses the salient points or drivers in the decision-making on generating plant. One issue that could become a significant driver is the need water at some power plants such as fossil stations. This might be seen as a secondary driver at this stage, but could become a significant driver in the future.

It would be interesting to also to study Southern Africa as a region as a whole including some of the rich water and also oil resources in the northern parts as this could shape the South African generation in the future as lower cost transmission over longer distances will become available.

One of the significant drivers that influenced the decision to install nuclear power in the Cape during the late 1970s was perhaps the transmission costs. Today transmission costs are much lower but still a significant factor in the Southern Africa Region due to the long distances involved. The present experience of the growth in the Western Cape and the lack of resources in the area will certainly influence the economic side, making sustainable methods more viable. In addition, the viability of renewable energy in the Northern part to supply the load points in South Africa is essentially burdened by the high transmission costs.

The work that Dr. Lilian Simon did is a good foundation to study both the local areas in South Africa and Southern Africa Region.

**Wikus Strydom:**

South Africa as a developing country finds itself in the fortunate situation of having an economy that is growing in leaps and bounds. This is a result of the post "apartheid" political era and an introduction to global markets. The tremendous growth phase is also accompanied by an increasing demand on logistical infrastructure. Harbours, rail infrastructure, public transport systems, road infrastructure as well as pipeline facilities are now found to be inadequate. Demand exceeds supply in most industries.

The picture depicted above is certainly not intended to be negative; however, it presents South Africans with a challenge of note for the future.

The efforts of Dr. Lilian Simon are noted as a valiant attempt to study and apply a model, which could bring decision makers closer to the true answers in our search for the sustainable energy of the future.

In a similar way as individual people are blessed with diverse talents, countries are blessed with various natural resources. South Africa is a country rich in mineral resources as correctly stated in this study. However, we do not have abundant resources of crude oil and are therefore reliant on others, at increasing costs.

The petroleum refining industry of South Africa is also presented with demand exceeding supply. The Moroane Commission was tasked during mid 2006 to investigate the fuel crisis experienced within the country during an introductory phase of “Cleaner Fuels”, which significantly reduced “heavy metal” components. It also interrupts business of commuters and transporters in various parts of the country as the need for higher-octane fuels establishes itself.

It is noted that mineral oil may very well play a role in the production of electricity in South Africa. The role could certainly not be a leading one.

As long as countries remove irreplaceable natural resources to meet increasing demand for electricity, we remove elements of our future. Renewable energy sources should therefore be diligently pursued and presented to responsible decision makers.

It is evident that coal and uranium will play a significant role in the future of local electricity production but we should not allow economic market forces to drive decision makers in the direction of non-renewable energy sources alone.

Dr Simon’s study reveals these mentioned needs very clearly in the analysis of the various drivers of the model. The study simplifies the relationship between variables to a point where decisions are more feasible.

One could only hope that the study and the subsequent use of the FCM Model would not simplify future decisions to the point where the "easy way out" is taken when economic forces are applied in an environment where a single major supplier dominates the market.

**Pr. Jean-Marie Génin:**

I am extremely pleased to give an advice on the study made by Dr. Lilian Simon about "Determinants of the sustainable energy of the future". I congratulate Lilian for his interest in sustainable development working for a company that makes great efforts towards that aim even though it is involved for coping with the increasing needs of energy. I want to stress that the work that Lilian did in our lab for his doctorate has nowadays a big impact in environmental engineering which was not guessed at the time he did it.

Before reading Lilian's approach using fuzzy cognitive mapping, I was not aware that such a tool existed for decision-making. The examples, which have been studied, seem very convincing and the interpretation of the findings look consistent with what we knew intuitively. Thus, the study gives some sound grounds to decisions taken in the past. In particular, I was impressed by the comparison between the countries I know the best: France, Germany and the US.

However, several points bothered me after reading Lilian's manuscript or at least caught my mind. It would have been interesting to show in an annex the complete development of the computation done on one specific example in order to try to understand how works the program. The reason is that I wonder whether the method does include already the answers within the assumptions, but as mentioned above this is because I did not know this method of investigation and I should read more about it.

In particular, as an example, if comparing two neighbouring countries such as France and Germany which have chosen obviously different policies whereas most factors are quite similar, I wonder whether the difference in the analysis is not merely psychological; the fear of nuclear power in Germany linked with no military incentive and some remaining coal mines (the price of coal extracted in Germany is 5 times that of the market) allows that country to try to develop wind farms. However, we are not at all sure that this solution will last and France is hoping that more electrical power from nuclear source will be sold more and more to Germany in the future. It would be interesting to make an overall simulation on Western Europe to see whether the diversity we observe now is beneficial or not. One can imagine that a nuclear program, which is rather well accepted in France and not in Germany, is as such more beneficial as two identical energy policies on both sides of the Rhine River.

Anyhow, his work is truly fascinating.

**Hugh Kennedy:**

First question: The research study has identified the main critical factors, which are taken into account when planning how to meet a country's energy needs going forward. It furthermore provides a useful analytical tool for demonstrating the interaction of different factors, which must be borne in mind when planning a strategy as well as a visual representation of this interaction.

This is very similar to the project identification and development process followed in the power generation industry to select preferred projects from the wide array of possibilities.

The output from the model of the different scenarios largely confirms what one would intuitively expect and is also confirmed in practice from the decisions of authorities, governments, utilities and others.

Second question: The identified scenarios provide a first indication of where countries should focus their attention when developing strategies for their electricity supply industry in the medium term.  The validity of past choices made, which have brought us to the current situation, are confirmed in that we see the relevance of current conventional technologies going forward.  At the same time, the scenarios show that alternative energy sources are becoming more relevant and that with a small change to some of the drivers the scenarios that are currently in a "limit cycle" quickly become stable.

Perhaps a sensitivity analysis of the output to the different drivers would assist in highlighting areas where policy choices are important to give clear signals to the market to drive development of the right technologies.

Comments: It would be interesting to test some of the scenarios developed with a more thorough financial analysis and taking into account the relative importance and subtleties of the influencing factors through assigning weighted scores rather than binary values.  It may then be possible to establish the sensitivity of the model to different factors and confirm its usefulness as an assessment tool suitable for decision-making.