Energy transitions and reducing carbon emissions
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Introduction

The way we use and produce energy is high on both the academic and the political agenda. Within academia, politics and society there seems to be an endless debate about energy and how we are to achieve an energy transition from ‘dirty’ finite fossil fuels to ‘cleaner’ renewable energy sources. Reading the literature about energy and climate change creates a sense of urgency in finding solutions about dealing with current and future problems arising out of our energy production (or rather energy extraction from our surroundings).¹ Although different theories are conflicting on the subject of how long we can still make use of the current resources of energy be it in terms of availability, affordability or looming environmental disaster, it is becoming a worldwide consensus that an energy transition is necessary if we want future generations to be able to maintain the same standard of living as we have in a stable climate.

The debate on energy transitions is being translated to political targets. The European Union for example, has set policy goals for energy as outlined in the three pillars of the Green Paper: security of supply, competitive energy markets and sustainability.² Additionally, the European Union agreed on a policy known as the “Triple 20” agreement which means a 20% reduction of energy consumption in 2020 compared to business as usual projections and a binding target of 20% renewable energy in total energy consumption.³ “Since the 1990s the EU has been engaged in an ambitious plan to become world leader in renewable energy, the EU’s renewable energy market has a turnover of 15 billion euro, employs some 300,000 people and is a major exporter. Renewable energy is now starting to compete on price with fossil fuels.”⁴ The European Commission adopted a long term commitment to achieve emission reductions of 80-95% in 2050.⁵

The influence of energy on society is immense. Vaclav Smil, an expert on the role of energy in history states that our energy infrastructure ought to be viewed as a principal factor in the analysis of human history equal to other history-shaping factors such as climatic

¹ We extract oil, gas and coal from our environment and convert them into heat, electricity and fuels. Therefore in my opinion energy extraction is a better term than energy production, since it better describes the process of using natural resources for our society.
changes and epidemics. Today, the global energy industry is worth about $5,000 billion annually with the book value of the global energy infrastructure being about $15,000 billion, making it by far the largest industry in every way.

There is not a clear definition of what constitutes an energy transition. Fouquet distinguishes minor, intermediate and major energy transitions. The shift from coal to gas in heating is considered a minor transition. The adoption of electricity or the switch from a horse to a car for transportation is considered an intermediate transition. Major energy transitions are the invention of fire, the development of agriculture and the Industrial Revolution. Grubler identifies two grand energy transition in modern history. The first is the steam engine powered by coal which was a radical technological end use innovation at that time. The second transition was the greatly increased diversification of both energy use technologies and energy supply sources (wood, coal, oil, gas, nuclear, hydro etc.) Meadowcroft has another distinction of energy transitions:

(a) a movement from a fossil fuel based (or dominated) energy system to a non-fossil fuel based (or dominated) energy system;
(b) a shift from a carbon emitting energy system to a carbon neutral (or low carbon) energy system;
(c) a transition from a non-renewable energy system to a renewable energy system.
(d) a movement from an insecure (vulnerable) energy system to a secure (robust) energy system.
(e) a change from centralized energy provision to a decentralized energy system.

From fossil to non-fossil could include nuclear energy. Nuclear energy could also be included in description b) since nuclear energy is not a carbon emitter. But since uranium is a finite resource it is by some not considered a renewable energy source (although the uranium reserves last a while longer than the fossil reserves). As we see above, Fouquet focuses on the scale of a transition with a historical view, Grubler on technology, Meadowcroft is describing options where we can go from here.

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We don’t know yet how the next transition will unfold. Because of the fear of climate change due to carbon emissions, the focus of many politicians, NGOs and concerned citizens is to realize a transition from fossil to non-fossil or from carbon emitting to non-carbon emitting. The difference between Meadowcroft’s option a) and b) is depending on whether you consider nuclear an option at all. Each new energy source humanity started using up until now share a common trait: they provided society access to larger quantities and higher qualities energy. The development of agriculture supplanted most hunter-gatherer populations because it focused the energy from the sun into food-bearing crops, which created much larger amounts of food per unit land area. The modern industrial era began in earnest in the late 19th century with the discovery of oil, and today is defined by the exploitation of the three major fossil fuels: oil, coal, and natural gas. Never before was society exposed to energy of such a high quality and in such large quantities. As will be explained in later chapters, the previous energy transitions were more or less spontaneous processes. The desired transition today to reduce carbon emission is in contrast, an energy transition that has to be realized through deliberate political action. In this thesis several referrals will be made to a spontaneous energy transition versus a policy-forced transition.

There is no agreement yet how to tackle the problem of reducing carbon emissions. Technically possible solutions are not always welcomed by society. On the other hand, solutions welcomed by society are not always technically feasible. Or desirable. Humanity sometimes seems to have a tendency to ignore complex problems for which it has no solution, or grossly simplify the problem. Only when our imagination is able to come up with a possible solution to something complex we start thinking about it. This also applies to the scientific community as Thomas Kuhn states in *The Structure of Scientific Revolutions*: “effective research scarcely begins before a scientific community thinks it has acquired firm answers.” Several academia argue that energy transitions in human society are very complex, hard to steer or influence, and the challenges we must deal with this century are enormous. Al Gore thinks it can be done in 10 years. Others think it can be done over a long period of time with considerable effort and some are outright pessimistic whether it can be done at all. Not surprisingly, the translation of all the knowledge on energy transitions to political decision making will be a pressure on the political system and those who must make

12 Idem.
the political decisions. The debate is fought over several dimensions. From a technical
dimension, there is uncertainty over which alternative technology provides the highest
potential. From an economic perspective there is uncertainty over when renewable
technologies can compete with fossil fuels. From a political perspective there is the question
on which policies to implement, what targets to set and how much money to allocate. The
study of energy transitions is in its essence an interdisciplinary issue comprising technology,
ecology, economics, sociology and politics. Energy is an integral part of society and too
complex to be understood by one discipline. There is no such thing as energology. Therefore,
analyzing energy transitions has to take an interdisciplinary approach.\textsuperscript{15} Where scientists from
several disciplines are studying an issue it is inevitable that scientists specialized in one field
have to make statements about fields in which they are not specialized. According to Kuhn
this may lead to many incompatible conclusions that may all be reached via legitimate
scientific methodology.\textsuperscript{16}

\textbf{What this thesis is not about}
Before giving the outline of this thesis I describe here what my thesis is \textit{not} about. There has
been a lot of discussion on the anthropogenic effect on the climate. I would like to mention
specifically that for the purpose of this thesis the need for an energy transition to avoid
climate change is considered a given. The public at large is concerned about the future of the
planet and the way we produce energy. Governments are aware of the concerns of their
constituents and most developed countries have policies and targets for changing their energy
infrastructure based on fossil fuels toward a more renewable system. This thesis will not be
about the debate on whether humanity has an influence on climate change, such as happened
with the IPCC in the weeks before the climate conference in Copenhagen. The focus will be
thus not on the ‘why’ but on the ‘how’ of an energy transition with the purpose of reducing
carbon emissions. There is strong scientific evidence that greenhouse gases, in theory, result
in more heat being trapped in the atmosphere and therefore can cause climate change. The
potential damage of climate change is enormous, be it in loss of crops, loss of land area, mass
immigration and the disruption of society. Thus, from both a security perspective and an
ethical perspective even a small chance of enormous damage should be enough to conclude
that energy transition is desirable. Besides climate change one should also think of the fact

that most developed countries are increasingly dependent on imports of fossil fuels from regions that are not always known for political stability. The prices of fossil fuels could rise significantly which will cost us a lot of money, let alone a potential destabilizing of the world economy. The risk of conflicts over access to fossil fuels becomes more imminent and let’s not forget fossil fuels will be depleted eventually.\textsuperscript{17}

This thesis is not focusing on the depletion issue. An argument for energy transitions other than reducing carbon emissions is the fact we could run out of fossil fuels. One of the reasons proponents of a forced energy transition such as Greenpeace and the European Renewable Energy Council (EREC) are opposing nuclear energy, is the fact that uranium is a finite resource.\textsuperscript{18} While this may be technically true, uranium reserves lasts for a few centuries even if the nuclear industry is expanded significantly.\textsuperscript{19} The latest estimates for natural gas are about 250 years.\textsuperscript{20} The fact that a specific resource is finite is no reason for not using that resource as long as it is available, even more when that resource is available for a few centuries. At the beginning of this chapter was specifically mentioned that the goal of an energy transition is reducing carbon emissions. Opposing an eventually finite resource that can reduce carbon emissions exactly because it is finite is an invalid argument, especially if that resource lasts longer than the average used time span of debating energy transitions to prevent climate change, which is about 20 to 50 years. In a very strict definition, most resources are finite eventually. The blades of wind turbines are made of oil-based plastics. Does that mean that wind turbines are not renewable? And the rare metals for the Toyota Prius batteries?

In a comparable thesis as this one with a focus on security of supply instead of carbon emissions, the depletion argument plays a different role if dependence on a finite resource is a threat to national security. But even then, in the context of security of supply, the focus will be more on supply and demand logistics and supply disruptions due to geopolitics than on

\textsuperscript{17} On the website of Thinktank Clingendael for example one can find many articles on energy security and the risk of conflict over energy sources; www.clingendael.nl
\textsuperscript{20} IEA, \textit{Are we entering a golden age of gas?} Paris 2011, p. 7
physical resource exhaustion.\textsuperscript{21} The climate change issue needs to be dealt with before 2050 while the depletion issue perhaps could just become urgent around that time. The emphasis is on the need to switch energy sources to prevent climate change long before we run out of fossil sources. It is important to keep this in mind while reading this thesis. If we would run out of carbon emitting fuels before reaching the threshold of climate change, the problem would solve itself and policy actions would be irrelevant.

In this thesis there will also be little focus on energy saving. I have several reasons for that. First of all, energy saving might make an energy transition easier because there is less energy that needs to be replaced with another source, but conservation is not a transition in itself and therefore not the main object of this thesis. Energy conservation could also prolong the use of that specific source that is used more efficiently or even increase consumption of that specific source. William Stanley Jevons in his classic \textit{The Coal Question} of 1865 noted that “It is wholly a confusion of ideas to suppose that the economical use of a fuel is equivalent to its diminished consumption”.\textsuperscript{22} Efficient use of an energy source could lead to increased use. Secondly, due to market forces and innovation society is already becoming more energy efficient. High oil prices will increase the demand in fuel efficient cars thus making society more energy efficient. Thirdly, if an energy transition can only happen with forced energy saving (perhaps through rigorous lifestyle changes), what will happen after the energy transition is completed in, let us say, 2050 and energy demand increases in the second half of this century? Do we have to re-open coal mines to meet demand?

\textbf{Outline}

The main question in this thesis is \textit{which energy source(s) deserve political support when the goal is reducing carbon emissions?} In chapter 1 a brief history of energy and energy transitions in our modern society will be laid out including an example of a previous attempt of a policy-forced energy transition. It is necessary to gain insight in the spontaneous processes behind energy transitions to know how we arrived where we are, and where we go if we do not intervene in the process. In chapter 2 an overview is given of several actors that call for a complete overhaul of our energy system, political actors calling for government intervention in the energy sector and some scientific proponents of a policy forced energy


transition including different opinions, perspectives in the current energy transition debate. Highly optimistic assumptions made by authors in the debate will be criticized in this chapter. In chapter 3 wind energy as a renewable energy source will be extensively analyzed. Wind energy is generally considered one of the more promising renewable technology at this moment and is therefore worth a close inspection. Chapter 4 will work towards a strategy how to approach the problem at hand from a pragmatic and problem-solving perspective. Some variables will be introduced that are mostly missing from the debate. Derived from this is explained which energy sources deserve political support. Uncertainty in forecasts and scenarios are included in the consideration. Chapter 3 and 4 are the most technical and economic. The reader will notice that the conclusions in the fourth chapter will differ significantly from what most of the renewable proponents argue in chapter 2. Chapter 5 is therefore devoted to provide some suggestions for further research on how to explain the public preferences in future energy sources using insights from social sciences.
1. Energy transition: a short history

In this chapter an outline will be given on energy transitions in recent history. As will be shown, spontaneous energy transitions seemed to have followed specific patterns. Specific variables are determining whether a source will be successful in a spontaneous process. A previous example of a policy-forced energy transition will be analyzed to view which strategies proved effective and which were not.

The rise of fossil fuels
As culture advanced during centuries or millennia, man increasingly used both more sources and amounts of energy. First hand tools, then domestication of plants and animals, then harnessing wind and water, later the coal powered steam engine, then fossil fuels up to nuclear energy. Especially the start of the Industrial Revolution and the increase in the use of coal and later oil was a milestone in energy history. Before the Industrial Revolution mankind relied mostly on wood, human and animal labour and small-scale wind- and watermills. Mankind was not using any depletable energy sources (wood can be a depletable source but is considered by the European Union as a renewable source\(^{23}\) on a large-scale and was therefore somewhat living in a sustainable society, although densely populated areas such as London experienced deforestation and rising prices of wood.

The substitution of wood for coal was a fundamental part of the Industrial Revolution. Coal had been known and used for three thousand years, however only marginally. Compared to wood, coal is dirty, it stinks, it requires different skills and techniques (such as mining) and it is toxic. But sixteenth-century London suffered from a problem familiar to urban conurbations in developing countries today: as the city grew, a larger and larger area around London became deforested, and as transportation distances increased, wood became more expensive. The poor had to switch to coal; the rich resisted at first.\(^{24}\) Coal was perceived in the beginning as a dirty smelly fuel and had a low social status. But it turned out that it was


easier and more efficient to fuel steam engines and trains with coal, and later also to produce electricity.

In the beginning of the coal industry, deepening coal mines penetrated the water table and flooded the mines. The water needed to be pumped away. Steam engines were developed first of all for pumping water out coal mines. Railroads were first widely used to transport coal out of the mines. Since steam engines burned coal, the new energy source was basically bootstrapping itself.\textsuperscript{25} Coal went to replace most of the market share of wood during the nineteenth century. In 1885 coal surpassed wood as the largest energy source in the U.S. and remained the largest worldwide energy source for about 70 years.\textsuperscript{26}

During the last decades of the nineteenth century oil was on the rise with Rockefeller’s Standard Oil in the U.S. and the Royal Dutch/Shell combination in the Netherlands and U.K. Oil was at first used as a cheaper substitute for whale oil in lighting.\textsuperscript{27} After the invention of the combustion engine and the diesel engine at the end of the nineteenth century oil became an important energy source for transportation.

Especially World War I and the preparation for war proved to be a major turning point in oil use. The British Royal Navy had converted their fleet just before the war to oil powered war ships because of the many advantages oil had over coal. The oil-powered ships were faster and had better maneuverability. Apart from that it was also quicker to reload the fuel tank. Less personnel was needed to fuel the engines so more men could be used on deck to do the fighting. Britain had large coal deposits in its own soil but no oil. Therefore the Royal Navy acquired a 51\% stake in the newly created Anglo-Persian Company that was producing oil in former Persia.\textsuperscript{28} This introduced a new dynamic to energy politics namely security of supply. Britain needed to control the oil flows out of Persia. This required exerting political influence in the Persian region and protecting the oil transports on the seas. Ironically the Royal Navy required a powerful fleet to secure oil flows from Persia to create a powerful fleet, as Churchill stated: “mastery itself was the price of the venture.”\textsuperscript{29}

World War I also saw the first oil-powered airplanes used in battle, oil powered trucks and motor vehicles to transport troops and material and the introduction of the tank. After the

\textsuperscript{25} Idem.
\textsuperscript{26} Bryce, R., \textit{Power hungry: the myths of green energy and the real fuels of the future}. 1\textsuperscript{st} ed. New York: Public Affairs, 2010, p. 47.
\textsuperscript{27} Yergin, D., \textit{The Prize: the epic quest for oil, money and power}. 1\textsuperscript{st} ed. New York: Simon & Schuster, 1992, p. 22.
\textsuperscript{28} Anglo-Persian is the predecessor of current BP.
\textsuperscript{29} Yergin, D., \textit{The Prize: the epic quest for oil, money and power}. 1\textsuperscript{st} ed. New York: Simon & Schuster, 1992, p. 156.
war it was said that “the Allied cause had floated to victory upon a wave of oil”. A French senator said that oil had been the blood of war and the blood of victory and now everybody wanted “more oil, ever more oil!”

After World War I the United States especially experienced a spectacular rise in automobiles going from 3.4 million registered cars in 1916 to 23.1 million by the end of the 1920s. The rise in registered cars continued to grow in the following decades with an increase of 60% in the first five years after World War II and with another 50% in the 1950s. A famous oil advertiser of the 1920s, praising the increased mobility that oil provided, talked about the “magic of gasoline” being the “juice of the fountain of eternal youth”.

It soon became impossible to imagine a world without oil. The same bootstrapping as mentioned before with coal happened later with the oil industry. The oil industry used a lot of oil to fuel its oil tankers and to provide the intense heat for petroleum refining. An estimated 5% to 10% of all oil produced between 1900 to 1920 was burned in refineries.

Many energy sources played an important role in the exploitation and development of the next energy source. For example, all early coal-mining was powered entirely by animate energy: men digging and transporting coal. The steam era was thus made possible by human muscles. In turn, the steam engine made possible the manufacturing of the products for the infrastructures for electricity, and steam engine-powered tankers were necessary to transport the first oil. This pattern might also apply to the coming energy transition. For example, the steel towers of wind mills are produced using fossil fuels and the plastic blades are synthesized from hydrocarbons.

Energy transitions don’t happen overnight

Energy use in modern history started with traditional sources such as wood and human and animal muscles. From there it went to coal in the second half of the nineteenth century, to oil in the first half of the twentieth century, combined with gas and nuclear energy in the second half of the twentieth century and perhaps to renewable energy sources in the twenty-first century. It is not however a universally equal trajectory throughout global history. There are

30 Idem, p. 183.
31 Ibidem, p.211.
34 Idem, p. 61.
many national and regional particularities driving and shaping such complex changes.\textsuperscript{35} Looking back, the transition from wood to fossil fuels cannot be regarded as a single event. It was a complex development involving many sectors switching to fossil fuels at different times and geographical locations between 1500 and 1920.\textsuperscript{36}

The substitution rate from one energy source to another is slow.\textsuperscript{37} In the beginning of the nineteenth century, wood and crop residues had a market share of about 95%. By the 1920s biomass contained about a third of all energy used worldwide. This sank to 25% in 1950 and in 1990 the share was about 10%\textsuperscript{38} (which is still more than all the electricity generated by nuclear fission). Around 1970 oil became the largest energy source.\textsuperscript{39} Important to note is that when fossil fuels replaced biomass as the most important energy source in the nineteenth century, it did not substitute the use of biomass in absolute terms, merely in relative terms e.g. market share. The total use of biomass has been steadily increasing from 1800 until now.\textsuperscript{40} There are large differences, however, in the market share of biomass. In the poorest African countries biomass constitutes 80% of all energy in comparison to only a few percent in affluent Western nations.

Coal’s peak in market share was around 1920 with a share of 70% of total global energy supply. Coal’s market share dropped to about 29% in the 1980s. Very important to note is that although the market share dropped, its absolute production rose six-fold from 700Mt of coal and 70Mt of lignite in 1900 to 3.6Gt coal and 700Mt lignite in the year 2000.\textsuperscript{41} Oil’s peak in market share was 43% around 1968 with a world production of about 55 million barrels per day. In 2008 oil’s market share was 35% with a world production of about 80 million barrels per day. That means a decline in market share from 43% to 35%, but an increase in production of 25 million barrels per day. So we see that when biomass, coal and oil were relatively replaced by other energy sources, their total production increased over time.

Analyzing the transition from one energy source to another cannot be done without defining when the transition began and when it was completed. Smil tried by choosing 5%

\textsuperscript{38} Smil, V., ‘Energy at crossroads: global perspectives and uncertainties’. 1\textsuperscript{st} ed. Cambridge; The MIT Press, 2003, p. 4.
\textsuperscript{40} Smil, V., ‘Energy at crossroads: global perspectives and uncertainties’. 1\textsuperscript{st} ed. Cambridge; The MIT Press, 2003, p. 7.
market share as a starting point, meaning that when a new energy source reaches 5% market share of total global energy supply, the energy transition towards that new source is underway.\textsuperscript{42} Smil used historical data from the Energy Information Agency from the U.S. Department of Energy and came to the conclusion that the transition from biomass to coal got started around 1840. About 50 years later the market share of biomass dropped below 50% and it was taken over by fossil fuels, mostly coal at that time.\textsuperscript{43} Coal became the dominant energy source in the nineteenth century but around 85% of total energy supply still came from biomass in the nineteenth century.\textsuperscript{44} Oil became the dominant energy source in the twentieth century but coal has provided the most energy in the last century. Overall during the twentieth century coal provided 37% of all energy, oil 27%, natural gas 15%, and still 20% by biomass.

Smil discovered a pattern in the rise of coal, oil and gas. He took the 5% share as a benchmark and counted the years when its market share reached the milestones of 10%, 15%, 20% and 25%. It took coal 15 years to reach 10%, 25 years to reach 15%, 30 years to reach 20% and 35 years to reach 25%. The patterns of both oil and gas turn out to be remarkably similar.\textsuperscript{45} Three sequences are no statistical proof to base future predictions on. Smil argues that the coincidence cannot be dismissed however. It might be that this pattern has nothing to do with energy but more with the accompanying technologies required to develop, produce, distribute and market new energy sources.

An explanation for the slow transition from wood to coal might be that human civilization lacked the abilities for large-scale commercial diffusion. Scientific knowledge was inadequate, there was a lack of high-performance materials (steel in particular), manufacturing processes were inadequate, required infrastructure took a long time to complete and large-scale competitive markets were absent.\textsuperscript{46} There is a limit on the speed at which technological change is diffused and implemented by society. In most cases, the material components of technology change much faster and more easily than society can adapt to the new developments.\textsuperscript{47} Decades are required for the diffusion and adoption of significant innovations. Even longer time spans are needed to develop infrastructures. Some parts of the energy infrastructure such as grids and power plants have a lifecycle of several decades.

\textsuperscript{42} Idem, p. 63.
\textsuperscript{43} Ibidem, p. 63
\textsuperscript{44} Smil, V., ‘Energy transitions: history, requirements, prospects’ (Santa Barbara 2010). 63
\textsuperscript{45} Idem, p. 65.
\textsuperscript{46} Ibidem, p. 106.
decades. The diffusion process is a process of learning, and humans learn slowly.\textsuperscript{48} Natural gas was brought to the market faster than coal (in terms of volume) This suggests an acceleration in the speed of energy transitions (in absolute supply) due to technological advancement. Later we will see that according to the above mentioned starting point for a transition, the transition to renewable energy sources such as wind and solar hasn’t begun yet.

Until now, it appears that an energy transition did not mean a physical substitution from one energy source by another, but merely that a new energy source was added to the full spectrum of energy sources used for wide range of purposes with a wide range of technologies. That is also the main reason why the transition from fossil to renewable will probably be considerably harder than from coal to oil for example. World energy use has increased seventy-fold since the onset of the fossil fuel era.\textsuperscript{49} So we have to replace about seventy times more energy than the amount of wood replaced by coal in the nineteenth century.

**What triggered previous transitions?**
As described above we have an understanding of how new energy sources gained in importance. In contrast to the how, it is not agreed upon exactly why the previous transitions happened. One explanation of why people switched from wood to coal is that forest were overexploited but this was more a local issue than a global issue. Forests now shed in form of biomass something like 100 TW when global energy demand is about 10 TW. No exhaustion in sight.\textsuperscript{50} However this calculation is only relevant if there is a global market for biomass, which was not the case in the nineteenth century where the transition from wood to coal in the nineteenth century was at least partially driven by a local shortage of wood as explained in the


example of wood prices in London above.\textsuperscript{51} The transitions both from coal to oil and from oil to gas were not driven by real shortages.\textsuperscript{52}

History would have taken a different course if traditional societies invented no other use for coal than as a substitute for wood in open fireplaces, or if the nineteenth-century adoption of oil ended with the production of kerosene for lightning.\textsuperscript{53} Decisive factors in energy use were often the quest for innovation and the commitment to deploying and perfecting new techniques. It was rather that innovation led to new technologies and applications such as oil-powered transport and later cooking on gas that required new and higher quality fuels such as gasoline in automobiles.

Jesse H. Ausubel, Director of the Program for the Human Environment of the Rockefeller University, states that the behavior and preferences of the end user drives the energy mix. Energy sources must conform to what the end user will accept. The constraints on what end users will accept become more stringent as spatial density of consumption rises i.e. the energy consumed per square meter (think of Manhattan with skyscrapers versus a rural village).\textsuperscript{54} The energy source that can most efficiently deliver to the end user while meeting the ever more constraints will eventually win.

Economies of scale are the determining factors in this process in the long run. And economies of scale match best with technologies that grow smaller, since it gives that technology a strong competitive advantage.\textsuperscript{55} In the twentieth century, power plants have gone from 10 kW to 1 million kW scaling up 100,000 times in power, yet the space it occupies remains about the same.\textsuperscript{56} This is the same process as computers getting more powerful while getting smaller. It is even suggested that the computer of the Apollo 11 rocket has the same computing power as an average smartphone today.\textsuperscript{57} This might suggest that the future of windmills is not very bright since wind turbines are getting ever more bigger and require ever more space if wind energy production is to be increased.

\textsuperscript{55} Idem.
\textsuperscript{56} Ibidem
\textsuperscript{57} http://downloadsquad.switched.com/2009/07/20/how-powerful-was-the-apollo-11-computer/ on July 10, 2011.
While Ausubel believes that more demands (in terms of quality) by end users drive the system, Rifkin notes that an energy transition is not always welcomed by society. The switch in energy regimes is often regarded as onerous and unwelcome. That is because human beings always seek out the easiest available energy resource to exploit first. The resistance to switch from wood to coal in England is a good example of this. Forests, as long as they are available, are a far more accessible energy source to harness, transform and use than coal. And also our hunter-gatherer ancestors had no urge to switch to an agricultural society as long as there was an abundant supply of edible plants and animals.\textsuperscript{58}

Bryce writes about the ‘Four Imperatives’ that determine the energy business: power density, energy density, financial cost and scale. Power density referring to the amount of power that can be harnessed in a given unit of volume, area or mass. Power density is measured by Watts per square meter. Wind energy needs more space to produce the same amount of power and has thus a Watts/m ratio. Energy density refers to the amount of energy contained in a given unit of volume, area or mass. For example joules per kilogram.\textsuperscript{59} The higher the power density and energy density of a certain energy source the more efficient it is in its usage. Oil for example has a higher energy density than coal and coal again has a higher energy density than wood. This means that for the same amount of energy produced you need less coal than wood. Scale refers to the amount of energy a source can deliver and financial costs refers of course to the price of that energy source.

Krupp believes the most important motive force of societal action by far is short-term Schumpeter dynamics.\textsuperscript{60} Schumpeter dynamics is a combination of the economy, politics, and technology driven by profits and economic growth. In turn, these are powered by technological innovation. Schumpeter dynamics, based on the Austrian economist Schumpeter, has become the central issue of industrialized and industrializing countries alike because it assures resonance between economic profits, maintenance of political power, support for technology and short-term wealth of the people.\textsuperscript{61} Schumpeter dynamics has a tendency to exploit all available physical and biological (including human) resources for its profits and growth drive.\textsuperscript{62} Schumpeter dynamics is fueled by energy. It constitutes an

\textsuperscript{58} Rifkin, R. \textit{The hydrogen economy: the creation of the worldwide energy web and the redistribution of power on earth}. 1\textsuperscript{st} ed. New York: Tarcher, 2003, p. 69.
\textsuperscript{60} Krupp, H., \textit{Energy politics and Schumpeter dynamics}, Tokio: Springer, 1992, p. 3.
\textsuperscript{61} Idem, p. 4.
\textsuperscript{62} Ibidem, p. 4.
immense inertia to prevent major changes unless it can perform its principal functions: to make profit and to grow through technological innovation.

Smil also describes a somewhat Schumpeterian energy transition process. New energy sources have profound impact on economic growth and innovation cycles. In the beginning, substantial investment is needed to develop new energy sources. The introduction of new energy sources elicits fundamental technical innovations. Schumpeter, who studied business cycles, noticed a correlation between new energy sources on the one hand and accelerated investment on the other. The first well-documented economic upswing (1787-1814) coincided with the spreading of coal and the introduction of stationary steam engines. The second expansion wave from 1843 to 1869 was driven by the diffusion of mobile steam engines (railroads and steamships). The third upswing from 1898 to 1924 was decisively influenced by the rise of commercial electricity generation and the replacement of mechanical drive by electric motors in factory production. The post-war economic upswing was associated with the global substitution of coal by hydrocarbons, the worldwide rise of electricity generation (including nuclear fission), mass car ownership, and extensive energy subsidies in agriculture. This expansion was abruptly halted in 1973 by the first oil crisis.

A life less carbonary
A trend that may be worth discussing is that we are already on a path towards decarbonization for the last 170 years, that is, using less carbon per dollar of output or kilowatt. Natural gas (CH₄) has a carbon/hydrogen ratio of 1:4. Coal has a carbon/hydrogen ratio of 2:1 and wood even a 10:1 ratio. The carbon/hydrogen ratio of 1:4 makes natural gas the cleanest of the fossil fuels. When we went from biomass to coal in the nineteenth century and from coal to oil and gas in the twentieth century it is estimated that carbon emission per unit of primary energy consumed globally has fallen about 0.3 % for the past 140 years. This doesn’t mean that total carbon emissions did not increase over the years. Energy use increased faster than the decarbonization speed of 0.3%.

According to Ausubel, the explanation of this decarbonization trend lies in the evolution of the energy system which is driven by an increasing spatial density of energy

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64 Ibidem, p. 240.
consumption. Coal had a good start in the nineteenth century but at the turn of the twentieth century the advantages of fluids over solids became evident. The transitions both from coal to oil and from oil to gas were rather based on new applications and new technologies that preferred higher quality energy sources over other sources. Cooking and heating with coal in high-rise apartments in major cities is not an option anymore. Electricity and/or natural gas (which is relatively clean compared to coal) are required in urban areas.\(^6\) Coal-powered cars also never had much appeal.\(^6\) Oil has a higher energy density than coal and is much easier to handle. It seems to be a transition from solid energy forms such as traditional biomass and coal to liquids, flexible, convenient and also more cleaner forms.\(^7\) Industrial processes and technologies are becoming more complex and require energy forms that are easier to handle, easier to store and more flexibly available. This process will probably lead to a preference of clean high energy-density sources such as gas and perhaps ultimately hydrogen, in a business-as-usual scenario.\(^7\)

Summarizing, the spontaneous energy transition process is influenced by the following factors:

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<tr>
<th>Drivers of energy transition:</th>
<th>Marchetti: economies of scale</th>
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<tr>
<td>Smil: innovation</td>
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<td>Ausubel: increased demands by end user</td>
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<td>Krupp: Schumpeter dynamics of technology, economy and politics driven by profits and economic growth</td>
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<td>Bryce: price, economies of scale</td>
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<th>Direction of the energy system:</th>
<th>Smil: higher quality fuels</th>
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<td>Bryce: increased energy density and power density</td>
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<th>Speed of the change in the energy system:</th>
<th>Smil: slow process</th>
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<td>Grubler: slow limited by speed of diffusion of technology and implementation by society</td>
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<td>Rhodes: slow, limited by speed of societal</td>
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\(^6\) Idem.


\(^7\) Idem, p. 253.
Energy transition: a previous example

Arguing for an energy transition is not a new 21st century concept. As shown in the previous sections the dynamics of energy history is a narrative of a search for ever better energy sources based on technology, economics and end consumer preferences. But nowadays we don’t want an energy transition because of technical or economic advantages but out of sociopolitical preferences to avoid climate change. To derive some lessons from history, an example will be given of another moment in history when there was widespread sociopolitical consensus for the need of an energy transition away from fossil fuels (mainly oil at that time).

Since WWII people had taken an abundant supply of cheap energy resources for granted, especially oil. They created an energy consuming society. In the 1960s concerns began to arise about the effect of human conduct on the environment. An often mentioned example of this is *Silent Spring* (1962) by Rachel Carson. Carson’s main thesis is that the use of pesticides is killing birds and even humans. Another influential book is *The Population Bomb* (1968) by Paul R. Ehrlich. Ehrlich argued in the book that humanity would experience mass starvations due to high population growth and lagging food production. In 1972 students from MIT published the *Limits to Growth* report for the Club of Rome. This report used computer models to show that humanity was facing resource depletion, environmental damage due to pollution. In the same year the United Nations organized the Stockholm Conference, the first major UN conference on environmental issues where issues such as environmental degradation and resource depletion were debated. One year after, in 1973, Arab nations cut of supply to Israel’s allies in response to the Yom Kippur war. There were oil shortages everywhere in the U.S and in some Western European countries. Prices increased fourfold and there were long waiting lines at gas stations and shortages of heating oil in the winter. The oil crisis had nothing to do with physical depletion but it did further
inspire the creation of many environmentally concerned NGOs and green political parties have been founded in OECD countries since the 1970s.  

Energy use, the means by which industrial society had been created and had persevered, was by the end of the 1970s widely recognized as the problem itself. President Jimmy Carter declared in 1979 the second oil crisis the “moral equivalent of war”. Prior to the crisis we took cheap supplies for granted, we also took the smooth and consistent running of technological society as a given. People were optimistic about the ability of technology to make everyone’s life better and richer. But the reality was not so simple. Suddenly, technology was uncertain, potentially dangerous and costly. It was not clear whether technology was the problem or the solution.

The starting point of the energy transition debate in the 1970s was, instead of climate change, more focused on security of supply and the risk of supply disruptions in the short term. On the long run (+10 years) there was the fear of declining oil production. As a response to the Arab oil embargo of 1973 Japan focused strongly on energy conservation and became one of the world’s most efficient users of energy. France concluded “it is not reasonable for such a country as ours to be hanging on the Arab’s decisions. We must pursue a policy of diversification of energy and try to decrease the need for oil.” What followed was a rapid development of nuclear power, a return to coal and the promotion of energy conservation. Not only in France was nuclear power and coal advancing. In 1975 President Ford of the U.S. proposed a ten-year plan to build 200 nuclear plants, develop 250 major coal mines and build 150 major coal-fired plants.

Vice-President Nelson Rockefeller proposed an even bigger transition with a $100 billion program to subsidize synthetic fuels and other high-cost energy projects that commercial markets would not support. The program came to a halt exactly because of the high costs of these projects. Research into coal-derived synthetic fuel as a substitute for oil had already before been heavily funded during WWII with the Synthetic Fuel Act of 1944. By the late 1940s some small pilot projects had been completed and the construction of larger prototypes were considered. Then came a period of increasing availability of cheap oil mainly

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82 Idem, p. 660.
from the Middle East. For that reason the synthetic fuels projects were also cancelled then. Exactly this start-stop process was repeated in the 1970s and 1980s.\(^3\)

John D. Sterman from MIT stated in 1981 that ‘the nation has been thrust into a major energy transition’ because of peak U.S. oil and gas production in the early 1970s and both the oil crises.\(^4\) Large scale solar, geothermal and fusion were at the end of the 1970s already hailed as future saviors by the end of the 1970s by the National Research Council.\(^5\)

According to Sterman ‘never again will the nation enjoy energy as abundant and inexpensive’. Looking back we see that Sterman’s concern for energy shortages was unnecessary and that the promised solar, geothermal and fusion technologies did not take off. Oil prices dropped in the mid 1980s, large offshore oil deposits were discovered in the Gulf of Mexico and the North Sea, new shale-gas extraction technology was developed causing also declining gas prices. OPEC lost its grip on the market and even on its own members. OPEC production quotas designed to prop up prices were frequently violated by its own members who feared of losing even more markets to non-OPEC producers and other fuels such as happened in electricity generation. Almost abruptly as the call for energy transitions began it was gone.

The Reagan administration appeared to regard the whole decade of the 1970s as an insignificant interlude. Government programs to develop alternative energy sources were cut or eliminated.\(^6\) Basically, there have been no dramatic changes in the energy infrastructure the last few decades. In fact, there have been no major changes in the energy infrastructure for the last 70 years. Our current energy system is still based on technologies and processes invented during the 1880s (steam turbine, internal combustion engine, thermal and hydro electricity generation) or during the 1930s (gas turbines, nuclear fission). The late nineteenth century inventors of the internal combustion engines, electric motors and steam turbo generators would most certainly recognize the unchanged fundamentals of today’s machines.\(^7\) Even photovoltaic, the technology for electricity out of solar radiation is a


nineteenth century invention. Although the technological fundamentals stayed the same, efficiency improved significantly. The average conversion efficiency of coal to electricity was less than 4% in 1900, in 1975 the efficiency for the first time reached over 40%.

The only significant change to the oil crises of the 1970s was that most of the electricity generation that was done with oil had switched to nuclear and coal by the early 1980s. Fortunately for the oil importing countries there are several technologies for generating electricity. Nuclear electricity generation fitted well in the constellation of centralized electricity generation in large power plants with wide distribution network. Under these particular circumstances, the introduction of nuclear power was almost reduced to the problem of fuel substitution (oil for uranium, which is widely available) in particular as external costs such as safety were carried by the government as was most of the research and development costs. The transport sector seemed not very susceptible for substituting oil with an alternative and continued to run on oil as it still does today.

Governments looking for alternatives considered what energy sources to focus on next. Natural gas could be a nice alternative but in the 1970s production was declining causing even a gas shortage in the winter of 1976-77. The U.S. National Research Council considered coal and nuclear the only readily available large-scale domestic energy source that could reverse the decline in domestic production of oil and gas. A balanced combination of coal- and nuclear-generated electricity is preferable, on environmental and economic grounds they claimed. Now we know that especially gas production has increased greatly due to new technologies in extracting unconventional gas and worldwide for the coming decades there is abundant supply of natural gas.

The example of the 1970s is in some ways different than the situation is today. In the 1970s it was mostly a security of supply issue while today it is focused on a combination of concerns including climate change and security of supply. Nevertheless we learn from this example that the price of energy is a determining factor in energy transitions. As long as energy prices are high there is a momentum for change, a window of opportunity that can be used to switch to other energy sources as France successfully did with nuclear electricity generation. France was probably successful in switching to nuclear because it fitted in the

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88 Idem, p. 30.
technological infrastructure with large scale centralized electricity generation with wide distribution networks. No solution had been found for oil powered transport such as for example synthetic oil derived from coal and as soon as the oil price dropped all momentum was gone.

The problem of predicting
The doomsday predictions of books like *Silent Spring*, *The Population Bomb* and *Limits to Growth* had a strong influence on policy making and public perception. The uncertainty of technological evolution and ecological trends continues to be an embarrassment to people trying to forecast technological change today.93 Scientists in the 1920s predicted that nuclear fission may become a source of energy but nobody knew how and when.94 Let alone being able in the 1920s to predict the institutional and political requirements needed for peaceful exploitation of nuclear energy. Smil has a very outspoken opinion when it comes to forecasting energy developments as he states that ‘energy forecasts are not worth the cheapest paper on which they get printed’95. The same applies to technical predictions, price projections or demand aggregates. In the 1970s for example, the expert consensus was that by the century’s end the world would be shaped by inexpensive nuclear energy.96

Typical forecasts offer little else but more or less linear extensions of business as usual.97 Forecasters of energy affairs have missed every important shift of the past two generations. They didn’t foresee the rise of OPEC during the 1960s, they were stunned by the price quintupling in 1973 and the quadrupling in 1979, they didn’t predict OPEC’s loss of power around 1985. They failed to anticipate the reduction in electricity demand growth in the Western world after the 1970s and seriously overestimated the promise of nuclear energy.98

Recent years have seen many claims about the coming peak-oil, the imminent peak of global output after which follows a gradual decline. These claims could miss their mark by decades. In any case, it is a lot more difficult to foresee what resource will become dominant

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97 Idem, p. 178.
98 Ibidem, p. 176.
after the hydrocarbon era. As Grubler states ‘uncertainty is a fact of life and technology is no exception’. The unpredictability of energy forecasts is not a new insight. Sterman stated in 1981 that energy predictions are both not useful and nearly impossible.

Smil’s advice is then to base energy policy not on quantitative models but ‘to do what really matters’ e.g. a more normative approach. Increased computing power won’t make us predict better. Including ever more variables won’t make us predict better because many of the really determining variables are beyond educated guessing. Sterman states jokingly that if you’re going to jump from an airplane “you’re better off with a parachute that an altimeter. My supervisor, Jaap de Wilde (University of Groningen) states that although scenarios are worthless in predicting the future, they are necessary in today’s world for designing policies. The value of scenarios according to De Wilde lies thus not in describing the future world but influencing the present.

**Conclusion**

Several trends can be derived from history. In the nineteenth century humanity started a switch from basically a renewable energy system to a fossil energy system. Coal gradually replaced wood. Later oil became the dominant energy source. Energy transitions are complex and protracted affairs spanning decades to unfold. Several drivers behind energy transitions have been identified. Ausubel states that the end user preference for higher quality fuels leads to the preference of oil over coal, gas over oil and perhaps someday in the future of hydrogen over gas. Bryce compiles four criteria that determine energy use: energy density, power density, scale and financial costs. Krupp identifies Schumpeter Dynamics as another important aspect of energy use. Krupp states that humanity has a tendency to use all available resources for growth and profit. Due to the desire for higher quality fuels we are already on a decarbonization trend of about 0.3% annually. But since energy consumption grows faster than the decarbonization trend, total carbon emissions remain rising.

Energy transitions up until now did not constitute a real substitution of a source but the addition of a new source therefore replacing the previous source in market share rather than

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103 Conversation with Dr. J. de Wilde on April 15, 2011.
absolute production. Replacing fossil fuels with renewable energy in absolute terms, which is the general preference in the energy transition debate in our time, will thus be considerably harder than previous transitions. On the other hand we have more technological and distributional capabilities to bring a new source on the market suggesting that when there is a viable energy source we should be able to distribute it quickly. There are several factors that influence energy transitions such as energy density, power density, end user preferences and financial costs.

As a consequence of the energy crises of the 1970s many initiatives were proposed for an energy transition away from oil. This succeeded in electricity generation, where oil was replaced with nuclear energy and coal. For transportation there was no alternative for oil. An important lesson of the 1970s is thus that while energy prices are high there is a window of opportunity for changes in energy use as long as no drastic changes are required in the energy infrastructure. But as soon as prices go down the momentum is gone and trends return to business as usual. The political response was focused mostly on restoring and securing access to energy supplies. Although environmental concerns and fear of resource depletion started already before the oil crises. As soon as security of supply was restored, the political momentum for the what the doomsday authors warned for was gone. Future predictions and assumptions are highly uncertain and of limited use other than influencing current policies and behavior. As will be shown in the next chapters, many authors nonetheless use assumptions about future developments.
2. How is the debate on energy transition currently being conducted?

This chapter will focus on the current energy transition debate. The debate on energy transitions is conducted over several dimensions: politics, economy and technology. There is not a universally agreed definition of an energy transition. Definitions, or rather descriptions, of an energy transition differ in the scale of the transition away from fossil fuels ranging from a 100% renewable system in a few decades to just using renewables as addition to fossil fuels to keep up with anticipated demand for energy. They differ in the speed with which the transition should or could unfold, ranging from just one decade to a century. They differ in the desired use of energy sources such as nuclear energy.

For the purpose of analyzing the debate, it is useful to use a general definition of an energy transition as a transition away from fossil fuels since fossil fuels are contributing to climate change and will be depleted somewhere in the future. Nuclear energy plays an ambiguous role in the current debate. It contributes to a reduction of carbon emissions but it is not by all parties involved considered a viable or even an ethical option. The European Union considers nuclear not a renewable energy, their description of renewable energy sources is: wind, solar, aerothermal, geothermal, hydrothermal, and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogas.\(^{104}\)

Despite the lesson from history that energy transitions are complex and slow processes there are several organizations that call for a complete energy transition to a 100% renewable energy system. They are supported by some in the academic world and political organizations have incorporated the need for a policy-forced energy transition. In this chapter an overview is given on the opinions that exist and their assumptions/premises are analyzed. The opinions described in this chapter are mostly from people or organizations in favor of a policy forced energy transition with some critical side notes added to the debate. The critical viewpoints on a policy forced energy transition will be in depth described in the chapters that follow.

**Environmental organizations**

Environmental organizations have a strong desire for a forced and fast energy transition. They combine this with a strong held conviction that everything is possible when we make ‘the

right choices’ and implement the ‘right policies’. Greenpeace states that the energy market is distorted. The current political system favors conventional energy sources over renewables for example by ignoring the external (environmental) costs of fossil fuels. Greenpeace states that political action is needed to overcome these distortions and create a level playing field for renewable energies to compete. Without political support, renewable energy remains at a disadvantage, marginalized by distortions in the world’s electricity markets created by decades of massive financial and political support to conventional technologies, according to Greenpeace.105

The main strategies of Greenpeace to encourage a shift to renewable energy are:106

- Respecting natural limits by phasing out fossil fuels because the atmosphere cannot absorb all carbon now contained in fossil fuels.
- Equality and fairness in the distribution because one third of the world has no access to electricity while industrialized nations use more than their fair share.
- Implement clean, renewable solutions and decentralize energy systems. There is no energy shortage but we must use existing technologies to harness energy more effectively and efficiently.
- Decouple economic growth from fossil fuel use e.g. lowering the energy/GDP ratio.
- Phase out dirty, unsustainable energy e.g. coal and nuclear.

If these strategies are implemented, Greenpeace believes that we can reduce carbon emissions by 50 – 80% in 2050 by reducing the lifetime of coal-fired power plant from 40 to about 20 years and high investments in energy efficiency and the development, even without the use of nuclear energy.107 Renewable energy targets need to be legally binding in order to be effective. Targets must be set in accordance with local potential and be complemented by policies that develop skills and manufacturing bases to deliver the agreed quantity of renewable energy.108 Greenpeace sees no role for nuclear energy in the future. Although nuclear energy is relatively cheap over the long run, has no carbon emissions and uranium is plentiful available for the coming decades or even centuries, these arguments are overruled by Greenpeace. They are worried about the risks and environmental damages caused by uranium.

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106 Ibidem, p. 36.
107 Ibidem, p. 10.
mining, transport and processing, the danger of nuclear weapons proliferation, the unsolved problem of nuclear waste and the potential hazard of an accident.\textsuperscript{109}

Greenpeace states that in the beginning their plans cost more than an energy system based on conventional energy sources but - if implemented now - costs begin to decline after 2020 due to declining production costs of renewable technologies. “Renewable energy 24/7 is technically and economically available, it just needs the right policy and commercial investment to get things moving.”\textsuperscript{110} Greenpeace assumes that a carbon emissions trading system will be established across all world regions in the longer term.\textsuperscript{111}

According to Greenpeace, a sustainable energy transition is also desirable because it creates millions of jobs and economic development.\textsuperscript{112} A research conducted in the UK and Scotland concluded however that for every job created in renewable energy, 3.7 jobs are lost elsewhere in the economy, at least partly due to higher electricity prices.\textsuperscript{113} The report further warns the UK government not to promote renewable energy for economic opportunities but should focus the debate on whether the loss of jobs and higher energy prices is worth the candle in terms of climate change. Comparable conclusions were drawn in Denmark where the economic value of wind industry employees is below that of average industry employees. At the long run it is likely that subsidizing the wind industry will only reallocate employment from other sectors to the wind industry, while creating no additional jobs through the subsidies\textsuperscript{114}

Greenpeace developed a model to calculate who ought to carry the costs of the energy transition based on the country’s contribution to climate change and the ability to pay. This should take inequity in economic wealth between countries into account. Individuals with an income lower than $7.500 are exempted from their climate responsibility. Based on these ratios, according to Greenpeace the U.S. is responsible for 36.3% of the costs of global climate policy in 2010.\textsuperscript{115}

Greenpeace is using strong normative language to increase their moral imperative to call for an energy transition. For example saying that energy needs to be distributed more

\textsuperscript{109} Idem, p. 9.
\textsuperscript{110} Ibidem, p. 40.
\textsuperscript{111} Greenpeace & EREC, Energy (r)evolution: a sustainable world energy outlook, 3\textsuperscript{rd} edition. Amsterdam, 2010, p. 52.
\textsuperscript{112} Idem, p. 7.
\textsuperscript{114} Centre for political studies, Wind energy: the case of Denmark. Copenhagen, 2009, p. 33.
\textsuperscript{115} Greenpeace & EREC, Energy (r)evolution: a sustainable world energy outlook, 3\textsuperscript{rd} edition. Amsterdam, 2010, p. 25.
equally between rich and poor and that the rich use more than their fair share. What constitutes a fair share of energy distribution and how this correlates with an energy transition to renewable energy is unclear. How the U.S. will be held responsible for 36% of the costs of global climate policy is also unclear and the likelihood of this ever happening seems highly improbable, especially after the failure of the Copenhagen summit in 2009 to establish a global climate regime.

A transition to renewable is also possible according to Greenpeace because some renewable technologies such as wind energy are already competitive. The wind energy industry is competitive because it has continued its growth in times of the financial crisis and economic downturn. This is a result of the inherent attractiveness of renewable technology. Greenpeace expects the economics of renewables to improve as they develop technically, as the price of fossil fuels continues to rise and as their saving of carbon emissions is given a monetary value. Greenpeaces’ definition of ‘competitive’ is thus ‘being able to attract investments in times of constrained financial markets’. Although during the financial crisis investments in wind energy were made, that does not make it a competitive industry delivering its product at competitive prices. The price of wind-generated electricity is far from being competitive compared to the price of electricity generated by coal, gas or nuclear. It is yet unclear if, when and how much fossil fuel prices will rise. It is still unclear if a global carbon tax regime will be implemented. The economics of renewable technologies will probably improve, but again, it is unclear to what extent.

The European Climate Foundation (ECF) assumes that the capital costs for wind energy will improve with 5% per doubling of cumulative capacity. They also assume that the capital costs for coal annually improves 1%. Wind has been growing with 27% due to favorable policies, meaning about a doubling of wind capacity in 3 years. The capital costs for wind are thus assumed to improve 5% in three years time if previously favorable policies are maintained in the future, while at the same time the capital costs of coal is also improving, at about 3% in the same period. The capital costs for both wind and coal are thus improving. Wind might improve slightly faster than coal but it is unsure if this happens and to what extent wind will enjoy favorable policies in the years to come, adding to the uncertainty of developments of the capital costs of wind and coal.

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116 Idem, p. 6.
Greenpeace is not the only environmental organization with a strong call for an energy transition combined with a strong conviction of the feasibility of such transition. The WWF published a report together with the Dutch energy consulting firm Ecofys and the Office for Metropolitan Architecture where they present their vision of a 100% renewable energy system in 2050.\textsuperscript{119} WWF agrees with Greenpeace that a major transition to renewable energy by 2050 can be achieved by the technologies already at hand. Projected investment costs over these years for the transition will not rise over 2% of global GDP (which doesn’t sound much but is about $1500 billion according to the World Bank\textsuperscript{120}) while not radically changing the way we live.\textsuperscript{121} Twenty pages later in the same report however, WWF states that: “changes in lifestyle have a critical role to play”, “will mean rethinking our current financial system” and “local, national and regional governance will need to be strengthened to secure an equitable energy future. We need international cooperation on an unprecedented level.”\textsuperscript{122} Furthermore according to the report, meat consumption must be halved in OECD countries by 2050. Mobility should change, walking or cycling on short distances, taking the train instead of flying, more home-working to reduce commuting. And apparently they think “people may also choose to travel more slowly, or have their holidays closer to home.”\textsuperscript{123} How these assumptions are justified by WWF remain unclear however but it seems quite a radical change in the way we live if we choose to travel slower than technically possible or voluntarily choose to limit our mobility or our food consumption. International cooperation on an unprecedented level is equally difficult to achieve. Strong political action is complex. Energy and climate policy inevitably involve a range of issues such as energy security, energy prices, economic growth, industrial competitiveness, technological innovation and the environment. Furthermore, at the international level there is a wide divergence in the position of the main players from developed to developing countries, from energy importing to exporting countries, and between the developed countries about the nature of a future international climate regime.\textsuperscript{124}

\textsuperscript{119} WWF, Ecofys, OMA, \textit{The energy report: 100% renewable in 2050}. Gland, 2011.
\textsuperscript{121} WWF, Ecofys, OMA, \textit{The energy report: 100% renewable in 2050}. Gland, 2011, p.23.
\textsuperscript{122} Idem, p. 43.
\textsuperscript{123} Ibidem, p. 67.
All over the world, people tend to spend about 13-15% of their income on mobility. Taxing mobility and energy allows a government temporarily to seize a portion of that travel money, but in the long run people will always maximize their mobility and access to energy. Mobility has been increasing about 2% annually the last century and is expected to increase in the future. And perhaps even more when major airlines like Air France-KLM begin with experimenting for commercial space flights in the near future. Changing human behavior in energy consumption is clouded with uncertainty. The Gulf of Mexico oil spill in 2010 for example, hardened public attitude to energy producers but changed little in the energy consumption habits by consumers.

In a more academic and theoretic formulation about humanity’s hunger for energy made by the late mathematician and chemist Alfred Lotka: “In every instance considered, natural selection will so operate as to increase the total mass of the organic system, to increase the rate of circulation of matter through the system, and to increase the total energy flux through the system, so long as there is a unutilized residue of matter and available energy. Natural selection tends to make the energy flux through the system a maximum, so far as compatible with the constraints to which the system is subject.” Perhaps this can be interpreted as such that all species, including humans, have a tendency to use as much energy as possible considering their tools and material constraints. Rationing our energy use and leaving energy potential untapped might be against our ‘nature’.

Anthropologists argue that the degree of civilization can be measured by the ability to utilize energy for human advancement or needs. Howard Odum, a pioneer in the field of natural energy systems states that one must bear in mind that it is energy, not human inspiration, that ultimately sets limits on human progress. The 20th century philosopher and mathematician Bertrand Russell noted that “every living thing is a sort of imperialist, seeking to transfer as much as possible of its environment into itself and its seed” The more evolved

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130 Idem, p. 40.
131 Ibidem, p. 48.
and complex a social organism, the more energy is required to sustain it and the more entropy is produced in the process of maintaining it.\textsuperscript{132}

This thesis will refrain from making further bold statements on human nature but would like to pose the question for the reader if we are able to constrain ourselves in the use of energy without a physical constraint on the availability of energy (i.e. letting the coal, oil and gas rest in the ground). And if radically constraining ourselves in energy use would be a wise thing to do considering the correlation between energy use and our degree of civilization and human advancement. As Bradley states it: “Inferior, high cost energy production penalizes lower-income consumers the most and poses a quandary for an estimated 1.6 billion who need modern forms of energy”.\textsuperscript{133}

Just as Greenpeace, the WWF reports also excludes nuclear energy as an option as they state that there is no solution for nuclear waste, the risk of nuclear weapons proliferation and that nuclear energy needs highly sophisticated and trained staff which is not feasible in poor countries.\textsuperscript{134} Recognizing the spatial requirements of new energy sources and energy infrastructure they state that “all large-scale energy infrastructure developments must satisfy independent, in-depth, social and environmental impact assessments.”\textsuperscript{135} WWF expects the financial requirement to be about $3.5 trillion a year (which is double the previously mentioned 2% of global GDP) and that financial savings will outweigh the costs due to less fuel requirements by 2040.\textsuperscript{136}

\textbf{Green politics}

One of the more visible participants (in mainstream media) in the energy transition debate in this century, Al Gore, proposes the most ambitious plan to convert the entire U.S. energy system to renewable energy in just ten years. This is made possible through a 5-step plan with fiscal incentives for renewable energy, investing in a new smart electric power grid, provide assistance to automakers to develop electric cars, increase energy efficiency in buildings and finally place taxation or a cap on carbon emissions.\textsuperscript{137} To convince us that it is possible he

\begin{flushleft}
\textsuperscript{132} Rifkin, R. \textit{The hydrogen economy: the creation of the worldwide energy web and the redistribution of power on earth}. 1\textsuperscript{st} ed. New York: Tarcher, 2003, p. 51.
\textsuperscript{134} WWF, Ecofys, OMA, \textit{The energy report: 100% renewable in 2050}. Gland, 2011, p. 18.
\textsuperscript{135} Idem, p. 63.
\textsuperscript{136} Ibidem, p. 73.
\textsuperscript{137} ‘5 steps of Al Gore’s green plan for renewable energy’. Retrieved from \url{http://www.bionomicfuel.com/5-steps-of-al-gores-green-plan-for-renewable-energy/} accessed on April 26, 2011.
\end{flushleft}
makes a comparison with the Apollo project to put a man on the moon, that was by many considered impossible at the time Kennedy announced the plan.\textsuperscript{138}

Groenlinks, the Dutch green-left party in parliament is strongly in favor of a forced transition to renewable energy. In their election program of 2010 they want to push renewable energy through fiscal incentives.\textsuperscript{139} Anti-pollution law should forbid the construction of new coal-powered plants, the existing nuclear plant in The Netherlands has to close and there will be no new nuclear power plants. Energy companies are obliged to a yearly increase in the supply of renewable energy and the governments pushes for expansion of wind power. The so-called renaissance of nuclear energy is not generally not welcomed in European countries. In Germany and The Netherlands for example, we’ve recently seen demonstrations against the use of nuclear energy.\textsuperscript{140} Most OECD countries have green political parties. Green politics generally aims for the creation of an ecologically sustainable society, rooted in environmentalism.\textsuperscript{141}

**Lobby/branch organizations**

Renewable branch organizations largely share the opinions with environmental NGOs and green political parties. The umbrella renewable organization for renewable energy in Europe, the European Renewable Energy Council (EREC) published a report in which they outline a pathway to a 100% renewable supply system by 2050. In its foreword, the President of the EREC states that 100% renewable is possible and that it clearly is not a matter of technology but rather making the right choices.\textsuperscript{142} The EREC talks about the need for *reinventing* the EU’s energy system.\textsuperscript{143} The EREC is optimistic stating that renewable energy is currently on its way to becoming the mainstream source of Europe’s energy system in the conceivable future.\textsuperscript{144} The installed wind capacity “met 3.7% of EU electricity demand, provided power equivalent to the needs of 30 million average European households."\textsuperscript{145}

\textsuperscript{141} A useful overview of green political organizations including the main issues can be found on http://en.wikipedia.org/wiki/Outline_of_green_politics.
\textsuperscript{143} Ibidem, p. 6.
\textsuperscript{144} Ibidem, p. 12.
The transition from fossil to renewable energy however seems in the first decade of the twenty-first century to be even slower than from wood to coal in the nineteenth century. In global terms, the renewable energy sources, excluding hydro and biomass, contributed about 0.45% of total supply in 1990 and 0.75% in 2008. This means an annual growth rate of 2.85%. Coal mining from 1850 to 1870 grew about 5% per year. Oil production from 1880 to 1900 grew more than 8% and natural gas production between 1920 and 1940 grew about 6%. During the period from 1990 to 2008 the combined growth of energy production of oil, coal and gas grew 57 times faster than renewable energy. The achievement of renewables in electricity production only, is a little better. Compared to the growth of coal, oil and gas in their respective beginnings, the energy transition to renewables at this moment hasn’t even started yet.

EREC assumes an increase in the carbon price up to 100 euro in 2050 with an increasing oil price up to $200 in 2050. Concerning demand they assume “full implementation of new policies to make substantial progress on energy efficiency”. Strong political, public and economic support for all renewable energy technologies is considered a given. According to EREC, this decade is an excellent window of opportunity. Europe has to invest a lot in new electricity generating capacity since 42% of the current electricity generating need to be replaced due to aging power plants.

Without questioning whether a reinvention of the energy system, as stated by EREC, is required for an energy transition, it is possible to say something about the feasibility of a reinvention of the energy system. In the previous chapter was described that the societal structure of the economy, politics, and technology driven by profits and economic growth, labeled Schumpeter Dynamics by Krupp is inert to changes that negatively influence the drive for profit and growth. Schumpeter Dynamics is so firmly embodied in 1) the present economic organizations and institutions, their networking and their leading representatives; 2) gigantic investments in means of production with long investment cycles; and 3) technology, mainly selected by close neocorporatistic networking between economy and politics. This aggregate has immense inertia because each element strives for its perpetuation and growth and this also perpetuates the linkages involved.

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147 EREC, Rethinking 2050: a 100% renewable energy vision for the European Union. Brussels, 2010, p. 17
149 Ibidem, p. 23.
This inertia could apply to energy substitution processes. In the first chapter is explained that
the French move towards nuclear was successful because it fitted in the constellation of the
energy system and was merely a fuel substitution from oil to nuclear. Established fuels can be
surprisingly persistent. New energy sources or techniques become dominant only after long
periods of gradual diffusion. As long as established sources are readily available and
profitable, their substitutes will advance only slowly. Even when new sources come with
superior attributes for the environment.\textsuperscript{152} Infrastructural arrangements are an important factor
explaining the persistence of established fuels. One could speak perhaps of a certain path
dependency. Our energy infrastructure and institutional arrangements are based on the
burning of fossil fuels in centralized power stations. The total value of the fossil and nuclear
infrastructure is worth $15-20 trillion. It is not expected that the energy industry will abandon
the fossil and nuclear infrastructure and invest, build and switch to a renewable infrastructure
before the old investments have been paid for.\textsuperscript{153} Anything beyond a marginal shift of only
about 10\% to renewable generation would affect the key infrastructural arrangements of the
energy industry such as load-factors and –centers and high voltage transmission lines from
supply to demand.\textsuperscript{154}

Societies in itself are quite inert as they rarely respond to an “anticipated” change in
their circumstances such as the risk of climate change in the near future.\textsuperscript{155} Changing fuels
within the infrastructural system is easier than changing the infrastructural system. An
interesting side note about France’s nuclear success story is mentioned by Yergin where he
claims that France could outstrip other countries in its commitment to nuclear because of “a
governmental system much more impervious than other Western countries to such outside
interveners as environmentalists.”\textsuperscript{156}

Rainer Hinrichs-Rahlwes, President of the European Renewable Energies Federation
(EREF) states that renewable energy are already cost competitive if external costs are
included in the price. He claims that the current goal of the EU to have a 20\% renewable
energy supply is ambitious enough. Market distortions, dominance of incumbents and lack if
internalizing externalities are the main barrier for the large-scale take off of renewable

\textsuperscript{154} Smil, V., \textit{Energy at crossroads}. Background notes for a presentation at the Global Science Forum
\textsuperscript{155} Rifkin, R. \textit{The hydrogen economy: the creation of the worldwide energy web and the redistribution of power
energies. Hinrichs-Rahlwes is an optimist. Removing the barriers and implementing a strong government support scheme should make it possible for 100% renewable in 2050.\textsuperscript{157}

The American Council on Renewable Energy (ACORE) together with the Electric Power Research Institute (EPRI) focus on electricity generation. They state in a report that they think that the renewable resource base is large enough for energy demand now and in the future. Only a small potential of all renewable resources are harvested at this moment. There are economic, environmental and societal barriers to overcome. This report is one of the few from renewable lobby or branch organizations that considers technical progress as a critical factor rather than claiming it is a matter of making the right choices.\textsuperscript{158}

**European Union**

The call for an energy transition has been incorporated in the energy policies from the European Union. The EU Energy and Climate package has a target to increase renewable energy to 20% of the EU’s gross energy consumption by 2020.\textsuperscript{159} The target is distributed differentially among member states based one national income and renewable potential. For example, Sweden which already has a high renewable production rate from hydropower must increase its percentage from 39% to 49%. The Netherlands on the other hand must go from 3.4% to 14%.

The European Commission stated in its plan for 2020 that Europe must reduce greenhouse gas emissions by at least 20% compared to 1990 levels, increase the share of renewable energy sources in our final energy consumption by 20%, and increase energy efficiency with 20%.\textsuperscript{160} The European Commission believes that achieving the renewable targets can be achieved with determined efforts by governments assuming that the energy industry plays its part in the undertaking.\textsuperscript{161} “Major investments have been made before in conventional energy sources, notably coal and nuclear. The time has now come to do the same for renewable energy.”\textsuperscript{162}

The European Commission is aware that there is a chance the Member States will not succeed in achieving their targets. According to the Commission this is attributable to the

\textsuperscript{159} EU website, http://ec.europa.eu/environment/climat/climate_action.htm
\textsuperscript{162} Idem, p. 4.
failure of including the external costs in the market price for fossil fuels. Another factor is that
the novelty, complexity and decentralised nature of renewable technologies results in
administrative hurdles.\textsuperscript{163} National policies have proven to be inadequate and to susceptible to
changing political priorities.\textsuperscript{164} The conclusion by the Commission is that a majority of
Member States are significantly lagging behind in their efforts to achieve the agreed targets.
The Commission has already initiated infringement proceedings against six Member States
for not fulfilling their obligations under the renewable electricity Directive.\textsuperscript{165}

The European Commission believes that boosting renewable energies should help
create business and jobs, have a potential to boost Europe’s industrial competitiveness,
promote innovation and bring business opportunities when European businesses can export
their renewable technologies.\textsuperscript{166} Meeting the renewable energy targets could result in $60
billion savings because of less oil and gas imports by 2020 and 600,000 jobs in renewable
energy according to the European Commission.\textsuperscript{167} The Directorate of Transport and Energy of
the European Commission labels wind, hydro, biomass and solar thermal as already
economically viable.\textsuperscript{168} Wind is considered the most promising for electricity.\textsuperscript{169} Biofuels is
considered the only large-scale substitute for gasoline and diesel in transport.\textsuperscript{170} Development
in the use of biofuels has been slow. The Commission says this is caused by the higher costs
of biofuels, the lack of appropriate support systems in Member States and an underdeveloped
regulatory framework in the EU.\textsuperscript{171} Thus, the only real alternative for oil in transport is so far
ineffective due to costs and policies according to the Commission. It is strange however that
the EU has an import tariff on (bio)ethanol of 45%.\textsuperscript{172}

The factor energy density also comes into play when discussing the use of biomass.
Coal has an energy density ( Joule/kg) that is twice as high as wood.\textsuperscript{173} Replacing the 3.6Gt
(=3600 billion kilograms) coal we now consume annually with biomass means that we need
about 7Gt of wood (= 7000 billion kilograms). The same principle applies for oil used in

\textsuperscript{163} Ibidem, p. 4.
\textsuperscript{164} European Commission, Renewable energy road map. Renewable energies in the 21\textsuperscript{st}
\textsuperscript{165} Idem, p. 7.
\textsuperscript{166} European Commission DG-TREN, Renewables make the difference. Brussels, 2007, p. 4.
\textsuperscript{167} European Commission, Europe 2020: a European strategy for smart, sustainable and inclusive growth.
\textsuperscript{169} Idem, p. 15.
\textsuperscript{170} European Commission, Renewable energy road map. Renewable energies in the 21\textsuperscript{st}
\textsuperscript{171} Idem, p. 7.
\textsuperscript{172} Ibidem, p. 7.
transport. The energy density of ethanol from crops is 24MJ/L which is 30% less than gasoline. Replacing 1 liter of gasoline requires 1.3 liters of ethanol. If all the world’s sugar cane crops were converted into ethanol, the total annual ethanol production would be less than 5% of the global gasoline demand in 2010. If the entire U.S. corn harvest was converted to ethanol, it would be only about 15% of the U.S. gasoline demand.174 Thus while biomass is considered a renewable source it could be questionable if it can deliver the scale required to replace oil.

According to the EC strong policy measures and frameworks are needed that encourage investments needed on the long term for the strategic challenges we face.175 Unfortunately the policy agenda is typically by the short term and in established technological fields. Failing to achieve the renewable energy targets “can only be considered a policy failure and a result of the inability or the unwillingness to back political declarations by political and economic incentives” according to the European Commission.176

The development recorded so far is made up of generally patchy and highly uneven progress across the EU, highlighting that national policies have been inadequate for achieving the EU target. While ambitious policies creating investor certainty have been adopted in some Member States, national policies have proven vulnerable to changing political priorities according to the Commission. The absence of legally binding targets for renewable energies at EU level, the relatively weak EU regulatory framework for the use of renewables in the transport sector, and the complete absence of a legal framework in the heating and cooling sector, means that progress to a large extent is the result of the efforts of a few committed Member States.177

Today’s renewable energy policy is completely nationalized and politicized by the Member States. The 2020 “three twenties” targets require strong EU deployment of advanced low/zero carbon technologies. On the road towards 2050 strong innovation push and pull programs are necessary, not only requiring massive investments but even more so stable and

177 Idem, p. 5.
effective regulatory regimes conclude researchers from the Clingendael International Energy Programme, a Dutch research institute.\textsuperscript{178}

The assumption that the energy industry plays its part is tricky. Popp, Newell and Jaffe from the National Bureau of Economic Research point out that markets are unlikely to provide proper incentives for the development of clean technologies if there is no effective public policy in place.\textsuperscript{179} Even if all market failures are resolved, there would still be private underinvestment in environmental R&D since many of the benefits to providing a cleaner environment are external. Especially for the energy technologies that are years from being economically viable and have a greater uncertainty, as most renewables are, despite the claims by renewable proponents that they are already economically viable.\textsuperscript{180}

**IGO\textsuperscript{s}**

The International Energy Agency (IEA) is optimistic as Nobuo Tanaka, the IEA Chairman states “there is ample evidence that when governments provide a sustained strategic framework for a clean energy future, the private sector rapidly invests in clean technologies and several OECD countries have already achieved tremendous clean energy deployment, leading the way for others to follow”.\textsuperscript{181} On the same page Tanaka also states that the growth of fossil fuels matched or even outpaced the developments of clean energy globally. According the IEA, the growth of renewable energy in the last decade has been driven mostly by policy support. The IEA states that wind power capacity grew from 17GW to 194 GW in a decade and global renewable electricity generation has risen with 2.7% annually since 1990. However, the IEA acknowledges that total electricity generation (including fossil and nuclear) rose 3% annually, thus faster than renewable generation. Achieving a halving of carbon emissions needs double digit growth annually up to 2050 and solar needs a growth of even 22% annually. These percentages have been achieved in the past few years due to strong policy support, but these growth digits must be maintained over several decades.\textsuperscript{182} To achieve this the IEA suggests several strategies:\textsuperscript{183}

- Phase out of fossil subsidies.

\bibitem{181}IEA, Clean energy progress report: IEA input to the clean energy ministerial Paris, 2011, p. 5.
\bibitem{182}Idem, p. 13.
\bibitem{183}Ibidem, p. 15.
• A price on carbon emissions  
• Increase public investments in innovation  
• Smart energy policies to remove non economic barriers

The IEA concludes that the development of renewable energy is strongly dependent on political support and that this support is required for years to come to continue the development of renewable energy. The IEA is less optimistic than the renewable proponents. It notices that policy support is weakening due to government austerity plans. As mentioned above, the ECF assumes declining costs for wind energy as long as there is political support. Declining political support for wind can thus diminish the declining costs for wind connected to the growth in capacity. Furthermore, the IEA are concerned about the high costs of an energy transition. Energy demand is expected to increase the coming decades. Industry is now responsible for about 40% of world energy demand. The IEA expects that if the best technology available in terms of energy efficiency would be used, energy use could be reduced by about 20-30 % but this won’t be nearly enough to offset anticipated growth in demand with industrial output expected to double or even triple in the coming decades. The IEA estimates that between 2010 and 2030 about $26 trillion of investment will be needed in energy-supply simply to meet demand for energy. If the demand is to be met with climate considerations, it would require additional tens of trillions of dollars

The International Panel on Climate Change (IPCC) observes that the transition to renewable technologies faces regulatory and acceptance barriers. Market competition only may not lead to significant reductions in carbon emissions. The IPCC agrees with the IEA that increased rates of deployment needs supportive government policies and measures. Addressing environmental impacts usually depends on the introduction of regulations and tax incentives rather than relying on market mechanisms according to the IPCC. Large-scale energy conversion plants with a lifetime of several decades give a slow rate of turnover of 1-3% per year. Decision today shape carbon emissions for decades to come. Small scale local production using low-carbon technologies is therefore better according to the IPCC since

small scale production facilities have a shorter lifespan and will be replaced quicker when a more efficient option is available.

Future policies should take into account the full costs of environmental, climate change and health issues relating to the use of fossil fuels, otherwise they will continue to be dominant to meet ever increasing global demand for energy. The calculations done by the IPCC on climate change have fueled the call for an energy transition by environmentalist, green politics and also the European Union. The IPCC does appear more skeptic however about the feasibility of a major energy transition in the near future. They expect that fossil fuels will play a significant role in the next few decades as they conclude that fossil fuels can only be partly replaced by renewable sources. Nuclear is in contrary to many others, an effective option to reduce carbon emissions according to the IPCC. The IPCC believes electricity storage technology is of critical importance if low-carbon energy options are to be better utilized. Unfortunately, despite decades of efforts there is still no viable, economical solution for storing large quantities of the energy we get from wind and solar that we can turn into power when we want it.

Science

Within the scientific community there is no unanimity on how the problem of energy consumption and carbon emission needs to be tackled. Because of this, a wide range of opinions exist from highly optimistic on the feasibility to highly skeptical and everything in between. Perhaps the most optimistic are Delucchi and Jacobson from Stanford University. The statements from environmental NGOs and renewable branch organizations receive support from Delucchi and Jacobson In *Energy Policy* they state that the change in our energy system is not the first large-scale project undertaken in world history. In World War II, U.S. aircraft production increased from 2000 units in 1939 to 300.000 units in 1944. In 1956 the U.S. initiated the construction of the Interstate Highway System which now extends for 47.00 miles and just like Al Gore they also make a comparison with the Apollo Project to put a man

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188 Idem, p. 255.
189 Ibidem, p.296.
191 Idem, p. 287.
on the moon in ten years. The large scale of a complete transformation of the energy system is not, in itself, an insurmountable barrier according to the two scientists.\textsuperscript{193} At this moment there is no lack of manpower, materials and energy sources that constrain the development of renewable technologies.\textsuperscript{194} Therefore Delucchi and Jacobson conclude that “the obstacle to realizing this transformation of the energy sector are primarily social and political and not technological. With sensible broad-based policies and social changes it may be possible to convert to 100% in 2050.”\textsuperscript{195} What the feasibility and/or the costs of these broad-based policies and social changes are remains unclear.

The Dutch research centre ECN together with the American NREL concluded that there are significant market barriers that prevent renewable technologies from competing with the traditional energy sources in the current market structure. One important barrier is that environmental externalities are not included in the market price conclude.\textsuperscript{196} Therefore renewable energy has a competitive disadvantage. The role of policy according to ECN and NREL is to overcome these disadvantages and make sure that the benefits of renewable energy that are not captured by the market are accounted for.

A workshop held at the Dutch research institute Clingendael in the Netherlands concluded that actions of governments play the main role in energy transition. Governments set out the main directions for energy transition, and within these conditions companies innovate, anticipate, act and react. Energy markets without specific renewable energy policies do not give enough incentives to companies to behave such that a significant transition to a low-carbon energy sector in the coming decades will take place.\textsuperscript{197} Clingendael is critical on the effectiveness of governments in implementing the right policies. “EU leaders produced two surprises after Kyoto. One is to translate Kyoto into a market based system i.e. the Emission Trading System (ETS). The other one, launched without very much analytical basis so it appeared almost as a gift from heaven was about long-term non-binding common ‘political’ targets in the form of the Triple Twenties.”\textsuperscript{198}

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\textsuperscript{194} Idem, p. 10.
\textsuperscript{195} Ibidem, p.10
\textsuperscript{197} CIEP, Lessons learned from the CIEP informal discussion group on global energy transition and international politics 2007. The Hague, 2008, p.10.
\textsuperscript{198} De Jong, J., Glachant, J.M., Hafner, M. A smart EU energy policy: final report. The Hague: Clingendael, 2010, p. 31
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The ETS is at the moment lacking credibility of carbon pricing policies due to the impossibility for current governments to commit credibly to a future carbon price path.\textsuperscript{199} The carbon market needs to be tightened and harmonized across the EU to be effective. This requires a strong and centrally regulated EC role, including effective monitoring and a centralized auctioning process. This is probably unfeasible with Member states (MS) comitology, as at least one argument relates to the fiscal sovereignty paradigm that MS are unwilling to surrender.

Ausubel is in general critical about carbon taxes or trading schemes for carbon emissions. A price of $30 for a ton of carbon (which is double the average price of carbon) with a global annual emission of carbon of seven billion ton would amount to $210 billion of extra revenue for governments. This sounds impressive but “it is still less than the annual sales of Wal-Mart.” The world economy can probably afford it without any guarantee that it will be beneficial for promoting renewables or averting climate change says Ausubel.\textsuperscript{200} The main beneficiaries of such a system are most probably lawyers, financial intermediaries, accountants and administrators. But then, Ausubel is not a strong proponent of a policy forced energy transition. Cheap energy could be more important for humanity than green energy according to Ausubel. The price of energy influences for example the price of pumping or desalinating water and the price of agricultural products (both use a lot of energy) and water and agriculture might require more attention in the near future than green energy.\textsuperscript{201} Besides that, there is also a lack of credibility of carbon pricing policies due to the impossibility for current governments to commit credibly to a future carbon price path.\textsuperscript{202}

One must keep in mind that if a credible pricing policy is implemented it will not just improve the economics of renewables vis-à-vis conventional fuels, but it will also create a whole range of market dynamics between the conventional fuels since there are large differences in the amount of emissions. Oil will become more competitive compared to coal. Gas will become more competitive compared to both coal and oil. Nuclear will become more competitive compared to all fossil fuels.


\textsuperscript{201} Idem, p. 495.

Many renewable proponents focus the energy transition on electricity generation and the reduce of the use of coal and nuclear. Amory Lovins, an energy researcher who was already participating in the energy transition debate since the 1970s and co-founded the Rocky Mountain Institute focuses on the use of oil in transport. He gave a speech on the TED Conference of 2005 about his book ‘On winning the oil endgame’ where he states that the “(U.S.) government doesn’t have to force us to do painful things to get off oil. The United States can completely eliminate its use of oil by 2040 and rejuvenate the economy at the same time led by business for profit because it is so much cheaper to save and substitute for the oil than to keep on buying it”\(^{203}\) According to Lovins, increases in efficiency in cars and airplanes will greatly reduce the demand for oil. The remaining demand for oil can then be replaced by ethanol from biomass, electric cars or eventually liquid hydrogen. Not everybody agrees on this. Lovins is also a long-time opponent of nuclear energy. In an article called *The Nuclear Illusion* he questions the statements that nuclear is competitive, necessary, reliable, secure and vital for fuel security and climate protection. According to Lovins, this is all false. He says that the available on shore wind power in the U.S. is twice the entire U.S. electricity consumption thus making nuclear superfluous.\(^{204}\) Lovins’ statements are not without criticism. Bradley Jr. comments on Lovins’ saying that the predictions for demand reduction by Lovins are highly overestimated while the costs (subsidies) of achieving the substantial demand reductions are grossly underestimated.\(^{205}\) Smil goes as far by stating that Lovins lacks critical thinking in his indiscriminate zeal against nuclear energy.\(^{206}\) In 1986 Lovins was asked about the future for nuclear energy. His response was “there isn’t one.”\(^{207}\) Since then about 130 new reactors have been build. At the moment there are 440 reactors in operation, 61 reactors are being build with another 158 planned (despite the disaster in Fukushima).\(^{208}\)

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Bryce (perhaps jokingly) states that “Lovins may be wrong, but at least he has been wrong consistently wrong – for nearly three decades”.209

Strategy consultancy company Boston Consulting Group published a report called ‘Groen licht voor groene stroom’ (Green light for green power) in which they analyze the Netherlands can comply to the European Triple Twenty agreement. One of the recommendations is for the national government to take measures to speed up the permitting process for renewable energy sources. Purpose of this measure is to take away the possibilities for local municipalities to delay and hinder the permitting process for, for example, windmills in the municipality.210 In a democratic country as the Netherlands it might be problematic however to enforce the development of large scale renewable energy on local communities without some form of public/civil consultation.

Another point in the BCG report is that the government should establish a stable subsidy system for all renewable technologies. For the long term, the government and the private sector should develop a vision to make sure the transition to sustainable technologies will not harm the competitiveness of Dutch industries.211 Discussions on how to implement subsidies for new energy technologies are not new. Sterman noted in 1981 that new energy technology subsidies in the beginning of the 1980s were more focused on ‘conventional non-renewable backstop technologies such as synthetic fuels from coal, shale oil, nuclear power and tar sand but that the market “may not favor the same ensemble of technologies as the subsidy”.212

In an e-mail conversation I had with Rutger Mohr, one of the authors of the BCG report he stated that a global carbon tax has the greatest chance of success in stimulating an energy transition because it prevents industries moving to countries with favorable carbon policies.213 The Centre for European Policy Studies (CEPS) also thinks that a global climate-change agreement would provide the necessary certainty for investors when making investment decisions.214 The chance for a global carbon regime is rather small unfortunately. According to Royal Dutch/Shell (hereafter: Shell), there has been a general increase in

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211 Idem, p. 8.
213 E-mail correspondence with Rutger Mohr date August 9th 2010
regulatory uncertainty since the Copenhagen climate summit. Shell thinks that the “room for policy maneuver is limited” due to the impact of the financial crisis and the worsening fiscal situation in many countries.

Indeed, the global recession has moved climate concerns far down the hierarchy of government objectives. This hits funding and political support for new technologies. Recent moves by the EU and the US regarding long-term liabilities show that political support for new technologies is far from secure. McNulty from the Financial Times observes that renewable energy is no longer a priority for the U.S. It is therefore according to Shell important to remain strongly focused on least-cost solutions today and advances in new technologies in the future.

Ausbubel makes a rather cynic remark about where the focus must be in realizing an energy transition on the spectrum of politics versus technology: “make sure you keep your mind on high-tech innovation such as the magnetic levitated train of Shanghai instead of the blah-blah from Brussels or Washington or the windmills from Denmark.” While technological innovation is indeed crucial for the coming energy transition, the importance of Washington and Brussels is not to be neglected. Michael Hoel of the University of Oslo writes about an interesting dynamic of technological change and substitution of energy. Hoel argues that if (international) climate policies are not optimally designed, advancement in renewable technology may even increase carbon emissions instead of reducing them. Furthermore, technological improvement of renewable energy cannot in itself be trusted as a good mechanism to reduce emissions. Different energy sources are not perfect substitutes of each other. Electric batteries for example have several disadvantages over oil that are not immediately resolved when electric driving is cheaper. Secondly, if renewable energy becomes cheaper, producers of fossil energy might have some maneuvering space for lowering the prices of fossil energy. When prices go down, consumption goes up. If the effect of increased fossil consumption is greater than the amount of fossil energy somewhere else in

217 Ibidem, p.46.
222 Idem, p. 16.
the (global) economy replaced by a renewable substitute, it could have the effect of an overall increase in fossil energy use. This implicates that there is task for governments to install a global climate regime to overcome these effects. Hoel states “a belief that technological progress in itself can help solve the problem of climate change is much too optimistic, to say the least. Improved technology of various types of renewable energy can be an important ingredient of mitigating the climate problem, but cannot be expected to be an alternative to a good international climate agreement directed directly towards emission reductions.” 223 For the detailed mathematical explanations I refer to the original article.

According to Hefner III, founder and CEO of GHK Company, an Oklahoma based oil and natural gas company, the best and most efficient path towards environmentally sustainable economic growth occurs when the marketplace is free to choose energy sources. On the short term without government intervention in the energy market this will be gas. Hefner III perceives government’s correct role in the energy marketplace is to provide resources for promising new technologies and set long term environmental standards. 224 The trend of decarbonization as mentioned in the previous chapter is a result of market forces.

Smil however downplays the forces of the free market in determining the use of energy sources. According to him it would be naïve to see twentieth century energy prices as the outcome of free market competition, or as a reflection of real energy costs. There is a large history of government manipulation of energy prices through financing, subsidizing, special regulations, tax credits and research funds. 225 All of these market interventions led of course to one form of energy being favored over another. To this day the fossil energy sector receives several tax benefits. In the US for example, oil companies can immediately write off so-called intangible drilling costs, and all independent oil and gas producers are allowed to deduct 15% of their gross revenue before taxes. 226

Smil doesn’t see the current global energy system as an outcome of free market but a combined result of market forces and government intervention. However, this does not means he believes that government intervention now can force an energy transition. According to him no renewable energy techniques currently under development can rival any of the fossil

223 Ibidem, p. 23
226 Idem, p. 84.
energy conversions during on the short term (20-30 years). On the long term it is a different picture. Countries can over the long term change their so-called energy identity. A good example is the difference in development of post-war Soviet Union in comparison to Japan. Japan has no significant energy sources of its own and is almost totally reliant on import. The Japanese government, trying to reduce its vulnerability of supply interruptions promoted state cooperation with industries, promoted technological innovation and made it one of the most energy efficient countries in the world. The Soviet Union with large fossil fuel reserves and a rigid central planning made it the least efficient user of energy in the world.

**Systematic/Complexity approach**

An interesting perspective on energy transitions is the discipline of transition management which is developed in The Netherlands. Rotmans, one of the founders of this discipline states that it has evolved somewhat as an underground discipline hardly visible by mainstream media. Rather than suggesting specific economic incentives for specific energy sources like the parties mentioned above, transition management has a more systematic focus.

At the core of transition management is the challenge of orienting long-term change in large socio-technical systems. Transitions are understood as processes of structural change in major societal subsystems such as politics, economics or science. They involve a shift in the dominant ‘rules of the game’, a transformation of established technologies and societal practices, movement from a dynamic equilibrium to another, typically stretching over 25-50 years. Societal subsystems respond differently to events. In case of an oil crisis, the economy reacts by raising prices and consequently reducing demand. Politics may look for military means to secure access to oil reserves.

Krupp, writing in the beginning of the 1990s describes how different societal subsystems not only respond differently but that so-called ‘paradigm distortions’ arise where the proposed solution is not specifically addressing the problem at hand. One example is George Bush Sr. claiming during his presidency that “electric cars can contribute in their way to a strong and growing economy” while the problem at that time was not about growing the

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economy but becoming less dependent on oil imports.\textsuperscript{232} The differentiation of modern societies in subsystems such as the economy, politics and technology results in societal complexity which cannot be controlled from a single center and which may cause uncontrollable externalities.\textsuperscript{233}

Rotmans, emphasizes that complexity reduces the potential of steering or influencing an issue.\textsuperscript{234} Adams portrayed this complex system as a system of many coordinating units (for example the whole value chain of oil from oil well to end consumer) without a single brain and that therefore it is hard to influence that system. If it were centralized, it might be somewhat easier, for then the center could be identified.\textsuperscript{235} When oil becomes less important in the energy mix, all the coordinating units would be less powerful, but the units are specifically trying to avoid that.

From an economic perspective, the issues of energy and environment are treated as market failures. From a political perspective they are treated as policy failures. From a religious perspective they have been attributed to moral deficiencies of individuals, institutions or society. But in terms of the perspective of transition management, systemic problems of society resulting from its very constitution. Its differentiated economic efficiency is achieved at the price of external costs caused in other subsystems outside that of the economy, the system of health for example in the case of pollution by power plants.\textsuperscript{236} That is why Rotmans and Loorbach describe the current energy and anthropogenic climate change problem as a system failure. System failures are locked-in flaws in our societal structures such as a technological bias, weak or dominant networks, institutional barriers and path dependencies.\textsuperscript{237} System failures cannot be corrected by market forces or current governmental policies.

According to Scholten, an energy transition is thus not just substituting one energy source for another. Scholten describes it as follows: a process of socio-technical evolution in which economic, institutional and technological structures develop interactively and change

\textsuperscript{232} Idem, p. 49.
\textsuperscript{233} Ibidem, p. 17.
\textsuperscript{234} Rotmans, J., Transitiemanagement: sleutel voor een duurzame samenleving. 1\textsuperscript{st} ed. Assen: Van Gorcum, 2003, p. 7.
drastically in the long run.\textsuperscript{238} A transition to a sustainable energy system requires, besides developing new technologies, institutions ensuring the proper functioning of these new technologies.\textsuperscript{239} As Scholten further explains, a nation requires a set of institutions compatible and supportive of new technologies. Existing institutional structures might pose an obstacle to the success of new technologies.

It has been suggested that transition management offers a promising approach. The use of economic incentives are likely to be too weak and probably too general to promote systems innovation, whereas a radical political changes in the energy system is likely to be too disruptive.\textsuperscript{240} Systemic change would require the resource and sustainability issues to resonate strongly across interfaces in heterogeneous societal systems and to become incorporated in or grafted onto the codes of at least the programs of the systems to be controlled, in particular the economy, politics and technology. Empirically this has not happened so far and it cannot be proven theoretically that it will happen.\textsuperscript{241} The discipline of transition management has been adopted by the Dutch government.\textsuperscript{242} The ‘Dutch approach’ on energy transition policy has not yet lead to remarkably high growth rates in renewables.\textsuperscript{243}

It is usually the case that in the early phases of a transition the focus is on exploring and developing technical alternatives instead of focusing on institutional reform.\textsuperscript{244} This renders institutional change premature since we don’t yet know which technology will be successful and which institutional reforms are needed. Rotmans agrees that the energy transition is in its early phase and hasn’t really took off yet. He cites the abundance of fossil fuels as the strongest barrier.\textsuperscript{245}

No substantial progress has been made in institutional reform in the Netherlands under the umbrella of transition management. This is sometimes ascribed to the over-representation

\textsuperscript{239} Idem.
\textsuperscript{245} Rotmans, J., \textit{Transitiemanagement: sleutel voor een duurzame samenleving}. 1\textsuperscript{st} ed. Assen: Van Gorcum, 2003, p.162.
of the existing energy sector in the various platforms according to Scholten.\textsuperscript{246} Indicative for this is Shell’s prominent position as the Chairman of the energy transition taskforce\textsuperscript{247}. The result of this is that platform members are urging for investments that benefit themselves.\textsuperscript{248} But we perhaps shouldn’t expect brilliant innovation in new energy sources coming from the conventional industries. As Schumpeter observed: ‘it is not the owners of stagecoaches who build railways’. The founder of the GM research labs made a statement in the same spirit: ‘Never put a new technology in an old division’.\textsuperscript{249}

**Conclusion**

Many authors claiming a forced energy transition is possible use optimistic assumptions. Greenpeace assumes that a global carbon regime will be implemented and that the U.S. will take responsibility for 36% of the financial costs to avert climate change. The European Commission assumes that the energy industry will play its part in the energy transition. WWF assumes that people will change lifestyles, reduce mobility and dietary consumption and that increased international cooperation is feasible. Many authors assume the political willingness to invest large sums of money in renewable technology. Greenpeace for example assumes 2% of global GDP, WWF assumes $3.5 trillion annually for several decades. European renewable energy lobby organization EREC assumes a strong increase in both the carbon price and the oil price. Delucchi and Jacobs state that historical projects such as increased airplane production during World War II, the moon landing and large infrastructural developments serve as proof that the energy transition is possible.

Nearly all authors ascribe a leading role for governments in steering towards a renewable energy system. The debate is far from a conclusion however as to what is the ideal governmental role in the energy market. From an economic point of view, there are basically four policy instruments to force the scale up of renewable energy technologies: feed-in tariffs, output subsidies, investment subsidies and output quota.\textsuperscript{250} Most proponents of a policy forced energy transition call for several of these options and produce scenarios in which they claim that if their strategies are implemented the energy transition will come into reality.

\textsuperscript{247} Information about this platform can be found at www.energietransitieplatform.nl.
Other frequently mentioned policy options are: investing in technological development, removing entry barriers, creating a level playing field and phasing out political support for fossil fuels. Several parties including the European Commission and Greenpeace cite creating new ‘green’ jobs as a benefit of a policy-forced energy transition just as Bush Sr. cited electric cars as an economic opportunity. But as we saw, that claim is debatable and should not be the focus of energy and climate policy.

Green politics and environmental organizations have their focus on policy and making the right choices rather than technological development and innovation. Their assumption is that the technologies currently at hand are sufficiently developed to realize the transition. The IEA, the IPCC and ACORE on the other hand appear more realistic and do mention specifically the need for technological development. While researching the opinions of the organizations on energy transition, the lack of focus on technological questions by the strongest proponents is somewhat puzzling. Among the proponents of a policy forced transition, nobody seems to be asking the critical questions whether the renewable technologies often mentioned in the debate (wind, solar, biomass) are the right technologies for this transition or at the right stage of development while at the same time nuclear energy is by several discarded as unethical or even unnecessary while it can greatly contribute to reducing carbon emissions. The European Union acts like it has integrated the opinions of the strong renewable energy proponents in its policy making process. In the scientific community the opinions diverge widely on how to approach the issue.

Several authors in this chapter make grossly optimistic assumptions in price developments, political willingness and the potential to influence people’s lifestyle into sobering energy consumption. As described in chapter 1, scenarios and assumptions have often been wrong and there is no reason to think this time will be different. Because of this, there is significant uncertainty whether the energy transition will become reality, even if all the strategies of for example Greenpeace or the EREC are implemented. The question then arises whether we should want to pursue a goal at great financial costs with so much uncertainty about whether it will pay off in the end.

In the next chapter a critical analysis will be made of wind energy to show that wind energy has intrinsic barriers and therefore might never become the transitional energy source. Where these barriers are present with the use of other renewable technologies such as solar and biomass, they will be included as well in the chapter.
3. An analysis of wind energy

In this chapter one renewable technology will be extensively analyzed. I have chosen for wind energy since that technology is often hailed as the most promising and the largest contribution of renewable energy is expected to come from wind in the near future.\textsuperscript{251} Wind is the renewable energy source with the lowest cost and is closest to reach grid parity (becoming competitive with conventional energy sources).\textsuperscript{252} Wind is supposed to be the “key to Europe’s energy future.”\textsuperscript{253} It is believed that wind can deliver on the scale required and that large scale development of wind will reduce the consumption of carbon emitting energy sources. This thesis will look into these assumptions.

There are dozens of renewable technologies that are, to some extent, somewhere in the future capable of delivering energy. Examples are solar PV, solar thermal, ocean energy, geothermal, energy from algae, tidal and wave energy, large hydro such as the Three Gorges Dam in China, small scale hydro. There are also the more futuristic (and perhaps fictional) energy technologies such as nuclear fusion or capturing solar energy via satellites in space. Besides hydro energy, most of these renewable technologies are so-called “backstop” technologies, meaning a technology that exists today but is too costly.\textsuperscript{254} Coal liquefaction as an alternative for oil is also a backstop technology. When the price of one technology gets too high, the backstop technology can be taken off the shelf and put into use.

The main benefit of course is that wind turbines emit no carbon dioxide during operation and therefore have no impact on climate change. Another important benefit is that locally produced wind energy produced makes the EU less dependent on supply disruptions from other parts of the world such as the oil crises of the 1970s. Large centralized power plants could cause problems in the electricity grid if suddenly a large plant is not delivering to the grid due to a malfunction. The effects are far smaller if one single wind turbine is down.\textsuperscript{255} Finally, an energy system dependent on wind is not dependent on a finite resource such as oil or gas. Wind energy experienced spectacular growth in the last decade and especially in

\begin{thebibliography}{9}
\item EREC, \textit{Rethinking 2050: a 100\% renewable energy vision for the European Union}. Brussels, 2010, p. 58
\end{thebibliography}
northern parts of Europe and near the Atlantic coast wind prospects appear promising. Therefore this chapter is focused on wind. It is not the first time in history that wind enjoyed great support: wind energy was also hailed as a promising technology back in the 1970s. The National Research Council concluded in 1979 that wind generators are already economic for a few sites and markets.\textsuperscript{256}

The purpose of this chapter is to analyze the characteristics of wind energy and its effects on the energy system. Many proponents argue that energy transitions are a matter of choices and implementing the right policies. I have chosen to focus on factors that are difficult to overcome by policy: scale, costs, geographical requirements, material requirements, load factors, intermittency and the need for backup generation. Denmark is widely considered a leader in wind energy development. It has the highest penetration of wind energy in their electricity market. It will therefore serve as a case study for analyzing the effectiveness of wind energy.\textsuperscript{257}

Inevitably this chapter has a somewhat economic and technical character. To analyze the prospects of wind energy a variety of sources is used among which, David Mackay, a physicist from Cambridge University, Vaclav Smil, energy expert at University of Manitoba, data from the IEA, economic analysis from the NBER and research from ECN. For technical analysis I turn to the Royal Academy of Engineering and Peter Lang, an engineer in the energy industry. For the Denmark case data is used from the Danish Energy Agency, the European Environmental Agency and the U.S. Energy Information Administration and an analysis from the Danish Centre for Political Studies CEPOS is included. In the final section innovation dynamics are explored. In this section I use among others insights from Arnulf Grubler, a specialist on energy and technology who teaches at Yale University and Jepma and Nakicenovic from the Energy Delta Institute in Groningen.

\textbf{State of affairs}

In 2011 there is about 195GW of global wind capacity installed of which 60\% is installed in Europe. Europe is clearly a leader in wind energy development. The European Union and the renewable branch organization EREC are projecting an installed capacity of 180GW by 2020.\textsuperscript{258} In 2010 the capacity was about 84 GW.\textsuperscript{259} According to global targets set by the IEA

\textsuperscript{256}National Research Council, \textit{Energy in transition, 1985-2010: Final report of the committee on nuclear and alternative energy systems.} Retrieved from \url{www.nap.edu/catalog/11771.html} on May 2 2011, p. 82
\textsuperscript{257}EWEA, \textit{EU energy policy to 2050: achieving 85-90\% emissions reductions.} Brussels, 2011, p. 41.
\textsuperscript{259}EWEA, \textit{EU energy policy to 2050: achieving 85-90\% emissions reductions.} Brussels, 2011, p. 15.
this needs to be 575GW in 2020.\textsuperscript{260} This means an annual growth rate of 12\% is required. From 2005 to 2010 the growth rate was significant with 27\% due to strong policy support.\textsuperscript{261} It is unsure whether this growth rate will be maintained. As mentioned in the previous chapter, the IEA is observing declining policy support.

Besides the European targets to double wind capacity in a decade there are some very ambitious plans for wind energy outside Europe that caught media attention. One of them is the so-called Pickens Plan. T. Boone Pickens, a Texan oil billionaire proposed a large plan to use wind energy as a solution to America’s oil addiction.\textsuperscript{262} The plan is to develop several large scale wind energy projects, one of which is a wind farm of 4000 wind mills in the Texan Panhandle, a windy region in the north of Texas.\textsuperscript{263} The electricity produced with wind is supposed to reduce the need for domestic natural gas which can then be used to replace imported oil in transport. The plan to replace gas with wind so that the gas can be used in transport could be problematic as will be explained later. The feasibility of transforming a large and complex system as oil-for-transport to gas-for-transport is also highly questionable in the short term. The plan of Pickens is not the only large scale plan for wind energy. China recently announced a project of installing 7000 wind mills and is subsequently hailed as a leader in renewable energy.\textsuperscript{264}

\textbf{Economics}

Most renewables, wind included, have certain economic characteristics in common: large fixed costs and low or no variable costs. Solar, wind, hydro, geothermal and tidal require substantial initial capital expenditures before any energy is produced but have no fuel costs.\textsuperscript{265} Energy from fossil fuels have lower initial capital expenditures but they have higher operating costs since they require the input of fuels. One of the benefits of wind energy is that when an individual wind mill is down due to maintenance only a small fraction of electricity production is affected. If a large centralized coal power plant is down a large portion of electricity production is affected.\textsuperscript{266}

\textsuperscript{260} IEA, \textit{Clean energy progress report: IEA input to the clean energy ministerial\textsuperscript{2} Paris, 2011, p. 12.  \\
\textsuperscript{261} Idem, p. 12.  \\
\textsuperscript{262} \texttt{Www.pickensplan.com/theplan}. Accessed April 22, 2011.  \\
\textsuperscript{263} \texttt{http://en.wikipedia.org/wiki/File:Texas_Panhandle.PNG}  \\
\textsuperscript{264} \texttt{http://www.worldwatch.org/node/4691} accessed on 7 March 2011.  \\
\textsuperscript{266} Delucchi, M.A., Jacobson, M.Z., Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. Energy Policy (2010), doi:10.1016/j.enpol.2010.11.045.}
The major climate benefit of wind energy is of course that they emit no carbon dioxide during operation. Wind energy is not totally free of carbon emissions when the whole value chain from mining the materials for the construction of windmills up the installation and maintenance of a windmill (also called: life cycle assessment) is included in the calculation. Carbon emissions produced by wind energy ranges from about 10 – 20 g CO₂/kWh (which is about 1-2 % of the amount a coal power plant would emit). In comparison; nuclear energy emits about 2 – 65 g CO₂/kWh and solar PV about 30 – 100 g CO₂/kWh.\(^{267}\) The wide margins of wind and solar PV carbon emissions are caused by geographical factors e.g. in a very windy area a wind turbine will produce more electricity and its life cycle carbon emissions are thus spread over more kWh.

Delucchi and Jacobson state that for some locations on-shore wind is already cheaper than conventional generation, or will be in the near future.\(^{268}\) If this is the case, then wind energy will be developed ‘spontaneously’ in those areas, without government/policy intervention. This may be beneficial for the energy transition but is not a proof for the feasibility of a policy forced energy transition, which this thesis is about. This thesis is about the feasibility of a policy forced transition going against the forces of the market. When a new source is becoming more attractive due to market forces, the logical consequences is that that energy source will be developed. The development of that energy source is in that situation not intended to restructure the energy system to reduce carbon emissions but simply to make money.

A key characteristic (in economic theory) about wind energy is that the best locations for windmills will be used first. All locations selected after that will be sub-optimal. This has already happened in developed markets where the best locations have been utilized.\(^{269}\) The consequence of this process is that the ‘location costs’ for wind energy can increase in later stages since less optimal locations are being used. The same applies of course for other decentralized energy sources such as hydropower and geothermal.


Scale of the transition

Energy is consumed at increasingly higher power densities. From less than 10 W/m$^2$ in cities in low-income countries to 500 W/m$^2$ in downtowns of large northern cities in the winter. The mismatch between increasingly higher spatial power densities of cities and the lower power densities of renewable energies requires a massive spatial restructuring with major environmental and socioeconomic consequences. It is not impossible, but the massive infrastructural reorganization should not be underestimated and inevitably, an energy transition along this path will be slow, costly and difficult.

Ausubel sees a great limiting factor for renewables in their spatial requirements. A conventional power plant of 1000MW fueled by coal, gas or uranium requires a few hectares. A windmills to equal the same plant needs about 800 km$^2$. The density of wind energy is less than 10W/m$^2$. A biomass plant needs about 2500 km$^2$ of good quality farm land to equal the output of a 1000MW power plant. Photovoltaic generation requires a carpet of about 150 km$^2$ to have 1000MW capacity. In Ausubel’s opinion green means: as less (visible) infrastructure as possible. There are also large differences in material requirements. A MW of nuclear energy for example requires 40 tons of steel and 190 cubic meters of concrete. A MW of wind energy requires ten times more steel and almost five times more concrete than a nuclear MW.

Judging scale in energy can be both confusing and mind-boggling. The example given above of a huge wind project with 7000 windmills that is planned in China gives the impression China is taking big steps in the development of renewable energy. China already added about 40GW of wind capacity between 2005 and 2010. This is a remarkable growth in absolute terms but it is dwarfed when the total energy supply of China is included in the calculation. Wind power in 2010 contributed about 1% of total electricity output in China. It is closer to the truth however to say that China has taken big steps in increasing its energy production from all sources. Between 2000 and 2008 China doubled its coal extraction and added 300 GW of coal-based electricity generation. That is more or less the capacity of 300.000 wind mills and more than the combined generation capacity of the UK, France,

274 IEA, Clean energy progress report: IEA input to the clean energy ministerial Paris, 2011, p. 44.
Germany, Italy and Spain together. Overall Chinese electricity production rose more than fourfold between 1990 and 2008.\textsuperscript{276}

Because of the high capital costs of power plants it is not to be expected that China will abandon the new generating capacity and turn towards renewable before all these power plants have been run out. The average power plant needs to run for 30-35 years to recover the cost and make a little profit.

David Mackay, a professor at the physics department of Cambridge university, calculated the potential of different renewable energy sources in the U.K. He was fed up with the emotional debate about energy transition where no-one talks about numbers.\textsuperscript{277} Most parties in the previous chapter elaborated about the choices we have to make and policies we should implement to achieve the transition, overlooking technical and economic factors.\textsuperscript{278} Mackay attacks those perceptions, basically depoliticizing the debate with the statement that the “debate is fundamentally about numbers, how much energy could each source deliver at what economic and social costs and at what risks”.\textsuperscript{279}

Mackay calculates the amount of onshore wind mills that are technically and geographically possible, explicitly ignoring economic factors and social factors but simply looking at the amount of space available divided by the space a single wind mill needs. He assumes that a maximum of 10% of British land area can be covered with wind mills with a capacity of 150GW (note that this is utterly unrealistic if social and economic factors are included, it means a doubling of total global wind capacity). If the windiest 10% of British land is covered with wind mills it would provide about 20kWh per person per day, just half of energy demand for British personal driving requirements which is about 40 kWh per person per day assuming an average of about 50km per car per day.\textsuperscript{280} Another calculation is done by Lovelock. He calculates that about 276.000 wind mills are required to provide the U.K. with energy which means about three wind mills per square mile with national parks, urban areas and industrial areas excluded.\textsuperscript{281} These assumptions ignore the technical difficulties of

\textsuperscript{278} Mackay could’ve received some attention in the previous chapter about the energy transition debate, but his focus is mostly on the technical potential of renewable energy sources, among which wind, so his calculations will be explained in this chapter.
\textsuperscript{280} Idem, p. 33.
\textsuperscript{281} Lovelock, J., \textit{The revenge of Gaia: why the earth is fighting back and how we can still save humanity}. 1\textsuperscript{st} ed. London: Basic Books, 2006, p. 107.
integrating such large amounts of wind capacity in the existing electricity networks and the social acceptability of seeing a wind mill out of every window.

Offshore wind energy provides higher potential since the wind is on average blowing harder off the coast. Offshore wind is more expensive than onshore due to higher construction costs, more material requirements and more difficulty in connecting offshore wind mills to the electricity grid. Mackay suggests a strip of 4 km around Britain filled with wind mills to calculate offshore wind potential. Leaving some room for shipping routes and fishing could provide 48 kWh per person per day, theoretically enough to provide electric cars for personal transport. The construction of the offshore wind mills is not beyond the impossibility in terms of steel requirements, but Mackay stresses it is in the order of magnitude of the 2710 Liberty class cargo ships\(^2\)\(^8\)\(^2\) that were produced by the Americans during from 1941 to 1945 to transport military resources across the oceans, and was considered a huge production achievement.\(^2\)\(^8\)\(^3\) The feasibility of a 4 km wide strip of wind mills around the U.K. is of course negligible.

Mackay makes calculations for all renewable sources just as he did with wind energy. Adding all potential renewable energy sources Mackay calculates a potential of 180 kWh per person per day. Total consumption adds up to 195 kWh per person per day. Renewables come close with 180 kWh, but he warns that all economic, social, and environmental constraints are thrown overboard. Also some renewable sources are incompatible with each other for example land covered with solar panels can’t be used for energy crops.\(^2\)\(^8\)\(^4\) The conversion of the different energy sources are also not included in the calculation. For example, energy from a wind turbine cannot be converted to energy in food for humans. The projected financial costs of achieving the technical potential are enormous. Mackay estimated for example to cover 5% of British land area with solar panels with investment costs of about £200,000 per person. When technical potential of renewable energy is adjusted for assumed social acceptability of surrendering most of the land area to energy production the potential is estimated at only a tenth of the technical potential at 18 kWh per person per day.\(^2\)\(^8\)\(^5\) It is equally impossible for the European Union as a whole to get off of fossil fuels without nuclear or solar in other people’s desert.\(^2\)\(^8\)\(^6\)

\(^2\)\(^8\)\(^4\) Idem, p.103.
\(^2\)\(^8\)\(^5\) Ibidem, p. 109.
It is safe to conclude that the right choices and right policies asked for in the previous chapter significantly overlook renewable potential and that the energy transition towards renewable energy in a short time span is highly unlikely due to the sheer scale of our energy use and the geographical space that wind and other renewables require. It does not mean that renewable energy has nothing to offer. It can seriously contribute to the fuel mix of the future but it does not mean that conventional energy sources will become superfluous.

**Load factor**

There is another factor that imposes a limit on the use of so-called intermittent or variable energy sources such as wind and solar. A 1000MW wind farm does not produce the same amount of power as a coal or nuclear power plant. A conventional power plant can operate 24/7 but the wind is not always blowing. The differences in load factor has major consequences for the requirements for an energy transition.\(^{287}\) In the summer of 2007 the capacity of the U.S. fossil-fueled stations was about 740GW and they generated 2.88 PWh of electricity. This means that the load factor or capacity factor was about 73% for base load coal fired stations, 92% for nuclear power stations and 25 % for peak load gas fired stations\(^ {288}\) In the same period, wind and solar electricity contributed just 35 TWh (less than 0.9% of the total) with a capacity of 17GW. With this installed wind and solar capacity and actual production, means that the load factor was only 23%.\(^ {289}\) The largest PV plant in Spain has an annual load factor of only 16%.\(^ {290}\)

The wind is not always blowing and solar is for at least half the time ineffective when it is night , and even more ineffective when it is cloudy during daylight. This means that replacing the production of for example a 1000MW base-load coal-fired plant you need to install about 3000MW of wind generation capacity. Then, calculating what is needed for the U.S. to be able to shut down all fossil and nuclear power plants they need to install about 1480 GW of renewable energy. That is 165% of the total generating capacity build in the U.S. between 1950-2007 with all energy sources combined.\(^ {291}\) The 1480GW renewable capacity has to be build between 2011 and 2050 to achieve a 100% renewable energy system. This means that in a 40 year period the U.S. would have to install 65% more than what was built over a 60 year period while going against market forces. Claiming that it is impossible is not

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\(^ {287}\) Base-load refers to the level below which demand never falls. Peak-load refers to the level of demand in peak times only such as during hot days in the summer due to air conditioners.


correct since it is unclear what will happen in the next years but it is safe to say that it will be a huge undertaking with great financial risk

**Intermittency**
The problem of a variable load-factor with wind energy as explained above creates problems with the balancing of the electricity network. The electricity must be maintained at the same voltage at all times. This need for balancing has great impact of the potential of wind energy and its potential to reduce carbon emissions. Peter Lang, a retired engineer with 40 years of experience in energy R&D who provides policy advice to the Australian government, made an analysis of the amount of greenhouse gas emissions reduced by wind power and the cost of the emission reduction.²⁹²

Wind power output is exponential to the wind speed. A small drop in wind speed causes a large drop in output. For example a wind speed drop from 9 m/s to 7 m/s halves the electricity output. To compensate for the variability of wind speed there are two options: storing electricity and back-up generation. For the scale that is required storage is less economic than back-up generation according to Lang.²⁹³ Therefore, the focus is on wind production with backup generating capacity. Coal generation is the cheapest form of electricity generation, and therefore in an electricity marketplace coal is the last source that will be displaced when the wind blows. Since coal and nuclear are base load energy sources and cheaper than gas turbines, wind power will firstly displace gas turbines (which are significantly cleaner than coal power in terms of both carbon emissions and other forms of pollution).²⁹⁴

Coincidently, the best energy source to use as a backup for wind power is natural gas. Gas turbines can follow load changes more rapidly than coal or nuclear power plants. There are two types of gas turbines: Open Cycle Gas Turbine (OCGT) and Combined Cycle Gas Turbine (CCGT). OCGT has lower capital costs, higher operating costs, uses more gas and produces more carbon emissions per unit electricity output. But OCGT can follow load changes more rapidly than CCGT and thus produces cheaper electricity in case of low load

²⁹³ Idem, p. 3.
factors. In the case of high load factors CCGT is cheaper. OCGT is the best option for flexible use with a limited load factor and will be used as backup for wind energy.\textsuperscript{295}

Since wind power cannot be called upon demand, it does not reduce the amount of conventional power generation capacity that is required. At times when there is no wind at all, the wind generating capacity needs to be replaced completely by other generators and does not lower the initial investment costs of power generation. Wind is simply an additional investment to the total power generating capacity.\textsuperscript{296}

The backup generators need to keep running on a minimum level, ready to scale up as soon as wind speed drops (called: spinning reserve, compare it with a car running stationary). This adds to the amount of fuel input, operational cost, maintenance and of course produces carbon emissions, albeit not in very large amounts.\textsuperscript{297} Scaling up the gas plant requires extra gas input, just as accelerating with a car requires more gasoline, and thus lowers the plant’s efficiency (the ratio of electricity output/gas input).\textsuperscript{298}

Since the backup plant has lower running time the price of the electricity is inevitably higher. The fixed investment costs to build the plant need to be earned back over a reduced amount of output because of the low load factor. Furthermore, the fuel costs will be higher. Transport of gas constitutes a significant part of the cost price of gas. There needs to be an infrastructure of pipelines capable of delivering at full capacity when required. Since the power plant will not run at full capacity most of the time, the fixed costs of the gas pipelines is spread over less MWh generated by the gas plant, thus further contributing to higher electricity prices.\textsuperscript{299}

The amount of carbon emissions with CCGT is about 0.577 tonne CO\textsubscript{2}/MWh. If wind and OCGT generate the same amount of power (assuming average wind speed) the emissions would be 0.519 tonne CO\textsubscript{2}/MWh. Therefore, the emissions avoided would be 0.577-0.519 =

\begin{thebibliography}{9}


\bibitem{297} Idem, p. 6.

\bibitem{298} Keep in mind that small change in efficiency has large impacts on the amount fuel input and carbon emissions. Consider this example: a coal power station with a capacity of about 600MW and an average efficiency of about 55% uses about 500 tonnes coal per hour and produces about 500 tonnes CO\textsubscript{2} per hour. If it is a base load installation it will run around 8000 hours per year. If the efficiency is lowered with only 1% it will need 500*0.01 = 5 tonnes coal per hour more and produces 5 tonnes per hour more CO\textsubscript{2}. Per year this amounts to 5*8000 = 40,000 tonnes more emissions per year. In its lifetime of about 30 years the power plant will then produce 40,000*30 = 1,200,000 tonnes more emissions.

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0.058 tonne CO₂/MWh. Nuclear energy can reduce emission by more than 750kg CO₂/MWh (compared to a coal plant). The cost for the emissions avoided are calculated by deducting the amount of emissions avoided by wind with OCGT with the CCGT only option, divided by the extra cost of a MWh produced with wind+OCGT. Depending on the range of diverging assumptions on the extra costs by the wind+OCGT option compared with the CCGT option Lang concludes that wind is a very costly option for reducing emissions ranging from $134 to $1149 per tonne CO₂ avoided. The cost of a tonne CO₂ avoided with nuclear is about $22. A government imposed price or tax on carbon emissions is not included in these calculations.

Regarding the intermittency problem, it has been suggested that the problem can be reduced by combining wind parks with solar PV in the same geographical area so that they can complement each other. To put it simple, if the sun doesn’t shine but the wind blows (or the reverse), we have stable electricity supply and don’t need a gas turbine as backup. While this may be true at some occasions at some locations, there will still be situations when there is no wind and no sun thus not reducing the required backup generation capacity. The possibilities for solar PV and wind parks are also inversely correlated in Europe for a large part: solar in the south, wind in the northwest. Verbong and Geels from Eindhoven University of Technology observed that there have already been European blackouts noticed due to intermittency of renewable energy. The general conclusion that can be drawn from this analysis is that wind energy does not reduce the required investments in conventional power plants. It does not reduce the dependency on fossil fuels, mostly gas, and it only reduces emissions to a small extent against a high price, if energy consumption is remains the same.

**The case Denmark**

In the previous sections several aspects of wind energy are analyzed such as the scale, intermittency and the difficulty to integrate it in the electricity infrastructure. Denmark is considered the leader in wind energy development and is therefore an excellent case for further inquiry. The benefits of wind energy for Denmark are several. The reputation of Denmark is positively influenced. Denmark received praises in the media because of its

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300 Idem, p. 12.
301 Ibidem, p. 10.
9
development of renewable energy and their leadership towards a sustainable future. Hannah Sentenac from Fox News says that Denmark is pointing the way. The U.S. has been outclassed and Denmark has now become a leader in the field of renewable energy.\textsuperscript{305} Thomas Friedman from \textit{The New York Times} states “If only we could be as smart as Denmark.”\textsuperscript{306} The European Union praises Denmark for already providing 18\% of electricity demand with wind energy.\textsuperscript{307} The production of wind electricity increased from 15,000 terajoule in 2000 to 24,000 terajoule in 2009. This is an increase of 160\%.\textsuperscript{308} The Danish wind industry is profiting greatly from this reputation. Vestas, the Danish wind turbine manufacturer is the largest wind energy company in the world with revenues of almost $7 billion. It has offices all around the world and employs 23,000 people.\textsuperscript{309}

The large increase in wind energy did not make Denmark a frontrunner in Europe in terms of reducing carbon emissions. In the same time period from 2000 to 2008 that wind production increased 160\%, coal consumption in Denmark stayed at the same level.\textsuperscript{310} The largest absolute emission reductions in Europe between 1990 and 2006 took place in Germany and the U.K. Between 2005 and 2006 emission reduced 0.3\% in the EU with the largest absolute reductions in France, Italy, Spain and Belgium. Denmark together with Poland and Finland on the contrary, experienced the largest \textit{increase} in carbon emissions.\textsuperscript{311} Between 1990 an 2006 carbon emissions increased with 2.1\% in Denmark. The European Environment Agency concludes that emissions in Denmark in 2008-2009 were above the Kyoto target.\textsuperscript{312}

The figures for absolute carbon emissions are of course important for atmospheric concentrations of carbon dioxide, it is not the best determinant to measure ‘how good a country is doing’ in terms of energy efficiency and clean energy. There is a strong correlation between economic growth and energy use. Economic growth leads to a growth in energy use so the factor economic growth needs to be included. Carbon emissions in terms of total electricity production decreased in Denmark. One kWh of electricity sold in 1990 amounted

\begin{thebibliography}{99}
\item European Commission, \textit{Renewable energy road map. Renewable energies in the 21\textsuperscript{st} century: building a more sustainable future}. Brussels, 2007, p. 111
\item \url{http://en.wikipedia.org/wiki/Vestas}. Accesses July 14, 2011.
\end{thebibliography}
to 937 grams of carbon emissions. In 2009 this was reduced to 567 grams. The U.S. Energy Information Administration published world carbon intensity statistics expressed in tonnes of carbon dioxide emissions per thousand (2000) U.S. dollars GDP. Denmark’s carbon intensity decreased from 0.63 in 1980 to 0.34 in 2000 and hovering between 0.30 and 0.35 ever since. This is a decrease of 47% since 1980 but without a decrease in the last decade. Thus while wind energy production more than doubled in the first decade of the twenty-first century, it did not lead to a significant decarbonization of the Danish economy. Over a thirty year period Denmark did only slightly better in terms of decarbonization speed than ‘gasoline guzzling’ U.S.A. that went from a carbon intensity of 0.93 in 1980 to 0.52 in 2006 which is a decrease of 44% during the same period. The decarbonization speed is a relative term.

In absolute terms Denmark is a more energy efficient economy emitting less carbon dioxide per dollar GDP. To the extent this is caused by policy measures or by geographical and climatological factors is unclear and might be worth further research. The U.S. has for example more extreme weather conditions with cold winters in the north and hot summers in the south, both seasons demanding a lot of energy (heating and air conditioning). Also because of the size of the country and a low population density in some areas, the U.S. has probably more long distance transport e.g. travel kilometers per person per year (or travel kilometers per dollar GDP) and more long distance transport of products and materials.

The Danish centre for political studies CEPOS did a controversial study to the Danish wind sector and observed that the Danish electricity system is still overwhelmingly dependent on large scale power plants for stabilization of the electricity system. The European Union praises the high contribution of wind energy to Danish electricity demand. CEPOS states that it is true that Denmark generates about the equivalent of about 19% of demand with wind energy. This does not mean that wind power contributes 19% of Danish electricity demand. On average 57% of wind electricity generated in West Denmark and 42% from East Denmark is immediately exported to Norway and Sweden that use hydro

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315 CEPOS has been accused of accepting funding from the U.S. oil and gas industry to conduct this study. The study is by some believed to be aimed at discrediting the benefits of wind. However, the director of CEPOS stated in an interview in the Copenhagen Post that the conclusions of the report were arrived upon independently. Story retrieved from [http://www.cphpost.dk/business/119-business/48553-oil-industry-behind-critical-wind-energy-report.html](http://www.cphpost.dk/business/119-business/48553-oil-industry-behind-critical-wind-energy-report.html). Accessed July 14, 2011.
317 Idem, p. 9.
power plants that are very easily turned up or down and can basically store up Danish wind-electricity. Because of this, wind contributes about 4-12% of electricity demand, depending on the amount of rainfall.\textsuperscript{318} In 2003, which was a very dry year, 84% of wind electricity was exported. Fortunately for the Danish wind industry, the Scandinavian hydropower plants were already built and paid for, as were the interconnectors between Denmark and Norway (950 MW capacity) and Denmark and Sweden (600 MW capacity) and therefore Denmark can access the hydro storage at low capital cost.

The specific circumstances in Denmark that create a greater technical and financial feasibility to integrate large scale wind energy into the system are not repeatable somewhere else since there are no hydro storage or export possibilities for every country.\textsuperscript{319} The availability of the existing infrastructure that didn’t need to be build by the wind industry hides the financial costs of wind energy if the system were to be replicated in other countries. The technology required for Denmark to have the same wind capacity and being able to use all that electricity within the country is yet to be invented.\textsuperscript{320}

In the previous chapter it was observed that some parties in the energy transition debate misuse the terms ‘competitive’ and ‘economically viable’ grossly exaggerating the real commercial value of renewable technologies. Wind power in Denmark still depends on continuing production subsidies with wind electricity being almost twice as expensive as the average spot price of electricity.\textsuperscript{321} And as always there is no such thing as a free lunch: Denmark has the highest electricity prices for households in Europe. The electricity price in Denmark is about 25% higher than in the Netherlands and more than double than in France.\textsuperscript{322} Worldwide Denmark is only surpassed by Japan, a country that has virtually no natural resources. A significant part of the price of Danish electricity is taxation, which is used to subsidize wind energy. The export of wind electricity to Norway and Sweden and the importing of hydro electricity contributes to high electricity prices in Denmark. Exports of electricity is often a low price while the importing of hydro is usually more costly.\textsuperscript{323} The subsidy on wind electricity is carried away when it is exported. It is estimated that the total value of exported subsidies between 2000 and 2008 is about a billion Euros, paid for by the

\textsuperscript{318} Ibidem, p. 11.
\textsuperscript{319} Centre for political studies, \textit{Wind energy: the case of Denmark}. Copenhagen, 2009, p. 11.
\textsuperscript{320} Idem, p. 25.
\textsuperscript{321} Ibidem, p. 8.
\textsuperscript{323} Centre for political studies, \textit{Wind energy: the case of Denmark}. Copenhagen, 2009, p. 16.
Danish households.\textsuperscript{324} It has to be noted that the net result for Denmark in financial terms could be positive when the Danish political support for wind energy helped Vestas become the world leader in wind energy it now is.

The amount of reduced carbon emissions is very limited in Denmark. Most of the wind electricity that is exported to Norway and Sweden do not replace fossil fuels since most of the balancing in those countries is done with hydro plants that do not emit carbon dioxide. At the same time in Denmark doesn’t have a system yet where OCGT is used as backup. The bulk of electricity generation in Denmark is done with coal-fired Combined Heat and Power plants (CHP) producing electricity and heat at the same time. These CHP plants cannot be turned off if there is an oversupply of wind electricity because they have an obligation to provide heat at the same time.\textsuperscript{325}

**Innovation**

Several technical difficulties in using large scale wind energy to replace fossil fuels could be overcome if wind technology would advance so that it becomes cheaper than fossil fuels or easier to integrate in the energy infrastructure. Al Gore strongly believes that renewable technology can become cheaper.\textsuperscript{326} Greenpeace believes that – if renewable policies are implemented now - costs begin to decline after 2020 due to declining production costs of renewable technologies. “Renewable energy 24/7 is technically and economically available, it just needs the right policy and commercial investment to get things moving.”\textsuperscript{327} In his speech Al Gore refers to Moore’s Law to justify his optimism. Since the 1960s, computer chips doubled their speed about every two years, called Moore’s Law.\textsuperscript{328} According to Smil “this helped create a warped image of universally accelerating technical progress”\textsuperscript{329}

Smil warns that it is fundamentally and thermodynamically impossible to increase the effectiveness of energy conversion technologies at the speed of microchip development. The photovoltaic effect for example, was discovered in 1839, the first practical photovoltaic cells were made by Bell Laboratories more than a century later in 1954. Today, 170 years after the

\textsuperscript{324} Idem, p. 22.
\textsuperscript{325} Ibidem, p 24.
\textsuperscript{327} Greenpeace & EREC, Energy (r)evolution: a sustainable world energy outlook, 3\textsuperscript{rd} edition. Amsterdam, 2010, p. 40.
\textsuperscript{328} Moore's law describes a long-term trend in the history of computing hardware. The number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years. http://en.wikipedia.org/wiki/Moore’s_law accessed 24 july 2010.
discovery, we still do not have PV cells that can compete with fossil energy technologies. There is no Moore’s law for energy systems and we cannot tell what the price developments will be of renewable technologies vis-a-vis fossil technologies.

Grubler describes a technology life cycle as follows\(^{330}\): a new technology evolves from a highly uncertain embryonic stage with many rejections and hurdles along the way. When a technology is established, the diffusion process starts and the technology undergoes continuous improvement. The technology interacts with other technologies and infrastructures leading to new applications of a technology. In the end, improvement potential is exhausted, negative externalities become visible and the diffusion stops. This moment is a window of opportunity for alternative technologies.

It is difficult to determine if we are now experiencing a window of opportunity for the widespread diffusion of renewable. Future technological innovation in fossil technologies could make fossil fuels more competitive in relation to renewable alternatives. The costs of finding oil in the U.S. for example decreased 40% over just a four year period between 1992 and 1996.\(^{331}\) Jepma and Nakicenovic describe several R&D projects in coal technology that can significantly increase the efficiency of coal-fired power plants while reducing carbon emissions by 15-33%.\(^{332}\) Another technology recently introduced is CO\(_2\)EOR (Enhanced Oil Recovery) where CO\(_2\) is pumped into oil wells to increase the pressure in an oil well which makes it possible to produce more oil from a well.\(^{333}\) The CO\(_2\) remains in the well. If this technology would be implemented on a large scale, producing oil would implicate storing CO\(_2\). It is not an energy transition of course but it would reduce carbon emissions.

Technological evolution is not linear. It is uncertain and dynamic.\(^{334}\) Fundamental research in one discipline could easily be construed as applied in a different field.\(^{335}\) A nice example of the uncertainty of innovation is that a breakthrough in generator design for gas turbines in the 1980s was not a result of R&D in energy technology but a spin-off from the aircraft industry in their attempt in making better jet engines.\(^{336}\) Grubler compares technological evolution and biological evolution. Just as biological evolution is the result of


\(^{333}\) Idem, p. 84.


experimentation, the right strategy for technological change is also experimentation with variety. A realistic history of technological innovation would consists mostly of failures. In many cases there are several solutions to a problem but it is always uncertain which is the best taking into account technical, economic and social criteria. Any technological change arises from within the economic system as a result of newly perceived opportunities, incentives, R&D, experimentation, marketing efforts and entrepreneurship. We are used to thinking of material progress as a steady, uninterrupted flow of new and better ideas substituting for older, more primitive ways of doing things. As Rifkin says “human advance is more a trial-and-error process.” The uncertainty of technological change and its inherent unpredictability is reflected for example in climate change models. Different assumptions about improvements in energy efficiency are often the largest source of difference among predictions of the costs of achieving climate objectives.

As already mentioned in Chapter 2, the ECF assumes declining costs for wind energy dependent on the speed of growth of wind capacity which again is dependent on political support for wind energy. Wind will probably improve to some extent. This improvement, or so-called learning curve has the characteristic of rather inflexibility. It is hard to speed up technological development. Scientists cannot be forced to come with an innovation sooner. According to Jepma and Nakicenovic, efforts to speed up innovation and the distribution of technology can have a counterproductive effect when too much pressure is applied on specific stakeholders. For example, implementing environmental standards can be designed to force technological development such as mandating standards that are not yet technically feasible. One can assume that some improvement of existing technologies is always possible, but it is unclear how much. Jaffe, Newell and Stavins conclude therefore that effective environmental standards inevitably have to be unambitious, or run the risk of being unachievable eventually, which can affect political effectiveness of future environmental policy.

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338 Idem, p. 69.
Henderson and Newell state that both innovation and technology adoption are crucial in reaching climate targets. A significant breakthrough in technology and/or associated costs are still required to achieve steep reductions in emissions. A good example of a technology where a breakthrough is required is electricity storage. When we have effective storage technologies, intermittent energy sources such as wind and solar can contribute substantially to reductions in base-load coal emissions of CO$_2$. As mentioned before, the IPCC believes that effective storage technology is of critical importance for the development of new energy technologies. There is uncertainty in the most straightforward technology development programs, if not for the ultimate success of the final designs, at the least for the amount of time it will take for the program to succeed. When some sort of breakthrough is required, as is the case with electricity storage, the uncertainties are magnified and the time frame made increasingly uncertain.

**Conclusion**

Wind is by many proponents of the forced energy transition considered the best option and labeled as the key to Europe’s energy future. Wind is assumed to be able to deliver the scale required to replace fossil fuels and will reduce carbon emissions. Wind cheaper than other renewable technologies but still far more expensive than conventional energy sources. The argument mentioned in the previous chapter that wind is ‘already competitive and economically viable’ does not hold.

There are ambitious targets for wind energy such as the 12% growth target by the IEA, Pickens Plan to make U.S. oil imports superfluous and China’s project of 7000 wind mills. On the grand scale of energy production and consumption these projects do not account much and will not be an absolute replacement of fossil fuels. The total potential for wind and other renewables as calculated in the U.K. is not sufficient to replace fossil fuels totally. The geographical requirements pose a significant risk to the social acceptance of large scale wind development. It is not evident that wind energy can deliver the scale required to replace fossil fuels.

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Load-factor requires about a tripling of renewable capacity compared to current conventional capacity increasing initial capital costs. The technological aspects of integrating an intermittent source as wind further limits its potential. The need for backup generation makes wind very costly and is not (cost-)effective in reducing both the dependency of fossil fuels and carbon emissions. This is shown with the Danish example where large scale wind development led to high electricity prices for Danish households without significant reductions in coal consumption and carbon emissions. Denmark’s carbon intensity did not reduce significantly faster than the U.S. Due to the intermittency and difficulty in integrating wind energy in the energy system it does not efficiently reduce carbon emissions. Specific Danish circumstances with international connectors and hydro storage options in Norway and Sweden are not existent in other countries. The Danish scale of wind energy development cannot automatically be replicated in other countries.

Improving the technology of wind energy or a breakthrough in electricity storage could significantly improve the attractiveness of wind relative to fossil energy sources. Al Gore and Greenpeace for example expect that renewable technology will improve significantly. However, innovation and technological development is highly uncertain. It is impossible to predict how innovation in the wind industry will influence its position vis-à-vis other industries that also continue to innovate. Technological development is a nonlinear process. It is difficult to influence. When a breakthrough is required it is impossible to predict when that technology can become widely available.

This chapter aimed to give a realistic view on the potential wind can play in the energy mix. The conclusions of this chapter are perhaps pessimistic compared to most of the opinions mentioned in the previous chapter. However, that does not mean that we have to be pessimistic about our potential to reduce carbon emissions. The reason we want an energy transition is to reduce carbon emissions now or reduce dependency on fossil fuels in the future. Energy transition is a means to an end, not an end in itself. Perhaps the focus should be on ways to reduce carbon emissions with our current energy system and in ways that do not require radical changes of our energy system with high government involvement, high costs and high uncertainty. In the next chapter I will propose a limited energy transition that will reduce carbon emissions in a cheaper way than renewable energy and does not require reinventing the energy system as EREC proposes, or stop taking distant vacations as the WWF proposes.
4: Low carbon gas & nuclear

In this chapter I will describe an incremental, partial (and admittedly temporary) solution where the amount of financial and technological uncertainty is lower than a policy forced energy transition to 100% renewable call for.

This chapter is about the ‘what’ of an energy transition. What exactly should we do? In the introduction of this thesis it was explained that the focus will not be on the ‘why’ but on the ‘what’ of an energy transition. Several distinctions of an energy transition were explained in the introduction, ranging from minor transitions such as the switch from coal to gas in cooking and heating to major transition such as the Industrial Revolution. As we saw in chapter two about the energy transition debate several parties call for a major energy transition away from fossil fuels, a complete reinvention of the energy system. Chairman of the European Commission Jose Manuel Barroso even calls for a new Industrial Revolution.348

My analysis in the previous chapters raises doubts about the possibilities of a complete energy transition away from fossil fuels in only a few decades because of scale, geographical factors, lifestyle adjustments, financial costs and ineffectiveness of intermittent renewables in reducing carbon emissions. Altogether it is important to realize that whatever energy policy the EU or the worlds’ powerful nations come up with, the fossil-fueled civilization will not come to a sudden end. It will be a prolonged decline, slow exit, and gradual shift onto new sources.349 Furthermore it is important to realize that there is no optimal solution. Climate change as the main driver for energy transition would be the first time in human history that energetic imperatives, especially the economic advantages of higher quality fuels, are not the principal impetus.350 Our poor understanding of the many intricacies involved in this unprecedented anthropogenic impact on our environment requires us to base our actions on imperfect information and to deal with some uncomfortably large uncertainties. Every choice we make is sub-optimal with certain costs, benefits and uncertainty. In previous chapters

sources were mentioned saying that renewable energy is on its way to become the mainstream source of Europe’s energy system in the conceivable future.

In this chapter I work towards an energy transition strategy to reduce carbon emissions. To get to what the best strategy is, I have to make a short sidestep to remind us of the ‘why’. As stated in the conclusion of the previous chapter, an energy system based on wind, solar and other renewable sources is sometimes confused as a goal in itself but it is a means to an end: reduced carbon emissions. If the ‘why’ is reduced carbon emissions and the possibility of a policy forced major transition to wind, solar etc. within a short time span is limited, we have both to broaden our range of options and limit our ambitions to achieve the desired end goal with greater certainty.

Uncertainty

The issue of uncertainty of energy related scenario’s has been mentioned in previous chapters. The table below gives an overview of optimistic assumptions made by authors mentioned in chapter 2 and (a few from) chapter 3.

<table>
<thead>
<tr>
<th></th>
<th>Technological</th>
<th>Economical</th>
<th>Sociopolitical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Gore</td>
<td>Totally renewable in 10 years is comparable to the Apollo project.</td>
<td>Fiscal incentives and a carbon tax are enough.</td>
<td>It’s a matter of choice.</td>
</tr>
<tr>
<td></td>
<td>Moore’s Law of computer chips provides an example of potential improvement of renewable technology.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenpeace</td>
<td>There is no need for nuclear energy.</td>
<td>Financial costs of energy transition will reduce after 2020.</td>
<td>Renewables just need the right policies to get things moving.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable energy is already economically viable.</td>
<td>A global carbon emission regime will be installed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>U.S. should be responsible for 36% of global climate policy.</td>
</tr>
<tr>
<td>WWF</td>
<td>There is no need for nuclear energy.</td>
<td>Costs of complete energy transition up to 2050 will not rise over 2% of global GDP.</td>
<td>We don’t have to radically change our lifestyle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>We will have to rethink our current financial system.</td>
<td>We need international cooperation to an unprecedented level.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Financial requirements are $3.5 trillion a year.</td>
<td>Meat consumption must be halved by 2050.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Net financial benefit after 2040.</td>
<td>Mobility should be reduced.</td>
</tr>
<tr>
<td>EREC</td>
<td>We have to reinvent the EU’s energy system.</td>
<td>Carbon price will increase to €100 in 2050.</td>
<td>It is not a matter of technology but of making the right choices.</td>
</tr>
<tr>
<td></td>
<td>Renewable energy is already becoming mainstream.</td>
<td>Oil price will increase to $200 in 2050.</td>
<td>Strong public and political support for renewable energy is considered a given in the future.</td>
</tr>
<tr>
<td>EREF</td>
<td></td>
<td></td>
<td>Implementing strong government support scheme should make it possible to</td>
</tr>
<tr>
<td></td>
<td>Renewable energy is already competitive if externalities were to be included.</td>
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<td></td>
</tr>
</tbody>
</table>

74
Market distortions are the main barrier to a renewable energy transition. Have a 100% renewable energy system in 2050.

<table>
<thead>
<tr>
<th>Source</th>
<th>Claim</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACORE</td>
<td>Renewable resource base is large enough for future demand. Technical progress is critical in harvesting that potential.</td>
<td>The obstacles to realizing a major transition are primarily social and political. Sensible policies and social changes should make it possible.</td>
</tr>
<tr>
<td>Delucchi and Jacobs</td>
<td>Full energy transition is technically possible. Large U.S. manufacturing and construction projects and Apollo projects prove that large scale development of renewable energy is possible.</td>
<td>National policies are inadequate. Failing to achieve renewable targets will be considered a policy failure.</td>
</tr>
<tr>
<td>European Union</td>
<td>Wind is the most promising renewable technology.</td>
<td>The energy industry should play its part in the undertaking. Major investments have been made in coal and nuclear so it is also possible with renewable. Boosting renewable energy is good for the European economy.</td>
</tr>
<tr>
<td>Amory Lovins</td>
<td>We can completely stop using oil. Onshore wind power in the U.S can provide all electricity needed now and in the future.</td>
<td>Capital costs of wind will decline by 5% per doubling capacity.</td>
</tr>
<tr>
<td>European Climate Foundation</td>
<td></td>
<td>No painful measures are necessary.</td>
</tr>
</tbody>
</table>

For reasons of clarity I tried to distinct assumptions in the three societal subsystems of technology, economy and politics but there is some overlap of course. I will not try to prove that these assumptions are all false (or true) for the simple reason that it is impossible to predict the future. It is important to realize that the logic behind these assumptions is not linear. As Hoel stated in Chapter 2, a lower price for renewable technology does not guarantee a lower consumption of fossil fuels. It can also not be understood by only focusing on one subsystem. For example, to say that a renewable energy technology is economically viable means that it can supply a product at a price that is competitive in the market for that product. If the product is an exact substitute, such as synthetic fuel oil is for petroleum, then that price must be equal or less than that of the product it is to displace. If some properties of the new product differ somewhat from the existing product, then the price must be such that the consumer would still want to purchase the new product instead of the existing product. Even a huge rise in oil prices might not encourage investment in alternatives for several years, until it became clear that the rise was permanent, not temporary.  

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Technological improvement of renewable energy cannot in itself be trusted as a good mechanism to reduce emissions. Different energy sources are not perfect substitutes of each other. Consumers will pay a premium for superior attributes. Electric batteries for example have several disadvantages over oil that are not immediately resolved when electric driving is cheaper. Oil was twice as costly as coal when its efficiency, convenience and relative cleanliness drove a transition away from coal. The economical improvement of an energy technology (e.g. lower price) does not automatically mean that it will substitute another source if the technical fundamentals are different (e.g. lower energy density, higher intermittency, less comfort in use). Furthermore, sociopolitical preferences also influence energy consuming behavior. The status of driving a BMW or Mercedes-Benz over a Toyota Prius is for many worth paying a financial and environmental premium for. Nuclear energy, while technologically and economically viable is not always popular among politicians and citizens.

A policy objective cannot be dealt with by focusing only on one societal subsystem (technology, economy, politics). As Krupp states in chapter 2, the differentiation of modern societies in subsystems such as the economy, politics and technology results in societal complexity which cannot be controlled from a single center and which may cause uncontrollable externalities. A strategy for an energy transition has to take into account the technological, economic and political variables or perhaps, as explained in chapter 1, does not require strong changes and intervention in Schumpeter Dynamics.

The assumptions in the table above are derived from scenario’s and forecasts. As described in chapter 1, scenario’s and forecasts are worthless in predicting the future but useful to influence current behavior or policies. Policy choices must consider the uncertainty of the outcome. Should we spend vast financial resources now, taking them from other worthwhile areas such as health and welfare, when the outcome could result in higher energy costs and lower economic growth? According to Cassidy and Grozzman, doing so may mean...

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hardship for some people now; if the renewable alternatives do not work out as hoped, hardship for many may result in the future.  

Should we make great effort to see if we can obtain a grand solution to our energy problems, or should we focus our efforts on more short-term technologies even though they may only help us forestall the need for a real solution? Cassedy and Grozzman state that the mix of choices and the emphasis in energy policy may finally depend less on grand questions such as reinventing the energy system or a new Industrial Revolution, but more on immediate concerns.

Because no proposed strategy by the renewable proponents has proven itself and remain hypothetical it seems indeed plausible to make decisions on the short term with known results rather than long term decisions with unpredictable results, especially since the long term unpredictable options have clear negative effects on economic growth (in the short term at least). Decisions that are perhaps technically feasible but have a negative effect on economic growth could risk losing political support in times of economic downturn. As described before political support for renewable energy already seems to be decreasing in OECD countries.

The uncertainty of the effectiveness of policies aiming to increase the share of renewable energy is significant. Sacrificing much now with such a risk that we won’t get the results in the future seems to me a bad idea. Therefore low carbon energy source such as gas and nuclear are viable options. They are not renewable but, as explained in the introduction, that is not a reason to discard them already. Below I will describe why gas and nuclear deserve political support in the attempt to reduce carbon emissions from energy consumption.

I

Gas versus coal
Fossil fuels are often are clustered as one group of sources we have to eliminate from our energy system. In reality there are large differences between coal, oil and gas in terms of carbon emissions and the emission of other pollutants. Coal currently provides 25% of total world energy supply but is responsible for 42% of carbon dioxide emissions. Replacing coal with natural gas (or nuclear for that part) would thus be a significant improvement in

358 Idem, p. 268.
reducing carbon emissions. The efforts to reduce carbon emissions are often combined with
the efforts to reduce pollution of the environment (a very real problem in major Chinese
cities).\textsuperscript{360} Besides reduced carbon emissions, gas and nuclear have several environmental
advantages over coal. A coal power plant emits several other polluters that gas and nuclear do
significantly less or not at all:\textsuperscript{361}

- Sulfur dioxide: causes acid rain,
- Small airborne particles: causes chronic bronchitis, aggravated asthma, premature
dead,
- Nitroce oxide: leads to smog formation which inflames lungs and causes respiratory
illness,
- Carbon mono-oxide: causes headache and places additional stress on people with heart
diseases,
- Mercury: where just 1/70th of a teaspoon in a 25 acre lake makes the fish unsafe to eat,
- Arsenic: causes cancer,
- Small amounts of lead, cadmium, and uranium, all damaging human health.

Perhaps counter intuitively, nuclear energy is not the main source of (human caused) radiation
in the environment. Coal power plants are the world’s major source of radioactive releases
into the environment.\textsuperscript{362} Coal mining releases radioactive radon gas which is confined
underground. Furthermore, burning coal releases amounts of uranium and thorium in the
air.\textsuperscript{363} In chapter three was explained that an intermittent renewable source such as wind does
not replace base-load coal power plants but replaces peak-load generation which is often done
with natural gas. A strategy to reduce carbon emissions should aim at replacing base-load coal
power plants first.

\textbf{Planetary boundaries}

The focus in this thesis so far has been on deciding which energy source to develop in the
near future in terms of carbon emissions. To make better choices on choosing the best next
ergy sources, other parts of the ecosystem, or better yet our planet, have to be taken into

\textsuperscript{360} Jepma, C.J., Nakicenovic, N., \textit{Sustainable development and the role of gas.} 1st ed. Amsterdam: International
Gas Union, 2006, p. 66.

\textsuperscript{361} Union of concerned scientist, ‘Environmental impact of coal power’. Retrieved from

\textsuperscript{362} Rhodes, R., Beller, D., \textit{The need for nuclear power: viewpoint on the world’s challenging energy future.}
May 24, 2011, p. 2.

\textsuperscript{363} Idem, p. 3.
consideration. It is not really the level of atmospheric carbon dioxide that we worry about, it is the climatic changes that is an outcome of increasing levels of carbon dioxide. Basically, the real goal behind reduced carbon emissions is avoiding climate change. This has implications for considering which energy sources to develop in the future. In this section is explained why spatial requirements of different energy sources mentioned in previous chapters have to be included in the energy transition debate.

Lovelock, a scientist and environmentalist perceived the earth as one physiological system with animate and inanimate parts interacting with each other, exchanging chemical components. Lovelock shares a conviction with Ausubel mentioned previously about the spatial requirements of renewables. In Lovelock’s words: “we have to stop using land surface as if it was ours alone. It is not: it belongs to ecosystems that serve all life by regulating the climate and chemical composition of the Earth.”\(^{364}\) It is unclear whether Ausubel’s conviction is also based on the notion of Earth as one interacting system. Ausubel states “To me the essence of green is no new structures, or at least few new visible ones”.\(^{365}\) They both share a preference of an energy system with minimal spatial requirements. Lovelock is focusing on carbon emissions as the most urgent danger to humanity, but he advises against using any more of the ecosystem and land surface than we already do, to grow energy crops for example. The reason is that the ecosystem functions as a regulator of the cycle of chemicals to maintain a stable climate. Lovelock is convinced that “greens should reconsider their naive belief in sustainable development and renewable energy, most of all they must drop their wrongheaded objection to nuclear energy. Even if they were right about the dangers, and they are not, its use as a secure, safe and reliable source of energy would pose a threat insignificant compared to the threat of intolerable and lethal heat waves and sea levels rising to threaten every coastal city of the world.”\(^{366}\) Lovelock continues: “renewable energy sounds good, but so far it is inefficient and expensive. It has a future but we have no time now to experiment with visionary energy sources, civilization is in imminent danger and has to use nuclear energy now.”\(^{367}\) Lovelock is not opposing renewable energy but he feels that the urgency of


climate change is such that we don’t have the time anymore to develop renewable energy technologies.\textsuperscript{368}

The Stockholm Resilience Centre (SRC), a research institute connected to the University of Stockholm further developed this planetary view and connect the carbon emission issue with other ecological issues of equal importance for the quality of life.\textsuperscript{369} The SRC takes the Earth System as a starting point. Earth System is defined as “the integrated biophysical and socioeconomic processes and interactions (cycles) among the atmosphere, hydrosphere, cryosphere, biosphere, geosphere and anthroposphere (human enterprise) in both spatial – from local to global – and temporal scales which determine the environmental state of the planet”. Humans are part of the Earth System, interacting with the other components. Besides carbon emissions the other critical boundaries as defined by the SRC are:\textsuperscript{370}

- Rate of biodiversity loss: \textit{boundary already exceeded}
- Nitrogen cycle (combined with phosphorus cycle): \textit{boundary already exceeded}
- Phosphorus cycle (combined with nitrogen cycle): \textit{approaching limit}
- Ocean acidification: \textit{approaching limit}
- Global freshwater use: \textit{approaching limit}
- Change in land use: \textit{approaching limit}
- Stratospheric ozone depletion: \textit{not exceeded}
- Atmospheric aerosol loading: \textit{not yet quantified}
- Chemical pollution: \textit{not yet quantified}

Shell included this view in their report Signals and Signposts.\textsuperscript{371} For the energy industry, CO\textsubscript{2} reduction is the chief concern and a focus of research and investment, but Shell warns for a too strong focus on solely CO\textsubscript{2}. The climate change issue includes the above mentioned boundaries. Continuing to pursue an environmental policy centered only on carbon emissions will fail to preserve the planet’s environmental stability unless the other defined boundaries are addressed with equal vigor.

The European Commission Directorate-General for Research Information and Communication conducted research into the externalities of different energy sources for

\textsuperscript{368} Ibidem, p. 1011
\textsuperscript{370} Idem, p. 22.
electricity production.\textsuperscript{372} The research calculated the external costs of several variables such as human health and carbon emissions. Surprisingly they excluded the factor special requirements out of the equation. The variable ‘ecosystem’ in the research is measured only by acid deposition and nitrogen deposition. In calculating the impact of energy crops, the factor land use change is not included while we are already approaching the limit according the SRC.\textsuperscript{373}

A strategy that is focused on reducing carbon emissions should take other critical planetary boundaries into account. Reducing carbon emissions by harming other boundaries might worsen the situation. A good example of a correlation between carbon emissions and other planetary boundaries is the ability of the oceans to absorb carbon dioxide. Oceans currently absorb about 25\% of anthropogenic carbon dioxide causing acidification. When ocean acidification rises, it reduces the ability of the ocean to further absorb carbon dioxide in the future and damages marine biodiversity.\textsuperscript{374} Loss of biodiversity can reduce the resilience of an ecosystem to adapt to climatic changes. Ecosystems with a low biodiversity are more vulnerable to disturbances and have a greater risk of undergoing catastrophic regime shifts.\textsuperscript{375} The extinction of the dinosaurs for example caused massive permanent changes in the functioning of Earth’s ecosystems. Conversion of forests and other ecosystems to agricultural and urban land has occurred at such a rate that we are reaching a point where further agricultural expansion cause severe damage to biodiversity and undermines regulatory capacities of the planet.\textsuperscript{376} We are already claiming a significant part of the planet’s space and resources for food production. The use of synthetic fertilizers has significantly increased crop production in the twentieth century but is disturbing balances in nitrogen and phosphorous cycles, causing oxide depletion in the ocean killing aquatic life. It is expected that world population will rise causing food production to place a further burden on the ecosystem. Synthetic fertilizers are made of fossil fuels. About 1.5\% of U.S. natural gas supply is used for fertilizer production.\textsuperscript{377}

\textsuperscript{373} Idem, p. 7.
\textsuperscript{375} Idem, p. 14.
\textsuperscript{376} Ibidem, p.17.
Burning large quantities of wood or energy crops could be more destructive to the ecosystem than using fossil fuels for energy. Researchers concluded that the use of cropland for biofuels actually increased emissions due to land-use change. The environmental impact of deforestation is clearly shown in the following example. Indonesia is the 16th largest emitter of greenhouse gas emissions in terms of energy use, agriculture and waste with emissions of about 500 Mt CO₂ equivalent. Deforestation and land use change in Indonesia amounts indirectly to about 2500 Mt CO₂ emission equivalent making Indonesia the 3rd largest contributor to climate change after the U.S. and China. Brazil would be the fourth largest contributor due to the deforestation of the Amazon rainforest. The large scale use of biomass and biofuels to replace fossil fuels could thus be more harmful to the ecosystem and to climatic stability than the use of fossil fuels.

At this moment there is not a perfect energy source (sometimes jokingly called ‘unobtainium’ by the scientific community) that is clean, cheap, reliable, requires no lifestyle and political changes, does no harm to other planetary boundaries and fits well into our current energy system. Perhaps the future technology of nuclear fusion could be such a perfect energy source. It has the benefits of scale, it does not require large spatial areas, it has no carbon emissions, it is not dependent on meteorological conditions like wind and sunshine, and in contrast to nuclear fission; no significant radioactive waste. The estimated lifespan for nuclear fusion ranges from 60 million years to 150 billion(!) years. But unfortunately, fusion technology is still far from becoming a reality. Solar energy could potentially play a significant role in our future energy supply. The theoretical potential of solar energy is enormous. In the picture below the red squares equal the amount of solar energy that reaches that surface to power the world(the biggest square) the EU and the Middle East and North Africa (the little square).

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There is however a large difference between the theoretical amount of solar energy available and the realistic amount that can be ‘captured’ and converted to commercial use. Just like fusion, large-scale commercial solar conversion is still in its very early stages.384

**Fuel substitution**

With the absence of the optimal solution, the second best solution is to base our choice for the energy sources in the near future on the fact that renewable technology appears not advanced enough at the moment to offer a solution. Betting on possible future technological breakthroughs is a liability. The current financial situation in many OECD countries and limited policy maneuverability are reasons to focus on low-costs solutions. With 42% of carbon emissions coming from base-load coal power plants, focusing on replacing coal power plants should have a priority. A strategy that fits in the current infrastructure is easier implemented than when we first need to reinvent the system or wait for a new Industrial Revolution. Including the planetary boundaries in the strategy is important to prevent negative or counterproductive side effects. Energy sources that require large amounts of land use change are thus at a significant disadvantage.

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The characteristics of natural gas and nuclear energy best fit the principles outlined above. The decarbonization trend as described previously continues with a further transition to gas and nuclear. In the light of the recent problems at the Fukushima nuclear power plant in Japan it could be considered a controversial statement to be in favor of nuclear energy. The analysis in this thesis is a rational choice based analysis based mostly on technological, economic, geographic factors and climatic concerns. Social preferences, public acceptance and democratic processes have been excluded mostly from the previous analysis. Drafting a strategy based on rational and physical factors has inevitably some weaknesses since the political and social implementation might be difficult. Reality is always more complex and chaotic than can be grasped by rationality alone. Just as the renewable promoters can be labeled naïve for their vision of a 100% renewable energy system, it can also be said that the claim for large scale development of nuclear energy is naïve because of public resistance to nuclear energy. The purpose of this thesis is however to draft an energy strategy based on technical, economic and physical factors so it may serve as a focal point for further debate.

**Nuclear**
The majority of the parties in chapter two are either against nuclear energy or deem it unnecessary in the quest for reducing carbon emissions. There are some clear benefits attached to nuclear energy. Nuclear emits about 95% less than coal when calculated over the entire lifecycle. Nuclear is a base-load energy source and is therefore effective in replacing coal-fired power plants. The high energy density of uranium is a great advantage over other fuels. One tonne of nuclear fuel equals about 2 – 3 million tones of fossil fuel. In comparison, one kilogram of wood produces about one kWh, one kilogram of coal about 3 kWh, one kilogram of uranium can produce about 400.000kWh, and with the latest recycling technology this can amount to nearly 700.00 kWh. This extremely high energy density can significantly reduce the environmental impact of mining and transporting the fuel. It was mentioned already that the availability of uranium poses no problems for the next few decades. Furthermore nuclear energy is a relatively cheap solution in reducing carbon emissions compared to renewable alternatives.

Nuclear energy has disadvantages of course. There is the issue of radioactive waste which is hazardous and has to be stored for a long period in underground storage facilities. A 1000MW nuclear plant providing electricity for about a million households generates about 30 tonnes of high radiation waste per year with a volume of 20 cubic meters, roughly the size of two large cars. Over its lifetime of about 40 years this would be 30*40= 1200 tonnes waste. Global high radiation waste of all nuclear plants together amounts to about 3000 tonnes per year. Current nuclear waste remains very hazardous for about 100 years. After that period, it can be stored rather safely in underground storage facilities. Further R&D in nuclear fuel recycling technology could significantly reduce both the quantity of radioactive waste as the duration it remains hazardous.

In energy issues, facts are not absolute but relative. It is impossible to come with convincing arguments that radioactive waste from nuclear energy poses no concern or risk. Radioactive waste is a disadvantage of nuclear energy but before discarding it right away one needs to realize that the alternatives are not free of toxins. The toxicity of coal has already been explained and for example solar energy also produces a lot of toxic waste material. A 1000MW solar PV plant would generate 6850 tonnes of hazardous waste from metals-processing alone over a 30-year lifetime. A comparable solar thermal plant (using mirrors focused on a central tower) would require metals for construction that would generate 435,000 tonnes of manufacturing waste, of which 16,300 tonnes would be contaminated with lead and chromium and is considered hazardous. In comparison with the total hazardous waste produced by industry in the U.S. the amount of waste from nuclear energy is still fairly small. U.S. industry generates about 50,000,000 cubic meter of solid toxic waste per year.

A global solar-energy system would consume at least 20% of the world’s known iron reserves, would require a century to build and a substantial fraction of annual world iron production to maintain.

There is always the fear of an accident at a nuclear power plants such as happened at Chernobyl in 1986 and Fukushima in 2011. This thesis will not argue that the risk of a serious nuclear accident is zero, but modern nuclear power plants as operated in the developed world could never experience a malfunction comparable to Chernobyl. The radiation quantities of

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388 Idem, p. 5.
391 Idem, p. 3.
the Chernobyl incident can be put in perspective. The amount of radiation released is about 5% of total natural background radiation humans are exposed to every year.\textsuperscript{392} The Chernobyl accident killed 31 persons directly and could possibly cause about 30,000 premature deaths over the next 70 years. One dam failure in China directly killed 29,924 people, yet hydro is not considered a hazardous energy source, in terms of fatalities.\textsuperscript{393} Natural background radiation will approximately cause about 50 million premature deaths in the same time span.\textsuperscript{394}

The amounts of deaths per unit electricity production between several energy sources from 1969-2000 has been published by the OECD.\textsuperscript{395} They concluded that coal is the most hazardous energy source and killed 2,259 people in OECD countries and 18,017 in non-OECD countries. China has an especially hazardous coal sector with ten times more fatalities than other non-OECD countries. Their conclusion was that nuclear energy killed 39 people per TWy (terawatt-year) compared to 1285 people for natural gas, 4883 people for hydro and 6742 people for coal.

A study conducted by MIT concludes that public acceptance is the main hurdle for nuclear power. It seems that people do not connect global warming concerns with carbon-free nuclear power.\textsuperscript{396} The researchers observed that there is no difference in the support for nuclear energy between those who are very concerned about climate change and those that are not, clearly indicating that the public is unaware that nuclear reduces carbon emissions. Educating the public about global warming, fossil fuel usage and low-carbon nuclear energy could improve this. MIT noticed an increase in the support for nuclear in the U.S. between 2003 and 2009.\textsuperscript{397} In the EU 46% could make the connection between nuclear and the fight against global warming. Despite this, Europeans don’t see nuclear as an answer to Europe’s energy challenges. A majority of the Europeans believe that the risks of nuclear outweighs the benefits. An OECD study noted a correlation between knowledge of and support for nuclear energy.\textsuperscript{398} Furthermore, there seems to be a correlation between overall trust of the public in government regulators and trust that nuclear power plants can be operated safely.\textsuperscript{399} Finally,
there is also a correlation between trust in the safety of nuclear energy and the presence of a nuclear power plant in a country. However, which comes first is unclear.\textsuperscript{400}

There is the fear that developing nuclear energy will lead to greater risks of nuclear weapons proliferation. Associating nuclear power with nuclear weapons ignores the obvious fact that several countries have developed nuclear weapons without even thinking about producing electricity. The U.S developed the nuclear bomb during World War II but it took more than a decade before they started using that technology for electricity production.\textsuperscript{401}

According to the IAEA, the availability of plutonium for weapons is not dependent on continued civil nuclear power activities.\textsuperscript{402}

Nuclear capacity will probably rise in the future with 61 reactors being built at the moment with another 158 planned. It remains unclear however if it is possible to create a low-carbon energy system that is dominated by nuclear. Nuclear technology has the potential to significantly reduce carbon emissions. The risks and disadvantages of nuclear can be downplayed when compared to the risks and disadvantages of alternatives. There are indications that educating the public might reduce the opposition to nuclear. Tightly linking nuclear energy with reducing emissions among the public might reduce resistance to nuclear somewhat but that won’t necessarily pave the way for a huge increase in nuclear energy. It is questionable if the current reputation of nuclear energy is a practical starting point for politicians to base a nuclear expansion strategy on. An international climate agreement as suggested in chapter four that is specifically focused on carbon emissions might improve the position of nuclear vis-a-vis coal. Natural gas, although less effective in reducing carbon emissions as nuclear, might have a better future.

**Natural gas**

Natural gas is already labeled as a transitional fuel to an energy system based on renewable energy and seems at the moment to have a bright future, be it as a flexible back up fuel for intermittent renewables or. Gas emits about 50% less carbon dioxide than coal.\textsuperscript{403} Generally, gas already tends to be the fuel of choice for power generation wherever access to gas is available and government regulation does not hamper market forces, because of increasing


efficiency of gas-fired technology, the shorter lead times to build a gas plant, low life cycle costs and environmental benefits. The efficiency of gas-fired generation is already higher than coal-fired generation and is expected further to increase in the coming decades. Gas could be both a ‘transitional’ fuel and a ‘destination’ fuel, at least for this century.

The European Gas Advocacy Forum (EGAF) published a report with analytical support from McKinsey & Co about an alternative trajectory to a low-carbon economy with a focus on gas. EGAF developed a model that focuses on low-cost generation electricity with gas and nuclear energy and has only 30-34% of renewable energy in 2050 instead of 100%, with achieving emission reduction of 80%. The advantages of this strategy are significant. Up to €450-550bn less investments are necessary than in the case of a complete transition. Due to the fact that less grid adaptation and geographical space for wind development is required the social acceptance will probably be higher. It allows new (renewable) technologies to mature further before they are implemented.

Households are expected to save €150-250 annually on their energy bill (compared to the electricity price forecasts with renewable energy). Because electricity prices are cheaper, energy intensive industries are less damaged and the EU won’t harm its industrial competitiveness. The gas infrastructure that is required is already in place. Gas turbines can be build in about 3 years, which is relatively quick compared to nuclear which takes about 10 years to build, significantly reducing the risk of investments in gas. A large scale wind farm takes about 6-8 years (including permitting procedures).

If zero carbon emissions is the desire, gas with CCS (Carbon Capture and Sequestration) is cheaper than zero carbon renewable technologies. Carbon capture and sequestration is a technology currently under development. With this technology, carbon emissions from a power plant are captured and stored underground in empty oil and gas fields. Implementing this practice at power plants adds up to the costs of fossil fuels. When

405 Idem, p. 37.
the price of coal, gas and wind is compared, coal is now the cheapest form and wind the most expensive with gas in between. When CCS is used, gas is the cheapest, with wind second and coal the most expensive. See the table below, prices in 2003 $\0$

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Costs $/MWh</th>
<th>Costs $/MWh incl. CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>$26</td>
<td>$61</td>
</tr>
<tr>
<td>Gas</td>
<td>$32</td>
<td>$49</td>
</tr>
<tr>
<td>Wind</td>
<td>$60</td>
<td>$60</td>
</tr>
</tbody>
</table>

Gas with CCS is thus at the moment the cheapest zero-carbon solution. CCS is however not free of public scrutiny. In the Netherlands for example, two demonstration projects of storing CO\textsubscript{2} in an empty gas field met with such public resistance because of fear of accidents, that the government decided to cancel the projects.\011 However, it would be economically wasteful to develop renewable energy if gas with CCS provides reliable low-carbon electricity at a lower price.

Green NGOs and other pressure groups could try to point out that replacing coal and oil with gas is just a ‘trick’ to postpone action and that fuel substitution will slow down innovation towards renewable energy systems.\012 Jepma and Nakicenovic are convinced that a transition to natural gas is a ‘minimum-regret’ option.\013 It is available in the foreseeable future, cheaper than renewable options, cleaner than coal and oil, can significantly reduce carbon emissions, has lower public resistance than nuclear, has lower impact on other planetary boundaries than most renewables and fits in the current infrastructure. The prospects for natural gas are such that the IEA just published a report called *Are we entering a golden age of gas?* where the IEA argues that business as usual will most likely lead to a greater role for natural gas in the near future.\014

**Conclusion**

In this chapter is explained that a strategy for using gas and nuclear to replace coal is a more sensible option than relying on pushing for renewable energy. The focus is not on replacing

\begin{itemize}
\item \010 Jepma, C.J., Nakicenovic, N., *Sustainable development and the role of gas*. 1\textsuperscript{st} ed. Amsterdam: International Gas Union, 2006, p. 46.
\item \012 Jepma, C.J., Nakicenovic, N., *Sustainable development and the role of gas*. 1\textsuperscript{st} ed. Amsterdam: International Gas Union, 2006, p. 96
\item \013 Idem, p. 35.
\item \014 IEA, *Are we entering a golden age of gas?* Paris 2011.
\end{itemize}
finite resources with infinite resources, but on reducing carbon emissions, which changes the range of energy sources to choose from.

Energy is not only about joules and kWh’s, it is interconnected with other elements of our ecosystem as explained by the SRC. An energy transition strategy should take into account potential damages done to other parts of the ecosystem that have an impact on climatic stability. This factor could increase the negative externalities of energy crops and energy sources with large spatial requirements. A research project by the European Union calculated the external costs of different energy sources, however the factor space was excluded from the research.

Special attention is given in this chapter to coal. Fossil fuels cannot be clustered as one. There are large differences between coal, oil and gas. Coal is the largest emitter both of carbon emissions, nuclear radiation and other pollutants. A strategy aimed at replacing base-load coal-fired plants will have the largest impact in reducing carbon emissions. Nuclear and gas are best suited to replace base-load coal plants. Nuclear energy is not enjoying public support at the moment. The risks of nuclear energy are perceived higher than the benefits. The societal hurdles for an energy system based on nuclear might be too high for large scale expansion. Gas has better chances for significant growth in the future. Gas can reduce carbon emission from coal plants by 50%. It has a flexible load-factor, gas turbines are relatively cheap and can be build rather quick. Furthermore, if CCS is applied, gas based carbon emissions can be reduced to zero at a lower price than renewable alternatives.

This thesis was about analyzing the possibilities for an energy transition to reduce carbon emissions. It turns out that most renewables fail to deliver at this moment the characteristics required for large scale take off. Gas and nuclear seem to be the most promising options at the moment. Interestingly though that the energy-climate debate is for a large part aimed at promoting renewables and dismissing all fossil fuels and nuclear together. It appears as if a renewable energy system became a goal in itself. In the next and final chapter, some analysis will be done on this phenomena; why do we want a renewable energy system as a solution for climate change when an in-depth rational analysis gives a strong sobering effect on renewable potential?
5. Social preference for renewable energy

There is a clear problem presented to humanity: reduce carbon emissions or suffer the consequences of climate change. Yet the problem is apparently not strictly approached with a problem-solving mentality. Why is the focus in politics and society more on a renewable strategy than on a low-carbon strategy? A colorful example of this way of thinking is the title a press release by EREC with the title *The EU needs renewable energy, not low-carbon rhetoric*. In previous chapters other statements were made such as ‘reinventing the energy system’ and ‘we need a new Industrial Revolution’. The exact content of the so-called low-carbon rhetoric is not mentioned in the press release by EREC. Prof. Arthouros Zervos, the President of EREC just states “instead of an undefined low-carbon rhetoric the EU needs a stable framework for renewable energy leading up to 2030 and a vision for 100% renewable energy by 2050”. Why Prof. Zervos thinks that a low-carbon framework is not effective compared to a renewable framework is left explained.

As explained in the previous chapter, the climate change issue needs to be solved by reducing carbon emissions. Switching to renewable energy is indeed a possible strategy but as is shown in the previous chapters, it is in the context of current technologies, economics and the energy system, not likely that it is the best strategy to reduce carbon emissions. In the previous chapter a strategy is outlined what the energy transition should entice if the goal is reduced carbon emissions. This thesis approached the issue from a rational problem-solving perspective, i.e. define the goal (reduce carbon emissions) and then analyze how this could be best achieved. Energy and climate policy making are (like most policy making) social processes shaped by interests, actions, knowledge, norms and values of the actors involved in policy making.

In this chapter we will look into the question why renewable is so broadly perceived as the goal, instead of just a means to an end? Thoroughly answering this question requires a new thesis, while this thesis only devotes one chapter to this issue. This chapter is therefore to

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be perceived as a thought provoking and extended ‘suggestions for further research’ where several directions of research are proposed where the answer to this question could be found.

In this chapter I will regularly refer to the low-carbon option, which is nuclear and natural gas, and the renewable option which is wind, solar, biomass, hydro etc. Environmentalists strongly prefer the renewable option over the low-carbon option. In this chapter I will describe five directions or suggestions for further research namely, ideological factors, the high complexity of energy and climate, our perception of logic and risk, the process of naming and framing and the issue of security of energy supply.

**Ideology**

Energy transitions rely for a large part on the development of new technologies and price developments between different energy sources. Politicians, environmental NGOs and concerned citizens often demand action and policies from the government that contribute to an energy transition. It seems that there is an underlying assumption that an energy transition can be realized through deliberate political action. One gets the feeling that the choice of future energy source is based on political ideologies.

Environmentalism is not politically neutral. The very beginnings of environmentalism in the end of the nineteenth century was more on the right side of the political spectrum. The popular perception was that those who advocated wilderness protection were elitist. Only the rich could afford time and money to “use” wilderness. The poor needed jobs in the woods and sawmills.\(^{417}\) In the 1960s and 1970s this changed. Rachel Carson’s 1962 bestseller *Silent Spring*, Paul Ehrlich’s 1968 bestseller *The Population Bomb* and the 1972 report *Limits to Growth* placed environmental concerns in the middle of public attention. The oil crises of the 1970s firmly established the idea that technological advancement was not always beneficial for society and major (energy) industries were perceived as the wrong-doers. The oil companies reported huge profits in 1973, much to the dismay of the consumer who was waiting in a gasoline-line hoping to get some fuel.\(^{418}\)

Today, environmental concern and the energy debate is at least partially divided on a right-left spectrum: rightwing: fossil and

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nuclear, leftwing: wind and solar.\textsuperscript{419} Bryce sums up the situation in the U.S. as “Republicans like nuclear, Democrats hate nuclear.”\textsuperscript{420} Patrick Moore, a co-founder of Greenpeace, states in an interview that he quit working for Greenpeace because he felt the organization was being hijacked by political activist that were pursuing anti-globalization and anti-capitalist agendas rather than focusing on environmental quality.\textsuperscript{421} 

Matthew Alan Cahn gives an explanation why environmentalism is now predominantly embedded in leftwing politics: “(Lockean) liberal society is fundamentally limited in its ability to resolve the problem of environmental degradation. There are two structural tensions between liberalism and environmental quality. First, liberalism’s emphasis on individual self-interest creates a problematic concept of communal good. Society, as manifest in liberal contract theory, exists not to find some higher good, but to protect individual rights. Communal good is limited to providing a stable environment for individual rights. As a consequence, individual and corporate property rights have consistently overshadowed community claims on resource management. Second, capitalism, as a system of economic production and distribution, has been characterized by a constant drive for expansion in search of increased productivity and profit. The impact of that expansion ethic has been overuse of limited resources and the degradation of our physical environment.”\textsuperscript{422} Thomas Dixon describes three types of environmental thinking: \textsuperscript{423}

- Neo-malthusian
- Economic optimists
- Distributionalist

The book by Ehrlich and the \textit{Limits to Growth} report are examples of Neo-malthusian thinking. Malthus was a reverend that published an article in 1798 called \textit{An Essay on the Principles of Population} where he explains that population growth exceeds increases in food production, inevitably leading to famine and mass starvation, or so-called ‘population

\textsuperscript{419} This seems to be the case for Dutch politics with the left a strong proponent of renewable and anti-nuclear, while the Christian Democrats at the centre of the political spectrum and the rightwing VVD are in favor of nuclear.


\textsuperscript{422} Cahn, M.A., \textit{Environmental deceptions: the tension between liberalism and environmental policymaking in the United States}. 1\textsuperscript{st} ed. Albany: State University of New York Press, 1995, p. 1

checks. Ehrlich’s *Population Bomb* and the *Limits to Growth* report became central to Neo-Malthusian thinking in the 1970s. Both predicted that unrestricted expansion of human civilization will lead to catastrophes due to limited resources before the year 2000. Both predictions did not become reality. Technological advancement for example, significantly increased food production forestalling the doomsday predictions by Neo-Malthusians. This belief in technological advancement is what Dixon labels ‘economic optimists’. The economic optimists are prevailing in global economic institutions such as the World Bank’s approach to resource problems in developing countries, and in business-oriented newspapers, magazines and books. The Neo-Malthusian view prevails more in mass media and in the green movement. The debate between Neo-Malthusians and economic optimists is a never-ending race between the Malthusian trap when human expansion exceeds the carrying capacity of the earth versus a more optimistic view that technological advancement continues to beat the Malthusian trap.

The distributionalist perspective focuses on poverty. Developing countries are likely to be affected sooner and more severely than developed countries by environmental problems. They tend to be much more dependent on environmental goods and services for their economic well-being and lack the resources to buffer themselves from the effects of environmental damage. The official definition of sustainable development as set by the Brundtland report *Our Common Future* of 1987 is perhaps a strong example of the distributionalist way of thinking: “development that meet the needs of the present without comprising the ability of future generations to meet their own needs”.

A powerful example of Neo-malthusian thinking can be found on the website of the Sierra Club, a prominent American environmental organization. They state on its website that it aims for the “development of adequate national and global policies to curb energy over-use and unnecessary economic growth.” As Bradley stated before, we have 1.6 billion people at this moment lacking access to electricity and could clearly benefit from economic growth. Bryce states cynically that “there haven’t been many countries in Africa that have expressed...

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426 Idem, p. 4.


concern about using too much energy or about too much economic growth. If Bradley and Bryce can be labeled as distributionalists is unclear at this point, but it is clear that the aim of the Sierra Club is to limit development.

Bradley is highly critical of environmentalists. He cites Ehrlich who believes that giving society cheap, abundant energy would be the equivalent of giving an idiot child a machine gun. And when nuclear fusion seemed briefly to be the ultimate renewable energy Jeremy Rifkin told the Los Angeles Times that nuclear fusion was “the worst thing that could happen to our planet.” He therefore asks the question if “the risks of anthropogenic climate change outweigh the risks of climate change policy?” And if “the real concern and mission of mainstream environmentalism is to reduce climate change and eliminate the risk of nuclear radiation, or to arrest the high levels of global development and population sustainability that increasingly abundant energy affords?” Bradley perhaps has quite a harsh opinion on environmentalist but it does appear as if environmentalists are opposing human development in general. This correlates with Cahn’s explanation that environmentalists perceive capitalism as part of the problem.

But how does the above description of environmental thinking relate to the question: low-carbon or renewable? The National Research Council observed an ideological bias already at the end of the 1970s as they state that the opposition to nuclear is caused by the fact that nuclear power symbolizes big government, big business, and an impersonal, centralized bureaucracy unresponsive to local needs and sentiments, while solar energy for example, represents a “natural” form of energy that can be controlled by average citizens. Rhodes gives a comparable explanation “the antinuclear movement is not about environmental issues, otherwise they would be pronuclear. It is more a movement of skepticism and hostility towards large corporations. The antinuclear movement is as much concerned about the centralization of energy production as it is about anything else.” The fact that nuclear

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energy is linked to the development of the atomic bombs and the arms race and risk of nuclear war deeply affected people’s attitudes towards nuclear energy. Decentralized solar technologies however, if deployed on a scale sufficient to provide a significant fraction of national energy needs, will require a large-scale mass production, distribution, and service industry that might not look so different from existing electric- and fuel-distribution networks.

In this paragraph the suggestion is made that the preference of renewable over low-carbon has a political ideological component. The leftwing embeddedness of environmental concerns causing it to be skeptical of big business and capitalism and preferring small scale decentralized wind and solar installations. Jepma and Nakicenovic were quoted in the previous chapter stating that replacing coal and oil with gas could be perceived as a trick by the fossil industry to postpone renewable investments. This could indicate that people who are environmentally concerned are more likely to be critical of capitalism and big business. The low-carbon option of nuclear and natural gas will be performed by big businesses, the same businesses that are now dominant in the energy sector. Therefore the low-carbon option might not have the same appeal as small-scale wind and solar installations owned and managed by local communities. This analysis is far from complete however. Further research on the relation between, and causation of, political ideology and energy source preferences needs to be done.

**Complexity**

One of the core characteristics of both the energy system and the ecosystem is that they are very complex. The problems arising out of energy use and the interaction with the ecosystem are not just ‘problems’, but complex *predicaments* comparable to other so-called intractable problems we are now facing (e.g. war, violence, poverty, epidemic disease). The challenges of complex systems are predicaments, not problems, because, since they are not mechanical, they cannot be ‘fixed’ or ‘solved’. Alternative, non-mechanistic approaches must be used to deal with them. Complex predicaments (like running a business, or coping with economic, energy or ecological collapse) have these four characteristics:

- The number of variables that can have an effect on the system/situation/event is infinite.

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435 Idem, p. 34.
437 Idem.
• Most of these variables are unknown or unknowable; only the most obvious ones can be listed or diagrammed.
• The relationships between cause and effect in the system are unfathomable; at best you can notice correlations that may or may not be meaningful.
• It is impossible to predict the outcome of an intervention in the system/situation/event (or when Black Swan events and other unforeseeable interventions will occur) 438

In the 1990s environmental concern was including all environmental problems: pollution, biodiversity, land degradation etc. Environmental security encompasses an almost unmanageable array of sub-issues, especially if we define “security” broadly to include general physical, social and economic well-being.439 Environmental systems are chaotic and non linear. Humans do not have infinite ability to understand and manage nonlinear, multivariate, chaotic processes of ecological-social systems.440 Today, in 2011, the core issue is carbon emissions. Perhaps the total picture of energy-environmental interaction was just too complex. There is no such thing as ‘energology’. Energy is in essence a multidisciplinary approach, it encompasses the economy, ecology, sociology, politics and many facets of the exact sciences among which: thermodynamics, aerodynamics, electronics, chemistry, petrochemistry, physics, geophysics, nuclear physics, civil engineering, agricultural science, meteorology, climatology etc. Most experts talk about their own expertise which seldom gives the full picture of the total energy-environment interaction. It is virtually impossible to be an ‘energologist’. This complexity and elusiveness could have its effect on the way the energy transition debate is conducted. Making it even more complex, the energy-environmental debate has to deal with different time spans causing technological, economical, political and ecological variables to change in uncertain ways. Are we deliberately stripping the debate of its complexity to make it more accessible to society and politics? CO₂ is bad, big business is bad, renewable reduces CO₂, renewable is local, ergo renewable is good. A logic that every layman can understand.441

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440 Idem, 124
441 Perhaps I’m doing the same by presenting the reader two choices in this thesis: low-carbon strategy or renewable strategy while there is an infinite amount of options in between.
Logic and Risk

There are two distinct types of logic a person or organization can apply in deciding how to behave. First there is the logic of consequence that is a rational approach where the consequences of decisions are analyzed. The logic of appropriateness is a perspective that sees human action as driven by rules of appropriate or exemplary behavior, organized into institutions. Actors seek to fulfill the obligations encapsulated in a role, an identity, a membership in a political community or group, and the ethos, practices and expectations of its institutions. Embedded in a social collectivity, they do what they see as appropriate for themselves in a specific type of situation.”

It is a vision of actors following internalized prescriptions of what is socially defined as normal, true, right or good, without, or in spite of, calculations of consequences and expected utility.

Perhaps, complexity makes us prefer to act on the logic of appropriateness instead of logic of consequence because analyzing and weighing the effects of policy choices is too difficult: ‘I don’t know how it all works so I choose what is appropriate and how I always chose and that is that capitalist expansion is bad and renewable is good because that reduces CO₂.’ Perhaps the concept of path dependency provides some explanatory insights. Path dependency means that (organizational) decisions are conceived of as historically conditioned. The modern environmental movement was born out of Neo-Malthusian doomsday predictions and embedded on the left side of the political spectrum. They might continue to base their actions and decisions on the same premises that they were founded on.

Speculating further of the logic of appropriateness, and this is purely hypothetical: Is it imaginable that applying the logic appropriateness leads to a greater extent of political correctness where:

- in a democratic society where politicians are confronted with public contestation and;
- the public has simplified the issue to ‘renewable reduces CO₂, and;
- the public clearly asks of its leaders to ‘do the right thing’;

That this could lead to a society that becomes more risk averse? This dynamic could create opposition to nuclear energy. Being in favor if nuclear energy requires a rational cost-analysis perspective. The risks of nuclear energy cannot be zero (as with any other technical projects). When the logic of consequences is applied, the risk of nuclear energy is compared to the

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443 Idem, p. 3.

benefits of having reliable zero-carbon base-load energy. Dick Taverne, a former British politician states “I am a pragmatic environmentalist. Risk must be weighed against benefit. I want analysis of the risk of damage to the environment to be based on evidence and recommendations for remedial action to be based on science rather than emotion. I care not only about the environment but about reason.” However, when the public opposes nuclear because of fear, it is hard for a democratic elected politician to tell the public that their fears do not outweigh the benefits.

Aaron Wildavsky was a political scientist and specialist in risk management. Wildavsky discovered that knowledge of the known hazards of a technology does not determine whether or to what degree an individual thinks a given technology is safe or dangerous. The most powerful factors related to how people perceive risk apparently are “trust in institutions” and “self-rated liberal and conservative identification.” In other words, these findings suggest strongly that people use a framework involving their opinion of the validity of institutions in order to interpret riskiness. Adherents of a hierarchical culture will approve of technology, provided it is certified as safe by their experts. Competitive individualists will view risk as opportunity and hence will be optimistic about technology. Egalitarians will view technology as part of the apparatus by which corporate capitalism maintains inequalities that harm society and the natural environment.

The results are that egalitarians fear technology immensely and think that social deviance is much less dangerous. Hierarchists, by contrast, think technology is basically good if their experts say so but that social deviance leads to disaster. And individualists think that risk takers do a lot of good for society and that if deviants don’t bother them, they won’t bother deviants; but they fear war greatly because it stops trade and leads to conscription. Thus, there is no such thing as a risk-averse or risk-taking personality. Think of a protestor against nuclear power. He is evidently averse to risks posed by nuclear power, but he also throws his body on the line (i.e. takes risks in opposing it by protesting). However there seems to be a risk-averse bias in society as Wildavsky explains that a great many people care more about avoiding loss than they do about making gains. Therefore, they will go to considerable lengths to avoid losses, even in the face of high probabilities of making

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447 Idem.
448 Ibidem.
considerable gains. Taverne describes this possible risk-averse bias as: “Possible risks from new developments loom larger in the public mind than possible benefits.”

The above description of risk perception might correlate with Bryce’s statement that conservative (hierarchic/competitive) Republicans like nuclear energy and that liberal (egalitarian) democrats hate it. Holsti has the impression that many of the theoretical arguments in debating environmental issues are really debates about optimism and pessimism, our very general outlook toward the world in which we live. Dixon suggest, correlating with Wildavsky’s observations, that such perspectives reflect deep personal orientations to the world more than empirical evidence. Optimistic personalities are more prone to the economic optimists type of environmental thinking. Pessimists lean to the Neo-Malthusian type. Again, further research is required on, for example, what the effect of logic of appropriateness is on the risk-averseness of society or, whether logic of consequence would lead to the preference of the low-carbon nuclear and gas option, and logic of appropriateness would lead to the renewable option.

**Naming & Framing**
Language is not politically neutral. It influences how we perceive reality. The political correctness to choose for renewable as suggested in the previous paragraph, can it be explained by linguistics? ‘Framing’ is the process of selecting, organizing, interpreting and eventually giving meaning to reality and to provide certain boundaries of analyzing and acting on a certain problem. ‘Naming’ is the process of labeling a perceived problem. How we label something strongly influence how we perceive something. Naming and framing processes together have a large influence on how we perceive a problem and how policy is socially constructed in the process. They also lead to a conceptual coherence of a situation and influences the search for solutions. The use of language is at least considered important

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452 Idem, p. 29.

by some corporation that have software programmes that automatically insert the word ‘sustainable’ before ‘development’ in every document.454

UC Berkeley Professor George Lakoff studied political language of Republicans and Democrats in the U.S. In an interview he explains the power of framing with an interesting example of Arnold Schwarzenegger. “In Arnold Schwarzenegger's acceptance speech for Republican candidacy for governor of California, he said, ‘When the people win, politics as usual loses.’ What is that about? Well, he knows that he is going to face a Democratic legislature, so what he has done is frame himself as the people, while framing Democratic politicians as politics as usual - in advance. The Democratic legislators won't know what hit them. They're automatically framed as enemies of the people.”455 Another example given by Lakoff is the phrase ‘Tax relief’ that came from the White House just after Bush’s inauguration. Use of the word ‘relief’ is not neutral. It implies an affliction. Someone who relieves you from that affliction is a hero. So when tax and relief is combined you get the metaphor that taxation is an affliction, and anybody against relieving this affliction is a villain. Reframing taxation could be done by focusing on the idea that taxes are the price of living in a civilized country with democratic institutions, infrastructure, education system etc. It could just as well be that taxation can be reframed as patriotism: Are you paying your dues to your country?456

Perhaps our attitudes towards renewable or sustainable are also influenced by how it is framed. For example, nuclear is, just as wind, not contributing to climate change in terms of emissions, but it is not considered green, and it is not considered sustainable because uranium is exhaustible. Long term gradual exhaustion of a resource does not have to be a policy driver per se for an issue that has to be solved in the next decades. But framing it as not sustainable (without referring to the two centuries that it might last), could influence public opinion on nuclear and gas.

Perhaps EREC is right, and is ‘low-carbon’ just rhetoric and is renewable a clear defined goal. If carbon is the problem, than the phrase ‘low-carbon’ basically suggests: ‘low problem’, like going from a severe illness to being mildly ill. Renewable is a clear concept and is more positioned as being the opposite of the illness (carbon-based energy system). Reinventing the energy system from carbon-based to renewable is perhaps more like going...

456 Idem.
from a severe illness to perfect health. To be true to the fact, natural gas is of course still causing carbon emissions and is perhaps only a strategy to offset the symptoms but not eliminating the cause of the disease (which is capitalist expansion and environmental degradation in Neo-Malthusian environmental thinking).

Another interesting example is using language to link the energy transition debate to other societal values. In Dutch politics the Green party just announced a collaboration with the Labour party claiming that politics should be ‘greener and fairer’. By using the term ‘green’ together with ‘fair’ suggests that a green society is a fair society, and it is difficult to argue that you oppose a fair society. Greenpeace uses the same logic. Besides a full energy transition they call for ‘equality and fairness’ in the distribution because one third of the world has no access to electricity while industrialized nations use more than their fair share. Green energy in most cases however means a higher energy bill, disproportionately hurting the poor, and might not be contributing to a fairer society.

Furthermore, in the societal perception there seems to be an unavoidable trade-off between short term wealth by the use of fossil and nuclear energy, considered cheap and a long term moral responsibility involving increased investments in renewable energy. Short term wealth is considered the exact opposite of long term (environmental) well-being. While there are situations where this trade-off is present, it is not always a binary issue. Imagine for example if humanity in 1900 decided to stop striving for short term wealth. What would this have done to the economic growth and technological innovations society today enjoys such as internet, automobiles, airplanes, increased agricultural production, medical technology etc. (although these developments could be considered exactly the causes of today’s environmental problems). Companies aim to develop technologies that increase the efficiency of, for example, combustion engines and power plants for the purpose of making money but this process can have a positive effect on future well-being.

Needless to say, the above examples are meager proof that our perspective on energy issues is influenced by linguistic constructions. However, further research could possibly uncover several unconscious biases in thinking about energy use and the environment caused by language more than hard facts.

Security of supply
Admittedly, reducing carbon emissions is only a small part of the total spectrum of energy policy. Besides climate change, energy policy is also about security of supply, energy prices, innovation, economic growth and green jobs. A thesis focused only on reducing carbon emissions and excluding concerns of security of supply, peak oil, and the prospect of resource wars, is inevitably a narrow view of what constitutes energy policy.

Perhaps a motivation behind the push for renewable energy is the security of supply issue. People could feel that oil dependency creates unwelcome military tension in the Middle East. Gas supplies that can be cut off such as happened between Russia and the Ukraine in the beginning of 2006 could also contribute to the desire for domestically produced (renewable) energy. Security of supply is for many countries a serious issue in formulating energy policy. Security of supply creates a whole new dynamic to energy policy with uncertain outcomes. The future growth of natural gas is very much dependent on how security of supply issues dominate energy policies. In such a scenario, the desire for self-reliance will probably diminish the preference for gas and could increase the preference for coal, nuclear and renewable. Renewable proponents have argued that indirect subsidies to fossil fuels are better spent supporting renewable technologies. Surprisingly, the military costs of protecting energy supplies overseas are not mentioned regularly while everything indicates that the costs are significant. It is hard however to calculate the direct external military costs of protecting energy sources in other regions. Estimates of U.S. military costs of protection oil flows from the Middle East range from around $6 billion up to $80 billion per year, depending on which costs are directly attributed to protection oil flows, and which are more devoted to political stability in general. Roger Stern, a professor from Princeton estimates the total military expenditures for oil between 1976 and 2007 at almost $7 trillion.

Reducing carbon emissions and having secure access to energy can be both complimenting or excluding each other. In terms of natural gas they could be excluding each other, in terms of renewable energy they could complement each other. In the debate they are not strictly divided as for example Greenpeace states that both climate change and security of

supply are reasons for an energy (r)evolution. Thomas Friedman, author of *The World is Flat* and columnist for the New York Times describes those who combine the goals of reducing emissions and security of supply ‘geo-greens’, people who “seek to combine into a single political movement environmentalists who want to reduce fossil fuels that cause climate change, evangelicals who want to protect God’s green earth and all his creations, and geo-strategists who want to reduce our dependence on crude oil because it fuels some of the worst regimes in the world.” Perhaps, those ‘geo-greens’ have a point and it is important to integrate the two goals into one policy. Especially if the goals are at some points exclusionary, a careful analysis needs to be done on the trade-off between those goals in that specific situation. I invite scholars to develop an approach to energy transitions where security of supply is the main incentive, and compare that to the conclusions from this thesis.

**Conclusion**

In this chapter several directions for further research are outlined for the possible explanation why society has a preference for renewable energy that seems to differ from the pragmatic problem-solving requirement. Firstly, there is suggested that the ideological element in the energy transition debate could influence the preference over energy sources. The modern environmental movement was rooted on the left side of the political spectrum, incorporating Neo-Malthusian thinking which makes it critical of capitalist development. Secondly complexity reduces our ability to grasp the energy-environment interaction fully. There might be a bias that, when we can’t compare the costs and benefits of all policy choices, we choose to do that which we know to be right, thereby ignoring the possible negative consequences of that choice. The logic of appropriateness and path dependency possibly explain that they hold on to their convictions. Fourthly there might be insights to be gained in analyzing the relation between risk-perception and energy source preferences. Furthermore, how the issues are framed can create a bias in our thinking. I highly recommend analyzing the social (perceived) characteristics of energy sources and how this correlates with public opinion. Finally other factors such as security of supply influence the debate and influence energy source preferences. An analysis of the trade-offs between an energy transition strategy to reduce

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carbon emissions and a strategy to secure energy supply could be of value to governments around the world.
Conclusions

This thesis tried to identify which energy sources deserve political support in changing our energy use to reduce carbon emissions. The energy transition debate is analyzed to see whether the assumptions made by several proponents of a forced transition to a renewable energy supply are realistic. At this moment there is a call from many societal and political actors for an energy transition forced by specific policies.

Chapter 1 analyzed the history of energy transitions and which factors caused the preference of one energy source over another. The density and form of energy plays an important part in the preference for an energy source. Specific technologies require energy sources with specific characteristics such as oil for combustion engines in automobiles. The end user has the final say in the development to higher quality energy sources. This leads to the preference of coal over biomass, oil over coal, gas over oil. The trend is towards energy sources with higher energy density. The preference for higher quality energy reduces the carbon emissions per produced unit energy, which is called the decarbonization trend. The previous energy transitions did not constitute a real substitution of a source but the addition of a new source, replacing the previous source only in market share and not in absolute production. Replacing fossil fuels with renewable energy in absolute terms will be harder than previous transitions. An energy transition to renewable energy sources such as wind and solar would be a transition to sources with a lower energy quality, providing less power per m² and with less dependency because of meteorological conditions.

The previous energy transitions were the result of more or less spontaneous processes. These transitions were slow processes covering several decades before an energy source provided a significant part of global energy demand. Energy transitions are the outcome of the development, adoption and distribution of new technologies. The speed of technological progress and distribution is limited which inevitably reduces the speed of an energy transition. A policy forced transition to lower quality energy sources could be significantly harder than spontaneous transitions and possibly taking more time to achieve.

After the oil crises of the 1970s several countries tried to reduce their dependence on oil. They largely succeed in replacing the use of oil in producing electricity. Several countries converted back to the use of coal and especially France was successful in replacing oil with nuclear. Replacing oil with nuclear in electricity production was successful because it did not require a radical change of the energy system. Nuclear fitted in the constellation of centralized
large scale electricity production. As soon as the price of oil dropped in the 1980s the momentum was gone, governments reduced funds for developing alternative and everything returned to business as usual.

The current call for an energy transition entails a preference for energy sources with lower energy qualities and without competitiveness in the market. It is safe to say that it will be a huge effort to achieve an energy transition via policies that goes against the forces that steered the previous energy transitions. This is not how many proponents perceive the energy transition issue. In the second chapter there are several parties that claim it can be done in a limited time period by implementing the right policies. Renewable proponents make optimistic assumptions such as that rich countries are willing to spend more on renewable energy, that the oil price will increase significantly, that industries are willing to invest in renewables, that lifestyle changes and increased international cooperation are feasible, that the international community is willing to invest trillions in reinventing our energy system and that a global regime for carbon pricing will be implemented. A leading role for governments in steering towards a renewable energy system is seen as a necessity by most. A questionable claim is mentioned in the debate is that the energy transition will create more jobs while the necessity in energy transitions is not a job shortage.

There appears to be a strong focus on policies rather than the required technological innovation. Technological advancement is considered sufficient as it is or is expected to improve the competitiveness of renewable energy vis-à-vis fossil energy. Scenarios and assumptions have so often been wrong. Basing a strategy on optimistic assumptions could be risky since the effectiveness might be low. Whether we should want to pursue a goal at great financial costs with so much uncertainty about whether it will pay off in the end is a question that remains to be answered.

Special attention is given to the potential of wind energy. There are several benefits to wind such as no carbon emissions and lower dependence on the import of fossil fuels. Wind capacity has been growing the last decade due to policy support. Future growth levels for wind are uncertain since price developments and policy support are uncertain. Wind will contribute to world energy demand in the future, but using wind to replace a fossil fuel on a global scale might be problematic.

The scale of development required for wind energy to be able to make a fossil fuel superfluous is enormous and poses problems with spatial and material requirements, intermittency problems and the required backup generation. Denmark experienced a great increase in wind capacity. The Danish are receiving international praise and the Danish
company Vestas is market leader in wind technology. However, the development of wind did not correlate with a decrease in fossil fuel consumption and a decrease in carbon emissions. Assumptions are made that wind technology will become cheaper and more competitive but just as any prediction it is impossible to know for sure.

The high levels of uncertainty in many assumptions about energy transitions and renewable energy are a risk and/or liability in seriously following this trajectory. The economic and societal costs of investing heavily in renewable energy is high while there is a significant chance of gaining nothing in return. That is why a low risk temporary solution seems to be a better choice at the moment. Natural gas and nuclear appear at the moment a sensible strategy in replacing high-carbon energy sources such as coal. The risks of failure are lower than the renewable option, the financial costs are lower and the required space and land use change is lower. The main question was to determine which energy sources deserve political support if the goal is to reduce carbon emissions. The answer is natural gas and nuclear.

During this thesis I discovered that the energy transition debate was not conducted on a problem-solving basis. That is why the final chapter is devoted to providing several suggestions for further research in explaining the appeal of renewable energy and the absence of rational problem-solving analysis in the energy & climate debate. In this chapter I suggest that further research is necessary in explaining the role of ideology in energy source preference, the role of complexity in the approach of the problem, the role of logic and risk perception in energy source preference, the naming and framing of the concept of sustainability and the issue of security of energy supply which is, besides climate change, another main driver of energy policy. I welcome research on these topics as well as analyses on effective strategies for energy substitution and to reduce carbon emissions.


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**Websites**


[http://www.guardian.co.uk/environment/2008/nov/10/renewable-energy-alternative-energy](http://www.guardian.co.uk/environment/2008/nov/10/renewable-energy-alternative-energy) on April 26 2011.


http://www.msnbc.msn.com/id/40258541/ns/technology_and_science-space on 19th of November 2010


http://nos.nl/artikel/233554-duizenden-bij-protest-kernenergie.html on April, 20 2011

http://ec.europa.eu/environment/climat/climate_action.htm
http://www.worldwatch.org
http://en.wikipedia.org/wiki/Liberty_ship
www.energietransitieplatform.nl.
http://en.wikipedia.org/wiki/Vestas
http://en.wikipedia.org/wiki/Moore's_law
http://en.wikipedia.org/wiki/Fertilizer
http://en.wikipedia.org/wiki/Our_Common_Future
http://en.wikipedia.org/wiki/Black_swan_theory
http://www.iaea.org/Publications/Booklets/Development/deveight.html
http://www.nu.nl/politiek/2371383/geen-opslag-co2-barendrecht.html
www.clingendael.nl
http://www.youtube.com/watch?v=KUx2hgxXfg&feature=player_embedded

Other

Conversation with Prof. Dr. J. de Wilde on April 15, 2011.