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# A New Take on Energy

A. Manickam, H. Matthee and B. ter Veer

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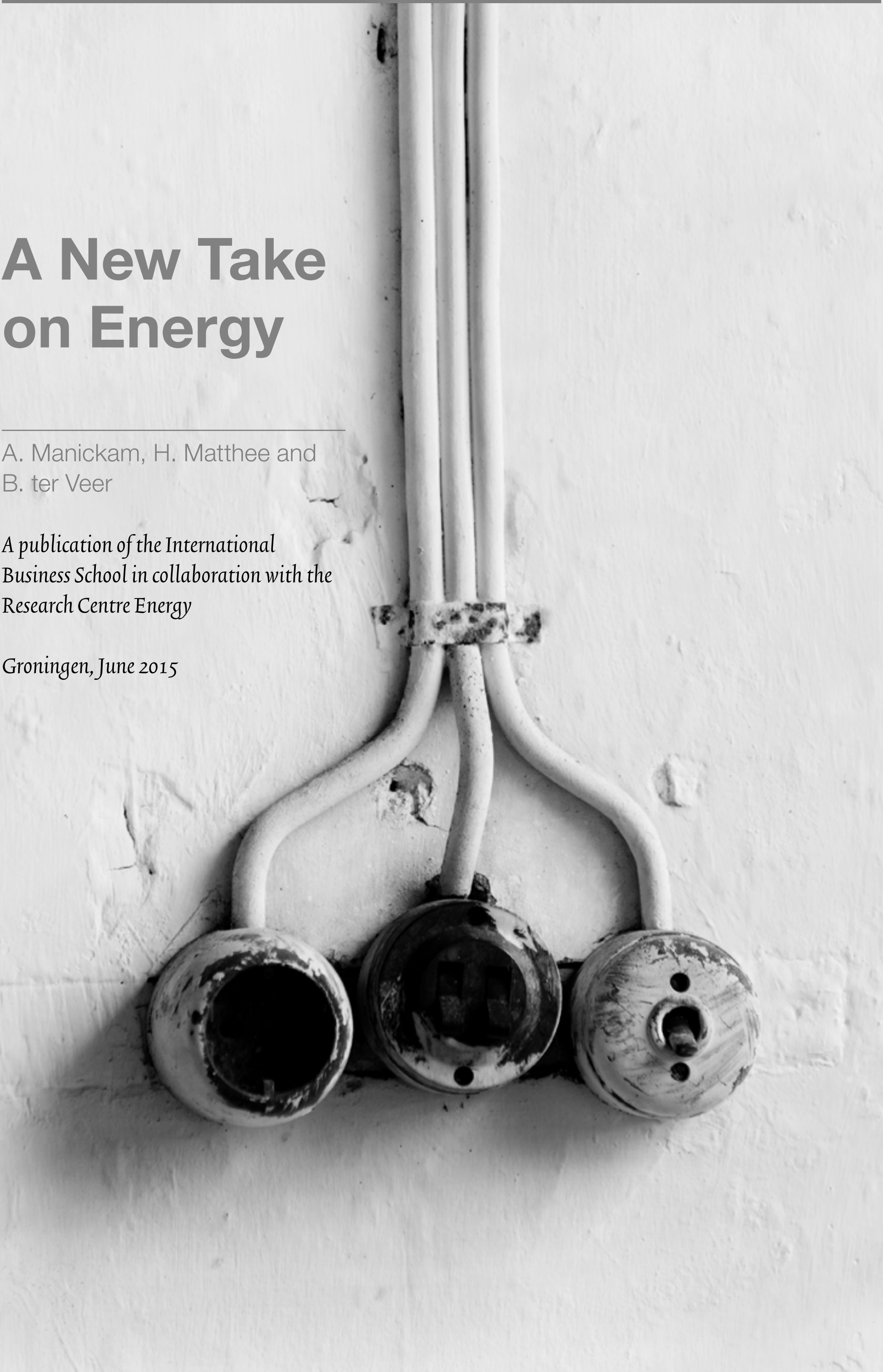

# A New Take on Energy

A. Manickam, H. Matthee and B. ter Veer

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# FOREWORD

This publication gives a different take on energy and energy transition. Energy goes beyond technology. Energy systems are about people: embedded in political orders and cultural institutions, shaped by social consumers and advocacy coalitions, and interconnected with changing parameters and new local and global markets.

This publication gives an overview and analysis of several dimensions of the energy field. The four chapters in this publication are extracted from *The Big Picture: The future role of gas*, a report by Energy Delta Gas Research (EDGaR) published in March 2015. The aim of that report was to provide the gas market parties and stakeholders with a view on the long-term 'big picture' of three potential end states by 2050. In end state one, renewable energies would dominate. In end state two, it would be business as usual. In end state three, gas would be dominant.

An overview and explanation of the three end states have been extracted from the original publication and appear in the first chapter. The second chapter consists of an analysis exploring key drivers of change until 2050, giving special attention to the role of international politics, social dynamics and high-impact ideas. The third chapter explores a case study of Power to Gas to illustrate how the development of new technologies could be shaped by regulatory systems, advocacy coalitions and other functions identified in the 'technology innovation systems' model. The fourth chapter explores the case of Energy Valley to understand how local or regional energy systems respond to drivers of change, based on their contextual factors and systems dynamics.

The current publication is an initiative to serve the the Hanze University of Applied Sciences Groningen, where energy is a strategic theme. The authors, who conduct energy-related research at the Hanze University, present new perspectives on energy that go beyond the regular focus on technology. These perspectives could be used to introduce energy-related themes, case studies and projects into the curriculum. For example, the Power to Gas case could be used; students could be asked to choose a different energy technology in order to explore the various functions in technology innovation systems. Another example would be to ask students to select a different regional system and to analyse its relevant contextual factors and systems responses, based on desk and field research.

Some of the findings in the publication could serve to support existing or to trigger new energy-related research and innovation activities at the Hanze University of Applied Sciences Groningen. The authors hope that these perspectives will also serve to stimulate the ongoing dialogue with business to promote energy transition.

Acknowledgements are due to Bert de Kiewiet and the Big Picture project team, the Energy Delta Gas Research program and the Research Centre Energy, Hanze University of Applied Sciences Groningen.

# 1. ENERGY TRANSITION END STATES IN 2050

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An overview of the three end states is illustrated in the diagram below. Details of these end states have been included in the sections below. All illustrations and texts in the rest of the chapter have been extracted from the original report with permission from the 'Big Picture Project'.

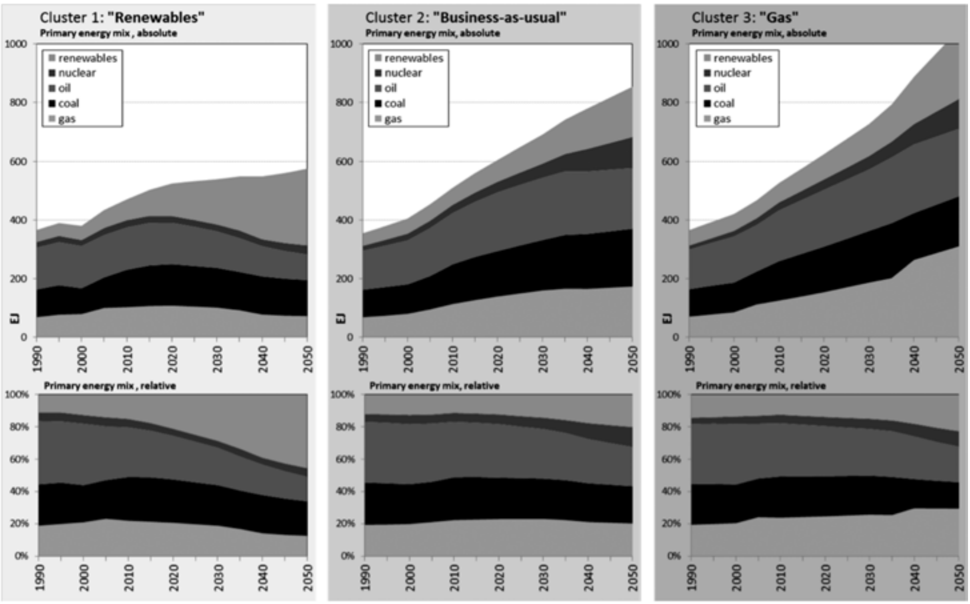


*Figure 1: Average energy mixes of the three identified clusters of future energy scenarios.*

In Figure 1 the upper graphs represent the average absolute contributions of the different energy sources to the energy mix. The lower graphs provide an impression of the average energy mix in relative terms.

## 1.1 Definition of End State

Energy markets are always changing, and therefore the end state of the energy transition should not be interpreted as a point in the future when all developments in energy markets have come to a halt. Synthesizing from the elements above, the end state should be interpreted as a time period in the future where humanity has altered the technologies with which it consumes energy, the quantities of energy it uses per region/technology, the energy sources it uses, a certain technological lock-in of vital parts of the energy system, confidence that the end state is 'sustainable' for the time being (be it just a few decades or longer) and a public consensus that we have reached a new status quo and no large systematic changes are expected from economic and technological perspectives and no more large changes are demanded by public opinion and politics (in their respective short term future). This definition of the energy transition end state will be used in this study as leading.

### 1.1.1 End state: Renewables

The end state 'Renewables' (RES) is characterized by the following factors:

- *Political:* Most effective policies and measures to promote RES, long term perspective, stringent regulations and in increasing cost of $CO_2$.
- *Economic:* Global population and GDP increases, investment in infrastructure increases.
- *Social:* Climate change awareness shift, increasing tensions between rural and urban communities.
- *Technological:* Significant development and maturity of the existing technologies, efficiency increase, modal shift in transport, increased R&D expenditure and innovation.
- *Environmental:* Significant emissions reduction after 2020.

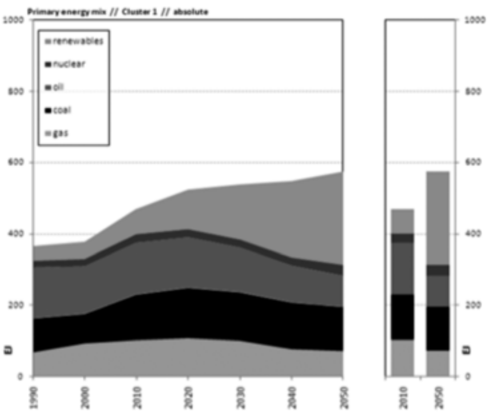


*Figure 2: Evolution of the Energy Mix in End State C1: Renewables*

The energy mix of the 'Renewables' end state is described in Figure 2 above. In this end state the world energy demand is presumed to be significantly lower than in other two end states. Renewables play an increasingly important part, becoming the major source in both absolute and relative terms by 2050.

In the 'Renewables' end state it is assumed that the level of political and/or policy intervention will be high. Governments take action to steer the energy system away from fossil fuels towards more renewables with a variety of policy measures. Especially the scenarios from environmental NGOs assume strong national and international policy actions, such as a forced phase-out of coal and an international framework for investing in climate change mitigation. It is assumed that governments invest heavily in infrastructure to facilitate renewables and in R&D to improve renewable technology. Most scenarios in this end state assume either a global or a regional $CO_2$ pricing system. The US loses its dominant position in the geopolitical system: it shares political dominance with China.

Most scenarios assume steady global economic growth, largely coming from developing countries. GDP growth is exogenous to the scenarios. More global economic integration with a decoupling of between economic growth and fossil fuels is assumed. It is expected that eventually economic growth will decouple from energy demand growth. An increasing price of $CO_2$ leaves no room for investments in fossil power generation.

All scenarios expect an increasing world population, reaching about 9 billion in 2050. The growth in population is mostly from the developing regions. Awareness shift by the public pushes for more political action to reduce emissions. Fear of climate change creates political turbulence with tensions between rural and urban communities, especially in countries with poor governance. Some scenarios assume a change in behaviour by the public in order to decrease energy consumption: such as reducing meat consumption or reducing mobility needs.

The environmental NGOs assume, besides a phase-out of fossil fuels, a phase-out of nuclear energy. Significant improvements in the efficiency and costs of renewable technologies are assumed due to heavy public R&D expenditures. The environmental NGOs assume almost a complete phase-out of fossil power generation. Other scenarios assume the implementation of CCS to reduce emissions. Some improvements are expected in utilizing hydrogen as an energy carrier, but no other fundamental breakthroughs are expected within the scope of the end state. Due to the increasing global integration, innovation spreads quickly between countries, increasing the use of more efficient technology and renewable technology. Information technologies stimulate the use of more demand side management solutions. Biomass plays a big role in most of the scenarios. Furthermore, wind and solar are mentioned as promising renewables.

Global carbon emissions peak around 2020 and begin to decline after that as an effect of international efforts to reduce emissions. One scenario assumes a growth in emissions because coal will increasingly be used when oil and gas reserves become depleted.

### 1.1.2 End state: Business as usual

The end state 'Business as usual' (BAU) is characterized by the following factors:

- *Political:* Focus on short term national security, developed countries assume more responsibility for climate change, RES support continues, increased $CO_2$ price.
- *Economic:* Global population and GDP increase and drive energy demand (especially in developing countries); energy efficiency grows in developed countries.
- *Social:* Income redistribution affects energy efficiency in developing countries, increased environmental consciousness.
- *Technological*: Increased energy efficiency, progress in CCS, hydrogen, and unconventional fossils.
- *Environmental*: Moderate emissions constraints

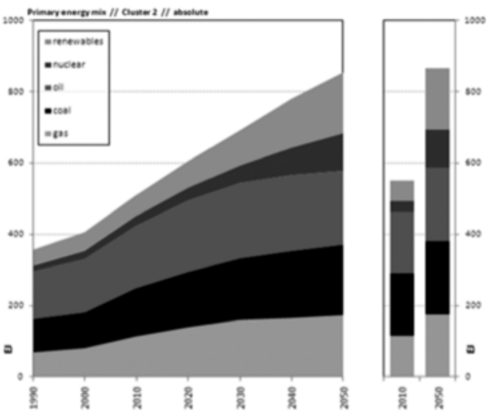


*Figure 3: Evolution of the Energy Mix in End State C2: Business as Usual*

The energy mix of the 'BAU' end state is described in Figure 3 above. In this end state the world energy demand is presumed to be significantly higher than in 'Renewables' end state, but still lower than in 'Gas' end state. Fossil fuels maintain their dominant position, regardless of both absolute and relative growth of renewables.

This end state is based on an extrapolation of current trends without major events that change the current path to increasing the use of all energy sources.

Developed countries assume a higher responsibility for preventing or mitigating climate change. There are policies in place to promote renewables (but on a smaller scale than in the renewables end state). In some regions in the world there is a $CO_2$ pricing system in place, but it is not assumed to be a global system. The political focus is more on short term national energy security. Major producers see their power increasing on the international arena. One scenario uses only policies that are already in place, another mentions a cautious implementation of recently announced commitments.

Global GDP increases around 3% per year, but energy intensity of GDP decreases gradually due to efficiency and high energy prices. GDP growth is assumed to be the main driver behind energy demand. Efficiency improvement is identified as a strong factor in reducing energy demand growth. The increase in demand for energy is due to the developing countries. OECD has a slightly lower demand due to efficiency.

World population is expected to rise to 9 billion in 2050. Income redistribution in developing countries could adversely affect energy efficiency and have a major impact on world markets.

The technological outlook in this end state varies between the scenarios. One scenario sees a large role for CCS in the future. Another explores the possibilities of hydrogen as energy carrier. Improved engine efficiency reduces energy demand in developing countries. Technologies in unconventional gas production help to increase supply. Due to less global economic integration as compared to the renewables end state, innovation spreads slower.

All scenarios assume an increase in carbon emissions. There are some efforts to reduce emissions, such as a carbon price or CCS in some regions. However, these do not off-set the increase in use of fossil fuels. On a local or regional level there is attention for pollution, environmental damage, however there is no international climate agreement.

### 1.1.3 End state: Gas

The end state 'Gas' is characterized by the following factors:

- *Political*: Focus on short term national security, RES support continues, increased $CO_2$ price.
- *Economic*: Global population and GDP increase, developing countries catch up in economic growth, high commodity prices.
- *Social*: Concerns about energy security.
- *Technological*: Progress in unconventional fossils' recovery, energy efficiency, CCS, no dominant technology.
- *Environmental*: Global emissions increase, no significant international agreements to reduce emissions in place.

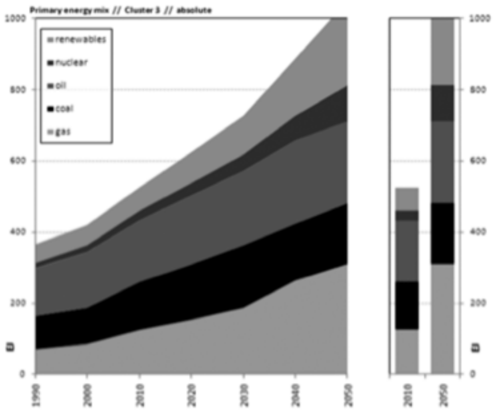


*Figure 4: Evolution of the Energy Mix in End State C3: Gas*

The energy mix of the 'Gas' end state is described in Figure 4 above. This end state has the largest increase in energy demand up to 2050 (compared to other end states). Comparable to the 'BAU' end state, fossil fuels maintain their dominant position, regardless of the growth of renewables. Notable for this state is the role played by gas: it becomes the main energy source in both absolute and relative terms by 2050.

Just as in the 'BAU' end state there is no international climate agreement in this end state. Some scenarios assume a $CO_2$ pricing system to be in place in OECD countries. Environmental policy is focused on the national or local level. The scenarios diverge on the political support for nuclear energy: some assume an extension of the lifetime of current nuclear power generation, and other scenarios assume a gradual phase-out.

Most of the scenarios assume a global GDP growth of over 3% per year. Europe experiences the slowest economic growth of all regions. Non-OECD countries have the highest GDP growth rates and also the highest increase in demand for energy. Due to the increasing demand for energy, energy prices are also gradually increasing. Oil prices are expected to increase faster than gas prices, therefore contributing to the competitiveness of gas. Lower gas prices are a result of growth in unconventional gas production.

World population increases to around 9 billion in 2050, with most growth coming from non-OECD countries. One scenario mentions the possibility of local social unrest due to resource scarcity and/or environmental damage.

Technological improvements increase the lifetime of fossil fuels. Oil and gas reserves and their recovery rates are increased. Improvements are realized in shale gas, coal bed methane, tight gas, underground coal gasification, CCS technologies and further developments of LNG markets. Some scenarios mention the adoption of electric vehicles, while another scenario assumes near-zero advances in transport technology. Most scenarios do assume some level of efficiency gains in energy use. The global share of gas in the energy mix increases with 33% in 2050, while the share of coal and oil declines. Furthermore, because some scenarios explicitly mention developments in gas technologies this end state is labelled the 'Gas' end state.

Global emissions increase significantly, however the increase is not equal between the regions. Emissions increase mostly in non-OECD countries. In Europe they decrease due to efficiency and the use of cleaner technologies.

## 1.2 Conclusions

This chapter identified three post-energy transition end states representing dominant views on energy futures in published literature. The end states are the result of analysis and grouping of various energy development scenarios, and are used as reference futures in subsequent chapters of this report. The end states are:

- *Renewables:* The Renewables end state is characterized by a high share of renewable energy sources in the world-wide energy mix alongside a sharp decline in energy demand growth towards the future.
- *Business As Usual (BAU):* In the BAU end states, the future (relative) energy mix is roughly the same as the present energy mix. However, a higher absolute energy demand is envisaged.
- *Gas:* The Gas end state assumes a significant portion of the energy demand to be fulfilled by natural gas. Furthermore, energy demand is expected to rise steeply towards the future.

*Note: Original Report, Kiewiet, Bert, ed. "The big picture: the future role of gas."Groningen: Gasunie, University of Groningen, Hanze University of Applied Sciences, 2015, to be found at http://www.edgar-program.com/publications/other-publications*

# 2. DRIVERS OF CHANGE IN ENERGY SYSTEMS UNTIL 2050

Author: Dr. H. Matthee – Hanze University of Applied Sciences Groningen

## 2.1 Introduction

A plethora of drivers of change remain likely or probable in shaping energy systems and futures. Drivers of change are defined here as any human- or nature-induced factor that cause changes. In this chapter, the drivers discussed could cause changes that would shape energy systems until 2050. Drivers here include those that cause change directly or by altering one or more direct drivers. Implicitly, some drivers discussed below are endogenous, where decision-makers influence some drivers, and others are exogenous, where drivers influence decision-makers. The drivers could have a positive or a negative effect at different stages and during different interactions and iterations.

The World Energy Council's publication on global energy scenarios until 2050 is based on 116 drivers, grouped in five areas.[1] This chapter is structured along the WEC framework, using the five interlinked areas, but with some changes in formulation, sub-elements and emphasis. The five areas are:

1. **Politics** - including international, regional, national, local and group politics and security challenges
2. **Social factors** - including demographics, consumer behaviour and high-impact ideas and institutions
3. **Economies** - including roles, cycles, finance and trade;
4. **Resources and the environment**
5. **Energy systems and technology**

## 2.2 Politics

### 2.2.1 International politics

International politics[2] will produce several important drivers of change, which could impact on energy futures until 2050 in direct and indirect ways. Energy is directly tied to the state security and foreign policy concerns of governments in Asia, Russia, the Middle East, North and South America, and Africa. The same is the case for European governments, including those of Germany, France, Britain and the Netherlands. The global energy sector will remain one of the most-politicized sectors until 2050.[3]

This means that issues from outside the energy sector may quickly embroil the sector in unforeseen and fast-moving shifts and escalations. This could affect the security of supply, but also change the nature of ownership, energy alliances, the relative importance of energy actors and the relative priority of developing different forms of energy.

International politics could also have a significant weakening or strengthening influence, in seemingly unrelated economic sectors, with a direct or indirect effect on the energy sector. For example, during the current stand-off between the Russian government of Pres. Vladimir Putin, the USA and EU member states over the Ukraine and Crimea, Russia's energy sector has become a key target for Western sanctions and also a key means of Russian pressure. Russian counter-actions have resulted in Western agricultural and other sectors being directly affected. They have also including the pursuit of a potentially stronger Russia-China energy alliance, efforts to strengthen the civilian nuclear sector in South Africa, competing with France in this regard, and renewed involvement in the civilian nuclear sector in Iran, against the foreign policy aims of most EU member states.

The shift of international power from the West to Asia and from an almost unipolar world to a multipolar world will be an important driver of change.[4] It is expected that China and India specifically will become more influential in regional and international politics until 2050. They will also experience a high absolute increase in energy demand during this period, which will reinforce the wider impact of developments in the energy sector.

One hundred years ago European actors constituted a much larger component of the world population and politically and economically dominated both the larger West and vast parts of the world and international energy sector. Today, Europe's global power has weakened and is weakening. The renewed strength of the USA, its focus on the Asia-Pacific, and the rise of Asian and other powers in a multipolar world order will reinforce Europe's weakened position.[5]

In individual cases, this could be reflected in the bargaining power of Europe-based actors. It could also weaken the commitment of other actors to political transparency, rule of law, protection of property rights, climate change, minority group rights and human rights. This could result in more reputational and operational dilemmas and risks for Europe-based energy actors in their external interactions, projects and partnerships.

The importance of state-linked corporations or privately-owned national corporate champions outside Europe could also act as a driver of change. In many states of Asia, Africa and the Middle East, energy remains a key source of government income and/or a key factor in maintaining domestic services and socio-political stability. In addition, state or state-linked corporations dominate the energy sector, whether in oil, gas or renewable energies. These companies often form part of the government's foreign policy, and operate in accordance with both strategic and economic imperatives. This is the case in China, Russia, India, Iran, Algeria, the Gulf Arab monarchies, Nigeria, and Brazil, among other countries. More than 80% of the world's oil and gas reserves are now controlled by national energy companies.[6] These companies will be competing and sometimes cooperating with EU-based energy companies.

National policies and their impact on property rights and protectionism will also be an important driver of change in the international energy sector. Governments, for political and economic reasons, have a long history of interfering with private property. Since 1990, over 75 emerging economy governments have nationalized foreign investments or been sued for unlawfully devaluing foreign holdings.[7] This approach could involve creeping expropriation in the form of regulations, taxation and local content or local ownership requirements, as in Iraq, South Africa and Russia, or outright expropriation, as in Russia, Bolivia, Ecuador and Venezuela. The economic failures due to such an approach could result in privatization projects, but privatizations carried out in those countries plagued with political instability could be renegotiated once a new government with different motivations and interests is installed.[8]

New alliances, new roles and new actors that emerge will also be important drivers of change. For many years after Western decolonization in the 1950s, Iran played the role of a guardian of Western interests in the Middle East. This changed after the Islamic Revolution of 1979. Similarly, Russia's role in Eastern Europe has changed with its actions in the Crimea and eastern Ukraine since early 2014. This state of affairs has had major political and economic repercussions, among others a closer energy alliance between Russia and China. Similarly, since the Arab Spring of 2011, energy-rich Arab monarchies in the Gulf, but also in Morocco and Jordan, have realigned in an effort to stave off the kind of revolts that appeared in Egypt, Tunisia and Yemen. Meanwhile, new actors like the south of Sudan's emergence as a state and the rise of the Islamic State of Iraq and Syria have changed the effective boundaries of authority in these three countries.[9]

### 2.2.2 Regional politics

Regional dynamics are likely to have an increased impact on international and national politics, and will therefore be an important driver of change. This was especially visible during the so-called Arab Spring or Arab Rebellion of 2011, when events in one country had considerable impact on other countries in a region.

The nature and effectiveness of regional governance arrangements will be an important driver of change. In principle, such regionalism is closer than international institutions to the sources of the problems to be tackled. Neighbouring countries are directly affected by threats stemming from respective regions. National leaders may be more familiar with one another in regional institutions, formal and informal. Regional instruments may also be mobilized faster than those of larger organisations.

Regionalism will however be weaker in some regions and sub-regions than others. ASEAN, for example, has developed over decades a distinctive style of regional cooperation based on a low level of institutionalisation, a non-intrusive agenda, informality, permanent consultation, and aversion to conflict. The dynamics between China, the two Koreas and Japan will be especially important for East Asian regionalism.

Brazil would be the only country with the critical mass to strengthen regional cooperation. However, the potential for regional fragmentation also remains strong, currently demonstrated by the Bolivarian Alliance, which only include a selection of South American countries.

In the Middle East, Turkey and secondly Iran will be the states with most potential influence in the period until 2050. However, it is likely that different sub-regional alliances will persist, of which Israel would also form at least an ad hoc part, either formally or informally. Similarly, no African country has sufficient influence and resources to steer regional cooperation at the continental level. Instead, alignments around Nigeria, South Africa, the Democratic Republic of Congo, Egypt and Ethiopia among others, will be important for the future of the continent.[10]

Another driver of change will be the decline or re-emergence of Russia as a regional power. If it declines, instability may give East European alliances led by Poland the need and the opportunity to adopt a more assertive policy to the east. The balance of power in Europe may in time move slightly eastwards, with Eastern Europe relying on US support and becoming more important as the demographic weakness of Germany and France has effect, while Turkey becomes stronger in the Caucasus, and areas to its northwest and south.[11]

Neighbouring states to the south and the east of EU are likely to experience considerable internal and regional turbulence during the period until 2050, constituting another driver of change. This applies to most states in these regions, and also to particular states that are important in European energy supply and transit, including Russia and Algeria. While the development of renewables will remain a component of EU global energy policies, these policies will focus on institutional, regulatory and investment predictability in energy producer and transit states to its east and south, rather than just a free market.

An interesting exception in this regard is Iran. It is quite possible that Iran, which already experienced an early "Persian Spring" of internal upheaval after the 2009 elections, will experience significant internal and regional political shifts in the period until 2050. The outcome could lead to the removal of Western sanctions against the country. Iran has the second-largest gas reserves in the world and the fourth-largest oil reserves.[12] Thus, such a shift could significantly influence the gas market, at least in Asia, but possibly also in Europe.

### 2.2.3 The EU as a region

The alignment and integration of member states in the EU will be an important driver of change. To date, the EU as a regional institution has been shaped and sometimes constrained by several factors. Some of them will be drivers of change: the interests of national governments, also in response to political shifts among their citizens and in the relationship between different parties; the capabilities of the relatively small bureaucracy and executive arms; clashing visions of the EU as enhancing economic competitiveness and a free market versus considerations of social cohesion, or of EU supranational governance versus responsiveness to national democracies.

The EU also quickly expanded in the past decade, with wide divergencies and sometimes tensions between individual countries and their institutions in the northwest, southeast and south of Europe. Some member states could come to diverge considerably from the liberal multiparty models dominant in the northwest, as indicated at present by the example of Hungary.[13]

Many of the key national governments in the EU, including those of Germany and France, are strongly engaged in maintaining or re-gaining national power over the EU. This is especially true for energy policy, which remains closely allied to foreign and security policy. In these policy areas, as Giles Merritt, the head of the Friends of Europe think-tank recently put it, the EU does not speak with a single voice, sometimes not even with a single squeak.[14]

Political decision-makers are also sensitive to their constituencies. European Parliamentary elections in 2014 reinforced a trend of limited participation by citizens of the member states, and saw the rise of EU-sceptic or –critical opposition parties. In many other parties in the Christian democratic, social democratic or market liberal traditions, national considerations largely trump EU ones.

Both important political decision-makers and their political constituencies thus do not seem primed for considerable stronger EU institutions. Strong corporations in the diverse energy sector of national states also have diverging interests and ambitions. As a result, national energy policies in Europe are likely to pursue several different routes simultaneously.

The relative resilience, skills and creativity of political elites in Europe will be a driver of change. For decades they have enjoined relative stability and prosperity in most of the EU, largely faraway threats, the remnants of post-colonial networks and influence in Africa, Asia and the Middle East, and the US-led NATO security umbrella in a bipolar and later unipolar world. This will change in the period until 2050, while political elites in Asia and other parts of the world, will become relatively more influential.

The EU's overall policies reflect the differences between member states and also different parties and stakeholders in member states between the competitiveness of markets and corporations, and social cohesion; and between supranational governance and regulation, and national democracies responsive to their citizens.

The fragmentation or alignment of EU-wide energy policies will be an important driver of change. Until about 2007, there was a consensus driving energy policy primarily with climate change in view, but the consensus has become fragile since the start of the economic crisis.[15] Internal energy policies in the EU, like foreign policies, could remain relatively fragmented until 2050. The capacity of EU institutions is limited, and further restrained by current economic conditions in many EU member states.

By 2010, most EU member states considered moving back into nuclear power. After the Fukushima disaster in April 2011, states like Germany, Belgium and Italy backtracked. However, France, the second-most powerful EU member state, also remains the most nuclear-dependent country, and countries like the Czech republic also remains committed to nuclear energy. To reduce geopolitical dependence on energy from unstable regions to the east and the south of Europe, nuclear energy could in future again constitute an attractive option in some European countries. This could in some ways align with the expressed aim of several Middle Eastern and Asian states to increase the role of nuclear power.

To date, the gas and electricity market in the EU are regional markets and also subject to national policy instruments. Renewable energies constitute a part of local or national markets. In contrast, oil and coal remain embedded in global markets.

### 2.2.4 National politics

The European Commission's *Roadmap for moving to a competitive low-carbon economy in 2050* suggests that, by 2050, the EU should cut its emissions to 80% below 1990 levels through domestic reductions alone. It sets out reductions of the order of 40% by 2030 and 60% by 2040. It also shows how the main sectors responsible for Europe's emissions - power generation, industry, transport, buildings and construction, as well as agriculture - can make the transition to a low-carbon economy most cost-effectively.[16] In the EU's electricity system, the rate of renewable energies of between 13 and 15% is still far off the current political goals under discussion of 45% for 2030 or 65-86% for 2050.[17]

However, national politics in Europe are likely to branch out in several directions simultaneously and remain an important driver of change. Even in the US, the shale gas revolution was enabled by support from the US Energy Department, the role of gas authorities, and exceptions to the Clean Water Act being allowed.[18]

The stakeholders and interest groups related to different forms of energy will also be an important driver of change. For example, coal production remains an important part of the energy sector in Germany, Spain, Poland and others, with a reluctance to reduce state aid. While many states have reduced carbon-production on their own territories, they have also increased carbon consumption by importing goods from carbon-rich producers in China and elsewhere.

National and corporate policies about the production and transmission of renewable energies will be another important driver of change. Many countries in the EU have access to renewable energy sources, but some more so than others, and with more efficient harvesting in some countries compared to others. Most countries may face a decision between cheaper electricity imports and the security of supply of domestic production. Thus, renewable markets are more likely to be buyer's markets and a view of electricity as a commodity, not a strategic good. 'Concerns about security of demand and supply are not expressed in diversification policies and the like, but in a power struggle over the ownership and decision rights with regard to control and management of the grid.'[19]

Another driver of change would be the greater impact of supply storage and disruptions where renewable energies are being used. When renewables form an important source of countries' energy, geopolitical interdependencies may then shrink to the size of the grid that connects producer, transit and consumer countries. On the one hand, this would increase the reliance of participating countries in a well-functioning electricity grid. On the other hand, any cross-border issues regarding energy supply would be more acute, because an interruption would directly lead to black-outs, and the difficulty in storing electricity would remove the option of strategic reserves.

One implication would be that countries with certain capacities would become more influential, changing the patterns of influence and power in Europe. For example, better-placed countries would be those with considerable storage capability, high reserve capacity, the ability to produce renewable electricity at times of high demand, or large interconnector capacity that allows the balancing of outputs of different areas.

An important driver of change would then be the role of large business with the experience in building and operating large power plants, and, implicitly, the viability or not of smaller alternatives. Most likely, the utilities will play a prominent role, and because of the strategic interests, states too. New roles for Distribution System Operators (DOS) in forecasting, local allocation of distributed generation in the network, and local balancing of generation and load, will also influence developments. Grid support services will become more important to address concerns about operational security and reliability.[20]

Access to components of the generators and transmitters of renewable energy will be a driver for change. Rare earth minerals are a crucial input for certain wind turbines, solar panels and batteries for electric vehicles. China has been active in acquiring control over a large share of the world's resources. If this would become a tool of geopolitical pressures, European energy sectors would be affected.[21]

### 2.2.5 Local/group politics

The shift to non-state actors as agents or spoilers of cooperation, reinforced by the communications revolution, will be an important driver of change. Transnational non-governmental organisations, faith-based organisations, multinational corporations, interest groups and civil society organisations will continue to be effective in reframing issues and mobilising public opinion. Opportunities will exist to expand the interaction between state and non-state actors and public-private cooperation. Those with hostile political or criminal agendas will be empowered by existing and new technologies and pose serious security threats.

Minority group politics could be an important driver of change in Europe, as well as in parts of Asia, the Middle East and Africa.[22] In the case of the US, the strong Hispanic minority, with its territorial and family links to Mexico and further south, will change the political landscape of the USA. Friedman and Huntington[23] foresee a strong possibility that the borderland between the US and Mexico, extending far into the US could become predominantly Mexican, with the US becoming a bicultural nation with other smaller minorities. Different constituencies could eventually influence energy choices at a federal state level.

In some cases, forms of class and generational politics could also combine with or oppose identity politics to influence energy policies. In the recent case of the referendum over Scotland's independence, for example, a political dispensation that had been in existence for almost 400 years was almost destroyed. The result would have been a new energy dispensation in the United Kingdom, due to the location of many of its energy resources close to Scotland. Even though the pro-independence camp lost, its substantial growth in support, especially among younger voters, the need felt by British politicians to make big concessions regarding devolution indicate that the issue is likely to re-appear on the agenda until 2050. In Spain, Belgium and Italy, among others, local and group politics could also strongly reshape the political order and local energy policy choices in the period until 2050.

Another driver of change would be the capacity of countries or even local communities to be able to become more self-sufficient in the production, transit and consumption of renewable energy. Where this does occur, the geopolitical considerations would reduce significantly compared to the current system, with its many dependencies in the supply chain.

A linked driver of change would be the choice of countries between using centralized, large-scale solar farms or wind parks to generate electricity, or using decentralized, small-scale individual solar panels and turbines. In the first case, geopolitical issues would largely revolve around communities wanting such forms of energy to generate revenue and jobs, or those, for example in part of western and southern Germany, who do not want it in their backyard. In the second case, it would be relevant whether the renewable energies generated are fed back into the grid, or whether net production would evolve into local energy markets and new regulatory frameworks.

An important driver of change would be to what degree the incentives of producers and consumers to cooperate weaken or overrule the incentives to compete. Producers compete for markets, but they share an interest in keeping prices high. Consumers compete for access to resources, but they also share an interest in keeping prices low. Producers and consumers rely on each other for revenues and energy, but also try to minimize their mutual dependence.[24]

## 2.2.6 Security challenges

Conflicts in regions that are major producers or consumers, is likely to be a driver of change until 2050[25]. This will especially be the case in the context of resource-scarcity. Such areas often become rife with corruption and organized crime, also in government institutions, so that the reputational risk and political risk to energy companies will remain high. Such conflicts will not only create short-term issues of supply, but shape energy security policies and preferences, as well as the operating practices of international and national energy companies.

Failed and failing cities outside Europe will constitute a key driver of change, also reinforcing migrant streams to developed countries. There will be an increase in the size and importance of ethnic minorities in many countries, also in Europe. A high proportion of young adult men in the Middle East and North Africa will reach its peak in the next decade, also in migrant communities in some European cities.[26] Some of them will be well-integrated and/or economically successful, while others may not be, with resulting social tensions.

Technological developments will allow migrants to maintain close links with their home communities and to transfer issues from the home country into the host country. Depending on the interests concerned, sometimes the energy interests concerned, governments of the host countries will have the impetus to intervene in the countries of origin or not.[27]

The rise of private security actors will be a key driver of change. In many locales outside Europe, they will constitute an important provider of security and enabler of robust operations and resilience during instability. Somewhat related, the interaction between asymmetric and symmetric forces and operations during conflicts will be an important driver of change.[28]

The expansion of alternative currencies will be a driver of change. It may make it easier to transfer and retain funds anonymously, harder to freeze the assets of criminals and rogue regimes, and reinforce the flexibility of actors and markets linked to forms of energy smuggling.[29]

The growing use of nuclear energy raises the possibility of fissile material obtained by non-state actors and countries hostile to the existing international order.[30] Unmanned energy-using systems will be a driver of change, paying an increased role during conflict, perhaps transforming the way battles are fought. Dual-use technologies and the military application of available civilian means may also play a role in this regard. In addition, there will be an increased reliance on space and cyber technologies, creating some vulnerabilities and an increased chance during conflicts of disruptive attacks with an effect on the energy sector.[31]

## 2.3 Social factors

Demographics will be a key driver of change. The global population is expected to increase considerably, with numbers including a rise from 7bn in 2011 to 9bn in 2050. Such an increase would result in a huge increase in energy demand, according to Shell by as much as 80% by 2060.[32]

Due to the huge increase in demand, investment in infrastructure will also be a key driver of change. An estimated two-thirds of demand will be in non-OECD countries, which are expected to outperform OECD economies by 2030. Increased access to energy sources and clean water, and affordable, safe and convenient mobility choices will be challenges. Managing pollution and traffic will be too.

The impact of demographic decline on Europe's working-age population is different. A lower potential growth rate is implied, and a lower-investment-to-GDP ratio is needed to keep the capital/output ratio constant. In some countries of Europe, higher investment may only lead to higher captal-output ratios and imply lower returns on capital.[33]

Income inequality will be an important driver at regional and local levels outside the OECD countries, and may shape the preferences of potential consumers.[34] The growth of a 'new middle class' will put pressure on prices, as a result of the increased demand. The middle class in many societies will also increase in influence. Estimates are that an additional 2.6bn people will attain at least middle income levels by 2050. Individuals also tend to consume most in their lifetime between the age of 16 and 40, and before consumers really begin saving for retirement.[35]

Government incentives and social activism to stimulate consumer demand for green goods and services, and public perception and corporate social responsibility as competitive differentiators could also be drivers of change in consumption, especially in some European countries.[36]

However, the acceptance of consumers or citizens, their willingness to tolerate a technology in their own environment, could play a major role when launching new products and manufacturing plants and services. The public takes a critical view of extensions to the grid infrastructure and the construction of wind farms and pumped-storage power plants in their immediate vicinity. People could use consumer pressure groups but also political and administrative opportunities to question decisions after the event, hindering both conventional and renewable energy projects and increasing the risk of total or partial failure.[37]

High-impact ideas will be a key driver of change. However, one cannot foresee all or even most ones in future, since many of them will result from complex interactions between people, symbolic systems, structures, and as yet-undeveloped technologies. However, at present, there are certain clusters of ideas with a probable high impact in future, also on the environment of energy. One idea would be derived from individualist and family-oriented traditions, and the formation and lifestyles of individuals, nuclear families and extended families. For example, in Indonesia, as people move upward into the middle class, they initially focus their spending on improving living conditions for their families rather than themselves.[38] In India, young consumers are both very competitive and motivated by the desire to make their families proud, whereas older Indians also have a family-oriented focus.[39] However, even in Europe, locational and regional variations play a role in this regard.

The second high-impact idea, related to individualist and family orientations, would be the position of women. Globally, in the labour market and unpaid household work, gendered division is the rule. Women are also underrepresented in the energy sector. In many cases, professional access to the energy sector is mainly based on a scientific or engineering education, in which women are under-represented, sometimes extremely so. The fields of skilled trade relevant to the energy sector such as construction, electric installation, plumbing, and installation of energy control or heating systems are dominated by males. [40]

Women as consumers may have closer knowledge about the energy services that are needed for different members of the family, different energy needs and different ideas about sustainable livelihoods. Another important question concerns the influence of women on policy concepts, planning, decision-making, and implementation, which is limited.

Gender, age and communitarian preferences may also shape the preferences and behavior of energy consumers. More men than women believe it is important that programs include the latest technologies, while more women than men are looking for programs that simplify their lives and are easy for the whole family to use.[41] Younger respondents prefer programs that use the latest technologies, are fun to use and are regarded as trendy. Consumers in emerging markets are also keen on programs that enable them to connect with a community.[42]

Cultural, religious and even political ideas may also shape production or consumption processes.

Islamic consumerism, cultural production and lifestyle choices may play a role.[43] Techno-nationalism or techno identity politics, where research and innovation are driven by sentiments and ambitions to service the greater good, are already visible in the civilian nuclear sector of Iran and other countries. It will also impact on the willingness to infringe on intellectual property rights and turn to industrial espionage and protectionism.

Themes of human rights, cross-sector partnerships, corporate social responsibility, sustainability and inter-generation equity and alternative business models form part of idea clusters that can have a major influence on future energy business models. However, it would be myopic to think that such models need to be compliant with the current dominant models in Western countries. In Malaysia, models of Islamic business governance have emerged. In China, strong sentiments of a social hierarchy, ethical structure, and a strong sense of family as the basic unit of production, with its rights of inheritance and views of the extended family, still pervade much of Chinese thought. Hinduism and the traditional caste system still influence power distance and hierarchical business practices, the concept of time and fatalism, and a smaller concept of personal space and group orientation. [44]

The empowerment of individuals *vis-à-vis* the state will be an important driver of change. Global literacy rates have improved from an estimated 73% in 1990 to about 84% in 2010 and an estimated 90% by 2030. Access to independent media and means of mobilization have enhanced the ability of actors. Greater interpersonal transnational flows and many networks connect more people. However, this should not result in assuming similarities in outlook or the disappearance of competing visions and ambitions. In many European countries, this empowerment is reinforcing dimensions of individualism; in Asia, Africa and the Middle East, many social institutions and norms of solidarity retain their influence and shape the conduct of empowered individuals.

Greater individual empowerment without sufficiently strong social institutions will also amplify overload and confusion, an unusual intensity in volatility due to the environment, sharp swings in confidence and demand and possibly herd behavior.[45]

In several ways, the balance of power has been slowly shifting from companies to consumers. Tools allow consumers to gain information about products, services and purchases. For example, they see their electricity expenditure, compare prices, and track their home energy use. They can make better decisions or even automate the decision process based on certain preferences.

However, several trends have also converged to create a field in which the so-called hyper-individual or hyper-consumer would participate. An individual can use skills and the value of freely available information to regain control in the market-place. One trend is maximizing behaviour for high-value purchases. Another is the rise of websites, apps and services that can mine data. For example, a real-time online price-monitoring service could suggest the best choice. The third trend is the quantified self, who is able to track and quantify many aspects of their lives now, whether through technology or legislative prescriptions. People learn and apply new methods of choice, self-monitoring, and information-gathering in their everyday lives. Modern lifestyles also pressure people to lead a more streamlined life. The expanding middle class will also expand the number of such consumers in emerging markets.[46]

A significant finding is that socio-economically and demographically, a person in the middle class of one country has more in common with a person in the middle class of another country. However, in terms of values and aspirations, people in the middle class or poorer classes in one country have more in common than people in the middle class in some regions. In addition, due to its low quality, many have opted out of public health and education systems, turning to private options. This has even been the case regarding electricity, where purchases of electricity generators have risen with income.[47]

## 2.4 Economics

Due to the extensive role of the government in most economies of Asia, the Middle East, Russia, Africa and South America, international, regional and national politics will remain an important driver of change in economies.

The state of Asian economies in general will be an important driver of change for Europe. However, the economic centre of gravity, in terms of the location of economic activity and average GDP, continues to move to Asia. China and India will be the most important countries to make the biggest changes to the overall energy landscape up to 2050. According to the World Energy Council, the total primary energy demand of China is expected to double by 2035, and that of India to increase by almost 150% during the same period.

Economic turmoil in emerging markets may also inhibit the projected growth in Asian countries until 2050. For example, inflows of capital have currently created substantial credit and real estate bubbles in China, Singapore and Hong Kong. The quality of economic growth and economic institutions has not always been controlled, in the case of China also due to ambitious local governments. Foreign exchange reserves are being reduced, often an indicator of worsening times. The IMF has warned of potentially prolonged market turmoil in emerging markets.[48]

An important driver of change would be the absence or presence of a second economic slowdown or crisis in Western countries, and a concomitant decline in energy demand. A second economic crisis cannot be ruled out yet. While governments have taken measures and consumer debt and financial sector debt in the US have since the 2008 crisis reduced by about 12% and 19% respectively, Western banks still remain too big, too interconnected and too undercapitalized, according to some experts. Some of the type of products that contributed to the crisis, like synthetic collateralized debt obligations, have re-merged in Wall Street, and federally guaranteed mortgages requiring small deposits are back in the USA. Meanwhile, volatility in major emerging markets and in Russia are impacting on the export-oriented European economies. [49]

Market movers will be a very important driver of change. Market movers include global companies with international supply chains; banks who can provide much-needed capital for increasing economy activity, venture capitalists who fund breakthrough technological research in order to gain larger shares in successful new market entrants, and entrepreneurs who offer new goods and services. The institutional rules of the game or incentive systems of global companies and entrepreneurs may be especially important for innovation in particular countries.

Economically interlinked mega-regions will be another driver of change. These include the meta-region spanning Amsterdam-Rotterdam, Ruhr-Cologne, Brussels-Antwerp and Lille, the English mega-region spanning London, Leeds, Manchester, Liverpool and Birmingham, the German mega-region encompassing Stuttgart, Frankfurt and Mannheim, and the Italian mega-region from Milan through Rome to Turin.[50]

An important driver of change will be the retention or possible substitution of the petrodollar system by a more independent currency system not based on the US dollar. Already, there have been efforts by countries ranging from China and Russia to India, Iran and Venezuela to do so. To date, the US political and military umbrella over Arab Gulf states combined with the US dollar-based investment fund holdings and bilateral trade agreements of these states, have acted as a strong constraint. However, as China's regional and global influence grows, this may not remain the case until 2050.

Investment to address growing energy demand and gaps in the infrastructure needed for the generation, transmission and distribution of electricity will be a key driver of change. It is notable that the new European Commission since late 2014 has expressly indicated its ambition to create a more attractive environment for foreign and local investment in the EU. In this regard, energy-related infrastructure, R&D and renewable energies are specifically mentioned.[51]

Infrastructure spending is most expected in Europe from the target set of achieving 20% of the energy production from renewable energy. Numerous projects are in the pipeline that range from tidal, solar, wind, bio fuel, bio waste, geothermal, and other resources. Carbon Capture and Storage systems will both require and be facilitated by a large-scale infrastructure. The choice of public and private financing instruments depends on the stage of development of the technologies or projects, but could also be shaped by EU $CO_2$ credits, spending priorities and regulatory hurdles.

Greater economic volatility and cyclicality and more uncertainty and risk will be an important driver of change. The recession has also provided governments, anxious to weather the downturn, with opportunities to take regulatory measures. Concerns about employment, debt, economic competitiveness, energy security and climate change are now being used to justify this. These measures are accelerating or delaying energy system change, depending on the political or economic circumstances.

## 2.5 Resources and environment

Rare earth elements will be a driver of change. China's policy of limiting REE exports has resulted in high prices, with an impact on the cost structure of the clean-tech industry which uses REE for manufacturing magnets and solar PVs. Reopened mines and development of resources will not affect this state of affairs in the short term.

Mining will be an important driver of change regarding the environment.[52]

Farmland will become a scarce resource and a driver of change, also because of non-OECD economies increasing their consumption of meat and agricultural commodities. As populations continue to grow, more pressure will be put on land, water, and forest resources.

Agriculture is still of major importance in the livelihoods of people in Asian and African countries, and more energy-intensive than manufacturing. Major projects of industrialization are also expected in non-OECD countries, concomitant with the emergence of new middle classes. With an apparent emerging stress nexus between water, energy and food[53], tightness of supply could feed off each other.

By 2050 it is expected that there will be an extra 2 billion people to feed worldwide. If they would want to consume as much nutrition as today's developed countries, global food production will have to rise by 110% over today's levels in the next 40 years. However, global food demand has been met by an increase in productivity and not an increase in the amount of farmland. Already, Middle Eastern countries and their sovereign wealth funds have begun to look overseas for growing crops needed for domestic consumption. Foreign ownership frameworks may be affected, with some flow-over potential to the ownership of foreign energy companies, as currently in South Africa. Demand for fertilisers will also increase, influencing the price of oil.[54]

Future energy emissions hinge on a patchwork of policy frameworks developing, especially in Asian economies. $CO_2$ policies adopted in the OECD over the next decades will be a key driver of change. This will slow overall emissions growth.[55] However, different countries will develop different strategies for decarbonising transport. Some countries will impose carbon taxes, others will develop or join emission trading schemes, while others will put in place technology or resource targeted plans. More expensive renewables could be favoured with technology developers chasing government subsidies and feed-in tariffs. There is a higher level of low-carbon technology transfer into developing nations.

Energy supply security could surpass environmentally-friendliness as a policy priority in most countries of the world. According to the World Energy Council, this is the result of scandals about the reliability of the science calling for climate change and failures in reducing emissions, as well as the increasing pressure on policy-makers to address economic recessions.[56]

As stated by the Word Energy Council, global energy until 2050 will be influenced by three aspects, namely growing complexity in energy systems, the high speed of change, and institutional tipping points and the failure to deliver of existing institutions.[57] Shell already indicated one of the implications in 2008, by indicating *There are No Ideal Answers* (TANIA).[58]

## 2.6 Energy and technologies

Selective government policies will be a very important driver of change, regarding the energy domain in general but also regarding technologies specifically. The energy policies of major powers like China and India are going to be of interest, given the shift in both power and economic importance to Asia.

China is estimated to be home to the most technically-accessible shale gas in the world. [59] At present, shale gas exploration has met with limited success. However, these initial setbacks also were the case in the US, and shale extraction technologies are developing at a high pace. As in the US, marked shifts could be possible in future. As indicated by Shell and BP but also by academic experts, gas, rather than oil, will be crucial for China's push away from coal, currently used for the major part of power generation. Gas will be important not only in reducing emissions, but in aligning grids to be more reliable when supplying alternative energies.[60]

In some scenarios for China, moderate growth could mean a slight decrease in coal, an increase in the next decade in the use of gas from 3% to 13%, of wind energy from 4% to 15%, of nuclear energy from 1% to 7%, of solar energy to 3%. Such a major increase is not foreseen for oil in the case of China under conditions of moderate economic growth.[61]

India's energy policy will be important regarding the position of coal in the global energy mix. Coal is the mainstay of India's energy sector and accounts for more than 50% of primary commercial energy supply, 69% of total primary energy supply (TPES) comes from coal-based thermal power stations and import dependency is growing. The new activist and business-oriented government of Narendra Modi in India, experiencing popular frustration about uneven energy services, are focusing on drastic measures to resolve the situation. Modi, after successes with solar energy in his state Gujerat, has now also envisioned solar energy and to a lesser degree wind energy as the most important sectors to address energy issues in India. This could be costly, but if so, in the case of India, the development of the nuclear energy sector would be the cheapest alternative of all.[62]

The global position of coal and nuclear energy, especially the former, are two variables that could rend the three end-state scenarios less accurate. According to the World Energy Council, China is expected to overtake the US to become the world's largest economy by 2020, but China itself is likely to be overtaken by India by 2050. This could result in a resource crunch between domestic energy resources and demand, especially for coal. Demand for coal in South Korea and Japan is also likely to remain strong. The global steel sector is also expected to continue to influence the demand for coal.

The exploration and production of unconventional gas from shale formations will also be an important driver of change. Rapid developments in technology have allowed the USA since about 2000 to strongly increase the recovery and production of natural gas from shale formations. Unconventional gas is relatively clean but will prolong the reliance on fossil fuels. It will reduce the drive toward renewable energy in the USA. However, much and expensive investment will be needed. Existing reserves of shale gas are often far from existing pipeline infrastructure and refineries designed to process heavier crude oil. Shale gas is also produced with fewer additional potential products than orthodox oil, and existing reserves in the US at present also seem to have a shorter lifespan.[63]

The impact of the US shale gas revolution on European energy policies and prices is another driver of change. The success of North America's shale gas production may inspire responses by other countries in the northern and southern hemisphere. Many European countries already have a high motive to redirect their energy security away from their current reliance on Russian gas. The current crisis over Ukraine and the Crimea, which is impacting on European economies due to a spiral of sanctions and counter-sanctions, is reinforcing this motive. However, it is likely that the situation will differ per country in

Europe. In some cases, like Austria, Croatia, Greece, Hungary and Bulgaria, the motive was previously lower and mutual gas projects with Russia were supported, even though they could reinforce energy dependence. [64]

The aftermath of the shale gas revolution could influence the mix between gas and other energy elements in consumer countries, promoting a greater share for gas in these mixtures. At present, gas contracts are often linked to long-term high-priced oil contracts. However, rising gas supplies and the option of several suppliers may result in many consuming countries becoming less willing than at present to contract large volumes of gas over a long period or to link it to oil supply contracts.[65]

Competition and sometimes cooperation between and International and National Oil Companies (IOCs & NOCs) will be a key driver of change. Trends that will shape their performance will be business models, diversification into other forms of energy, joint ventures, the stipulations of negotiated contracts, and changing business practices.

Oil supply and oil prices will be an important driver of change, the latter also in decisions to produce shale gas. How OPEC responds to oil prices could influence events. However, the current geopolitical divisions between Saudi Arabia and other GCC states on the one hand and Iran, Syria and Iraq on the other, could also be reflected in OPEC finding it difficult to respond to a crisis. Just after the shale gas revolution in the US, Iran, Venezuela, and some North and Sub-Saharan African producers differed strongly from Saudi Arabia and other GCC states in OPEC.[66] Likewise, OPEC members' different interests may be difficult to reconcile if some of the above drivers and enablers are active.

Oil demand will be another important driver of change.[67] Oil demand projections by energy majors often do not take into account the major impact new government policies could have, also in India and China. Other factors could reinforce the effect of oil demand destruction. These would include current economic turmoil in key oil markets, political pressures that may make alternative energy sources more attractive, the counter-productive effect of high oil prices, and the potential oil substitution impact of renewable energies and policies related to them in key markets.

Oil demand destruction could result in significantly falling oil revenues for states in the Middle East and North Africa, affecting available budgets and the ability to provide sufficient services for often growing populations. The cost of social stabilization systems and other needed investment as oilfields decline may sharply reduce the actual benefit from even high oil prices. This is evident in Saudi Arabia, where the estimated cost of the social stabilization has increased from about $50 per barrel of oil in 2002 to $94 per barrel in 2012 and $98 today.[68]

This, in turn, could trigger instability in one or more countries of the region in the next decade, reinforcing insecurity on Europe's southern border. Given the social and demographic situation of the region, the soft warning in the IEA's *World Energy Investment Report* in 2014 remains relevant. If the oil price stabilizes around current levels and increases only moderately to 2035, "governments that have become accustomed to burgeoning hydrocarbon revenues could be in for a difficult period of adjustment." [69]

The possibility of oil demand destruction in many ways challenges the accepted wisdom that oil demand will continue to grow, especially in Asian countries. However, this is a complex issue involving many actors, possible interactions and less visible feedback loops. Unintended consequences and new events could result in many quick shifts, as has happened in the energy markets in the past decades and also with the shale energy revolution, which was largely unforeseen in the 1990s.

As indicated by Paul Stevens, higher oil prices and/or oil price volatility could persuade governments to turn to alternatives.[70] The International Energy Agency has developed several possible scenarios, based on governments' choice for renewable energies. In the so-called *450 Scenario* governments introduce policies until 2035 to reach the globally accepted aim of not more than a 2 degree Celsius increase in global temperatures. Oil demand in such a scenario would drop by 13% compared to today.[71]

However, the majority view among analysts still is a tremendous rise in oil demand. Non-OPEC conventional crude supply will then also be a driver of change. It has been falling, but the fall could be slowed by new discoveries like that in deep water off Brazil and reserves in existing fields being upwardly revised with the application of new technologies, viable in higher oil price environments. This decline could also be mitigated by supplementary sources like unconventional oil and biofuels. Interactions between individual types of energy, their markets and their prices will reinforce complexity, also the virtual impossibility of forecasting the future nature and extent of global demand.[72]

Drivers in the technology domain have the potential to significantly change the energy sector but also its position relative to other sectors, like electricity, transport, construction, and telecommunications. Important new developments, the convergence or re-constitution of different domains in production or consumption, and disruptive innovations and breakthroughs are assumed until 2050. This is due to the current state of technologies, the time period involved, continuous challenges and the current speed and scope of new knowledge generation.

Some areas of potential technological developments or breakthroughs would be continuing engine developments with improved efficient combustion, electric vehicles, 'plug-in' hybrids and mass market fuel cell hybrid vehicles, oil recovery- horizontal drilling, 4-D seismic, downhole enhancements and shale gas technologies. They would have strong implications for improved recovery.

The outsourcing of R&D to Asia will be an important driver of change. Already increasing, this will include the transfer of entire laboratories, subcontracting to Asian research organizations, and through collaborative R&D projects. Uncertainties over human resources, fraud, and unclear property rights will only have a limited effect on this trend. However, the extent to which innovation is strongly guarded or extensively shared or copied will be important. Such an outsourcing will interact with the extensive focus on R&D in the policies of China and other Asian countries.[73]

The reversal of an Asian brain drain to some Western countries will be an important driver of change. Asian knowledge elites increasingly leave their mark on the world's top multinationals, high–tech companies, and universities. Conditions for research and innovation in Asia still leave much to be desired. Whether it is solved by a more open and competitive approach, or a closed and exclusionary one, will shape change.

The speed, lead-time and direction of development for new energy technologies will be an important driver of change. New energy technologies must be demonstrated at commercial scale and require thirty years of sustained double-digit growth to build industrial capacity and grow sufficiently to feature at even 1-2% of the energy system. The policies in place in the next five years shape investment for the next ten years, which largely shape the global energy picture out to 2050.

Energy efficiency will be a very important driver of change in most corporations and economies.[74] In several countries, the potential gains in this regard are still substantial. The relevant technologies and learning curves could change quickly.

## 2.7 Key findings

This chapter identified multiple drivers of change in energy systems until 2050. They would cause change directly or by altering one or more direct drivers or recombining in diverse ways. Drivers could influence decision-makers, and in some cases decision-makers could influence drivers. The drivers could have a positive or a negative effect at different stages and during different interactions and iterations. They could shape but also be shaped by energy systems in complex ways.

A key finding is that the international political and economic order is becoming more multipolar than three decades ago, and that drivers of change can have a different effect in different parts of the world. If one looks at the world as a whole, components of end state 2 (Business as Usual) and end state 3 (Gas) seem more plausible than those of end state 1 (Renewables).

Given the policies and strategies in the EU, the EU may differ from the world as a whole in this regard, with components of end state 1 also being plausible there. Internal energy path dependencies, forces and interactions in the EU are not aligned, and not likely to be aligned well soon. There is a significant chance that end state 1 could at least partially emerge in some member states or regions of the EU only, rather than in the whole of the EU. In this regard, it is also relevant that renewable energies constitute a part of local or national markets, whereas oil and coal, for example, remain embedded in global markets. It cannot be excluded that at least parts of Europe would reach a significantly different end state compared to major parts of the world by 2050.

The role of social and political actors on energy systems is likely to be more prominent, based on global trends. In Europe, this will be noticeable at the local, national and international level. At the local level, high-impact social ideas like green consumerism and limited acceptance of energy systems that result in major trade-offs, could be important drivers of change. Nationally, the empowerment of individuals and communities relative to the state and as producers of some forms of energy and the politicization of energy-related issues will be key drivers of change. Internationally, energy issues will at least remain important or become even more so in the foreign and security policies of countries and the geopolitics of non-state actors.

What does this mean in practice for European energy planners and policy-makers? The variable impact of drivers of change, but also of path dependencies, diverse frameworks of global and EU-level actors, and the increased potential for self-organization, means that the scope and impact of known unknowns, unknown knowns and unknown unknowns in energy systems until 2050 can be potentially vast.

The identified drivers of change and the complex ways in which they can interact and reshape futures confirm that lock-in effects remain among the greatest risks. In EU member states, flexibility and modularity, rather than energy platforms only focused on one end-state, would be highly advisable.

# REFERENCES


1 See World Energy Council, World Energy Scenarios: Composing energy futures to 2050, 2013.

2 See in general EUISS, Global Trends 2030: Citizens in an Interconnected and Polycentric World, Brussels 2012. Also see National Intelligence Council, Global Trends 2030: Alternative Worlds, Washington DC 2012.

3 Daniel Scholten and Rick Bosman, The Geopolitics of Renewable Energy: a Mere Shift or Landslide in energy Dependencies?, 2013, p. 9.

4 Shell, New Lens Scenarios: A Shift in Perspective for a World in Transition 2013 at http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html

5 Sarah O. Ladislaw, Maren Leed, Jane Nakano, Frank A. Verrastro, Molly A. Walton Contributor: Michelle Melton, Andrew Metrick, Jane Nakano, and Frank Verrastro, New Energy, New Geopolitics http://csis.org/publication/new-energy-new-geopolitics

6 For an overview, see Ian Bremmer, The End of the Free Market (Penguin, New York, 2010), pp. 85-145.

7 Rachel Wellhausen, Multinational Corporations, Nationality, and Government Breach of Contract, APSA 2011 Annual Meeting Paper, MIT Political Science Department Research Paper No. 2011-15.

8 Ian Bremmer and Preston Keat, The Fat Tail (Oxford University Press, 2009), pp. 132, 138.

9 "Israel's Defense Minister: Mideast Borders 'Absolutely' Will Change", NPR, 23 October 2014.

10 Jakkie Cilliers, Barry Hughes and Jonathan Moyer, African Futures 2050 http://www.issafrica.org/publications/monographs/african-futures-2050

11 George Friedman, The next 100 years: A forecast for the 21st Century (Anchor Books, New York, 2009), pp. 144-151.

12 Country Analysis Brief Overview, Iran, http://www.eia.gov/countries/country-data.cfm?fips=ir

13 See also Daniel Hegedüs and Kai-Olaf Lang, "Defekte Demokratie in einem EU-Mitgliedstaat" in Volker Perthes and Barbara Lippert (eds.), Ungeplant bleibt der Normallfall: Act Situationen die politische Aufmerksamkeit verdienen, SWP Foresight 2013, pp. 38-41.

14 Giles Merritt, A New Departure for the EU, Brussels Thinktank Dialogue – State of the Union 2015, Brussels 28 January 2015. For a current discussion of the issue, see also Clémentine dÓultremont, Aurélie Faure, Marco Giuli, Revisiting energy security in turbulent times, IFRI Discussion Paper, Brussels, 28 January 2015.

15 Oliver Gedden, "Der Wille fehlt", Neue Zürcher Zeitung, 26 June 2014, p. 20 and Oliver Gedden and Severin Fischer, "EU-Energy Roadmap 2050 – Surrogat für eine ehrgeizige Dekarbonisierungspolitik?", Energiewirtschaftliche Tagesfragen, October 2012, pp. 41-44.

16 See http://ec.europa.eu/clima/policies/roadmap/index—en.htm.

17 Aurelie Faure-Schuyer, The EU Electricity Policy Outlook for the Smart Grid Roll-Out, IFRI, Paris 2014, p. 4.

18 Kirsten Westphal, “Die ‘Batterie Revolution’ vorantreiben”, in Perthes and Lippert, op. cit., pp. 6-11.

19 Scholten and Bosman, op. cit., p. 19.

20 Scholten and Bosman, op. cit., p. 20. See also Faure-Schuyer, op. cit., p. 8.

21 Koroshy, Korteweg and De Ridder, Rare earth elements and strategic mineral policy, TNO and HCSS, The Hague 2010.

22 http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=6765752; Raul L. Madrid, The Rise of Ethnic Politics in Latin America, Cambridge University Press, 2012; http://indrus.in/politics/2013/06/11/russia—must—fight—ethnic—criminal—gangs—extremism—putin—26045.html; http://www.hf.uio.no/ilos/om/organisasjon/styret/moter/2012/vedlegg030912/neoruss-prosjektbeskrivelse.pdf;

23 Friedman, op. cit., pp. 223-227 and Samuel P. Huntington, Who Are We? America’s Great Debate (Simon and Schuster, London 2004), pp. 316-324.

24 Scholten and Bosman, op. cit., p. 11.

25 See in general EUISS, op. cit. and National Intelligence Council, op. cit.

26 Gunnar Heinsohn, Söhne und Weltmacht: Terror im Aufstieg und Fall der Nationen (Orell Füssli , 2003).

27 Ministry of Defence (UK), Global Strategic Trends – Out to 2045, pp. 8, 21; Perthes and Lippert, op. cit. See also Andreas Rinke and Christian Schwägerl, Elf Drohende Kriege: Künftige Konflikte um Technologien, Rohstoffe, Territorien und Nährung, C. Bertelsmann, München 2012 and Gwynne Dyer.

28 Mark Oprach, Hybrid Warfare – neue Dimensionen der territoriale Bedrohung, Konrad Adenauer Stiftung No. 3, 2012, pp. 59-63.

29 Ministry of Defence, op. cit., p. 75.

30 Ibid., p. 21.

31 Ibid., pp. 55, 67, 165.

32 Shell, New Lens Scenarios, op. cit.

33 Daniel Gros, “Investment as the key to recovery in the euro area?”, CEPS Policy Brief No. 326, 18 November 2014, pp. 3 and 5.

34 World Energy Council, op. cit., pp. 60-63.

35 HSBC, Consumer in 2050: The rise of the EM middle class, London, October 2012, p. 2; http://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Africa%20in%2050%20Years%20Time.pdf.

36 World Energy Council, op. cit., pp. 72.

37 Ibid., pp. 77-79.

38 https://www.bcgperspectives.com/content/articles/center—consumer—customer—insight—consumer—products—indonesias—rising—middle—class—affluent—consumers/ and http://www.nielsen.com/us/en/newswire/2012/reaching-indonesias-middle-class.html

39 See http://pitchonnet.com/blog/2012/10/15/indian-youth-is-expressive-but-family-oriented-satyaki-ghosh/

40 Fox, M. D., Johnson, D. G., and Rosser, S. V. (2006) (eds.). Women, Gender, and Technology. Champaign, IL: University of Illinois Press; Karlsson K., and McDade S., (2001), "Introduction," in Generating Opportunities: Case Studies on Energy and Women (New York: UNDP, 2001). Available on line at www.undp.org/energy/publications/2001/2001a.htm; Yuval and Verturi, Questioning Women's Role in Energy Development http://www.vigyanprasar.gov.in/Radioserials/8Women—and—Renewable—Energy.pdf

41 Accenture, Revealing the values of the new energy consumer, 2011 at http://www.accenture.com/SiteCollectionDocuments/PDF/Resources/Accenture—Revealing—Values—New—Energy—Consumer.pdf

42 Ibid.

43 Oliver Roy and Amel Boubekeur (eds.) Whatever Happened to the Islamists? Salafis, Heavy Metal Muslims and the Lure of Consumerist Islam. Columbia University Press, New York 2012.

44 http://www.communicaid.com/access/pdf/library/culture/doing-business-in/Doing%20Business%20in%20India.pdf.

45 Shell, New Lens Scenarios, op. cit.

46 India Energy Book 2012, http://indiaenergycongress.in/iec2012/ieb2012/ieb2012.pdf, p. 5; http://www.ksoils.com/whitepapers/KS—WHITEPAPER—INDIAN—CONSUMER—MARKET.pdf; http://www.brasil.gov.br/para/press/press-releases/august-1/brazils-middle-class-in-numbers/br—model1?set—language=en; http://www.worldbank.org/en/news/feature/2012/11/13/middle-class-in-Brazil-Latin-America-report; http://www.brasil.gov.br/para/press/press-releases/august-1/brazils-middle-class-in-numbers/br—model1?set—language=en; http://www.worldbank.org/en/news/feature/2012/11/13/middle-class-in-Brazil-Latin-America-report; http://siteresources.worldbank.org/LACEXT/Resources/OverviewMiddClass.pdf, p. 11.

47 http://siteresources.worldbank.org/LACEXT/Resources/OverviewMiddClass.pdf, p. 11.

48 Asia Confidential, January 2014at http://asiaconf.com/2014/01/em-banking-crises-are-next

49 "IMF Warns G20 of Deflationary Risk, Emerging-Market Turmoil", Bloomberg, 19 February 2014. Also see Amy Myers Jaffe and Meghan L. O'Sullivan The Geopolitics of Natural Gas, Belfer Center (Harvard Kennedy School, July 2012, pp. 12-13.

50 Florida, Gulden, and Mellander, "The Rise of the Mega Region", Cambridge Journal of Regions, Economy and Society Vol. 1 No. 3 (2008) pp. 459-476.

51 See Jean-Claude Juncker, A New Start for Europe: My Agenda for Jobs, Growth, Fairness and Democratic Change, European Parliament, 15 July 2014 at http://ec.europa.eu/priorities/jobs-growth-investment/index—en.htm

52 http://planningcommission.nic.in/reports/sereport/ser/isid—mining%20—report1206.pdf.

53 Shell, New Lens Scenarios, op. cit.

54 World Energy Council, op. cit., pp. 121-124.

55 Shell, Energy Scenarios to 2050: Signals & Signposts, February 2011 http://future-and-politics.org/category/eu-economic-foresight-2012-2013/

56 World Energy Council, op. cit., pp. 103-4.

57 Ibid., p. 244.

58 Shell, Energy Scenarios 2050, op. cit., p. 7.

59 "China's ambitions to double output by 2030 rely on unconventional sources", 4 February 2014, at http://breakingenergy.com/2014/02/04/chinas-ambitions-to-double-output-by-2030-rely-on-unconventional-sources/ and "WGC Survey: China could be biggest shale gas producer by 2030", Oil and Gas Journal, 6 July 2012 at http://www.ogj.com/articles/2012/06/wgc-survey-china-could-be-biggest-shale-gas-producer-by-2030.html
60 BP Energy Outlook 2035, January 2014, p. 89.
61 See also China's Energy Future, Boston Consulting Group at http://www.bcgtelaviv.com/documents/file127070.pdf and Wang Tao, China Energy Future at a Crossroads, http://carnegietsinghua.org/publications/?fa=54986
62 "Modi to Use Solar to Bring Power to Every Home by 2019", Bloomberg, 19 May 2014 at http://www.bloomberg.com/news/2014-05-19/modi-to-use-solar-to-bring-power-to-every-home-by-2019.html
"Securing India's energy a major challenge for new PM Modi", CNN, 26 May 2014 at http://www.edition.cnn.com/2014/85/26business/india-energy-modi
63 World Energy Council, op. cit., p. 244.
64 Judy Dempsey, "Europeans Are Prolonging Their Dependence on Russian Gas", 8 May 2014 at http://carnegieeurope.eu/strategiceurope/?fa=55538 and "Conscious uncoupling", The Economist, 5 April 2014 at http://www.economist.com/news/briefing/
65 Amy Myers Jaffe and Meghan L. O'Sullivan, The Geopolitics of Natural Gas, Belfer Center (Harvard Kennedy School, July 2012, p. 14 and in general HCSS, The Geopolitics of Shale Gas, Number 17, Hague Centre for Strategic Studies 2014.
66 "U.S. Oil Boom Divides OPEC", Wall Street Journal, 27 May 2013.
67 Jaffe and O'Sullivan, op. cit., pp. 7-10, 15 and HCSS, Geopolitics of Shale Gas, op. cit.; "BP: Shale gas, tight oil to reshape global markets by 2030", Oil and Gas Journal, 5 February 2013, http://www.ogj.com/articles/2013/02/bp--shale-gas--tight-oil-to-reshape-global-markets-by-2030.html and BP Global energy outlook 2030 at http://www.bp.com.
68 "Oil exporters must be wary of dependence on oil revenues", 8 April 2013 at http://oilprice.com/Energy/Crude-Oil/Oil-Exporters-Must-be-Wary-of-Dependence-on-Oil-Revenues.html; Murad Alazzany and Robert Sharp, "Re-Energizing Yemen's Energy Sector", Yemen Times, 2 June 2014, http://www.yementimes.com/en/1784/business/3916/Re-Energizing-Yemen%E2%80%99s-Energy-Sector.htm; Peter Salisbury, Yemen's Economy: Oil, Imports and Elites, Chatham House, October 2011 at http://www.chathamhouse.org and Mohsin Khan and Svetlana Milbert, Yemen's Economic Quandary, Atlantic Council, 22 August 2013 at http://www.atlanticcouncil.org/en/blogs/menasource/yemen-s-economic-quandary.
69 International Energy Agency, World Energy Investment Outlook, p. 54.
70 Stevens, OPEC's Dilemma, ibid.
71 IEA, op. cit., p. 84.
72 Westphal, Unconventional Oil and Gas, op. cit.
73 Shell 2050 (2008), p. 41 and WES 2050 op. cit., p. 244. Also see Friends of Europe, Energiewende made in China: Paving the way towards green growth, November 2014, p. 6.
74 World Energy Council, op. cit., p. 244.

# 3. CASE STUDY: POWER TO GAS - A TECHNOLOGICAL INNOVATION SYSTEM APPROACH

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## 3.1 Introduction

The three end states presented in Chapter 1 show a considerable share of renewable energy in the energy mix as it develops. This corresponds with the European energy policy and plans as they are stated in Energy 2020[1], Energy trends 2030[2] and the Energy Roadmap 2050[3].

The growing share of renewable energy will for a large part be realized with wind, hydroelectric and solar power. Besides having both low life cycle carbon emissions, wind and solar power are also intermittent energy sources. This increases the need for overall flexibility in the energy system strongly[4/5].

The energy system has to adapt to intermittent energy sources, such as wind power and solar energy, which provide energy in a fluctuating manner. Energy storage is the solution. In times of excess electricity production the energy has to be stored. Power to Gas is a technology that offers this storage option.

The basic principle of the power-to-gas concept is the bidirectional linking of the existing infrastructure units (the electricity grid and the gas grid) with the goal of establishing a new way of managing loads and generation, which enables high proportions of fluctuating electricity generation from renewable energy sources to be accommodated in the energy system. To date, this link only exists in terms of generating electricity from natural gas (gas to power), but not vice versa (power-to-gas)[6].

The power-to-gas principle is shown in Figure 1: Power-to-gas concept for bidirectional coupling of the electricity and gas grids.. Excess electricity is converted into hydrogen using electrolysis. The hydrogen can be used in three ways[7]. In the first place the hydrogen can be injected in the gas grid but only up to a limited amount since the gas grid is designed to transport and store natural gas and not hydrogen[8/9]. Secondly the hydrogen can be converted into methane. Methane can be injected into the gas grid on a large scale. The $CO_2$ that is needed for methanation can be provided by a bio gasification plant[10] or through carbon capture storage (CCS). The third option is of course to use the hydrogen in industry and transportation and not inject it into the gas grid.

Figure 1 below shows that the natural gas grid can store the excess renewable energy. It is important to notice that the storage capacity of the gas grid is large and that the storage can be used to cope with seasonal fluctuations as well.

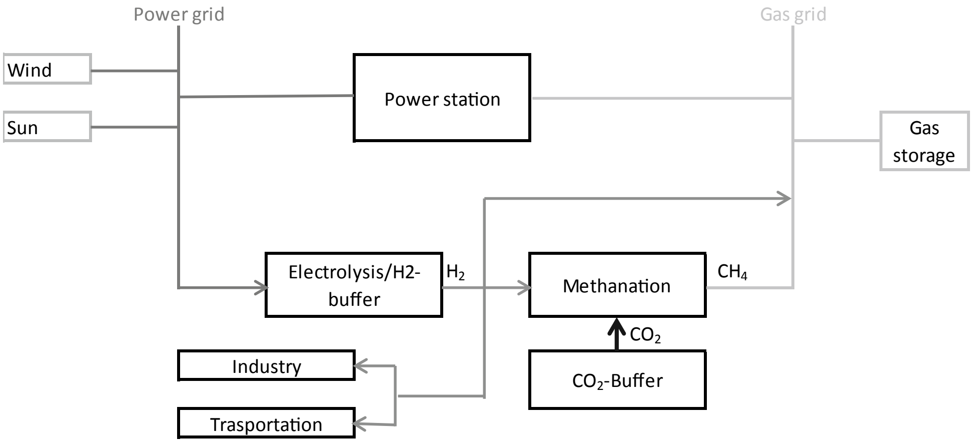



*Figure 1: Power-to-gas concept for bidirectional coupling of the electricity and gas grids.*

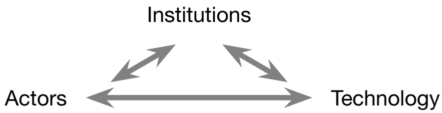
Three end states were defined. These end states require technological innovation. One innovation that is needed to accommodate the end states is the storage of excess renewable energy. Power-to-gas can provide this storage but the technology is facing hurdles. This chapter describes the factors that will determine if power-to-gas will be an important technology in the energy transition.

## 3.2 Methodology – a system approach

What will determine if power-to-gas will be an important technology in the energy transition over the next years? A technology does not develop in one place and it is not developed by one actor. One can look at the development of a technology as a process that takes place in a technological innovation system (TIS). The TIS includes all actors and institutions that are involved in the development, diffusion and utilization of a technology.

The central idea of this analysis is that the analysis of technological change should focus on systematically mapping the activities that take place in innovation systems resulting in technological change. Since these activities have the function to contribute to the goal of the innovation system, which is the generation and diffusion of innovations, the activities are often called functions of innovation systems[11/12].

Many actors and institutions are involved in the development of power-to-gas. Since the actors and institutions do not act alone they are viewed as a system with multiple interdependencies.




*Actors* are numerous, ranging from public to private and from innovator to end-user. *Institutions* are governments, agencies, law and others. A system approach is used to emphasize the dynamics between actors, institutions and technological factors[13].

The basic unit of the analysis is the event. Within the context of a TIS analysis, an event can be defined as an instance of rapid change with respect to actors, institutions and/or technology, which is the work of one or more actors and which carries some public importance with respect to in this case the Power to Gas TIS. Examples of such events are studies carried out, conferences organized, plants constructed, policy measured issued, etc.

A successful system should fulfil the following functions:

1. Entrepreneurial activities
2. Knowledge development
3. Knowledge exchange
4. Guidance of the search
5. Market formation
6. Resource mobilisation
7. Support from advocacy coalitions

This Technological Innovation System approach is based on Motors of sustainable innovation by Roald A. A. Suurs.

The main research question is: *In what way does the power-to-gas Technological Innovation Systems affect the energy technology trajectories leading to the end states?*

Using the Technological Innovation System approach the sub questions are:

1. *How does the power-to-gas Technological Innovation System perform on the defined functions?*
   The answer to this question will provide insight in the strengths and weaknesses of the Technological Innovation System. Are there for example significant entrepreneurial activities, is there meaningful knowledge development and exchange, and so on. The progress will be recognized through so called events. An event can be a publication, a commercial initiative, a new subsidy or any other signal that can be considered as a contribution to the Technological Innovation System.
2. *What progress does the power-to-gas Technological Innovation System need to make to accommodate the different end states?*
   This question will address the end states. The focus will be the contribution that power-to-gas can have related to the different end states. It is possible that power-to-gas will be more relevant for one end state compared to the other end states.

The TIS approach has a technology as its starting point. The development of a technology is not place based. At different locations all over the world entrepreneurial activities can start and research can be initiated. On the other hand regulation and policies are most of the time not worldwide and technology often develops in a regional context. This study looks at the power-to-gas TIS from a European perspective and will put some emphasize on the Dutch situation.

## 3.3 Entrepreneurial activities

Entrepreneurs are at the core of any TIS. The classic role of the entrepreneur is to translate knowledge into business opportunities, and eventually innovations. The entrepreneur does this by performing market oriented experiments that establish change, both to the emerging technology and to the institutions that surround it. The entrepreneurial activities involve projects aimed to prove the usefulness of the emerging technology in a practical and/or commercial environment. Such projects typically take the form of experiments and demonstrations[14]. Public actors can be entrepreneurs as well, as long as their actions are directed at conducting market-oriented experiments with an emerging technology.

Over 30 power-to-gas demonstration plants are currently reported on the internet and in literature[15/16/17]. At this moment most projects are in the construction or planning phase. The largest existing plants will be discussed.

In 2013 Audi opened a power-to-gas plant in Werlte (Germany) with a 6 MW capacity. It converts surplus renewable electricity in hydrogen and methane. The renewable synthetic methane, called Audi e-gas, is provided for Audi customers of the A3-tron g, an Audi vehicle. Customers can order a quota of e-gas when they purchase the car. This enables them to take part in an accounting process that ensures that the amount of gas that they put in their vehicle at the natural gas filling station is supplied to the grid by the Audi e-gas plant[18].

Also in 2013 E.ON inaugurated a power-to-gas (P2G) unit in Falkenhagen in eastern Germany. The unit uses wind power to run electrolysis equipment that transforms water into hydrogen which is injected into the regional gas transmission system. The hydrogen becomes part of the natural gas mix and can be used in a variety of applications, including space heating, industrial processes, mobility, and power generation. The unit, which has a capacity of two megawatts, can produce 360 cubic meters of hydrogen per hour[19].

In Grapzow (Germany) E.ON has installed in 2012 a 1 MW power-to-gas system connected to a 140 MW wind farm. The plant's owners have the option to use the hydrogen in an internal combustion engine to produce electricity, or inject it directly into the local natural gas grid, depending on operational needs[20].

Enertrag installed in Prenzlau (Germany) three 2 MW wind turbines directly connected to an electrolyser[21]. The hydrogen that is produced is used in several ways. During low wind periods, the stored hydrogen, mixed with biogas, can be used to fuel two combined heat and power units, for additional electricity production. From the point of view of the grid operator, the hybrid power plant will then be operating as a base load power station. The hydrogen can also be used for fuelling cars. TOTAL Deutschland GmbH is a partner in de project. Total operates service stations where cars can be fuelled with wind-hydrogen produced in Prenzlau. The hydrogen is transported in tankers from Prenzlau to Berlin[22].

| City | Project name | Operating since | Application |
|---|---|---|---|
| Hamburg | Wasserstofftankstelle HafenCity | 2012 | Production of hydrogen<br>Hydrogen used for transportation (busses) |
| Werlte | Audi e-gas Project | 2013 | Production of methane<br>Injection in gas grid<br>Certificates for Audi vehicles |
| Frankfurt Am Mein | P2G demo Thuga group | 2013 | Production of hydrogen<br>Inject in gasgrid |
| Herten | H2Herten | 2013 | Production of hydrogen<br>Hydrogen used for transportation and other fuel cells |
| Niederaussem | CO2rrect | 2013 | Production of methane and methanol |
| Bad Hersfeld | Metanisierung am Eichhof | 2012 | Production of methane<br>Inject in gasgrid |
| Stuttgart | Verbundproject Power-to-Gas | 2012 | Production of methane |
| Falkenhagen | Pilotanlage Falkenhagen | 2013 | Production of hydrogen<br>Inject in gasgrid |
| Grapzow | Windpark RH2-WKA | 2012 | Production of hydrogen<br>Use hydrogen to produce electricity<br>Inject in grid |
| Prenzlau | Hybridkraftwerk Prenzlau | 2011 | Production of hydrogen<br>Use for electricity<br>use for transportation |
| Schwandorf | Power to Gas in Eucolino | 2012 | Production of methane using Microorganisms.<br>Injection in grid or storage. |
| Rozenburg (NL) | P2G in Rozenburg | 2013 | Production of methane<br>Injection in local grid |

*Table 1: Operating power-to-gas plants in Germany (10) and the Netherlands (1).*

Analysing the existing projects it is obvious that they all use electrolysis to turn electricity into Hydrogen. After all, that is what makes them power-to-gas projects. There are some differences that stand out. First of all there is the option of methanation. Six of the existing projects produce methane and inject it into the gas grid. The methanation is realized using different technologies. The other five projects do not methanise the hydrogen. Three out of those five projects use the hydrogen in the transportation sector. The other two projects inject the hydrogen in the gas grid or convert it back into electricity.

All those projects can count as entrepreneurial activities as defined in the TIS literature. They are market oriented experiments trying to prove the usefulness of the emerging technology. It is also important to notice that all projects have a recent date. Initial plans are of course made some years ago but the operating projects have gone into production over the last few years. For the power-to-gas TIS this means that entrepreneurial activities have taken off and have a positive effect on the emerging technology.

## 3.4 Knowledge development

The knowledge development function involves learning activities, mostly on the emerging technology but also on markets, networks, users and other factors. Learning activities can be laboratory experiments but also trial projects. Without knowledge development there will be no technological innovation[23].

Power to Gas uses electrolysis of water to produce hydrogen. The technology is not new; Zenobe Gramme invented the Gramme machine in 1869 to produce hydrogen using electrolysis of water. It is therefore arbitrary to decide when power-to-gas started as a technology to be used to transform surplus electricity into gas. In this chapter, research over the last 10 years is considered to be part of the power-to-gas TIS. The largest studies are categorized according to their main topic and will be discussed briefly.

### 3.4.1 Studies on electrolysis and hydrogen

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a public private partnership founded in 2008 supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realizing their potential as an instrument in achieving a carbon-lean energy system[24]. The FCH JU helps to carry out the 7th framework programme for research and technological development (FP7). For 2013 the FCH JU contributes €68 million to 27 projects[25]. The projects are categorized in five so-called application areas:

- Transportation and refuelling infrastructure;
- Hydrogen production and distribution;
- Stationary power generation and CHP;
- Early markets;
- Cross cutting issues.

Most FCH JU projects are relevant for the power-to-gas TIS. The programme is therefore a positive contribution to the TIS.

### 3.4.2 Studies on power-to-gas and the gas network

The Naturalhy project was funded by the European commission's sixth framework program (2002 – 2006) for research, technological development and demonstration[26]. The project started in 2004 and the final report was published in 2010. The project studied the possibility to use the existing natural gas system for hydrogen. The possible impact of adding hydrogen to natural gas on the durability of the network was an important part of the project. Also measures to control and monitor the condition of the network were analysed. Safety aspects of adding hydrogen to the network were another subject. The end user aspects were studied as well. Research was also done on the possibility to separate hydrogen from a hydrogen/natural gas mixture by the use of membranes.

The main goal of the Naturalhy project was to identify showstoppers. This also determined the scope of the project. Materials that are used in the natural gas system which can easily be replaced by another – hydrogen proof - material were for example not considered to be a potential threat to the durability of the network. The final report emphasizes that given the size and the complexity of the project it is important not to jump to simple conclusions. The general outcome of the project though was that no showstoppers were identified. For the power-to-gas TIS the Naturalhy project therefore was a positive impulse.

In Germany the DVGW carried out an extensive study analysing the main power-to-gas issues[27]. In the first place the H2-tolerance of the German natural gas grid was researched. The main conclusion is that the existing gas infrastructure can handle a 10% volume addition of $H_2$ in the gas grid. Furthermore four possible power-to-gas applications in Germany were studied. One of the subjects was the difference between injecting hydrogen into the local grid versus injecting into the interregional grid. Injecting in the local grid causes a significant limitation in the $H_2$ volume that can be added. The DVGW also examined the economics of power-to-gas. The variables that are most important to decide on the financial feasibility of power-to-gas are the utilization of the power-to-gas installation (in hours) and the price of electricity.

The HyUnder project studies the possibilities for large scale and long term storage of renewable electricity by hydrogen underground storage in Europe. The project compares hydrogen underground storage with other storage options. Given de European energy policy goals the need for storage is explored. The conclusion is that, although a thorough quantification of the energy storage needs in the EU has not been undertaken yet, the necessity of energy storage to compensate the intermittency of renewable energy is obvious and that energy storage will play a key role in the future European energy structure, as it is described in the Energy 2020 program and the Energy Roadmap 2050 by the EU. The project also concludes that the only feasible option for large scale energy storage is to employ underground hydrogen / SNG storage in salt caverns. SNG provides the additional option to be stored in all kind of storages in the natural gas grid. Because of high investment costs systems with hydrogen underground tube storage or storage in pressure vessel bundles are not appropriate for long term storage of large volumes[28].

### 3.4.3 Studies on power-to-gas in the energy system

In June 2013 DNV KEMA published "Systems analyses Power to Gas: a technology review"[29]. The study compares power-to-gas to other energy storage technologies. The technologies should fulfil several functions, in the DNV KEMA study so called service applications:

- Frequency support: stabilizing the grid frequency almost instantly in case of very sudden large decreases in power generation
- Uninterruptable power supply: providing emergency power when the input power source fails
- Community energy storage: store energy at a local level
- Home energy storage: storage dedicated for household applications
- Forecast hedging: the use of stored energy to mitigate penalties when real-time generation falls short
- Time shifting: the storage of energy generated during low demand periods and discharged during high demand periods
- Transmission and distribution capacity management: possible avoidance of network upgrades

The study concludes that the value of power-to-gas is in its able to deliver community energy storage services, time shifting and transmission and distribution capacity management. This outcome contributes in a positive way to the knowledge development function.

### 3.4.4 Studies on the financial feasibility of power-to-gas

In 2006 the Institute for Energy and Transport (IET) – part of the joint research centre (JRC) from the European commission- published "Bridging the European wind energy market and a future renewable hydrogen-inclusive economy". The approach of this study is to determine, via life-cycle cost-benefit assessment, the long-term competitiveness and economic implications of power-to-gas. The study takes into account that the costs and benefits of power-to-gas are aggregated at different economic levels. The investment costs and product revenues for example are assumed to be the project owners. The benefits from improved network management are realized by the consumer of electricity in the price he pays for electricity. The benefits from local environmental conditions (avoided particulate emissions) are enjoyed by the local community of consumers. The benefits for global environmental conditions (reduced greenhouse gas emissions) are enjoyed by all members of society.

The function of knowledge development was definitely met by this study. It is hard to categorize the contribution as positive or negative. Four scenarios are outlined varying in the wind penetration in the energy mix and in the strength of the hydrogen and climate change push. The production costs of Hydrogen through power-to-gas are much higher than the Hydrogen market price. In other words, power-to-gas is an expensive way to produce Hydrogen. The additional benefits of power-to-gas, avoided $CO_2$ emissions and avoided balance costs, are not compensating the high production costs. A scenario with high wind penetration, low electricity prices and high $CO_2$ and hydrogen prices gives a positive cost-benefit outcome demonstrated in lower electricity prices. The study assumes that electricity companies will pass on benefits to the consumers through lower prices.

In September 2008 ECN published "Conversion of excess wind energy into hydrogen for fuel cell applications"[30]. The study starts with estimating the excess wind energy in the Netherlands in 2020. The political ambition to have 6 GW offshore and 2-4 GW onshore wind power in 2020 is taken as a starting point. Using the electricity demand data and the wind speed data from 2004 the result for 8 GW installed wind power is an excess wind power of about 4.5 TWh. The minimum cost estimate for producing hydrogen using the excess wind power is 4.4 €/kg. The costs are high because the load factor for the electrolysers is low. Using all wind power to produce hydrogen results in production costs of 5 €/kg. Even though the use of the capacity of the electrolysers improves, the costs of electricity – using a mean of 0.08 €/kWh- raises the costs of the hydrogen.

DNV KEMA reports using different sources that the estimates of excess wind power differ from 0.5 TWh per year to 10 TWh per year in 2050. Another KEMA study from 2010 concludes that a 12 GW wind capacity in 2020 in the Netherlands will lead to no more than 0.5 TWh curtailment per year[31]. Different scenarios are considered. The relatively low curtailment implies less need for power-to-gas technology.

The conclusion regarding the knowledge development function is that there have been many power-to-gas research programs and publications over the last 10 years. The general outcome for the power-to-gas TIS is positive. The knowledge base is growing and so far no showstoppers are identified.

## 3.5 Knowledge exchange

The function of knowledge exchange concerns the exchange of information through networks, publications, conferences and other means that are used to share information. Knowledge exchange is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government, competitors, and market. Here policy decisions (standards, long term targets) should be consistent with the latest technological insights and, at the same time, R&D agendas should be affected by changing norms and values[32/33].

For the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), cooperation between government, businesses and research institutions is a main target. The three members of the FCH JU are the European Commission, the NEW Industry Grouping and the N.ERGHY Research Grouping. The NEW Industry grouping has 68 companies working in the field of fuel cells and hydrogen and they represent a major part of the sector[34]. The N.ERGHY Research Grouping represents the interests of European universities and research institutes in the FCH JU. Currently 58 international research institutions are a part of N.ERGHY[35]. As mentioned before the FCH JU has 27 projects carried out and they are all Hydrogen related. The projects themselves all have several organizations participating.

The International Energy Agency (IEA) is an autonomous organization which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA's four main areas of focus are: energy security, economic development, environmental awareness, and engagement worldwide. The IEA has developed a Hydrogen Implementing Agreement. The strategy of the IEA's Hydrogen Program is to facilitate, coordinate, and maintain innovative R&D activities through international cooperation and information exchange. Knowledge exchange is stimulated by the IEA because of its focus on international cooperation. Task 24 from the Hydrogen Implementing agreement provides an overview for technologies which have direct influence on development and implementation of systems integrating wind energy with hydrogen production.

The Joint Research Centre Institute for Energy and Transport (JRC IET) provides support to European Union policies and technology innovation to ensure sustainable, safe, secure and efficient energy production, distribution and use and to foster sustainable and efficient transport in Europe. The SETIS program belongs to the key scientific activities of the JRC IET and provides information on 37 fuel cells and hydrogen projects and 45 wind energy projects[36].

The entrepreneurial activities that are a part of the power-to-gas TIS are also a clear example of the knowledge exchange function. Appendix B shows the partners per project. Almost all projects have multiple partners with different backgrounds such as research institutions, gas companies, electricity companies and suppliers of power-to-gas technology.

The North Sea Power to Gas Platform is an example of a network of stakeholders that come together to share information and experiences. The platform was initiated in 2012 and has had five meetings since the start. 14 member organizations have joined the platform.

The research that is seen as a part of the knowledge development function contributes to the knowledge exchange function in two ways. First of all, the research programs in general result in publications, presentations and conferences. In the second place, just like the entrepreneurial activities, most research programs have multiple partners participating in the projects. Appendix C shows the participating partners in the largest recent power-to-gas research programs. Since almost all research programs and entrepreneurial activities involve several participants the conclusion is that the knowledge exchange function in the power-to-gas TIS is fulfilled in a positive way.

## 3.6 Guidance of the search

The guidance of the search function refers to the activities within the TIS that shape the needs, requirements and expectations of actors with respect to their further support of the emerging technology. Usually, various technological options exist within an emerging technological field. The guidance of the search function represents the selection process that is needed to direct scarce resources to the most promising options[37/38].

For power-to-gas the growth of intermittent renewable energy is crucial. Only when there is significant excess renewable electricity it becomes urgent to have power-to-gas technology. The European Commission states in its Energy 2020 strategy that it will implement the SET plan without delay[39]. One of the six initiatives in the SET plan is the European wind initiative. The key objective of this initiative is to double the power generation capacity of the largest wind turbines, with off-shore wind as the lead application[40]. The European wind initiative is now being implemented by EU institutions, member states, TPWind and the European Energy Research Alliance (EERA). The budget of the European wind initiative is €6 billion (public and private resources)[41].

In March 2013 the Dutch government published "Rijksstructuurvisie Windenergie op land". It was decided that for onshore wind energy a number of areas were considered to be fit for wind projects of 100 MW and more. These projects will have to answer to national regulation whereas smaller projects have to meet local (provincial) regulation. This way the Dutch government wishes to realize 6000 MW onshore wind energy by 2020. The vision includes subsidies for 2013 for a total of €3 billion for the production of renewable energy (not just wind). For offshore projects the new national policy will appear in 2014.

The guidance of the search function at a high level compares power-to-gas to other technologies to store intermittent renewable energy. Those other relevant large scale energy storage technologies are pumped hydro energy storage, compressed air energy storage and stationary batteries. Research shows that the strengths of power-to-gas technology are the possibility to offer storage on a large scale and to store energy in the range of hours to several weeks. On the other hand the power-to-gas energy efficiency is low compared to other storage options[42,43,44,45]. As far as guidance of the search is concerned the comparison with other storage technologies seems to encourage further power-to-gas development based on its strengths. Improving the energy efficiency is a priority.

Within the power-to-gas TIS the guidance of the search function has several subjects. They can be analysed in a structured way using the power-to-gas process. The first step is the conversion of excess electricity into hydrogen using electrolysis. The electrolyser uses either Alkaline, Polymer Electrolyte Membrane (PEM) or Solid Oxide Electrolysis (SOE) technology. Alkaline electrolysis is a well-established technology but the efficiency of the process, the purity of the hydrogen and the performance at low loads should improve. PEM technology is more efficient but has higher costs. SOEC electrolysis is in a laboratory stage[46/47]. Currently several projects study Alkaline and/or PEM electrolysis[48/49]. On this subject the guidance of the search is ongoing. There are no recent breakthroughs that are decisive for the choice of electrolysis technology.

After the conversion of excess electricity into hydrogen there are different ways to use the hydrogen. First of all the hydrogen can be used in transportation or in industry. The FCH JU reports 20 projects concerning transportation and refuelling infrastructure[50]. Some of the entrepreneurial activities also involve transportation. In more than 10 European cities hydrogen fuelling stations can be found[51].

The hydrogen can also be added to the gas grid. This option has three main advantages. The storage capacity of the gas grid is large, the existing infrastructure can be used and the transportation of gas is cost-effective. Two large studies suggest that adding hydrogen to the gas grid is probably feasible under certain conditions[52/53]. One of the conditions is the percentage of hydrogen that is added to the natural gas. Converting the hydrogen into methane is an alternative route. Methane behaves like natural gas and can be added to the gas grid without restrictions. On the other hand methanation makes the power-to-gas process less energy efficient and $CO_2$ is needed to produce the methane. Both methods are currently used in the entrepreneurial activities that are discussed[54/55/56] and there is ongoing research on the injection of hydrogen and methane into the gas grid[57]. Again it is too early to say if hydrogen is going to be added to the gas grid on a large scale and if methanation is going to be used while doing this.

If hydrogen is added to the gas grid it might be desirable to be able to separate the hydrogen from the gas mixture for other applications later on. Using a membrane system this separation is possible but has high capital costs[58]. The FCH JU has one project concerning separation[59]. It seems that the separation technology does not have the centre of attention in the power-to-gas TIS.

In the power-to-gas TIS the guidance of the search function involves two main issues. In the first place power-to-gas has to become more energy efficient. Several electrolysis technologies are being studied but there is no best technology identified yet. In the second place it is not clear in what way the produced hydrogen should be used to get the highest benefits out of power-to-gas technology. If hydrogen transportation is going to be applied on a large scale it may not be necessary to inject hydrogen into the gas grid. On this subject the guidance of the search function is in progress and has not identified a preferred solution yet.

## 3.7 Market formation

The market formation function involves activities that contribute to the creation of a demand for the emerging technology, for example by financially supporting the use of the emerging technology. In case of sustainable innovations, there is usually no commercial product unless the institutional framework is adjusted to account for external costs. Therefore, in this case, the system function is typically fulfilled by governments, through the setting up of formal institutions[60].

### 3.7.1 Regulation

For power-to-gas the market formation is in the first place facing a lack of regulation. At this moment the responsibility concerning power-to-gas is unclear. Is power-to-gas the responsibility of the electricity producer, electricity distributor, gas producer, gas distributor or some other party? Despite all the power-to-gas demonstration projects it is unlikely that there will be large scale power-to-gas plants before the regulator has set up the regulatory framework. In the Energy agreement[61] power-to-gas is mentioned when adaptations in the energy infrastructure are discussed. The Energy agreement states that energy storage is needed and that power-to-gas technology has to be examined. Responsibilities or the need for regulation are not discussed. Recent changes in the Gas law and the Electricity law have not provided a regulatory framework for power-to-gas. Still such a framework is necessary for market formation to develop.

Regulation is also important to achieve economically viable P2G implementation. At present, the only value that can be gained from P2G technology is in the production of a gas with re-sale value – hydrogen or SNG. Much of the real value to the energy system comes from elsewhere - in the avoided capital cost of extra infrastructure, in the enabling of maximum utilization of renewable electricity, and in the increase in renewable content of the gas networks. All these need to be given value through appropriate regulation to give P2G developers the confidence that they can implement a market ready solution[62].

### 3.7.2 Regulatory risk

There is a direct relation between market formation and the perceived risks. When the businesses consider the project risks too high then there will be no market. What risks do businesses face when they invest in power-to-gas technology? Two risk categories that can be identified (among others) are regulatory risk and market risk[63].

Regulatory or institutional risk concerns the risk of adverse changes in the policy context. Policies and measures might change during the project cycle which may have significant impacts on the profitability of a project. Examples are changes to or even ending of policy support schemes or changes to the market design. As most markets for renewables are being regulated under policy schemes, this risk is of particular importance to renewable energy technologies[64]. Once installed the regulation has to be reliable in the long run. Regulatory risk is caused by unexpected changes in the rules[65].

The policy context for power-to-gas includes the Energy 2020 strategy, the European wind initiatives and in the Netherlands the national plans for wind on land and wind at sea. It is important that the plans of the government are perceived as convincing. In response to the plans of the government Energie-Nederland, a Dutch organization for the assembled Dutch energy producers, transporters and other parties, signals some problems. Some of the assigned areas are not chosen from a technical feasible point of view. In reality there might be not enough sufficient space for 6,000 MW in the plans. Another concern that Energie-Nederland has is the availability from the subsidies for wind projects. The regulation provides incentives to apply for subsidies with low cost projects. In the end those projects don't turn out to be financial feasible. Bigger and more expensive wind projects miss out on the subsidies and will not be realized according to Energie-Nederland[66].

The CPB (the Dutch agency for economic policy analysis) adviced negative on the Dutch onshore wind plans. A cost benefit analyses shows that the economic crisis and the large availability of coal due to the shale gas growth in the USA has caused excess electricity producing capacity. Expanding the capacity – with wind energy or otherwise – will not be profitable. The CPB advises to postpone the new wind projects for five years[67].

### 3.7.3 Gas quality and regulatory risk

To store hydrogen in the gas grid is not only a matter of technological feasibility. It is also necessary that adding hydrogen is confirmed by the relevant regulation. In 2011 KEMA and Arcadis published "Gaskwaliteit voor de toekomst", a study on the possible composition of gases in the system[68/69]. The study was ordered by the ministry of economic affairs, agriculture and innovation. First the study mentions the requirements that the policy on gas quality has to meet. For power-to-gas the most important requirement is that there is a need for a policy that offers certainty for investments. If power-to-gas eventually means a gas grid containing 10% hydrogen then this has to be according to the future gas quality standards. As long as these standards are not clear investors will hesitate to invest in power-to-gas. The most important conclusions of the report is that the gas quality for the future needs further specification to give investors in appliances and producers of gas the right information that they need for their decisions. This is also recognized by the topteam energy, a platform that is a part of the Dutch topsector policy. The need for (international) regulation is one of the problems that the team would like to solve[70].

### 3.7.4 Economic risk

Important economic risks are demand risk (uncompetitive pricing policy of renewable projects) and price risk (changes in market prices of energy carriers and/or certificates for climate change abatement of renewable production)[71].

If the hydrogen or methane is too expensive due to the high costs of power-to-gas technology there will be a lack of demand. Power-to-gas installations are expensive and since they are only used when excess electricity is available the installation will not be operating all the time. This means that the high fixed costs have to be compensated in limited time. The revenue of power-to-gas will probably not cover the costs if the revenue is restricted to the price that is received for the gas. An additional benefit of power-to-gas is the contribution to the balancing of the electricity network. The value of this contribution could be considered to be revenue as well.

Because power-to-gas does not seem to be financially feasible different models are looked upon. In Germany there is a proposal to obligate the regional energy producers to buy the green gas at a price that covers the costs for the investor. The extra costs will be passed on to the consumers. Since the green gas is a small part of the total energy use the extra costs will be limited[72].

Compared to other options (batteries, pumped hydro systems and others) the large scale and long-time storage of excess electricity through power-to-gas looks promising. Large scale stationary storage of hydrogen enables synergies with both e-mobility by the application of hydrogen powered fuel cell electric vehicles and the direct utilisation of hydrogen in industry. Given the achievable prices for hydrogen in different applications, based on the assumption that hydrogen in the transport sector can be sold in a bandwidth between 6 €/kg$H_2$ (hydrogen delivered to refuelling station) and 8 €/kg$H_2$ (accepted hydrogen sales price at the refuelling station for end users), it is revealed that hydrogen as a fuel provides the most valuable sales pathway. The other utilisation pathways may, in fact, offer a larger potential in light of volume, but their potential with regard to economic opportunities is clearly below that of the transportation sector. Also a major disadvantage of the methane systems is their comparatively low overall efficiency[73].

Another approach is taken by the CENER Centre[74]. Their model provides an economical assessment of a wind-hydrogen energy system. They emphasize the possibility to sell wind electricity at the best possible price. When prices are low, the energy should be stored as hydrogen. Selling at the best possible price might improve the overall rate of return. For a 42 MW wind farm using historical data it turns out that adding power-to-gas to the system results in a better price (€/kWh) but not in a higher rate of return. The investments needed for the power-to-gas equipment bring along higher costs that are not made up for by the extra revenues due to better trading.

SEO Economic Research studied the costs and benefits of different measures to reduce $CO_2$ emissions[75]. They qualify power-to-gas as a costly but necessary technology to meet the 2050 target of 80% reduction of emission. The most cost efficient technologies are energy savings, wind on land, $CO_2$ capture and nuclear energy. ECN and the Planbureau voor de leefomgeving published a roadmap for 2050[76] where they also find that given the reduction of emission target a growth in renewable energy production should be expected. This growth creates a need for storage that power-to-gas can fulfil.

### 3.7.5 Market formation

The market formation function in the power-to-gas TIS identifies a number of barriers. In the first place there is a lack of regulation and it is therefore unclear who has the responsibility to balance the electricity network applying power-to-gas. Secondly it is unsure whether current regulations will result in a sufficient growth of intermittent renewable energy. There are European and national programs and plans to support this growth but they may not be sufficient and they are criticized for being unrealistic. A third barrier is the lack of long term regulation on the subject of gas quality. Finally power-to-gas does not seem financially feasible. The contribution of power-to-gas in balancing the network has to be taken into account because other costs may be avoided. The conclusion is that the market formation function identifies a number of problems for the power-to-gas TIS.

## 3.8 Resource mobilization

Resource mobilization refers to the allocation of financial, material and human capital. The access to such capital factors is necessary for the development of the power-to-gas TIS. Typical activities involved in this system function are investments and subsidies[77]. As discussed above, there is only a need for power-to-gas if there is a large amount of intermittent renewable energy. This means that the funds directed at stimulating renewable energy in an indirect way increase the need for power-to-gas. Therefore looking at the function of resource mobilization requires a broad perspective. Investments and subsidies for power-to-gas technology represent direct resource mobilization for the TIS but resources for intermittent renewable energy sources are relevant as well since they contribute to market formation.

### 3.8.1 Subsidies

Subsidies can be found at both European and national level. The Seventh Framework Programme from the European Union wants to make Europe the leading world forum for science and technology. The specific program Cooperation – a part of the Seventh Framework - aims to support cooperation between industries, research centres and public authorities. Energy is one of the nine themes of the Cooperation program. The budget allocated to the Energy theme is € 2,350 million for the period 2008 – 2013. A share of €467 million of this budget is earmarked for research on fuel cells and hydrogen and is implemented by the fuel cells and hydrogen joint undertaking (FCH-JU). The €467 million from the FCH-JU is matched by €470 million from the industry[78/79].

Only a part of the Seventh framework programme budget for the Energy theme is spent on research related to hydrogen. The Energy Policy for Europe introduces a set of European energy measures that should realize the goals of the Energy theme. The measures and goals concern among others the internal energy market, energy efficiency and renewable energy. The budget for the Energy theme is therefore not at all earmarked for power-to-gas technology. The funds directed at stimulating renewable energy in an indirect way increase the need for power-to-gas. An example is the more than €110 million that has been provided by the European Union since 2002 for wind energy research[80/,81].

The Dutch government's industrial policy is based on nine so called top sectors. Energy is one of the top sectors and is divided in seven Top consortia for Knowledge and Innovation (TKI). One of the TKI's has gas as its subject. The TKI Gas has a €50 million budget in 2012 but only a small part is invested in power-to-gas related topics[82/83].

### 3.8.2 Investments

It is important to realize that the European and national subsidies do not finance research and pilot projects by themselves. They are always matched by other funds that are also needed to have sufficient resources. Whether research or projects are financed through subsidies or private investments depends on the life cycle stage that the technology is in[84].

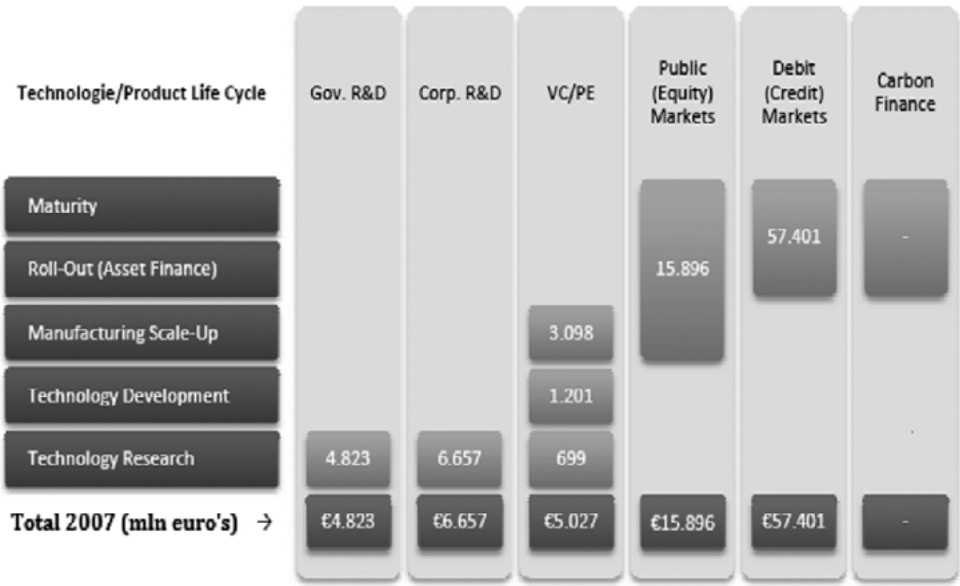



*Figure 2: Global capital market for sustainable projects 2007. (Biemans, 2009)*

Figure 2 shows that a technology in its early stage –technology research and technology development - is financed through subsidies, businesses and venture capital. The entrepreneurial activities in the power-to-gas TIS (Table 1: Operating power-to-gas plants in Germany (10) and the Netherlands (1).) confirm this. All activities have private and public parties involved.

Using the broad perspective where the growth of intermittent renewable energy is a positive contribution for the power-to-gas TIS Figure 3 shows the installed capacity for electricity generation from renewables in the European Union. It is clear that there is a large growth of installed wind capacity that implicates a growth in mobilized resources as well. The solar energy is among the other sources of renewable energy and has grown as well.

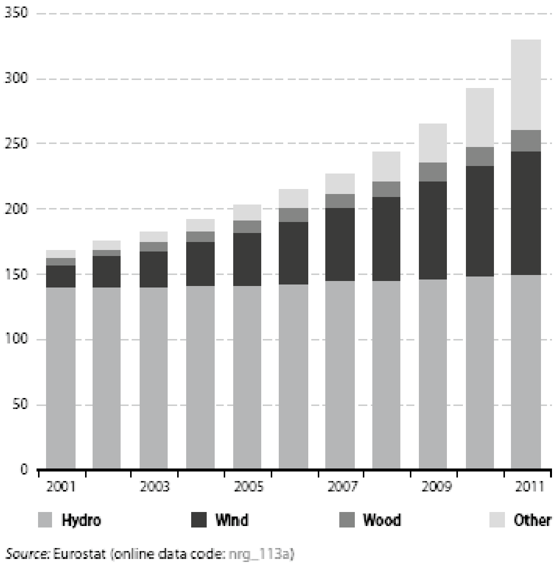



*Figure 3: Installed capacity for electricity generation from renewables, EU-2885*

Bloomberg[86] reports rising new investments in renewable energy in Europe between 2004 and 2011. In 2012 and 2013 new investments fall to a lower level. For the power-to-gas TIS the fall in new investments is negative. Looking at the need for a strong growth in intermittent energy sources a rise in new investments in renewable energy is needed.

The conclusion concerning resource mobilization is that the large amount of entrepreneurial activities in recent years shows that resources have been available. On a European level subsidies exist and are matched by private capital. The growing installed capacity for electricity generation from renewables also contributes to the power-to-gas TIS in a positive way.

## 3.9 Support from advocacy coalitions

The rise of an emerging technology often leads to resistance from actors with interests in the incumbent energy system. In order for a TIS to develop, it is necessary to overcome this resistance. Lobbies and advice activities are used to create support from advocacy coalitions[87/88]. To analyse the support from advocacy function, the lobby groups that are related to power-to-gas have to be found. In the European transparency register 15 lobby groups are registered with hydrogen mentioned in the description of the goal of the organization. Over 50 lobby groups have wind in the description of their goal[89]. Some of the lobby groups have hydrogen or wind energy as their core business other lobby groups have other goals that come in the first place. For them the promotion of hydrogen or wind energy is a secondary goal. The largest lobby groups that focus on hydrogen or wind energy will be described briefly.

The European gas research group (GERG) was founded in 1961 and promotes innovation in gas technology. GERG wants to strengthen the safe transport, distribution and use of natural and renewable gases. It is a major objective of GERG to maintain strong links with the European Union and to contribute to the discussion of policy on activities concerning natural gas R&D in Europe by making available its expertise, advice and support[90]. GERG is therefore an important advocacy coalition with 28 gas industry members from 14 countries.

The European Hydrogen Association (EHA) represents 21 national hydrogen and fuel cell organisations and the main European companies active in the hydrogen infrastructure development. The EHA communicates on important issues regarding industrial and regulatory needs to key decision makers at EU level[91].

The NEW industry grouping (NEW-IG) has 68 companies working in the field of fuel cells and hydrogen and they represent a major part of the sector. Their objective is to promote the interests of the fuel cells and hydrogen industry at a European level by engaging with European decision-makers[92].

The N.ERGHY Research Grouping represents the interests of European universities and research institutes in the FCH JU. Currently 58 international research institutions are a part of E.NERGHY

The European Wind Energy Association (EWEA) promotes the utilization of wind power in Europe and worldwide. It represents 700 members from almost 60 countries. The EWEA develops and communicates effective strategic policies and initiatives to influence the political process in a direction that maintains and creates stable markets and overcome barriers to the deployment of wind energy[93].

The support from advocacy coalitions function is met by the power-to-gas TIS as far as the existence and presence of lobby groups is concerned. Whether the lobby activities result in the desired actions is another matter. The entrepreneurial activities, the existing research programs and the available funds all suggest that the lobby activities do have the desired results. Examples of issues that are not realized so far are gas quality standards that allow hydrogen in the gas grid and the legal framework for power-to-gas.

## 3.10 System dynamics

So far the different functions from the power-to-gas TIS have been discussed separately. This has given a valuable insight in the progress that has been made in each function. It also has been a static approach. In this section the system dynamics will be discussed.

The power-to-gas TIS seems to start with entrepreneurial activities. The expected growth of renewable energy will cause more intermittent electricity and a balancing problem on the electricity grid. The guidance of the search function starts the entrepreneurial activities. Innovative research, including demonstration projects, is initiated. The businesses and research institutions then require resources to cover part of their costs and to compensate the financial risks they take. In the power-to-gas TIS funds have come available and projects have started. The outcome of the projects feeds back into the dynamic system and is an impulse for new projects. The entrepreneurial activities interact with knowledge development and knowledge exchange. This too has been observed in the power-to-gas TIS.

Figure 4 shows an illustration of the dynamics between functions. It is possible to place the events that have been discussed in this chapter in this dynamic system. The policy context for power-to-gas includes the Energy 2020 strategy, the European wind initiative and in the Netherlands the national plans for wind on land and wind at sea. The energy policy activates the guidance of the search. The expected growth in wind and solar energy causes a (potential) balancing problem on the electricity networks so a solution has to be found. Business and research institutions start projects and claim resources. The most important events concerning knowledge development are the FCH JU projects, the Naturalhy project, DVGW research and the HyUnder project. The entrepreneurial activities are a response to the guidance of the search impulse as well. Research centres and businesses build advocacy coalitions to lobby for resources to support research and entrepreneurial projects.

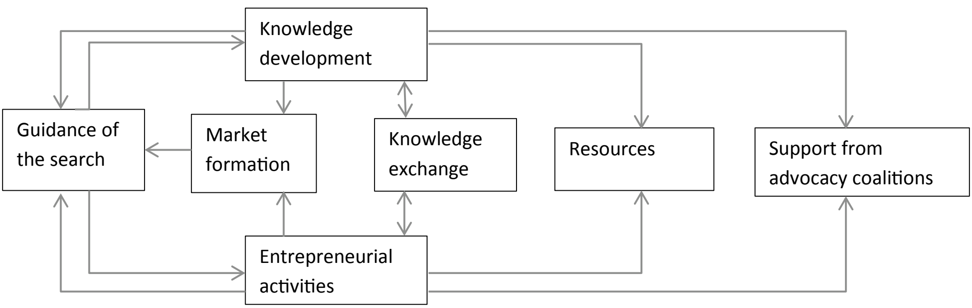



*Figure 4: The power-to-gas TIS as a dynamic system.*

So far the general outcomes of the projects have resulted in positive feedback loops. Most research and demonstration projects support the feasibility of power-to-gas. The guidance of the search is continued at the same path and new projects are initiated. The seventh framework programme is followed by Horizon 2020 supporting new power-to-gas related projects. The fuel cells and hydrogen joint technology initiative (FCH JTI) resulted in the foundation of the fuel cells and hydrogen joint undertaking (FCH JU). The entrepreneurial activities have also resulted in new and more projects. In Stuttgart a ZSW pilot project from 2009 has been followed by a larger project in 2012. In Eichhof a Fraunhofer IWES power-to-gas pilot has resulted in a second phase including methanation.

Negative feedback loops are found looking at the market formation function. Appropriate regulation to achieve economically viable P2G implementation is missing[94]. The Energy 2020 strategy has to be carried out but are not perceived by all as convincing[95/96]. There is also a need for new regulation on gas quality standards[97/98]. So far the identified problems have not resulted in a drastic change in the guidance of the search. New research and pilot projects are still carried out even though the market formation is lagging behind.

## 3.11 Conclusions

The power-to-gas TIS shows a lot of progress on most functions. Over the last years a growing number of research projects and entrepreneurial activities have been developed. This has led to knowledge development and knowledge exchange. Funds to finance the projects have become available. An important matter now is if the need for power-to-gas solutions is urgent enough to keep the power-to-gas TIS in an upward spiral. This urgency is in TIS terminology part of the guidance of the search function.

The first conclusion has to be that a convincing European and national energy policy aimed at a substantial growth of wind and solar energy is the most important condition for power-to-gas to become a needed and applied technology. The European energy policy and plans as they are stated in Energy 2020[99], Energy trends 2030[100] and the Energy Roadmap 2050[101] do show this commitment. The European wind initiative – part of the SET plan - wants to enable wind energy to supply 20% of Europe's electricity in 2020, 33% in 2030 and 50% in 2050. It is clear that the European ambition is large enough to cause a need for power-to-gas technology. The implementation of the ambition has to be a driving force for power-to-gas to become widely applied. If the implementation of the European plans gets delayed or if the ambition is scaled down, this will obviously reduce the need for power-to-gas solutions.

The need for a substantial growth of wind en solar energy asks for support from advocacy coalitions. The growth of wind and solar energy cannot be taken for granted based on the presence of an ambitious formulated European energy policy. The large investments cause criticism and this could result in a turning point for renewable energy. A significant and continues effort to organize support for growth of wind and solar energy are a second condition for power-to-gas to play a part in the future energy system.

Power-to-gas technology has to be improved to eliminate a number of technological and economic barriers. To add 10% hydrogen to the natural gas network measures have to be taken to ensure that the existing gas turbines, appliances, steel tanks and underground storages are ready for a changed gas mixture. Another pathway is methanation. Using hydrogen to produce methane offers the advantage that methane can be injected into the natural gas network without restrictions. In both cases an increase in energy efficiency of power-to-gas technology is needed to improve the power-to-gas business case. Entrepreneurial activities, knowledge development and knowledge exchange are needed to realize the requested progress.

The regulatory framework for power-to-gas at the moment shows some deficiencies. Power-to-gas is the linking pin between the electricity grid and the natural gas network. Regulation is needed to determine if power-to-gas is the responsibility of the electricity producer, electricity distributor, gas producer, gas distributor or some other party. Despite all the power-to-gas demonstration projects it is unlikely that there will be large scale power-to-gas plants before the regulator has set up the regulatory framework.

Another regulatory issue are the gas quality standards. To store hydrogen in the gas grid is not only a matter of technological feasibility. It is also necessary that adding hydrogen is conform the relevant regulation. The gas quality standards for the future need further specification to give investors in appliances and producers of gas the right information that they need for their decisions.

Power-to-gas installations are expensive and since they are only used when excess electricity is available the installation will not be operating all the time. This means that the high fixed costs have to be compensated in limited time. The revenue of power-to-gas will probably not cover the costs if the revenue is restricted to the price that is received for the gas. Additional benefits of power-to-gas are the contribution to the balancing of the electricity network, the avoiding of capital costs of expanding the electricity network and the utilization of renewable electricity. The value of this contribution could be considered to be revenue as well. Regulation is needed so that the power-to-gas investor does not only carry the costs but also gets rewarded for the realized benefits.

The legal framework, the gas quality standards and the regulation to support investments are all part of the market formation function. The power-to-gas advocacy coalition can contribute to the market formation function by lobbying for the needed regulation.

Using a TIS approach to analyse power-to-gas development has been useful. The position that power-to-gas will have in the future energy system will depend on the realization of wind and solar ambitions, the technological progress on power-to-gas energy efficiency and the making of a regulatory framework both for gas quality standards and for investment conditions. All TIS functions need to make progress but this is especially true for the market formation function.

What will determine if power-to-gas will be an important technology in the energy transition over the next years? One can look at the development of a technology as a process that takes place in a technological innovation system (TIS). The TIS includes all actors and institutions that are involved in the development, diffusion and utilization of a technology. For a technology to develop successfully the TIS should fulfil several functions. For power-to-gas technology pilot projects are realized, studies are carried out and funds are available both for projects as for research. The functions called entrepreneurial activities, knowledge development, knowledge exchange and resource mobilization are all met. The function that faces the most problems is called market formation. There is not yet a regulatory framework for power-to-gas. Investors in power-to-gas also need to be rewarded for the benefits that they realize such as the contribution to the balancing of the electricity network, the avoiding of capital costs of expanding the electricity network and the utilization of renewable electricity. Policy directed at market formation is therefore recommended.

## Key Findings:

- Power-to-gas technology needs a substantial growth of wind and solar energy.
- Research and entrepreneurial activities are contributing to power-to-gas technology.
- A legal framework is needed to enable potential investors to take long term decisions.

# REFERENCES


1 *European Commission (2010). Energy 2020. A strategy for competitive, sustainable and secure energy. Retrieved from EU website: http://ec.europa.eu/energy/energy2020/index—en.htm*

2 Capros, P. a.o. (2010). EU energy trends to 2030 – UPDATE 2009. Retrieved from EU website: http://ec.europa.eu/energy/observatory/trends—2030/doc/trends—to—2030—update—2009.pdf

3 *European Commission (2011). Energy roadmap 2050. Retrieved from EU website: http://ec.europa.eu/energy/energy2020/roadmap/index—en.htm*

4 EIA (2013). International Energy Outlook 2013. Retrieved from International Energy Agency website: http://www.worldenergyoutlook.org/publications/weo-2013/

5 *Grond, L a.o. (2013). Systems analyses Power to Gas: a technology review. Retrieved from DNV-GL website: http://www.dnv.com/resources/position—papers/systems—analyses—power—to—gas—a—technology—review.asp*

6 Specht, M. a.o. (2009). Storing bioenergy and renewable electricity in the natural gas grid. Retrieved from the Etogas ebsite:http://www.etogas.com/fileadmin/user—upload/Publikationen/Wind2SNG—ZSW—IWES—SolarFuel—FVEE.pdf

7 *Iskov, H and N.B. Rasmussen (2013).* Global screening of projects and technologies for Power-to-Gas and Bio-SNG. Retrieved from Danish Gas Technolog Centre website: *http://www.dgc.eu/publications/reports*

8 Naturalhy (2009). Preparing for the hydrogen economy by using the existing natural gas system as a catalyst. Retrieved from the Naturalhy website: http://www.naturalhy.net/docs/project—reports/Final—Publishable—Activity—Report.pdf

9 Muller-Syring, G. a.o (2013). Entwicklung von modularen Konzepten zur Erzeugung, Speicherung und Einspeisung von Wasserstoff und Methan ins Erdgasnetz. Retrieved form DVGW website: http://www.dvgw-innovation.de/fileadmin/dvgw/angebote/forschung/innovation/pdf/g1—07—10.pdf

10 *Iskov, H and N.B. Rasmussen (2013).* Global screening of projects and technologies for Power-to-Gas and Bio-SNG. Retrieved from Danish Gas Technolog Centre website: *http://www.dgc.eu/publications/reports*

11 *Hekkert, M.P. a.o. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting & Social change. 2007 (74). Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0040162506000564*

12 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

13 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

14 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

15 *Grond, L a.o. (2013). Systems analyses Power to Gas: a technology review. Retrieved from DNV-GL website: http://www.dnv.com/resources/position—papers/systems—analyses—power—to—gas—a—technology—review.asp*

16 *Iskov, H and N.B. Rasmussen (2013).* Global screening of projects and technologies for Power-to-Gas and Bio-SNG. Retrieved from Danish Gas Technolog Centre website: *http://www.dgc.eu/publications/reports*

17 DVGW (2013). Pilot- und Demonstrationsprojecte im Power-to-Gas-Konzept. Retrieved from Dena website: http://www.powertogas.info/power-to-gas/interaktive-projektkarte.html

18 Audi media services (2013). World premiere: Audi opens power-to-gas facility. Retrieved from Audi website: https://www.audi-mediaservices.com/publish/ms/content/en/public/pressemitteilungen/2013/06/25/world—premiere——audi.html

19 EON *(2013). E.ON inaugurates power-to-gas unit in Falkenhagen in eastern Germany. Retrieved from EON website: http://www.eon.com/en/media/news/press-releases/2013/8/28/eon-inaugurates-power-to-gas-unit-in-falkenhagen-in-eastern-germany.html*

20 *Fuel cells bulletin 2013 (10). German wind site with 1 MW hydrogenics P2G energy storage.*

21 *Enertrag. Enertrag hybrid power plant – brief description. Enertrag, Dauerthal. Retrieved from Enertrag website: https://www.enertrag.com/en/project-development/hybrid-power-plant.html*

22 *Fuel cells bulletin 2012 (5).* Wind-hydrogen used for first time at vehicle fuelling station in Germany. Retrieved from ScienceDirect website: http://www.sciencedirect.com/science/article/pii/S1464285912701487

23 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

24 FCH-JU, *2013. Annual activity report 2012. Retrieved from FCH-JU website: http://www.fch-ju.eu/page/documents*

25 FCH-JU, 2012. *Fuel cells and Hydrogen Joint Undertaking. Who we are. Retrieved from FCH-JU website:* http://www.fch-ju.eu/page/who-we-are

26 Naturalhy (2009). Preparing for the hydrogen economy by using the existing natural gas system as a catalyst. Retrieved from the Naturalhy website: http://www.naturalhy.net/docs/project—reports/Final—Publishable—Activity—Report.pdf

27 Muller-Syring, G. a.o (2013). Entwicklung von modularen Konzepten zur Erzeugung, Speicherung und Einspeisung von Wasserstoff und Methan ins Erdgasnetz. Retrieved form DVGW website: http://www.dvgw-innovation.de/fileadmin/dvgw/angebote/forschung/innovation/pdf/g1—07—10.pdf

28 Landinger, H. (2013). Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Long Term Storage of Renewable Electricity by Hydrogen Underground Storage in Europe. Retrieved from the HyUnder website: http://www.hyunder.eu/images/Presentations%20Conference/Session%202%20Benchmarking%20of%20H2%20storage%20Landiger%20Simon.pdf

29 *Grond, L a.o. (2013). Systems analyses Power to Gas: a technology review. Retrieved from DNV-GL website: http://www.dnv.com/resources/position—papers/systems—analyses—power—to—gas—a—technology—review.asp*

30 Kraaij, G.J. and M. Weeda (2008). Conversion of excess wind energy into hydrogen for fuel cell applications. Retrieved from the ECN website: ftp://ftp.ecn.nl/pub/www/library/report/2008/e08063.pdf

31 Benz, E. a.o. (2010). Installatie van windenergie in het Nederlandse elektriciteitssysteem in de context van de Noordwest Europese elektriciteitsmarkt. Retrieved from Olino website: http://www.olino.org/wp-content/uploads/2010/12/Integratie-van-windenergie-in-het-Nederlandse-elektriciteitsysteem-in-de-context-van-de-Noordwest-Europese-elektriciteitmarkt.pdf

32 *Hekkert, M.P. a.o. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting & Social change. 2007 (74). Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0040162506000564*

33 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

34 NEW-IG (2014a). New energy world industry grouping. Members. Retrieved from the NEW-IG website: http://www.new-ig.eu/members

35 N.ERGHY (2014). Research on fuel cells and hydrogen. Members. Retrieved from the N.ERGHY website: http://www.nerghy.eu/en/intern/108.php

36 SETIS (2014). Strategic energy technologies information system. Retrieved from the SETIS website: http://setis.ec.europa.eu/technologies/Electricity-storage-in-the-power-sector

37 *Hekkert, M.P. a.o. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting & Social change. 2007 (74). Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0040162506000564*

38 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

39 *European Commission (2010). Energy 2020. A strategy for competitive, sustainable and secure energy. Retrieved from EU website: http://ec.europa.eu/energy/energy2020/index—en.htm*

40 *European Commission (2007). A European strategic energy technology plan (SET plan). Retrieved from EU website: http://ec.europa.eu/energy/technology/set—plan/set—plan—en.htm*

41 Windplatform (2014). Introduction to the European Technology Platform for Wind Energy (TPWind). Retrieved from the Windplatform website: http://www.windplatform.eu/home/

42 Acker, T (2011). IEA wind task 24. Integration of wind and hydropower systems. Retrieved from National renewable energy laboratory website: http://www.nrel.gov/docs/fy12osti/50182.pdf

43 Landinger, H. (2013). Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Long Term Storage of Renewable Electricity by Hydrogen Underground Storage in Europe. Retrieved from the HyUnder website: http://www.hyunder.eu/images/Presentations%20Conference/Session%202%20Benchmarking%20of%20H2%20storage%20Landiger%20Simon.pdf

44 *Hoskin, A (2013). IEA-HIA Task24. Wind Energy & Hydrogen Integration. 2007-2011. Retrieved frim Internnational Energy Agency website: http://ieahia.org/pdfs/Task—24—final—report.pdf*

45 Zucker, A. a.o. (2013). Assessing storage value in electricity markets. JRC scientific and policy reports. Retrieved from the Joint Research Centre website: http://publications.jrc.ec.europa.eu/repository/handle/111111111/29496
46 Carmo, M a.o. (2013). A comprehensive review on PEM water electrolysis. International journal of hydrogen energy. 38 (12), 4901-4934. Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0360319913002607
47 *Grond, L a.o. (2013). Systems analyses Power to Gas: a technology review. Retrieved from DNV-GL website: http://www.dnv.com/resources/position—papers/systems—analyses—power—to—gas—a—technology—review.asp*
48 SETIS (2013). The list of projects relevant to the Fuel Cells and Hydrogen Joint Technology Initiative. Retrieved from the SETIS website: http://setis.ec.europa.eu/setis-deliverables/project-mapping
49 *FCH-JU, 2014a. List of projects for hydrogen production and storage. Retrieved from FCH-JU website:* http://www.fch-ju.eu/Projects%20by%20application%20area/Hydrogen%20production%20and%20storage
50 *FCH-JU, 2014b. List of projects for transport and refueling infrastructure. Retrieved from FCH-JU website:* http://www.fch-ju.eu/Projects%20by%20application%20area/Transport%20and%20refuelling%20infrastructure
51 *Hydrogenics, 2014. Hydrogenics selected references, fueling stations. Retrieved from Hydrogenics website:* http://www.hydrogenics.com/docs/default-source/pdf/renewable-projects-references---fueling-stations.pdf?sfvrsn=0
52 Naturalhy (2009). Preparing for the hydrogen economy by using the existing natural gas system as a catalyst. Retrieved from the Naturalhy website: http://www.naturalhy.net/docs/project—reports/Final—Publishable—Activity—Report.pdf
53 Muller-Syring, G. a.o (2013). Entwicklung von modularen Konzepten zur Erzeugung, Speicherung und Einspeisung von Wasserstoff und Methan ins Erdgasnetz. Retrieved form DVGW website: http://www.dvgw-innovation.de/fileadmin/dvgw/angebote/forschung/innovation/pdf/g1—07—10.pdf
54 *Grond, L a.o. (2013). Systems analyses Power to Gas: a technology review. Retrieved from DNV-GL website: http://www.dnv.com/resources/position—papers/systems—analyses—power—to—gas—a—technology—review.asp*
55 *Iskov, H and N.B. Rasmussen (2013).* Global screening of projects and technologies for Power-to-Gas and Bio-SNG. Retrieved from Danish Gas Technolog Centre website: *http://www.dgc.eu/publications/reports*
56 DVGW (2013). Pilot- und Demonstrationsprojecte im Power-to-Gas-Konzept. Retrieved from Dena website: http://www.powertogas.info/power-to-gas/interaktive-projektkarte.html
57 EDGaR (2014b). From monogas to multigas. Projects. Retrieved from EDGaR website: http://www.edgar-program.com/themes/from-monogas-to-multigas
58 Naturalhy (2009). Preparing for the hydrogen economy by using the existing natural gas system as a catalyst. Retrieved from the Naturalhy website: http://www.naturalhy.net/docs/project—reports/Final—Publishable—Activity—Report.pdf
59 *Hy2seps2 (2014).* Hybrid Membrane - Pressure Swing Adsorption (PSA) Hydrogen Purification Systems. Retrieved from HY2 website: http://hy2seps2.iceht.forth.gr/

60 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.

61 SER. (2013) Energieakkoord voor duurzame groei. Retrieved from the SER website: http://www.ser.nl/nl/publicaties/overige/2010-2019/2013/energieakkoord-duurzame-groei.aspx

62 Judd, R. and D. Pinchbeck (2013). Power to Gas Research Roadmap. Offering a Solution to the Energy Storage Problem? Gas for Energy, 2013 (2). Retrieved from GERG website: http://www.gerg.eu/public/uploads/files/publications/GERGpapers/SD—gfe—02—2013—fb—Judd.pdf

63 *Jager, D. de and M. Rathmann (2008).* Policy instrument design to reduce financing costs in renewable energy technology projects. Retrieved from Ecofys website: http://www.ecofys.com/files/files/report—policy—instrument—design—to—reduce—financing—costs—in—renewable—energy—technology—pro.pdf

64 *Jager, D. de and M. Rathmann (2008).* Policy instrument design to reduce financing costs in renewable energy technology projects. Retrieved from Ecofys website: http://www.ecofys.com/files/files/report—policy—instrument—design—to—reduce—financing—costs—in—renewable—energy—technology—pro.pdf

65 Kerste, M. and J. Weda (2010). Financing the transition to sustainable energy. Retrieved from the SEO website: http://www.seo.nl/pagina/article/financing-the-transition-to-sustainable-energy/

66 Energie-Nederland (2013). Brief aan minister Kamp over wind op land. Retrieved from Energie-Nederland website: http://www.energie-nederland.nl/zet-in-op-7000-mw-wind-op-land/

67 Centraal Plan Bureau (2013). KBA structuurvisie 6000 MW windenergie op land. Retrieved from CPB website: http://www.cpb.nl/publicatie/kba-structuurvisie-6000-mw-windenergie-op-land

68 Levinsky, H. B. and M. L. D. van Rij (2011). Gaskwaliteit voor de toekomst. Deelrapport 1: technisch/economische inventarisatie van gevolgen gaskwaliteitvariaties voor eindgebruikers. Retrieved from Rijksoverheid website: http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/03/28/gaskwaliteit-voor-de-toekomst-1.html

69 Klooster, J. a.o. (2011). Gaskwaliteit voor de toekomst. Deel 2. Retrieved from Rijksoverheid website: http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/06/06/gaskwaliteit-voor-de-toekomst-deel-2.html

70 Topteam energie (2012). Internationaliseringsoffensief. Retrieved from the Topsectoren website: http://topsectoren.nl/energie/topteam

71 *Jager, D. de and M. Rathmann (2008).* Policy instrument design to reduce financing costs in renewable energy technology projects. Retrieved from Ecofys website: http://www.ecofys.com/files/files/report—policy—instrument—design—to—reduce—financing—costs—in—renewable—energy—technology—pro.pdf

72 Antoni, J and J. Kostka (2012). Wege zur Wirtschaftlichkeit von Power-to-gas-Anlagen. Retrieved from DVGW website: http://www.dvgw-innovation.de/fileadmin/dvgw/angebote/forschung/innovation/pdf/wirtschaftlichkeit—powertogas—anlagen.pdf

73 Landinger, H. (2013). Assessment of the Potential, the Actors and Relevant Business Cases for Large Scale and Long Term Storage of Renewable Electricity by Hydrogen Underground

Storage in Europe. Retrieved from the HyUnder website: http://www.hyunder.eu/images/Presentations%20Conference/Session%202%20Benchmarking%20of%20H2%20storage%20Landiger%20Simon.pdf
74 Aguado, M. a.o. (2009). Economical assessment of a wind-hydrogen energy system using WindHyGen software. International journal of hydrogen energy. Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0360319909000160
75 Daniels, B. a.o. (2012). Kosten en baten van $CO_2$-emissiereductie maatregelen. Retrieved from SEO website: http://www.seo.nl/pagina/article/kosten-en-baten-van-co2-emissiereductie-maatregelen/
76 *Hajer, M (2011). Verkenning van routes naar een schone economie in 2050. Hoe Nederland klimaatneutraal kan worden. Retrieved from the Planbureau voor de leefomgeving website: http://www.pbl.nl/sites/default/files/cms/publicaties/PBL-2011-Routekaart-energie-2050-500083014.pdf*
77 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.
78 *European Commission (2014c). An energy policy for Europe. Retrieved from EU website:* http://europa.eu/legislation—summaries/energy/european—energy—policy/l27067—en.htm
79 *FCH-JU, 2014c. Members. Financing. Retrieved from FCH-JU website:* http://www.fch-ju.eu/page/members
80 *European Commission (2014b). Research & innovation. EU support for wind energy. Retrieved from EU website:* http://ec.europa.eu/research/energy/eu/index—en.cfm?pg=research-wind-support
81 *European Commission (2014c). An energy policy for Europe. Retrieved from EU website:* http://europa.eu/legislation—summaries/energy/european—energy—policy/l27067—en.htm
82 TKI-Gas (2014). Systeemfunctie van gas. Retrieved from the TKI-Gas website: http://www.tki-gas.nl/hoofdlijnen/systeemfunctie-van-gas
83 Topsector energie (2014). TKI-Gas. Retrieved from the Topsector Energie website: http://topsectorenergie.nl/wp-content/uploads/2013/10/TSE—Factsheet-TKI-Gas-NED.pdf
84 Biemans, M. a.o. (2009). De kapitaalmarkt voor duurzame projecten. Retrieved from SEO website: http://www.seo.nl/uploads/media/2009-25—De—kapitaalmarkt—voor—duurzame—projecten—-—De—regels—van—het—spel—zijn—het—zelfde—maar—het—spel—verloopt—anders.pdf
85 *Eurostat (2013). Energy, transport and environment indicators. Eurostat pocketbooks. Retrieved from: http://epp.eurostat.ec.europa.eu/portal/page/portal/publications/collections/pocketbooks*
86 Bloomberg (2013). Global trends in clean energy investment. Retrieved from UNEP website: http://www.unep.org/pdf/GTR-UNEP-FS-BNEF2.pdf
87 *Hekkert, M.P. a.o. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting & Social change. 2007 (74). Retrieved from ScienceDirect: http://www.sciencedirect.com/science/article/pii/S0040162506000564*
88 Suurs, R.A.A. (2009). Motors of sustainable innovation. Towards a theory on the dynamics of technological innovation systems. Universiteit Utrecht, Utrecht.
89 *European transparency register, 2014.*http://ec.europa.eu/transparencyregister/public/consultation
90 *GERG, 2014. About us. http://www.gerg.eu/about-us/officers*

91 European Hydrogen Association (EHA), 2014. EHA Mission. Retrieved from European Hydrogen Association: http://www.h2euro.org/eha/about-eha/eha-mission-2
92 NEW-IG (2014b). New energy world industry grouping. Mission. (2014) Retrieved from the NEW-IG website: http://www.new-ig.eu/about-us/mission-objectives
93 *EWEA (2014). Vision, mission and values. Retrieved from the European Wind Energy Association website:* http://www.ewea.org/mission-vision-values/
94 Judd, R. and D. Pinchbeck (2013). Power to Gas Research Roadmap. Offering a Solution to the Energy Storage Problem? Gas for Energy, 2013 (2). Retrieved from GERG website: http://www.gerg.eu/public/uploads/files/publications/GERGpapers/SD—gfe—02—2013—fb—Judd.pdf
95 Centraal Plan Bureau (2013). KBA structuurvisie 6000 MW windenergie op land. Retrieved from CPB website: http://www.cpb.nl/publicatie/kba-structuurvisie-6000-mw-windenergie-op-land
96 Energie-Nederland (2013). Brief aan minister Kamp over wind op land. Retrieved from Energie-Nederland website: http://www.energie-nederland.nl/zet-in-op-7000-mw-wind-op-land/
97 Levinsky, H. B. and M. L. D. van Rij (2011). Gaskwaliteit voor de toekomst. Deelrapport 1: technisch/economische inventarisatie van gevolgen gaskwaliteitvariaties voor eindgebruikers. Retrieved from Rijksoverheid website: http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/03/28/gaskwaliteit-voor-de-toekomst-1.html
98 Klooster, J. a.o. (2011). Gaskwaliteit voor de toekomst. Deel 2. Retrieved from Rijksoverheid website: http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/06/06/gaskwaliteit-voor-de-toekomst-deel-2.html
99 *European Commission (2010). Energy 2020. A strategy for competitive, sustainable and secure energy. Retrieved from EU website: http://ec.europa.eu/energy/energy2020/index—en.htm*
100 Capros, P. a.o. (2010). EU energy trends to 2030 – UPDATE 2009. Retrieved from EU website: http://ec.europa.eu/energy/observatory/trends—2030/doc/trends—to—2030—update—2009.pdf
101 *European Commission (2011). Energy roadmap 2050. Retrieved from EU website: http://ec.europa.eu/energy/energy2020/roadmap/index—en.htm*

# 4. CONTEXTUAL AND SYSTEMIC FORCES IN ENERGY VALLEY, THE NETHERLANDS

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## 4.1 Introduction

This chapter describes how contextual factors and system reactions influence end state developments based on a systems approach. The chapter uses the case study of Energy Valley of the Netherlands to illustrate the influence of contextual factors on the regional energy system and how the system responded and developed. The illustration below captures system interactions with its context and eventually the resulting end state.

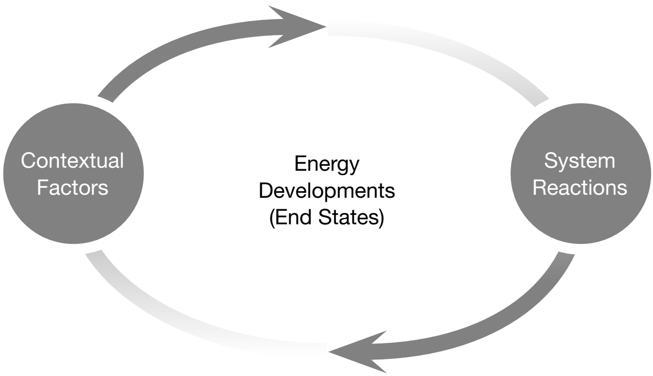


*Figure 1: Systems approach*

The illustration above shows that energy systems respond to contextual factors and this in turn affect contextual factors. Decisions and behaviour in this energy system are influenced by contextual factors, which in turn result in energy developments. This continued loop of interactions would finally result in a particular 'end state' for such a system. The term 'end states' has been described in the introductory chapter and this chapter shows how such end states could be influenced by various contextual factors and systemic responses.

When talking about 'energy systems' this analysis takes a broader perspective and looks at 'energy' as being embedded in social, economic, and political systems and that such a system could be a district, region, country, or a regional block such as the EU. The analysis looks at 'energy' as being located in a specific location with a defined boundary and it can be of different scales. In the research, Energy Valley was examined as an energy system embedded in a larger energy system, which is the national energy system and this in turn, is embedded in a European energy system. Each of these systems can be examined separately, but each of these next level systems is interconnected and contributed to other levels. EU decisions and developments influenced Dutch decisions and developments and therefore that of Energy Valley. At the same time, Energy Valley developments reflected national and EU developments. This analysis compares Energy Valley and national energy developments to that of EU developments for similarities and differences in their systems patterns and behaviour later in the chapter.

Finally, it must be noted that this chapter builds on a previous chapter on 'drivers of change', which focuses on the macro level contexts in which energy developments take place, whilst this chapter looks at contextual factors influencing energy developments at the micro level, specifically from a systems perspective.

The rest of the chapter has 5 sections. Section 4.2 describes salient aspects of Energy Valley and the research to be able to frame the analysis presented in this chapter. Section 4.3 4.3 describes 'contextual factors' and how these framed Energy Valley's energy system developments initially and then in Section 4.4, the 'system responses' are described and again, Energy Valley's energy system responses are illustrated to show what this means. In Section 4.5, a comparison of Energy Valley's energy system development and that of the EU is discussed to understand how energy systems are embedded in larger regional systems and how these systems interact. In the final section 4.6, implications of the analysis [and of a systems approach] are discussed in the light of 'end states'.

## 4.2 Research on Energy Valley case study

Energy Valley is an energy cluster covering the Northern part of the Netherlands and was established in 2003 by stakeholders including local policymakers in response to EU and national energy liberalization policies. Energy Valley faced two major strands of development. The first, a gas driven national energy sector facing the transition to more sustainable, liberalised European energy market and the second, the economic development of a periphery region. Energy Valley cluster as a case study offered exploration into these two interconnected developments driven by changing EU and global contexts.

Energy Valley was established in 2003 and has seen changes in its scope, visibility and developments as a result of changes in its context. In order to understand how energy systems develop, the research chose a complex adaptive systems approach, which offered a systems perspective on how systems change due to responses of its agents to changes in its environment. This approach offered both micro and macro level systems perspectives which meant that local micro interactions and behaviours of agents could be understood within broader macro level energy and contextual developments. The study looked at system developments at the local, national and EU levels and these examples will be used to illustrate how energy systems develop in their (local) contexts. The research on Energy Valley was a qualitative study based on stakeholder and expert inputs supported by secondary sources of information.

## 4.3 Contextual factors

Contextual factors in this analysis include drivers of change, history and geography of the system, stakeholders and collective definition and boundaries of the energy system.

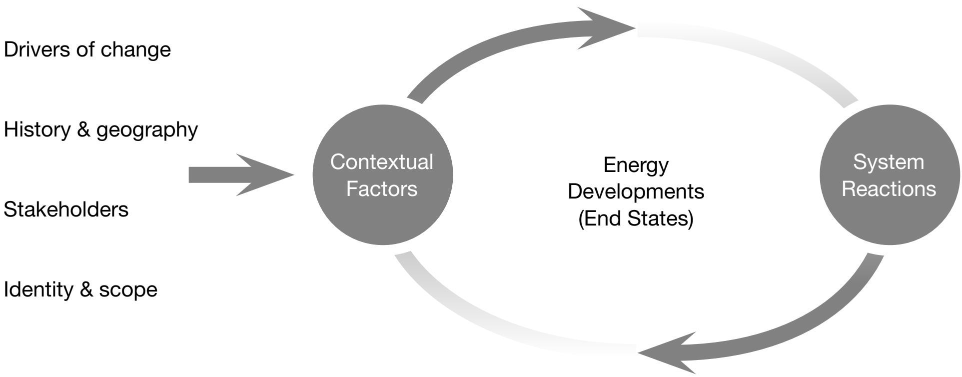


*Figure 2: Contextual Factors in Energy Systems*

To illustrate, discovery of gas in the North NL and the development of the gas industry for NL and EU determined the key stakeholders, namely, gas corporations, the national government and regional governments. This led to an energy system built on gas as the key resource. This initial energy system dominated by gas with its stakeholders and definitions of the system responded to specific drivers of change.

### 4.3.1 Drivers of change

Drivers of change in this analysis are understood to be drivers that change the system as a whole. It has been found in this study that drivers in energy systems can be external or internal drivers. The case study of Energy Valley illustrates which drivers of change were relevant to its system changes. There were nine significant external drivers and seven internal drivers. Below are some highlights of these drivers of change and their relevance to a gas dominated system of Energy Valley.

#### External drivers of change in Energy Valley

- *Geo-political shifts*
  Major geo-political shifts such as the emerging power shifts towards Asian economies and the renewed Russian political threats to Europe are examples of drivers that required strategic responses in Energy Valley.
- *Energy security threats*
  Dependence on external energy sources (EU imports 53% of its energy needs and of this, imports for crude oil is 90%, natural gas is 66% and solid fuels 42%) and incidents such as the recent Russian threats to European gas supply (Russian gas contributes 39% of its gas imports) needed to be addressed.
- *Large scale power outage and blackouts in Europe*
  The need for improved grid infrastructure across Europe to increase reliability is directly linked to energy security issues. Major outages and blackouts in Europe that had cascading effects in other parts were present in the recent past and therefore all regions had to comply with new EU directives and legislations to mitigate such effects, including major grid investments.
- *EU market liberalization*
  EU liberalization of electricity and gas markets was introduced to support consumer choice and increased competition. Energy systems are directly affected.
- *EU legislations*
  The legislations supported EU's goal towards a more reliable and sustainable use of energy and more flexible markets led by demand-side focus. Specific legislations governed grid interconnections and efficiency of energy systems to support development of a European internal energy market. Energy Valley needed to comply.
- *Sustainability and climate change*
  Long-term energy sustainability agendas that included climate change resulted in compliance of Member States to meet $CO_2$ and renewable energy targets. The EU saw gas as a fossil fuel and this had implications for Energy Valley and the Netherlands.

- *New energy resources and balancing*
  EU targets for renewable energy and energy efficiency (Policies: 2020, 2030, 2050 Energy Roadmaps) were directly relevant to developments in Energy Valley. The increased need for balancing as a result of large-scale introduction of renewable energies offered new opportunities for the gas sector in Energy Valley.
- *US cheap coal and shale*
  The US shale revolution and its move towards increased renewable energy in their energy mix resulted in excess and cheap coal being dumped in European markets, including the Netherlands. This had a strong impact on energy demands by power plants and therefore affected climate change and sustainability agendas and developments locally.
- *Technology developments*
  The shale revolution, cheaper solar and wind energy, viable smart grid technologies, bio-fuels, fuel cells and hydrogen fuels are examples of the impact of technological developments on market developments. Unpredictability was a major concern.

### Internal drivers of change in Energy Valley

- *Depletion of gas resources*
  Depletion of the Groningen gas reserves has been estimated around 2030 at the current rate of extraction. Energy Valley's gas contributes almost two-thirds of the energy needs of the Netherlands. Earnings in 2013 were more than 15 billion euros from gas revenues. The gas industry has direct implications for local and national economies.
- *New gas reserves and biogas*
  Biomass gasification, production of syngas, creation of green gas hubs are examples of new developments in Energy Valley changing the local gas and energy sectors.
- *Increased earthquake risks*
  Increased earthquakes and damage to property directly related to gas exploitation in the Energy Valley region were creating tensions between local population, local politicians and gas corporations and national government where conflicts in interests, roles and power relations played a role.
- *National policies*
  As mentioned earlier, government economic interests in the gas revenues were conflicting with citizen safety and electoral pressures. Long-term gas contracts and legal obligations to trading partners outside of the country versus citizen and green movements were tensions in the system. National policies were leading and therefore relevant to Energy Valley's energy system.
- *North Netherlands as economic lag region*
  Energy Valley is a periphery region of the Netherlands that has lower economic growth than the national average (-3% vs. 0.75% in 2014). Regional development agendas were competing with energy transition developments and national economic priorities.

- *Citizen movements and developments*
  As mentioned earlier, a growing distrust in energy corporations and government related to conflict of interests regarding gas exploration and earthquake risks, the rising energy prices and need for autonomy and self-sufficiency were some of the key motives of citizens and grassroots movements to initiate decentralized energy solutions. Parallel to this was also the 'green' sustainable movement. Citizens producing energy were dubbed 'prosumer', producing consumers.
- *Role of local governments*
  The urgency of local governments in the economic lag region of Energy Valley to create jobs and economic growth was prevalent. The depletion of gas resources was a major threat to further economic depression coupled with youth urban migration pulls. Earthquakes risked aggravating the attractiveness of the location. The regional development agenda was a strong driver in the region that included job creation, innovation boost and mitigating earthquake issues.

### 4.3.2 History and geography

Discovery of gas in the 1950s has and continued to have a major impact on the local energy system of Energy Valley. The region has built its infrastructure, energy mix and economic development policies based on the *gas industry and revenues*. The Dutch government has a dominant stake in the gas resources (50% state ownership) and are directly connected to national strategic interests. The local energy system of Energy Valley is therefore tightly connected to the national energy system. The *trading history* of the Netherlands and its current 'BV NL' ('Netherlands Incorporated') strategy framed economic interests as being leading. Gas is traded internationally and has larger implications beyond Energy Valley.

The *periphery and lag region* positions of the region meant that economic and social structures needed to be addressed. The region is dominated by *agriculture and rural economies* on the one hand, and, *large chemical and energy intensive manufacturing industries* related to national policies of the past related to availability of cheap energy. *Energy expertise* and energy related industries were dominant. However, there were other economic sectors dominant in the Energy Valley region and *regional differences* were present, for example, water and recreation, food and agro-based industries (Friesland), horticulture (North Holland North), agriculture and dairy farming (all provinces), forestry and tourism (Drenthe) and heavy industry and harbour facilities (Groningen), etc.

*Lack of strong R&D investments and knowledge centres*, public and private centres were also key feature of the system. The limited knowledge base was a key concern for Energy Valley.

### 4.3.3 Stakeholders

Energy Valley was initiated to address a serious threat of losing the local gas industry and expertise built up in 50 years as a result of EU liberalization policies and future gas depletion. The need to preserve existing gas expertise in the local economy was an important driver to Energy Valley. The key stakeholders developing Energy Valley were therefore *regional governments, gas corporations* and *local educational institutes*. However, gas dominance in Energy Valley's energy landscape meant that *gas industry* stakeholders and the *national government* had strong positions in the current system.

### 4.3.4 System definition - identity and scope

Identity and scope of an energy system is directly related to its key stakeholders. In Energy Valley, stakeholders from policy, business, academics, and regional development agencies were present and 'policy' included local and national policy makers and decision-makers. *Dominant stakeholders* in the energy system were identified as the national government, gas related stakeholders and provincial governments due to historical and geographical factors. This meant that the differences in stakeholders resulted in different definitions and boundaries for the system. Given the dominance of its particular stakeholders, *three main frames, 'economic', 'energy transition' and 'regional development',* were evident in Energy Valley. This in part led to complex and conflicting agendas as already mentioned in earlier sections.

The regional development focus of local policy makers meant that initially a *regional and internal focused* strategy was present although the national and trading aspects of the gas business had strong national and international scopes. The activities supported by Energy Valley's strategic focus in the initial working programmes were very much on energy and regional developments.

### 4.3.5 Interconnectedness of contextual factors

Drivers of change, history and geography, stakeholders and system definition are all interconnected as captured in the previous sections. The illustration below captures this interconnectedness.

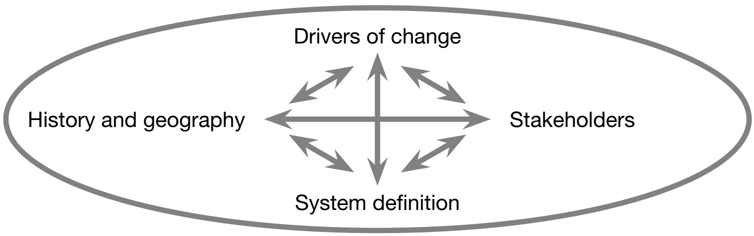


*Figure 3: Interconnected Contextual Factors*

Energy Valley's gas dominated system determined its stakeholders, and therefore their conceived identity and scope of the energy system and both these factors were shaped to a large extent by its (perceived) history and geography of gas and socio-economic factors related to national and regional interests. Drivers of change are connected to an energy system's definition, its identity and scope, as certain drivers influence decisions of scope, need new strategic focus, etc. In Energy Valley, the need to redefine gas dominance in its initial energy system was due to drivers of sustainability, pending depletion of local gas sources, etc.

## 4.4 System reactions

According to complexity approaches, systems change when agents in the system respond to changes in their environment. The total system change can be understood by exploring different aspects of a system that contribute to such a change. In this analysis, aspects contributing to system reactions include: *'pulls' of the system* which is the direction in which a system tends to move; *coping strategies* of agents that include developing and gathering new knowledge, resources and skills; *differences that matter* for future strategies; *transforming interactions* and collaborations. Finally, these aspects add up to a macro level system change visible in *emerging system patterns*.

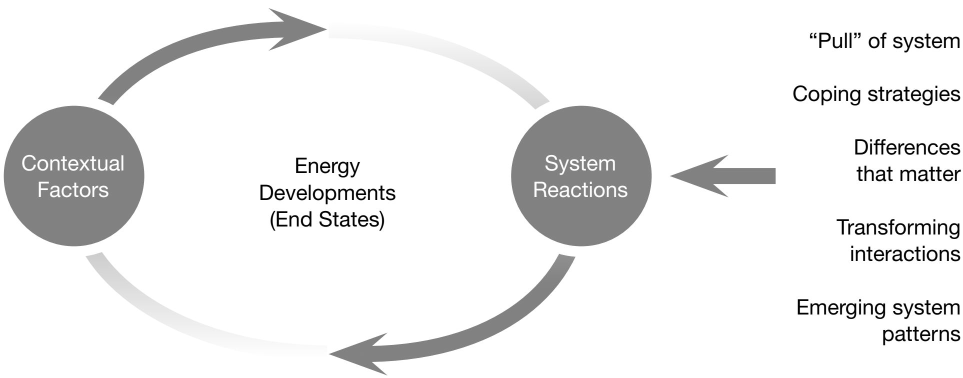


*Figure 4: Contextual Factors and System Reactions in Energy Systems*

To illustrate system reactions in Energy Valley, there was a pull towards more sustainable and decentralized energy solutions, connections between gas, oil and renewables. In addition, a key coping strategy was the creation of Energy Academy Europe that would bring fragmented knowledge, research, education and stakeholders together. An example of transforming interactions and collaborations was found in EnTranCe, a multi-stakeholder open innovation environment close to market. Examples of emerging system patterns were the increased presence of bottom-up initiatives next to top-down policy directives, interplay of gas and electricity, cross-sector collaborators such as bio-based economy. The following sections give more details on the system reactions of Energy Valley.

### 4.4.1 'Pull' of the system

A system responds to changes in its environment and there is often an underlying direction towards which the system tends to move. In Energy Valley, the drivers of change and responses by individual agents in the system resulted in more complexity and increased unpredictability and a general movement towards the 'outside'.

The energy system was initially an internal and regional oriented system. But the changes in the context saw various shifts in this system. One example was the position of 'gas' in the energy mix. It was no longer secure due to the increase in new sustainable energy solutions. This meant that a pull to redefine and reposition gas in the new energy system. Related to this was the decentralization movement of citizens and grassroots organizations. This also meant a tendency towards more demand-side focus instead of the traditional supply-side dominance.

The lack of R&D, innovation resources and facilities, talent, policy constraints, etc. resulted in a tendency to explore possibilities outside the local system. Pilots in the UK were carried out where regulations were less stringent for new innovations. The strong 'pull' to seek solutions outside Energy Valley was a serious threat of further depletion of capacities and attractiveness of the region if this resulted in a 'cluster drain'. Programmes and mandates from the European Union supported internationalization tendencies, and provided additional resources to regional systems, enhancing the attractiveness of 'the outside'. Being connected internationally was not in itself negative, but the 'pull' of the outside could be a threat if it did not contribute to strengthening the system's capabilities.

### 4.4.2 Coping strategies

There was a need to deal with the changing landscape of Energy Valley's energy system. Stakeholders identified different strategies for its future and these included creating new and different infrastructure to deal with the emerging (complex) energy system; including new stakeholders such as local intermediaries, citizen and grassroots organizations, Small and Medium-sized Enterprises (SME), etc. in the search for broader system-wide changes; creating new cross-sector value chain collaborations; creating educational programmes with multi-disciplinary competences; creating new institutions and innovation spaces, etc. All stakeholder groups underlined the urgency for different approaches and changes in the existing policy, business, education and innovation practice. There was also an acknowledgement of the need for both large-scale and decentralized solutions, and a more inclusive strategy.

### 4.4.3 Differences that matter

In order to meet the new challenges due to the changes in Energy Valley, the innovation potential of the system had to be analysed. Exploring 'differences that matter' in a system with new combinations of potential differences in a system could result in innovation. In Energy Valley, new and different competences and capacities needed to be explored to resolve the increasing complexity in the system through new combinations (German notion of 'neue Kombination'). For example, *innovative SME collaborating with large corporations and industry* with their resources and market reach could result in accelerated commercialization of innovations, including access to international markets. *Combining fragmented research and knowledge disciplines* present in the different universities in Energy Valley could accelerate more focussed and collective solutions for energy development challenges. *Regional differences* in Energy Valley with differences in goals, ambitions, resources, market structures, networks, etc. could be used to forge new networks, new cross-sector solutions, new business model testing, etc. The *regional and national interests* were also significant and could offer different solutions to both systems. Energy Valley had physical space and large agricultural land and farms that offered biomass solutions as a sustainable energy source whilst national government needed to deal with $CO_2$ targets and these two different goals could be achieved through the use of the differences of each system. Potential or 'missing' stakeholders in Energy Valley such as environmental groups, civil organizations, and 'prosumers' had different values, goals and motives from the established stakeholder groups. Combining these differences could offer a broader reach to the energy sustainability agenda.

### 4.4.4 Transforming interactions

When interactions take place that come from new combinations, a change takes place that transforms the original interactions. An example in Energy Valley was the creation of EnTranCe which began in the skybox of the local football club where informal discussions of different local energy businesses and the energy research centre led to the creation of an open innovation multi-disciplinary centre where businesses, students and research could come together to solve energy transition challenges. The 'gas' stakeholders had a strong systems approach and this has been adopted in EnTranCe as a key competence. Energy Academy Europe is another example of a collective initiative that resulted in a special institution for energy to overcome fragmentation and lack of 'energy' in curricula.

A different example of transforming interactions was the integration of energy – between electricity and gas, renewables and existing energy systems, micro-level energy system management for homes and neighbourhoods, meso-level energy hubs connecting businesses in transition parks, green gas hubs, and macro-level energy collaborations across regional boundaries such as in Hansa Energy Corridor and ENSEA (North Sea) projects.

Another example of transforming interactions in Energy Valley were the development of integrated energy vision clustering strengths of the different Provinces in 'De Plus van Noord Nederland', of different sectors in the 'Bio-based Economy', and aligning to national agendas in the 'Green Deal' and 'Switch' agreement and programmes.

A more inclusive strategy of extending dialogues to consumer and grassroots movements on energy developments in Energy Valley region meant that the system was changing in terms of its relationship to these groups, from end users to participants and increasingly strategic partners.

### 4.4.5 Emerging system patterns

The transforming interactions of Energy Valley were visible indications of changes in the system. These changes were coming together due in part by the responses of agents in the system and their coping strategies, building on innovation potential of 'differences', and the underlying 'pulls' of the systems. On a systems level, new or emerging patterns could be discerned in Energy Valley. These patterns indicated that the energy system was becoming *more complex*, which is partly due to the system becoming *more 'open'* as seen by the inclusion of new players, new sources of energy, more international orientation, new business models, etc.

The scope of the system was changing to become both *more local* and *more international* and there was evidence for a *more systemic approach* that went beyond the traditional notion of energy systems. Following the systemic approach, a more emergent and organic development of the energy system was visible even as more policy and top-down coordination was taking place in Energy Valley. Included in this shift were *more flexible and varying* strategies that embraced both local and international developments, traditional and renewable energy solutions on small and large-scale as necessary, thematic and on-line community developments that were self-organizing as well as strategic projects focused on 'gas and energy roundabout' policies in line with national, trans-regional and EU developments. Collaborations on international and EU levels across Energy Valley's system were another emergent pattern that reflected major shifts of the system from the once regional and locally oriented system.

### 4.4.6 Interconnectedness of system developments

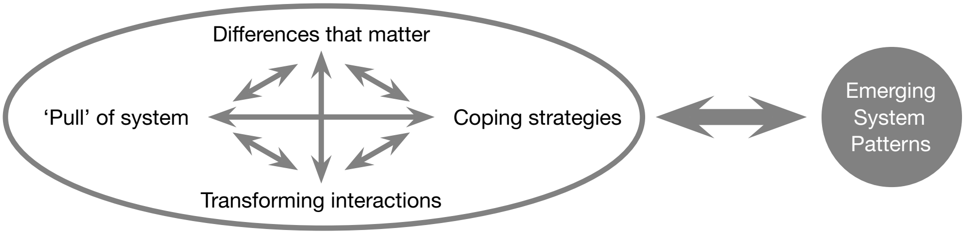


*Figure 5: Interconnectedness of System Reactions*

The system reactions are interconnected as shown above in the diagram and together these result in macro level system patterns as already described in the section above. When gas is re-positioned as a balancing power source in Energy Valley ('pull' of system), then realizing an integrated fossil, renewable and gas energy system ('differences') is more feasible. This allows other energy carriers to be seen as complementary rather than competitors (transforming interactions), which in turn facilitates open innovation and collective initiatives as 'coping strategies'. More collaborative and integrated approaches become part of new system patterns.

## 4.5 System patterns in Energy Valley/NL and EU

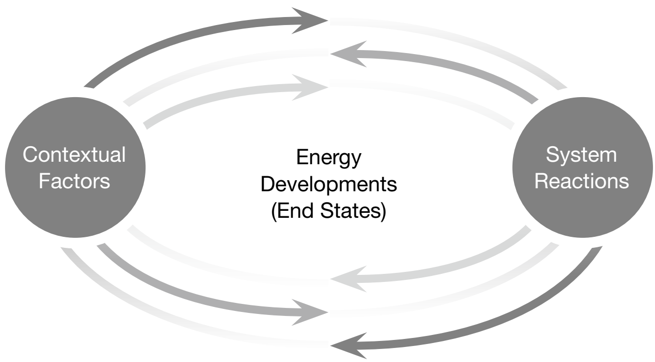


*Figure 6: System in System interconnections of Energy Developments*

The analysis explored how Energy Valley and the Dutch national systems reflected system patterns at the EU level. Complex Adaptive Systems (CAS) approach explains how systems are embedded in larger systems and how systems interact and feed into each other. The diagram above captured the embedded nature of energy systems as understood by CAS.

In the comparison of the three levels, Energy Valley, the Netherlands and the EU, the shifts in the contexts were similar, namely, the *growing complexity and unpredictability* of energy system developments as were the *external drivers of change* (geo-politics, financial and euro crises, new technological advances, energy market developments, etc.). Similarly, in all three levels, *energy systems were embedded in larger socio-, political, economic and ecological systems*. In all three levels, *economics was leading* and this framed energy developments in terms of enabling competitiveness. Common themes related to this are energy security, sustainable energy solutions, $CO_2$ mitigations, innovation, and smarter grid connections. *Regional social cohesion* and job creation was a key issue to Energy Valley and the EU.

On the other hand, whilst Energy Valley and the NL had a gas-dominated history similar to the UK, the EU had a wider diversity of energy sources and systems. The 'pull' of Energy Valley's system was to *keep gas in the energy mix* whilst the EU was focussed on *independence of external sources of fossil fuels* plus its commitment to *climate change* resulted in a strong 'pull' towards renewables. At the same time, the EU had a *diverse 'energy system'* with 27 different Member States (MS) with their different infrastructures, energy sources and socio-economic structures stemming from their different history and geography. In Energy Valley on the other hand, whilst regional differences were present, *national economic frame and policies were dominant*.

A common system development in all three levels was the acknowledgement of a *need for collective commitments* to build multi-disciplinary competences, cross-sector and new value chain innovations, new business and governance models, and more trans-regional and international collaborations to meet the new and complex challenges of energy. There were more visible coordination and connections in energy infrastructure and markets in all levels, more and different alliances and collaborations, new governance structures, more decentralization of energy movements, more trust and engagement to realize collective goals, more sustainability, technology and consumer push, etc. The system level patterns at all three levels had some differences but in general, there were many parallels in their system developments.

## 4.6 Implications for end states and energy futures

The system of Energy Valley at the beginning of the analysis showed how gas was the dominant factor in the system and how the stakeholders, strategies and solutions were all related to the traditional gas sector. In the second part of the analysis, the system reactions, the role and definition of gas in the new Energy Valley system had changed. Gas was also bio-gas, sync gas, gas from different sources and players, gas was also connected to smart grids and had re-positioned itself as a balancing and storage carrier within a more diverse energy system. This meant new and different 'coping strategies' including new competences and expertise beyond gas. A different aspect of the system change was the earthquake risks brought about by gas exploitation. The position of gas in the larger socio-economic system was weakened by such developments. The future of gas in the energy mix in Energy Valley has become polarized between the local and national economic interests and therefore new 'coping strategies' needed to be considered where citizen acceptance and national interests needed to be balanced.

### 4.6.1 Contextual factors, system behaviour and end states

In this analysis, the role of contextual factors has been explored in the light of Energy Valley's energy system and the resulting system reactions. The analysis also included an exploration of how Energy Valley was embedded in the national and EU systems. Based on this analysis, a number of conclusions can be drawn that have implications for end state developmental pathways. The following considerations play a role in these developments and can contribute or limit end state developments. The considerations have been categorized under their respective headings of contextual factors, system reactions and system in systems.

**Contextual factors and end states**

**Role of contextual factors**

Energy systems are more than technological systems

Each energy system is subject to local and global contextual factors and it is more than only drivers of change, it includes history and geography, stakeholders and system definition

Interconnectedness and unpredictability of system interactions as a result of contextual factors

*Box 1: Elaboration on role of contextual factors*

Energy transition is not only a technical challenge but economic, (geo) political, environmental, behavioural and (civil) societal aspects play an important role. Moreover, these aspects are interconnected and unpredictable and are therefore difficult to anticipate and know what impact they could have on chosen pathways.

The future is not predictable (gas prices, earthquakes, technological advances) and therefore more attention is needed to 'fitness' of strategy to drivers of change where alertness and responsiveness to current trends and developments are important. Too much focus on long-term planning may miss current trends and opportunities elsewhere.

Focus on one dominant energy system (e.g. gas dominance) could lead to lock-in effects inherent in contextual factors. External drivers of change, e.g. a major earthquake, could have major impacts on such future end states. A diverse energy mix offers flexibility and resilience.

### System reactions and end states

**System reactions**

Due to unpredictability of energy future, planning strategies are limited in their value and therefore, more resilient strategies are needed. These could include

- being open to broader developments
- creating trust amongst a larger group of stakeholders and engaging with 'new' stakeholder
- engaging in interdisciplinary solutions, innovations and knowledge sharing
- supporting new businesses to reach critical mass, and to be part of the energy system
- creating broader system definitions and approaches, e.g. energy as eco-system
- acknowledging self-organizing processes next to coordinated policy

*Box 2: Elaboration on system reactions*

Interconnectedness and unpredictability of 'other' factors increases the urgency to engage and include stakeholders outside of energy in developments to expand the perspective and scope of strategy frameworks of energy clusters.

- Connections (especially to outside the 'normal') as opposed to fragmentation and 'silos' are vital to break down 'lock-in' risks and to make an energy system more resilient:
  - Including other stakeholders, for example, engaging politicians at all levels, connecting to consumers and consumer intermediaries especially since consumer and demand-side focus is becoming more influential
  - Connections to other disciplines instead of mono-disciplinary approaches
  - Connections in an enlarged scope, examples being gas to renewables, international connections, other sectors, value chain approach instead of product development in isolation
- Building ecosystems to accelerate innovation and knowledge sharing:
  - Includes open innovation, international, interdisciplinary, inter-sectorial, consumer involvement, focus on variety, etc.
  - Government's role in facilitating ecosystems including capacity building and knowledge development to support knowledge acceleration and excellence.
  - Major push needed to boost start-ups, large corporations and R&D centres to create critical mass to attract and keep expertise and talent in the region.
  - Attractiveness of the region is a major challenge that would influence future of the cluster. Energy Valley needs to deal with this to avoid 'cluster drain'.
- Centre and periphery issues where relevant such as a shift to include stakeholders in the margins (environmentalists, 'prosumers', consumers, innovators, funding partners), or a shift in system position from peripheral regions to more strategic positions as was the case in Energy Valley.
- Better alignment and connections between future scenarios and frames of key players need to be addressed. Balancing 'frames' of climate change, competiveness and economics, regional cohesion agendas and other local frames needed since this could result in affecting end state developments. Particularly, where
  - energy as a theme served different goals and agendas
  - major differences and misalignments in urgency and priorities were present
- Systems, and particularly complex systems, are subject to self-organizing processes. Acknowledgement of such processes and facilitating decentralized initiatives as part of good governance is needed in addition to coordination through top-down policies and guidance
- Building trust as a key aspect of energy system developments is important since this is strongly connected to how local energy systems react to new and planned development pathways. This includes
  - trust between different types of businesses, between government and businesses, citizens and governments and businesses
  - trust in large scale investments and projects especially when new technology is involved
  - trust in the 'care-taker's role' of the government and the long term sustainability of societies

## System in system and end states

**System in systems**

Local and EU energy systems are interconnected

- Lower level systems feed into higher-level systems and therefore various local energy systems' developments and their respective energy end developments will contribute to a higher order system of end states

*Box 3: Elaboration of system in system*

- Local energy systems are connected to EU systems and this offers opportunities to connect and tap into competences, resources, energy sources, to increase scope, scale and capabilities to accelerate energy system developments locally but it also works both ways and offers national and EU level systems opportunities to accelerate and influence their preferred energy developments.
- On a systemic level, being aware and connecting to other systems' developments is an opportunity for growth, visibility and influence and at the same time, it increases complexity and unpredictability of end state pathways.
- Local energy systems tend to be 'locked in' to their contextual factors and system reactions as described in this analysis. Connecting to other local energy systems and to the EU could help temper lock-in pulls. At the same time, at the higher EU level, the diversity of the different local energy systems and their end state pathways and goals make the EU system more resilient. Diversity of the higher level system could act as a buffer for any lack of resilience of energy systems to external shocks (drivers of change) and therefore an issue to be considered for the 'big picture' is that there could be different end states in a larger EU system but that the higher level system of the EU needs to be diverse and resilient to future drivers of change.

## 4.6.2 Complex energy systems

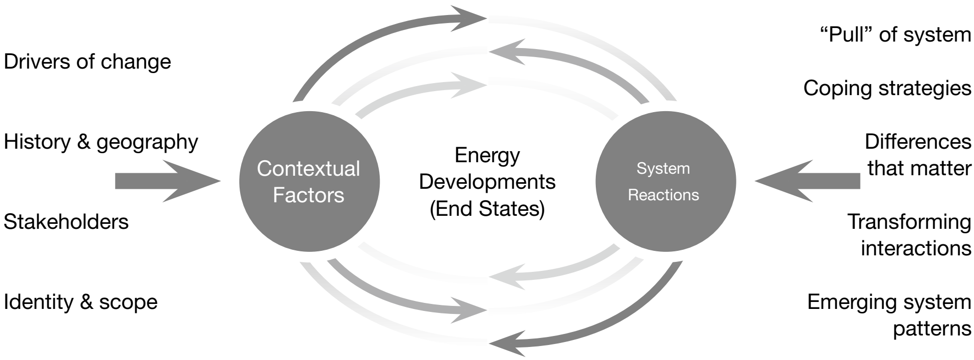


*Figure 7: Complex Systemic Energy Developments*

Based on the systems analysis as described in this chapter end states are determined by contextual factors of the (local) energy system and the energy system's reactions to such changes. The configurations for a specific energy system are continuously being shaped by the interaction of contextual factors and system reactions. And end states of local systems feed into higher-level end states, which in turn are affected by contextual factors and system reactions that then determine energy end states of the whole system-in-system. For Europe, local and regional energy end states feed into the European end state developments and therefore a systemic analysis of local and European end state contextual factors and possible system reactions could provide a more specific picture of constraining and supporting factors towards end states. In addition, as mentioned in the system in system analysis, the notion of different end states in local energy systems is a plausible scenario, which in turn could support a more diverse and resilient energy system at the EU level. This last consideration, of systemic interconnectedness, could become a relevant agenda in the EU's development of its Internal Energy Union and its end state pathways.

### 4.6.3 Implications for Big Picture - 3 End states

Potential limiting factors as 'risks' have been identified below for the end states, particularly from the EU perspective, to illustrate key contextual and systemic factors that could affect pathways to energy end state scenarios.

- **Risk of underestimation of 'system reactions'** as energy systems are not technology systems but social systems
  - System reactions on unexpected incidents such as nuclear disasters, shale gas risks, offshore oil disasters, earthquakes, political crises have shown their impact on energy policies and practice.
  - System reactions on slow trends (boiled frogs), for example, climate change, and on sudden breakthroughs (game changers), for example, fracking technology.
  - Micro level system reactions on price developments, ecological damage, push for autonomy and self-sufficiency, etc., as seen in the 'prosumer' and green movements, decentralized energy systems and emergence of small innovative firms.

  **End States**: Larger risk in BAU, less risk in GAS, and least in RES.

- **Risk of miscalculation of role of governments** and regulations at European, national and regional levels
  - European Union's drive to be independent from foreign supplies (energy security focus) and its transition to low carbon society. Captured in new 'Resilient Energy Union' vision of secure, sustainable, competitive, affordable energy for every European.
  - EU's ambitions translate to national and regional regulations, for example, renewed focus on North Sea Grid to reduce Russian gas supply dependence.
  - European Union's innovation policy and funding programmes focus on strengthening regions and clusters to increase competitiveness of small and medium businesses, particularly in new emerging industries. Energy efficiency, smart grid and decentralized innovations are energy related examples. This includes shifts to regional vs. national levels, strengthening the regional and local energy systems primacy.

**End States**: BAU and GAS scenarios more vulnerable than RES.

- **Lock-in risk due to current dominance of fossil fuels**
  - Assumption of abundant fossil fuels (gas in GAS scenario), power of fossil fuel corporations, short-term thinking and growth of energy needs results in more exploration, more infrastructure for fossil and non-fossil, more expertise, etc. (more of same = lock-in).
  - Underutilization of 'other solutions' (as in RES scenario), cross-sectoral, cross-disciplinary open innovation developments.

**End States**: BAU and GAS have largest risk, RES least.

The table below captures the risks with a brief explanation for EU end states.

| Key Risks | Risk for BAU | Risk for GAS | Risk for RES |
|---|---|---|---|
| **Underestimation of 'system reactions'** | ++ | + | - - |
| | *Short-term thinking particularly in BAU scenario makes it more vulnerable*<br><br>*In RES, variety of stakeholders including demand-side innovative firms, NGOs and consumers reduce tunnel vision and increase flexibility of system.* | | |
| **Miscalculation of role of governments and regulations** | ++ | + | - - |
| | *Current dominance, lobby and short-term thinking of fossil fuel industry feeds into optimism of continued influence and lack of alternatives for current scenarios on the short-run*<br><br>*National sovereignty still dominant in EU and fossil fuel industry have powerful positions*<br><br>*EU ambition to be low carbon and energy independent is a push for RES* | | |
| **Lock-in risk** | ++ | + | - |
| | *Similar to 'role of government' risk*<br><br>*Current dominance and power of fossil industry and a lack of alternatives strengthen search of solutions in 'known' RES are dependent on new innovation and therefore less risk of lock-in* | | |

*Table 1: Implications of Risks for End States shift*

## 4.7 Key findings

### General

- EU's end states are unpredictable due to contextual factors and energy systems reactions
- Local energy systems influence EU end states and v.v.
- Local energy mix variations in end states (e.g. gas dominance in NL) contribute to EU's diversity and less lock-in risk, and this increases EU energy system's resilience.

## Risks

- Underestimation of 'system reactions'
- Risk of miscalculation of influence of governments and regulations especially BAU
- Risk of lock-in especially in BAU and GAS

## Opportunities

EU's combined drive for energy independence and low carbon economy ambitions create opportunities for leadership in innovation (push for RES)

*Note: The 'Contextual and Systemic Forces in Energy Valley' analysis was based on a PhD research project focussing on energy cluster dynamics that overlapped the study of 'end states' in the context of Energy Valley. Drs. Karel van Berkel was part of the research team contributing to the study. (Expected completion of PhD thesis, 2015).*

# REFERENCES

Asheim, B. and Parrilli, M.D. (2012). (Ed.) Interactieve Learning for Innovation: A Key Driver within Clusters and Innovation Systems. Hampshire:Palgrave Macmillan.

Bosman, R., Avelino, F., Jhagroe, S, Loorbach, D., Diercks, G., Verschuur, G. and van der Heijden, J. (2013). Energielente op komst? De (on)macht van bottom-up en top-down in de energietransitie. Dutch Research Institute For Transitions, Erasmus University Rotterdam. E 2013.02.

Carbonara, N. Giannoccaro, I and McKlevey, B. (2010). Making Geographical Clusters More Successful: Complexity-Based Approaches. E:CO, 12(3), 21-45.

Cherp, A., Jewell. J. and Goldthau, A. (2011). Governing Global Energy: Systems, Transitions, Complexity. Global Policy. Vol. 2(1): 75-88.

Energieonderzoek Centrum Nederland. (2014). Nationale Energieverkenning 2014. Petten. www.ecn.nl/energieverkenning. Retrieved: 10 October 2014.

Energy Valley. (2010). Background Study Hansa Energy Corridor. Archive Material from Energy Valley.

European Forum for Clusters in Emerging Industries (EFCEI). (2013). Policy Roadmap - Actions for new linkages needed: A policy roadmap for stimulating emerging industries. http://www.emergingindustries.eu/Upload/CMS/Docs/Policy—roadmap.pdf .

European Policy Brief. (2010). Innovation Futures in Europe: A Foresight Exercise on Emerging Patterns of Innovation, Visions, Scenarios and Implications for Policy and Practice. DG Research, INFU Newsletter, October.

Jones, H. (2011). Taking resposibility for complexity: How implementation can achieve results in the face of complex problems. Overseas Development Institute, Working Paper 330.

Kaloudis, A. and Pedersen, T. E. (2008). (Ed.) Sectoral Innovation Systems in Europe: Monitoring, Analysing Trends and Identifying Challenges: The Energy Sector – Final report. Olso: TIFU.

Lorentzen, A. (2008). The Scales of Innovation Spaces. In Querejeta, M. J. A., Landart, C. I. and Wilson, J. R. (eds.) Networks, Governance and Economic Development: Bridging Disciplinary Frontiers. Cheltenham: Edward Elgar Publishing, p. 40 – 56.

Mans, P., Alkemade, F., Valk, van der, T. and Hekkert, M.P. (2008). Is cluster policy useful for the energy sector? Assessing self-declared hydrogen clusters in the Netherlands. Energy Policy, 36 (2008) 1375–1385.

Martin, R. and Sunley, P. (2007). Complexity Thinking and Evolutionary Economic Geography, Papers in Evolutionary Economic Geography, Utrecht University, 07.03

Mischen, P.A. and Jackson, S.K. (2008). Connecting the dots: Applying complexity theory, knowledge management and social network analysis to policy implementation. Public Administration Quarterly, 32(3): 314-338.

Rijksdienst voor Ondernemend Nederland. (2014). Rapportage Hernieuwbaar energie 2003-2013. www.rvo.nl. Retrieved: 22 September 2014.

Science Business Report. (2012). The Energy Technology Road Map: How to Plan Europe's Energy Future. Science Business Publishing, retrieved from **www.sciencebusiness.net**
Viitanen, J., Markkula, M. & Soler, C. R. (est. 2012). Systemic Development of Regional Innovation Ecosystems: Modernizing the Triple-Helix. Academic.edu: https://www.academia.edu/3984588/Systemic—Development—of—Regional—Innovation—Ecosystems—Modernizing—the—Triple—Helix. Retrieved: 9 July 2013.

**Documents on The Netherlands, Northern Netherlands and Energy Valley cluster**

De Plus van Noord-Nederland: Roadmap samenwerking noordelijke clusters, versie 1.3 (2013).
Energieakkoord Noord-Nederland (2007)
Energiemonitor Noord-Nederland 3e editie (2014)
Green Deal (2011). http://www.energyvalley.nl/uploads/bestanden/e32eb386-aee4-476c-be76-60414b3fd5e8
Nationale Energieverkenning 2014, Energieonderzoek Centrum Nederland, Petten 2014
OECD Reviews of Innovation Policy: Netherlands 2014, OECD Publishing. http://asset.keepeek-cache.com/medias/domain21/—pdf/media1796/281693-wl5ayagv99/large/0.jpg
Position Paper: The Northern Netherlands and the EU 2020. SSN (2011)
Rapport: Aardgasbeleid in Nederland: actuele ontwikkelingen. Rijksoverheid (2014)
Rapport Eindadvies van de Commissie Duurzame Toekomst Noord-Oost Groningen: Vertrouwen in een duurzame toekomst (2013)
Research and Innovation Performance in Netherlands, Country Profile 2013 European Union (2013)
Research and Innovation Strategy for Smart Specialization RIS3 Northern Netherlands. SSN (2013)
Strategische agenda voor Noord-Nederland 2007-2013. SSN (2005)
Summary Report of Energy Agreement for Sustainable Growth (Energieakkoord voor duurzame groei, 06-09-2013) SER (2013)
Switch: Noordelijke Energie Agenda (2014). Bestuurlijk Overleg Noord-Nederland en Stitching Energy Valley
Topsector Energie website: http://topsectorenergie.nl
Werkprogramma's, documenten en rapporten van Stitching Energy Valley