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# ENERGY MODELS AND SCENARIOS IN THE ERA OF CLIMATE CHANGE

**Briefing Report** 

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### **Abbreviations**

BP British Petroleum

CDIAC Carbon Dioxide Information Analysis Center (U.S. Department of Energy)

CO<sub>2</sub> Carbon dioxide
FiT Feed-in-tariff
EU European union

EU-ETS EU Emissions Trading System

GDP Gross Domestic Product

IAM Integrated assessment model

IEA International Energy Agency

IMF International Monetary Fund

IPCC Intergovernmental Panel on Climate Change

IRENA International Renewable Energy Agency

OECD Organisation for Economic Co-operation and Development

NOAA National Oceanic and Atmospheric Administration (in the United States)

RE Renewable energy

RES Renewable energy sources

REN21 Renewable Energy Policy Network for the 21st Century

TPES Total primary energy supply

UNEP United Nations Environment Programme

VRE Variable renewable energy

WB World Bank

WEC World Energy Council
WEO World Energy Outlook
WWF World Wildlife Fund

### **Energy terminology**

Energy models: use and combine data from different sources to describe the energy sub-system such as energy demand and supply. Energy models can be useful tools in energy planning such as investment plans, legislation and regulation. The emergence of many energy models coincided with the need to develop the industrial economy, which explains why they follow a positivist approach and the values of modernisation and neo-classical economics. Models may also be misused to legitimate political decisions under narrowly framed assumptions. Some models struggle to take into account the role of ecological limits or power relations. Energy models are not neutral, good or bad in themselves, but it is important to identify who benefits from the use of a particular energy model.

**Energy scenarios:** are used to assess the impacts of different developments under assumptions of certain outcomes, and are not policy recommendations. Different scenarios can help decision-makers in providing a range of scientific evidence. Energy scenarios can be divided into forecasting scenarios that aim to minimise uncertainty based on historical data and backcasting scenarios that map future development pathways.

**Forecasting:** is a commonly used tool in energy scenario-building, and describes a series of events from the present state leading to a state of future, following prevailing trends. Energy outlooks based on forecasting methodology that are presented to policy-makers typically include a business-as-usual case and alternative scenarios. In forecasting scenarios, the concepts of risk and uncertainty have a central role.

**Backcasting:** is a strategy tool to determine the most favourable future scenario and to identify what are the necessary steps to achieve this preferred future. Energy backcasting is closely policy-oriented as it explicitly focuses on policy implications. This makes backcasting useful for the optimisation of energy demand, a goal which can be obscured in the more traditional energy supply and demand models.

**Assumptions:** are set by the modeller in making a model. When an energy model is constructed, several assumptions have to be made about the scope and the structure of the model. Experience from previous modelling exercises teaches that all models are somehow "biased" by traditions and preconceived opinions from the model developer, the model user, and also the model client.

**Carbon neutrality:** refers to energy scenarios where energy production and consumption are attained without carbon-related emissions. Low-carbon energy scenarios aim to depict pathways to this goal.

**Absolute decoupling – relative decoupling:** In the context of energy, absolute decoupling refers to a situation where economic growth is attained without increases in energy demand. Relative decoupling, in turn, implies that economic growth is achieved with greater efficiency of production.

**Lock-in effect:** explains why particular economic or energy infrastructure limits the range of available energy choices. The International Energy Agency (IEA) has suggested that because of the present rate of fossil fuel based energy consumption and infrastructure choices, the world economy is likely to "lock into" a minimum of +2°C degrees global warming trajectory already by 2017.

**EROEI**: is the ratio that describes the amount energy that needs to be consumed when energy is produced (Energy Return on Energy Investment, or Energy Returned on Energy Invested). Because the estimation of EROEI is complicated, experts may make differing EROEI estimations.

**Fossil fuel subsidies:** are production or consumption subsidies that lower the cost or price of fossil fuel-based energy generation, for instance through financial transfers, taxation or under-pricing.

**Grid parity:** refers to a point in time, at which a developing technology produces electricity for a similar cost as traditional technologies in a selected area. For instance, when the production costs of renewable energy become lower, this technology becomes increasingly competitive compared to retail electricity prices, and can even reach grid parity in market comparison.

**Feed-in tariff (FiT):** is an established policy mechanism to accelerate and support investments into renewable energy technologies. Typically, a feed-in tariff provides renewable energy producers a guaranteed grid access, long-term contracts, and a price to match the cost of technology.

**Energy intensity:** measures how efficiently a country uses energy by calculating what is the total energy use per unit of output. Countries vary widely in their energy intensity performance.

### Units of energy

#### Unit of energy

Joule J GJ Gigajoule: One billion (109) J Terajoule: One trillion (1012) J TJ Exajoule: One quadrillion (1015) J EIBTU British thermal unit (1 055 J) Quad Quadrillion (1015) BTU; roughly equal to 1 exajoule kWKilowatt MWMegawatt GW Gigawatt TWTerawatt kWh Kilowatt hour MWh Megawatt hour (1 000 kWh) GWh Gigawatt hour (1 000 MWh) TWh Terawatt hour (1 000 GWh) Tonne of oil equivalent (approximately 41.9 GJ) toe Mtoe Million tonnes of oil equivalent

### **FOREWORD**

Produced by Finland Futures Research Centre (FFRC), this report "Energy models and scenarios in the era of climate change" has aimed to improve understanding on how energy models and scenarios are used and deployed, to explain how dominant scenarios and future forecasts can be challenged, and build capacity for the development of alternative energy scenarios. With regard to debates about energy and climate change, the report summarizes experiences from past energy policy research in the Mekong region in Southeast Asia, Eastern Africa and Nordic countries. This research has received contributions and challenges from the Finnish Ministry of Economy and Employment and Ministry of Environment, VTT Technical Research Centre of Finland, Finnish Energy Industries, SKM Market Predictor, Greenpeace, and The Finnish Local Renewable Energy Association, whom we would especially like to thank for their time and expertise as the discussions have served as interesting material. "Access to Sustainable Energy for All" project has received funding from EuropeAid of the European Commission. Finally, the report has aimed to capture the summary of findings gathered during the research, and does not reflect the views of individual organisations.

### EXECUTIVE SUMMARY: ENERGY MODELS AND SCENARIOS IN THE ERA OF CLIMATE CHANGE

In recognition of the climate change challenge, this report has studied how energy models and scenarios have been deployed in energy policy in order to contextualise the assumptions that guide public policy-making to build up the capacity of decision-makers, experts and citizens alike.

### Fossil fuel-based energy consumption drives climate change

Energy represents over 80% of human-caused greenhouse gases. Energy consumption is rising and the world energy system is 82-percent reliant on fossil fuels. Investments into the current energy infrastructure cause a considerable "lock-in" effect because they bear a long trajectory. The fossil fuel economy plans to burn approximately 2 795 Gt of carbon, which is a carbon budget five times too high, if the world aims to stay below an average +2°C warming. In the 20th century, energy consumption has not fallen, and only energy efficiencies have been obtained as a result of technology improvements. In 2011, the support to renewable energies stood at USD 88 billion while fossil fuel subsidies were estimated to range from USD 523 billion to USD 1.9 trillion.

### Could energy scenarios of the industrial era undermine a low-carbon energy future?

Today, energy models should be understood as representations of the energy sub-system whose functions are embedded within a physical reality. The emergence of many energy models in the 1950s largely coincided with the need to develop the industrial economy. Detailed techno-economic models were only developed in the early 1970s as a response to the oil crisis. Past research seems to suggest that certain energy forecasting scenarios have exaggerated future energy demand, which has justified the construction of large energy plants, and in turn lead to overcapacity in industrialised and developing countries (and consequently higher carbon emissions levels). The use of historical energy consumption data and forecasting scenarios may partially explain why this might have been the case. For such reasons, it is important to recognize that assumptions in energy modelling and policy-making always reflect normative choices and judgment on the part of the modeller, or the decision-maker.

### The 21<sup>st</sup> century aspires for deliberative and open energy policy to meet climate targets

If the world is to meet the climate change targets, low-carbon energy scenarios and energy models may help in the evaluation of future energy options. Past evidence suggests that traditionally, public administration has tended to listen established industry actors more closely than small-and-medium-sized enterprises, advocacy groups, or communities. An aspiration to openly discuss politics that influence citizens is known as the deliberative turn in democracy, and challenges established policy-making institutions at the national and international level. In terms of recommendations for climate change mitigation and energy policy, some of these institutions may have taken overly conservative stances. A step towards the acceptance of a diversity of views in energy policy and energy modelling could be the opening of all assumptions that guide policy-making and model-making.

Although scenarios are not policy recommendations, this report also finds that certain energy scenarios search pathways that meet the climate targets more determinedly than energy scenarios that tend to favour a business-as-usual situation.

### 1. INTRODUCTION

This briefing report "Energy models and scenarios in the era of climate change" produced by University of Turku, Finland Futures Research Centre (FFRC), aims to improve understanding on how energy models and scenarios are used and employed. It is hoped that by giving an overview of energy consumption and production and the role of energy modelling in energy planning, this report can provide useful insights to the readers. In addition, this report may also build up capacity in the development of alternative energy scenarios and explain how or why dominant energy scenarios and future forecasts can be challenged. The report has been written for the use of decision-makers, researchers, non-governmental organisations, advocacy groups, activists, or for anyone interested in the issues of energy policy, energy planning or climate change.

Energy cuts across social, economic and security interests as well as climate and environmental concerns. The global energy system is interconnected in terms of import and export of electricity and energy commodities such as oil, gas, coal. All such standpoints may be considered as relevant normative factors that may guide assumptions when energy models and scenarios are designed. Climate change, though, is perhaps the most difficult problem humanity is forced to tackle and demands urgent action (IPCC 2013; 2007; 2001). By comparing the existing energy infrastructure and the current carbon emissions path, the International Energy Agency (IEA) predicted already in its World Energy Outlook 2011 that the world will become locked into a trajectory of more than +2°C of global warming by 2017. Because investments into energy infrastructure bear a long trajectory, they hold considerable "lock-in" potential. Regardless of this fact, almost all influential energy scenarios suggest that in the long-term time horizon, energy consumption is likely to increase and the world energy system remains based on fossil fuels (IPCC-SRREN 2011). Finding such stagnancy in the 21st century in scenario building, lack of interdisciplinary discussion and predictive capacity is somewhat astonishing.

This report presents an overview of energy use and climate change, and discusses different approaches to energy modelling and scenario-building that have been employed in the past. This report also presents three case studies of energy policy and energy modelling, energy forecasts and discusses related problems using examples from different continents: Finland in Northern Europe, Thailand in Southeast Asia and Kenya in East Africa. These experiences have been chosen to analyse power structures that underpin energy policy related knowledge production and policy mechanisms in different types of country contexts, around the world. The data is based on a literature review and is supported by expert interviews and research experience about contemporary debates.

This report also discusses observed problems related to energy modelling, scenario-building and energy policy. Past research suggests that official energy scenarios have tended to exaggerate future demand (Grönfors 1990). Energy forecasts especially in the North, but also in the fast growing economies of the South have been used as tools to justify for large, centralized energy plants leading to overcapacity. This has made energy scenarios self-fulfilling predictions and extra-capacity on the supply side, which has encour-

aged over-consumption. Much of energy modelling and scenario-building have been based on an epistemological foundation of a techno-rationalistic and economically motivated research paradigm. Energy modelling research has typically employed macroeconomic modelling and focused on economic and technological development. Such research mainly examines cost optimisation in the supply side when the demand is given, while downplaying the role of ecological, social and political dimensions in energy and economic policy.

It is useful to understand that country-based energy outlooks and energy scenarios are typically coordinated and commissioned by the ministry in charge of energy policy, conducted in cooperation with state-affiliated research institutes, and by researchers with particular modelling expertise. Internationally, the annual World Energy Outlook by the Paris-headquartered International Energy Agency (IEA) is perhaps the most often-cited global energy outlook. Also major energy companies in oil and gas sectors produce their own outlooks such as the BP Energy Outlook by British Petroleum or Shell Energy Scenarios by Royal Dutch Shell. Certain other international organisations and research institutions have made contributions to the energy debate with their reports, including the Global Environmental Outlook by the United Nations (UN); State of the Future by American Council of the United Nations University; and World Energy Scenarios by the World Energy Council (WEC). Apart perhaps from the Energy [R]evolutions series produced by Greenpeace, non-governmental organisations have less often constructed global or national energy scenarios.

Certain energy scenarios have not foreseen unprecedented events or anticipated the pace of technology change. Recently, a rapid fall in the price of solar energy and an increase in the industry development have outpaced past predictions. On the other hand, while certain scenarios have been able to anticipate technological changes, almost all have failed to address consumption patterns. Some might suggest that policy-influencing institutions at the highest international level have taken overly conservative stances when it comes to the necessity of policy changes to mitigate climate change. Because most energy-related information is provided by the industry and the state, evaluating this information is rather challenging for communities, advocacy groups or others concerned with energy choices in the era of climate change.

In both energy policy and energy-modelling, the role of assumptions cannot be ignored. In policy-making, normative judgment is exercised by both politicians and civil servants, when they assess and value different competing objectives. In scientific practice, assumptions manifest in relation to the worldview and theories that underpin energy model-making. In industrialised countries, the so-called top-down energy models have tended to adhere to existing production and consumption patterns, which has also shaped assumptions about future energy demand in an influential manner. In developing countries, searching for optimal development paths, energy futures and infrastructure are yet to shape. Therefore, alternative energy modelling and scenario building could serve as powerful tools that let a broader range of opinions and expertise to participate in the debate – to avoid the "lock-in" effect.

In the wake up to the climate change threat, certain low- and no-carbon scenarios have emerged. Already, backcasting scenarios have helped to illustrate the magnitude of changes that are required in energy systems and infrastructure at all levels: local, national, regional and/or international. Bottom-up energy assessments can be used to improve the linkage of energy production and citizens' energy needs at a local level. Opportunities of democratic decision-making in energy policy might also enhance the local ability to

reach development goals and targets, when it is known in detail what is needed to eradicate poverty *and* support low-carbon development pathways<sup>1</sup>.

The structure of this report is as follows. Chapter 2 presents the global energy system in the context of climate change and provides a historical view to the rapid increase of energy consumption. Chapter 3 presents what energy models and energy scenarios are and how they have evolved to meet certain historical needs. The chapter also discusses the advantages and drawbacks of different modelling approaches. Chapter 4 elaborates three country-based case studies – Finland, Thailand and Kenya in sub-Chapters 4.1, 4.2 and 4.3, respectively – to reflect their energy policy debates in relation to particularities of each country. Chapter 5 discusses the role of citizens in energy policy who are concerned of and influenced by energy choices. The participation of citizens is a valuable tool in democratic decision-making, and their opinions may contradict the 'facts' that are captured and represented in the energy models and supposed to aid decision-making. Finally, the report provides General Conclusions with a list of key messages to capture some of the learnings and provide recommendations.

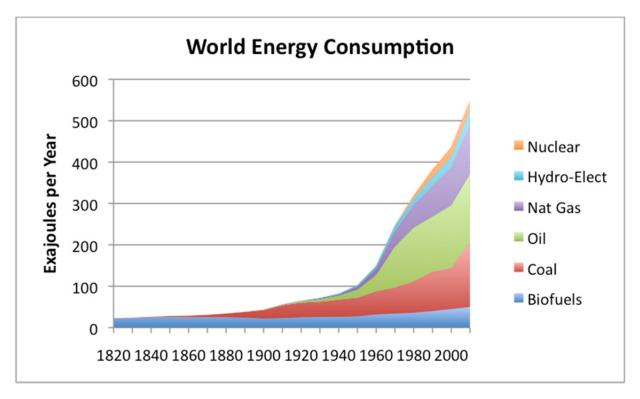
It is sincerely hoped that this briefing report is able to improve the understanding of all relevant stakeholders about the need of climate change mitigation and how this concern should be reflected in energy modelling and scenario-building and the energy choices made now that will influence generations to come.

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For instance the difficulties of the initial stages of the Emissions Trading System (EU-ETS) of the European Union, or challenges related to UN-led carbon schemes such as REDD+ could likely benefit from a more coherent understanding of the interrelations of energy, climate change and what are the economic and social impacts of these initiatives.

### BACKGROUND

Economies across the world are highly dependent on fossil fuel based energy (IPCC-SRREN 2011; Peters et al. 2011), after they have been built according to the planning principles of modernisation. What is more, energy consumption based on non-renewable resources increases continuously. Between 1973 and 2012 the total primary energy supply in the world increased from 6 to 13 Gtoe, which signifies that energy production more than doubled in only 40 years (IEA 2013b). In the 2010s, the global energy system is 82-percent reliant on fossil fuels – a ratio which has not improved in the past decades. In 2001, mineral fuels such as petroleum, coal and natural gas accounted for 89% of the total energy use (Maddison 2005a). Affordable crude oil, most of which has been discovered and exploited during the last hundred years, in particular has catalysed economic growth. In contrast, in 1820 – only two hundred years ago – 94% of world energy consumption resulted from the use of *organic* materials (ibid., 15)<sup>2</sup> (cf. Figure 2.1).



**Figure 2.1.** World energy consumption 1820-2010 (Tverberg 2012; based on Smil 2010 and BP Statistical Data since 1965).

<sup>&</sup>lt;sup>2</sup> Pre-industrial economies rely relied in biomass as their primary material source. In contrast, between 1900 and 2005 the extraction of construction materials grew by a factor of 34 (Krausmann et al. 2009).

Simultaneously, energy represents over 80% of anthropogenic (human-caused) greenhouse gases<sup>3</sup>. In 2011, global CO<sub>2</sub> emissions were 31.3 Gt CO<sub>2</sub> annually (IEA 2013a; cf. Figure 2.2). McKibben (2012) has explained that the fossil-fuel economy plans to burn an amount 2 795 Gt of carbon globally, which is a carbon budget five times too high, if the world aims to stay below an average +2°C warming (see also Berners-Lee and Clark 2013). These estimates are also echoed in the IPCC Fifth Assessment (AR5) report (2013)<sup>4</sup>. Several energy forecasts assume mixed positions in how to reach to this fact: although energy forecasts expect energy use to increase for decades to come, simultaneously many of them are aware of the necessity of sharp reductions in fossil fuel based emissions. As it stands, there is a substantial gap between political ambition and practical reality to achieve climate change targets (IEA 2013a; UNEP 2013).

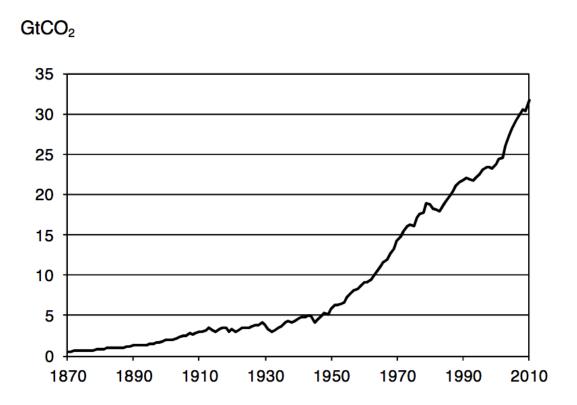


Figure 2.2. Trend of CO<sub>2</sub> emissions from fossil fuel combustion, 1870-2010 (IEA 2013a, 8) Source - CDIAC, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., US.

<sup>&</sup>lt;sup>3</sup> In 2009, 43% of global CO<sub>2</sub> emissions from fuel combustion stemmed from coal, 37% from oil, and 20% from gas (IEA 2013a; IEA 2011). In 2011, oil accounted for 33.1% of global energy consumption, and coal for 30.3% - which was the highest figure since 1969 and also increased carbon emissions levels (BP 2012b). Yet, coal accounted for 44% of the global CO<sub>2</sub> emissions because of its heavy carbon content per unit of energy released.

<sup>&</sup>lt;sup>4</sup> CO<sub>2</sub> emissions account for 70 % of the atmospheric global warming potential of greenhouse gases. Other GHGs include long-lived gases such as CH<sub>4</sub> (20 %), N<sub>2</sub>O (5 %) and F-gases like HFCs, PFCs and SF<sub>6</sub> (5 %) (Rydén 2010).

### Box 2.1. Avoiding an "energy Armageddon"

There remains too much fossil fuels to be consumed to limit global warming (IPCC 2013; see also McKibben 2012). Even with an uptake of unconventional natural gas, the cleanest of fossil fuels, global warming will exceed +2°C (IEA 2011, 42). What is more, new oil discoveries and technology improvements are further postponing energy companies' investments into non-emitting energy technologies. Dieter Helm, an economist focusing on energy issues, has provided an excellent overview of the market dilemma. According to Helm (2011), if increasing coal demand, increase in Middle East production, the increased use of cheap unconventional gas, potentially great quantities of unconventional oil in Brazil, Canada and the U.S. are combined; supply could keep fossil fuel prices low and renewable and nuclear prices high also in the future. Such drivers would hinder the development of renewable energy technologies and supply an abundance of fossil fuels into the world energy system. Also, climate change would advance beyond safe limits, with potentially drastic economic and social consequences.

See also: BP (2012); Helm (2011); IEA (2011); McKibben (2012)

Energy modelling attempts to depict this global landscape. However, making an accurate representation needs to account for a multitude of dimensions. One consideration is the "absence of a level playing field", as argued by the REN21 (2013) network. According to different estimates, fossil fuel subsidies ranged from USD 523 billion to USD 1.9 trillion in 2011. In turn, support to renewable energy technologies in the same year amounted only USD 88 billion (Tagwerker 2014)<sup>5</sup>. Certain enquiries of a reform of energy subsidies have already been conducted, including an IMF report that was published in 2013 (see IMF 2013), and certain countries have mapped conducted a mapping of those domestic policies that can be perceived as subsidies harmful to the environment. From an economic perspective, yet another consideration is the fact that the energy supply side is constrained by an imperfect market. The imperfect cartel of OPEC countries accounts of 40% of current oil production and of about 70% of proven reserves (Fournier et al. 2013). Finally, the role of energy as a geopolitical topic is difficult to ignore: industrialised economies depend on raw energy exports from the African and Middle East regions and Russia (cf. Figure 2.3) as well as the manufacturing abilities of China and Southeast Asia through the interconnectedness in the world trade system.

<sup>&</sup>lt;sup>5</sup> There are different calculation techniques and measures for fossil fuel price and production subsidies globally (See also: Tagwerker 2014; UNEP 2011; IEA et al. 2010)

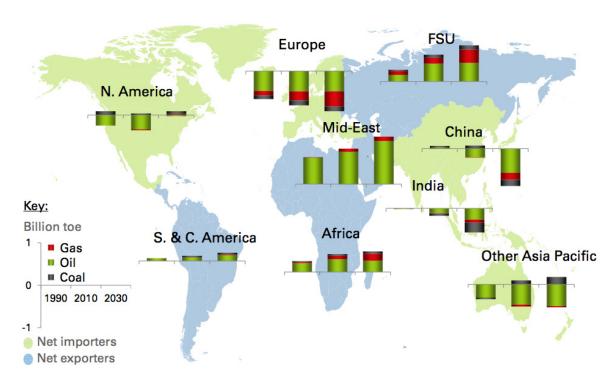


Figure 2.3. Energy imports and exports (BP 2012).

Over the recent years, certain megatrends that have changed the world energy landscape can be high-lighted. Following the growth of the world economy, the demand of fossil fuel-based energy has rapidly increased, as exemplified by the recent increase in coal-based energy production in China (IEA 2013a, 14). There also seems to be an increased difficulty to discover *conventional oil* (Gautier 2008; IEA 2011, 2013). But, contrary to past peak oil scenarios, only conventional reserves seem to have peaked<sup>6</sup>. In turn, it is now expected that *unconventional reserves* such as oil shales and tar sands could supply large quantities of fossil fuels to the world energy system (Helm 2011)<sup>7</sup>. In recent years, unconventional supply that in 2013 already accounted for almost 5% of total oil production, has surged mainly from light tight oil in the United States, oil sands in Canada, natural gas liquids, and deepwater production in Brazil (Fournier et al. 2013). Advances in drilling technology and other developments are further facilitating further energy extraction from natural resources (Malanima 2010).

Several experts expect the price of oil to remain at high levels in the future compared to the age of easily accessible oil in the 20th century. A *resource pyramid for energy* exemplifies the logic of natural resource ex-

According to the International Energy Agency (2013, 447), it has become fashionable to state that the shale gas and liquid tight oil (LTO) revolutions in the United States have made the peak oil theory obsolete. IEA explains that the basic arguments have not significantly changed. For the purposes of *the peak oil argument*, the advent of technology breakthroughs, including in LTO, may shift the overall peak in time, but not change the conclusion. Once the peak is reached, decline inevitably follows rather quickly.

The sufficiency of global resources for both energy production and as materials is difficult to determine because new findings naturally increase this figure. The R/P-ratio used by US Geological Survey, measures the sufficiency of currently known reserves to production, and according to BP (2012b), in 2012 current coal reserves were sufficient for 112 years of global production, oil reserves for 54.2 years; and natural gas reserves for 63.6 years.

ploitation from the energy perspective (cf. Figure 2.4)8. The EROEI figure helps to explain why easily accessible energy resources such as crude oil demand fewer resources than unconventional oil (and therefore are also less costly). In turn, when more difficult resources are harnessed into use, energy production in itself demands increasing amounts of energy. Resource extraction tends to raise the amount of energy required to extract energy and production costs. Furthermore, higher production costs can potentially transfer into energy prices in the world energy market.

### Resource Pyramid (for energy)

The largest 1% of oil fields provide 50% of world production.

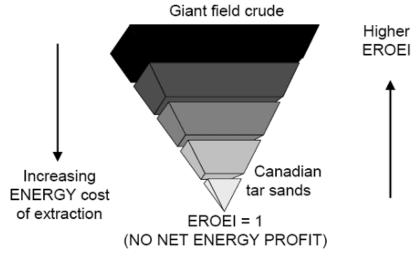


Figure 2.4. Resource pyramid for energy (Lardelli 2008).

Because energy demand is increasing as a result of economic growth (Chiou-Wei et al. 2008; Lee and Chang 2007), the mitigation of climate change would demand that the use of fossil fuels is *decoupled* from economic activity. Nevertheless, as has been explained in the beginning of this chapter, in the 20th century energy consumption did not fall. Instead of the *absolute* decoupling of energy consumption and economic growth (in terms of GDP), only *relative* decoupling has been achieved (cf. Figure 2.5). Or, to make it more clear, technological development has only been able to obtain improvements in energy efficiency (Jackson 2011). The *rebound effect*, also known as the Jevons paradox, further complicates matters. The rebound effect is an observation, which suggests that even when energy efficiency is achieved in a selected area of economic activity, savings are typically re-invested into economic activity elsewhere, which as a net effect results in increased energy consumption.

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<sup>8</sup> In energy economics, the EROEI-ratio describes the ratio of energy returned on energy invested

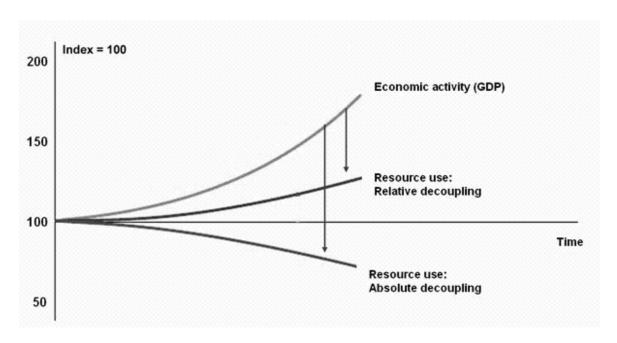


Figure 2.5. Absolute and relative decoupling: resource use and GDP (Raworth 2012b).

### Renewable energy and the role of supportive policies

Despite the climate change urgency and concerns of low access to energy still in many places around the world, the share of renewable energies (RE) in the global energy production mix is marginal. Depending on what energy sources are included and the used methodology, estimates of the share of RE varies between 2.1% (BP2012b) and 12.9% (IPCC-SRREN 2011, 9)9. Nevertheless, between 2000 and 2012, the installed global renewable electricity capacity doubled from 748 GW to 1,470 GW. This has included an increase of wind power generation worldwide by a factor of nearly 16, and an increase of solar power generation by a factor of 49.

In 2012, countries with most renewable energy included China, United States, Brazil, Canada and Germany. Germany leads in cumulative *solar photovoltaic* (PV) installed capacity, the U.S. leads in *geothermal* and *biomass* installed capacity; China leads in *wind* and Spain in *solar thermal electric generation* (STEG) (US 2012). The prices of wind and solar energy are falling, which has made these technologies increasingly competitive with conventional energy sources.

Nevertheless, their penetration is still dependent on a robust policy environment (REN 2013). Feed-in tariffs (FiT) for renewable energy have been acknowledged as a useful policy tool because they guarantee independent power producers a fixed price of producing clean energy into the national electricity grid (UNEP 2012). Perhaps the most ambitious policy scheme has been set by Germany with the *Energiewende*, or energy transition, which seeks to promote the deployment of renewable energy technologies with multiple measures in household, regional and national level. It is noteworthy, though, that an energy system

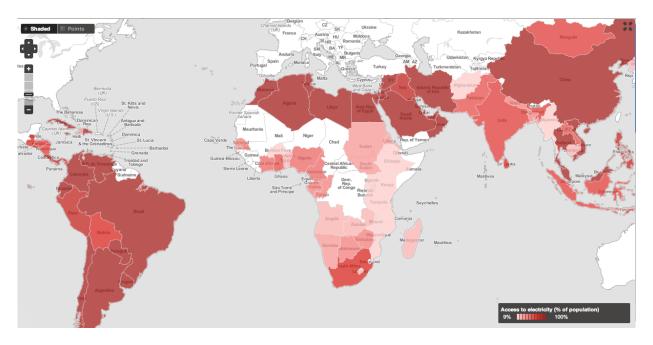
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Even in terms of electricity generation, worldwide renewable energy accounts for only 23% (4,892 TWh) (US 2012).

based on a large amount of renewable energy sources, such as solar and wind that have a low load factor, demands changes in energy infrastructure and technologies. Changes are needed to be able to control demand (e.g. peak cutting), increasing focus is needed on storage capacity and transmission systems. In addition, more inclusive delivery structures could encourage energy self-sufficiency and reduce fossil fuel dependence<sup>10</sup>.

### The lack of electricity in developing countries and an overview of different strategies

Although the world energy profile is often depicted from the perspective of industrialised countries, at the same time, citizens and industries across developing countries severely suffer from the lack of energy access, or the unreliability of electricity generation (cf. Figure 2.6). A large share of the developing world suffers from energy poverty or the lack of access to modern energy services, which undermines health, education, environmental quality and opportunities of economic empowerment. The United Nations experts have described energy as "the missing development goal" (Brew-Hammond 2012).



**Figure 2.6.** Access to electricity in emerging and developing economies (World Development Indicators 2014).

In the rural areas specifically, state-led electrification schemes as well as development projects have attempted to tackle energy poverty. In this regard, the IIED (2013) suggests that *a pro-poor approach* to energy delivery modelling is beneficial. Useful tools for this purpose are participatory identification of 'energy gaps', stakeholder mapping, market and context analysis as well as the design of an appropriate delivery

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Other suggestions include "smart grid" systems regionally to better control the balance between electricity production and consumption, or even region- or continent-wide "supergrids".

model and support services (ibid.). In addition to grid connections and improvements, also off-grid energy solutions such as the deployment of small-scale renewable energy have been tested in order to improve local energy self-sufficiency.

### The market dilemma, climate change and energy policy

In the light of current evidence, it seems that markets alone cannot steer the world into a safe climate path. Traditionally, markets have been governed with legislation and policies to minimise market externalities. Politics can shape markets and encourage technology change through a raft of measures such as stimulate the uptake of non-fossil fuel based energy generation at any given level – local, regional or international, or target the eradication of fossil fuel subsidies. A recent dramatic observation is the recognition of the potential of a future "carbon bubble"<sup>11</sup>. If fossil fuel resources would have to be left on the ground, this would signify that considerable investments made by large oil and gas companies into the exploration of fossil fuel resources would prove of no future value, and signify major losses to any shareholders. In order to prepare for such a scenario, a shift in public policy targets and the principles upon which energy investments have traditionally been based on would rapidly be needed.

### Box 2.2. Energy-related policy objectives across countries

Objectives derived from environmental policy include the decreasing of CO<sub>2</sub> emissions and promotion of renewable (or low-carbon) energies. The latter may also come from promoting domestic energy sources. Promotion of energy efficiency has an economic origin as a policy goal. However, energy policy has a list of other diverse objectives. Energy can also be considered as a mean to reach more primary objectives set in other policy fields such as industrial, economic, environmental, social, regional and even foreign policy. Typically, energy policy objectives at least target the securing of the availability of sufficient energy at reasonable prices. Security of supply stems from national interests. Reasonable price, in turn, is a pure economic objective. These kinds of energy-related policy objectives are repeated in almost all national energy policy documents by using different wordings. In practice, these policy objectives will be met – or not – with or without specific policy instruments. This formulates a framework for the market-based operations, and the market can be something between state-owned monopolies and fully open market.

### Conclusions

Solving the energy dilemma is one of the major challenges of our century. Multiple data (see Scripps 2014) show that the level of carbon emissions is rising, and at an increasing rate, already passing the threshold of 400 particles per million (ppm) (See Annex 1). Simultaneously, energy consumption, especially from fossil fuels, continues to increase. Importantly, the timeframe of change in energy infrastructure is considerable, typically decades or possibly a hundred years. This shapes the economic perspective and limits the ability to assume a straightforward approach to a radical transformation. The necessity of an energy transition seems

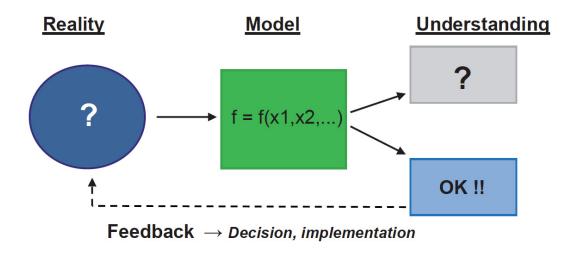
<sup>&</sup>lt;sup>11</sup> In referral to past experiences of economic bubbles such as financial, market, price or housing bubbles.

inevitable, which poses numerous questions in relation to how these energy investments are financed, what policy choices are appropriate, what kind of research and development (R&D) is needed, and how the rights of citizens are protected amidst such potentially large societal changes.

### 3. WHAT ARE ENERGY MODELS AND SCENARIOS?

### Energy modelling approaches: benefits and limitations

In the energy sector, energy models have also been used as a basis for investment plans, legislation and regulation (Unger 2010). A model needs to be able to account for all of the factors affecting the system (Ryan and Sanquist 2012) to provide a useful schema of reality (See Figure 3.1). Models can be used for *mapping* or *exploring*, and are typically used for the aim of policy-making. Boumans (1999, 67) describes model making "like baking a cake without having a recipe". Typically, energy models have been employed to depict the future energy demand and supply of a country or a region (Herbst et al. 2012). This chapter describes how energy models describe the energy system and how they bring authoritativeness to energy policy-related decision-making. In the next chapter, case studies further illustrate how energy-modelling exercises are closely linked with the evolvement of societal structures and the needs of the state machinery and economic life. At the end of the briefing report, a list of selected energy models is found (See Annex 2).



**Figure3.1.** Schematic view of energy models (Unger 2010)

### Energy modelling in a historical perspective: an extension of neoclassical economics

Energy models have been employed as tools to improve energy systems and energy infrastructure across industrialised countries. The emergence of macroeconomic energy models in the 1950s largely coincides with the need to develop the industrial economy. Detailed techno-economic models were then developed in the early 1970s as a response to the oil crisis (Herbst et al. 2012).

Understandably, energy models have conventionally modelled the technical features of the energy system, and in linkage with the national economy. Neo-classical economics and the modernisation theory dominated energy modelling assumptions in the 20th century (Luukkanen 1994). Still today, they have con-

siderable normative influence. However, this fact (that the modelling of economic-energy structure is not embedded into considerations regarding a societal imperative to adapt to changes in the physical reality) is often not often made explicit. But energy models can also be understood as representations (Hacking 1983) of the energy sub-system, whose functions are embedded within a larger physical reality.

#### Box 3.1. Modelling approaches and the fundamental role of assumptions

Science is the first institution assumed to provide solutions to practical problems (Carrier 2004). Hacking (1983) suggests that science has two roles: intervening and representing.

Yet, there are multiple ways to think, work and adapt to the material world, as already noted by Aristotle who pondered how to abstract (Frigg and Hartmann 2012; Hacking 1999). Modelling provides one means of classifying and exhibiting information. Models are employed for evidence-based policy-making, and at times even tailored in the aid of public policy. Morrison (1999) even suggests that models are 'autonomous agents' that have functional independence in knowledge production.

Communication to decision-makers and citizens, or the "model clients" about the assumptions, practice and results that shape a model construct is fundamental because models can heavily influence their perceptions. When an energy model is constructed, several assumptions have to be made on the scope and structure of the model. Previous modelling experiments have shown that every model is "biased" by traditions and preconceived opinions from the model developer, the model user that updates and develops the model, and also the model client for whom the model results are intended (Unger 2010) The modeller's conception of the world and the theory the modeller has of the development of societies affects the selection of the system structure and the variables (Luukkanen 1994). These reflect differences in scientific paradigms, theoretical approaches as well as the model aims. There may also be considerable uncertainties even in important assumptions.

Different models can be seen to share features from several model classes (Luukkanen 1994). Models can be divided into cognitive models (improve knowledge of reality) and decisional models (help an institution make the best possible decision). Though in practice, both types influence perceptions. Mathematically, models can be static or dynamic; deterministic or stochastic; linear or non-linear; ergodic or externally controlled. Computational methods can vary between network models, equilibrium models, optimization models — or system dynamic models. Also mathematical formulations in models may differ: some models are descriptive (simulating models), while others are normative (optimization models).

### Integrated assessment models (IAMs) as an alternative starting point

An alternative starting point to energy modelling can be the employment of integrated assessment models (IAMs) that explicitly account for changes in the natural world. Integrated assessment models include physical and social processes to account for atmospheric composition, natural changes (climate and sea level), ecosystems, human activities, and economic aspects (Springer 2003). IAMs can also be used as a basis of considerations how to address climate change, and to derive costs of climate change mitigation and adaptation. This logic was famously exemplified in the Stern review (Stern 2006). From the perspective of policy-makers as model clients, rather than assuming a macroeconomic perspective in science that excludes natural scientific observations from the model, information of the physical reality, including climate change, can contextualise decisions in energy policy and the future energy system. As earth system models, the benefit of IAMs is their ability to describe simultaneously the natural science basis and the impacts of economic activity on the natural systems, which makes them useful tools for model-based learning. It must be noted, though, that a drawback of integrated assessment models is their breadth and complexity. Because of the

vast amount of data IAMs (are able to) merge to show the inter-linkages of different systemic connections, decision-makers and citizens may struggle to assess their limitations. Because the IAMs do not provide a detailed account of the qualities of the energy sub-system, bottom-up (engineering-based) and top-down (economy-based) energy models have been employed for this purpose (Grubb et al. 1993; Springer 2003; Proença and St. Aubyn 2009).

### Bottom-up energy models: the approach of natural scientists and engineers

In the modelling of the energy sub-system, *bottom-up energy models*, or partial equilibrium models, can be divided into supply-side and demand-side models. *Supply-side models* such as EFOM (Finon 1979), MARKAL (Fishbone et al. 1981) and PRIMES (Capros et al. 1997) begin modelling by looking at electricity production from different power plants, which is then matched with energy demand. In bottom-up modelling, energy demand is treated as given, which helps in the optimisation of the energy system. LEAP model (Heaps 2012) is an example of a *demand-side model*, which begins its modelling from the household-level (See 4.2 for an example of bottom-up application of the LEAP model). Using historical data of energy consumption and a micro-fit programme, LEAP can illustrate how energy consumption is dependent on the activity in different economic sectors<sup>12</sup>. In the accounting framework of LINDA (Luukkanen et al. 2012, 24), the model user can input assumptions of future changes in economic sectors.

Electricity market models which are able to show hourly, daily and seasonal variations (cf. Figure 3.2) have become increasingly relevant because of the significant changes of the electricity industry, including deregulation and competition to improve economic efficiency (Ventosa et al. 2005). In the past, the operation and planning of the electricity sector was mainly simulated using cost minimisation model (Herbst et al. 2012). Also, if the future energy systems are based on increasing amounts of electricity generation from variable renewable energy (VRE), electricity market models will be increasingly relevant to energy modelling. Because of the intermittent nature of wind and solar, electricity market models can help in the optimisation of energy systems based on energy demand.

<sup>&</sup>lt;sup>12</sup> LEAP has also been employed as a 'top-down' energy model, for instance by ASEAN Centre For Energy.

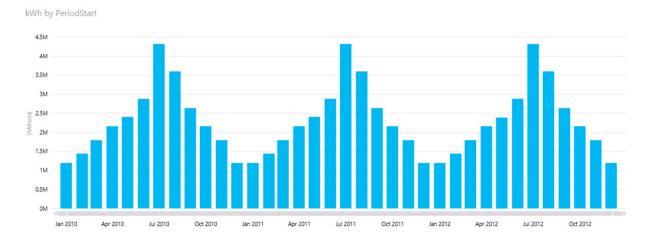


Figure 3.2. Electricity market model: an example of seasonal use (adapted from Peev 2013)

A bottom-up approach can also help in defining how different power plants (hydropower, coal and gas power plants) should adjust their power output as well as what kind of transmission capacity is needed from the electricity grid to match changes in electricity demand. These make bottom-up models useful in the backcasting of energy futures (See 3.2). For instance, when LINDA and LEAP models are used in scenario building, they acknowledge that the structural change of an economy also changes energy intensities sectorally. On the downside, bottom-up models often only exist on national scale; depict energy demand independent of prices; and some mainly focus on representing the energy sector (Springer 2003). Also, long-term scenario-building with bottom-up models is difficult due to the vast amount of auxiliary parameters needed in the modelling of future trends. To give an example, behavioural change has been difficult to model, even if an alteration in consumer preferences could increase or decrease energy consumption.

### Top-down energy models: the view of the public administration and economists

Top-down energy models include computational general equilibrium (CGE) models, econometric models, inputoutput models, and system dynamics models that treat the energy system as a part of the macro-economy (Herbst et al. 2012; Unger 2010). Top-down models aim for the optimisation, or an economic equilibrium, between supply and demand for energy. CGE models have been employed to analyse policy implications for economies, and have become a standard tool in many countries and international research organisations (Honkatukia 2013)<sup>13</sup>. In econometric modelling, economic theory, mathematics and statistical methods are combined (Herbst et al. 2012, 115) and energy is treated as an input to economic growth, and the typical variables of the macro-economy such as labour, capital and natural resources.

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Herbst et al. (2012) mention GEM-E3 model of the European Commission, the GTAP model consortium, and the modelling work of the World Bank

According to critics, top-down models have been used for decision-making to produce forecasts, which have often consciously been pushed through or employed to oppose certain energy developments (Luukkanen 1994). These problems stem from the employment of neoclassical economic theory as the theoretical foundation to top-down energy modelling (cf. Box 3.2). While top-down models simultaneously fail to capture the opportunities of technological development (Unger 2010, 19), they also advocate a narrative, in which techno-rationalistic solutions inevitably seem like the only plausible approach to energy questions.

#### Box 3.2. Values, rationalism and neoclassical economics in energy modelling

A theoretical challenge related to practically *all* energy modelling is the approach of rationalistic thinking. The quantification of certain aspects of the qualitative properties of a system is difficult to express in conventional models (Luukkanen 1994, 100-109). Rationalism manifests also in energy models that are derived from macroeconomic modelling. Many economic formulas are derived from rationalistic equations following the idea of a *homo oeconomicus*, a self-interested individual who acts in the markets. The problem of neoclassical economic theory is that it was developed at a time, when ecological limits received less emphasis in scientific practice. Contrary to the normative stance of ecologists or ecological economists, neoclassical economists ignore the fact that the economy is embedded in a broader reality. Therefore, models based on neoclassical theory may struggle to adapt to exogenous issues such as the increase of carbon emissions.

In top-down energy modelling, neoclassical economic theory is particularly influential. Macroeconomic modelling expects markets to assume the lowest technology cost and follow perfect rationality. Cost-benefit analysis assumes that income distribution, technology, market structure, entitlements, and consumer preferences are all structurally stable. Also, discounting is employed, following observations by economists, according to which people value the present more than the future moment. In reality, though, macroeconomic variables are subject to change (Luukkanen 1994). Furthermore, market rationality is merely one factor that guides citizens and institutions (Daly and Cobb 1994; Galbraith 1973; Kahneman 2011; Ostrom 1990). Another problem of cost-benefit analysis is that it assumes that "more is preferred to less", even if it may be difficult to know when is more really more (Swaney 1987, 1768; quoted in Luukkanen 1994). In turn, discounting, which has been employed to estimate the costs of climate change in influential reports such as the 2006 Stern review, is eventually a narrow framing to make decisions regarding the future of societies.

Nevertheless, even *integrated assessment models (IAMs)*, as accounting frameworks, are underpinned by rationalism. In the case of IAMs, a major challenge to an exercise of what could be deemed as 'appropriate or fair' stems from moral considerations in trade-off situations. IAMs are formulated from parameters and units, but it is, for instance, merely impossible to weigh the value of economic growth against ecological values such as the survival of certain species. Even if certain estimates of the economic benefits of the natural world in addition to its intrinsic value can be recognised, it is difficult to assign living beings and biodiversity with exact values (Faith 2008; Stuart et al. 2010; TEEB 2010; Vermeulen and Koziell 2002)<sup>14</sup>.

Rationalism also penetrates other recent accounting approaches. *Greenhouse gas accounting* has already institutionalised into national statistical bureaus in the 2000s. Schilgen (2013) proposes an altogether different approach, namely *energy accounting*. Energy accounting would calculate physically measurable amounts of commodities, goods and services. This would turn around the quantity theory – away from subjecting the energy system and the physical world to the aims of economic growth. In theory, energy accounting could replace or complement the role of monetary accounting. Interestingly, many countries already have constructed energy accounts because of the 1970s oil crisis (Lange 2003).

Accounting frameworks at least have certain value in themselves. Even if policy-makers are left with the responsibility of the final decisions, when trade-offs are noticed, a good model is able to make them understood.

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Scarcity of species is only one means of demonstrating the value of protection and preservation of natural life. Several traditions emphasize a responsibility of the preservation of other species. Recently, approaches emphasizing the benefits and services derived from ecosystems have been emphasized (see: TEEB 2010)

### Bottom-up models indicate lower costs to climate change than top-down models

Because of their flexibility, bottom-up models tend to indicate lower costs of climate change mitigation than top-down models (Unger 2010, 19). Bottom-up energy models typically include larger shares of renewable energy and low-fossil technologies, and in energy modelling this makes these technologies increasingly competitive over a long-term period. In contrast, top-down energy models, which are based on historical data, suggest that society would have a low willingness of technological substitution. Top-down energy models present costs for technology change higher than bottom-up energy models, and following their log-ic makes acting on climate change seem more difficult (ibid.). Problematically, public administration and economists have tended to rely on top-down models. Bottom-up models, in turn, have often been constructed and used by engineers, natural scientists and energy supply companies (Herbst et al. 2012, 113).

Because top-down models are ineffective in assessing technological evolution to achieve a low-carbon economy (Proença and St. Aubyn 2009), this raises profound points of consideration with regard to climate change action. In the past, energy scenarios have mainly been constructed for the state and the energy intensive industries (Luukkanen 1994; Midttun and Baumgartner 1986). Furthermore, top-down models have relatively straightforwardly assumed that with economic growth, also energy demand must continuously increase. This could have undermined views of alternative solutions to climate change to solve the dilemma of a fossil fuel-based energy system.

While economy-led approaches have paid limited attention to the role of ecological limits, including climate change, top-down approaches also have certain problems from an economic perspective. Based on the economics of climate change, it makes sense to rather act sooner than later, because the costs of inaction will only increase over time (Stern 2006). In addition, an aggregate view pays limited attention to any changes that may happen over time in the economic structure and sectoral energy intensities and downplays the significance of the household level perspective.

### Hybrid models and input-output models

Hybrid energy models mix the bottom-up and the top-down approaches, and could improve understanding about and attempt to overcome limitations of both approaches. Hybrid models have emerged only recently, perhaps because of the lack of interdisciplinary research teams or necessary funding (Herbst et al. 2012). ADAM project in Switzerland is a recent example of a hybrid approach where a macroeconomic model (E3ME) was combined with bottom-up models from four final energy sectors (industry, residential sector, services, and transport) (ibid., 127).

Input-output energy models provide more sectoral level detail than macroeconomic models. In input-output models, energy demand depends also on the changes in different economic sectors and industrial structure, not only GDP growth. However, input-output models are based on historical data, and unlike real economic systems that are dynamic, these models struggle to predict structural changes and the long-term future

(Herbst et al. 2012; Liang et al. 2010). Yet, an analysis of such impacts would be beneficial to the analysis of development trajectories of countries, especially in the developing world.

System dynamics models such as TIMER- and POLES-models investigate long-term changes in the global energy system, including the impact of a renewables based energy system.

### Can models be misused?

An energy model is only a tool meant to improve understanding of an underlying mechanism, the hypothesis of the methodology and the validity of data. Ignoring a model's methodological limitations and going beyond its function as simply an aid to decision-making, this signifies the misuse of a model (Luukkanen 1994, 186-191). Unfortunately, energy models have also been used to provide scientific justification for veiled political choices. A model should also not become more important than the modeller or the planner because often less complicated methods than modelling can be used. Actual dialogue between the model-makers and the decision-makers is highly relevant (ibid.). For instance, if the results of a cost-benefit analysis are given without an explanation of all the used assumptions and weighs, this means that the public is denied access to the full picture of the problem-framing (ibid.). Typically in the past, when econometric models have been applied, the negligence of these models of ecological impacts could have been hidden from the decision-maker. Models may also be developed by actors to promote their interests and/or worldview (ibid.). And while this is necessarily not a negative issue, such ideological foundations, as systematic codifications of cognitive and social structures (cf. Box 3.3), need to be made explicit.

### Box 3.3. Role of framing in decision-making and the framing effect

Different framings of results may significantly influence the way they are interpreted by decision-makers. Behavioural economists criticize the assumptions of neoclassical economists and have demonstrated that psychological factors play an important part in human behaviour. Daniel Kahneman and Amos Tversky have worked extensively on heuristics, bias of decision-making and prospect theory. *Framing effect* refers to one type of cognitive bias, and proves that depending whether a choice is represented as a loss or a gain, people react differently. In 2002, Kahneman was awarded a Nobel Prize in Economics for the integration of psychological research into economic science, and human judgment and decision-making under uncertainty. See also: Kahneman and Tversky (1971; 1974; 1979); Kahneman et al. (1982); Kahneman (2011).

### Benefits, drawbacks and limitations of energy modelling

Energy modelling is considered useful because it is an efficient, feasible and necessary means of understanding complex systems. Different approaches to energy modelling can depict an overall picture of total energy demand and supply, and a consistent accounting of energy resources, including imported energy as they move through the production, transformation, inventory, and consumption phases of their life cycle to help determine lowest possible costs (Luukkanen 1994). Modelling can provide a basis for the discussion of the nature of the problem, and if the model assumptions are expressed in an understandable form, also comparisons between different approaches can be made and their validity discussed (ibid.). Bottom-up ap-

proaches can provide an elaboration of needs at a localised level (household, community, or region) and more detailed analysis from an engineering perspective, whereas top-down models excel in providing an aggregate perspective and an economic-oriented view.

The employment of energy models also has obvious drawbacks. Often times, the distinct structure and variables of the model actually limit the view of an overall problem. As more scientific understanding becomes available, models need to be improved or adjusted because science, rather than being definite or rigid, should reflect the best information currently available. Especially older energy models may be of limited use to answer contemporary or future challenges. In terms of their scope, energy models have mainly focused on the optimisation of suitable technologies. Also, the optimisation of cost efficiency has been held as the main assumption of comparability, based on certain assumptions on the development of current and future production costs (Luukkanen 1994). In turn, the valuation and measurement of ecological and social impacts has been rather limited.

Conventional energy models also struggle to capture the significance of *power relations* of existing political institutions in energy policy, or to represent the institutional links that exist between forecasting, planning and policy implementation (Midttun & Baumgartner 1986; quoted in Luukkanen 1994). Institutions work as filters by selecting and classifying information that goes into an energy model; and organisational structures and policy networks enable or limit public opportunities to participate in the decision-making process (Hay 2006; Sabatier 1993). For instance, the climate change-related policy goals of a Ministry of Environment may often be in conflict with the goals of a Ministry of Economy. Yet, many public administration officials – decision-makers and civil servants in key positions in relevant ministries – are economists who have been trained according to the paradigms of neoclassical economics. In turn, climate change and the necessity of an energy transition are only gradually becoming framed as economic gains.

In many countries, the organisations involved in energy forecasting are strongly linked to specific industrial sectors producing and distributing energy. Paradoxically, present societal structures tend to support structures built based on historical needs, but most technological advances and new developments have benefited from state support, including R&D investment and market development, in the early stages. Another fundamental political limitation to energy modelling is the role of the already existing fossil fuel based energy infrastructure, which in itself is a disincentive in the markets for investments in low-carbon energy technologies<sup>15</sup>. Finally, energy choices of individual countries or regions are not only shaped by economic or ecological motives, but also security considerations and historic experiences (Helm 2011)<sup>16</sup>. Ultimately, all models have their limitations (cf. Table 3.1).

Many countries lack comprehensive policies for the strategic development of renewable energy (UNEP 2012)

For instance, Poland is 95% dependent on coal, and values energy security based on domestic resources because trade relations and energy reliance with neighbouring countries, Germany and Russia, is difficult due to the burden of historic events (Helm 2011, 77)

Table 3.1. Summary of the limitations and benefits of energy modelling

#### Limitations of energy modelling

- Models and scenarios may be interpreted beyond their purpose as "truths"
- Results may be communicated in a limited manner across sectors and groups
- Often does not mention that energy modelling excludes impacts to the physical world
- Neglects aspects that can't be modelled
- Top-down energy models may reduce complexity too much
- Has focused in the lowest cost assumption, which can legitimate narrowly framed decisions, undermine the role of political sphere, democratic processes and cooperative patterns
- In reality, political systems and decisionmakers are not rational
- Challenge of modelling transboundary politics
- May struggle to predict sudden changes or technological development

#### Benefits of energy modelling

- Reduces complexity
- Can produce information for the aid of decision-making
- Can help in determining the lowest possible option
- Can give an overall picture of total demand as well as production facilities and can factor in imported energy.
- Certain models also exhibit hourly and seasonal variations
- Could help in the exploration of different energy choices and policies
- Is considered efficient, feasible and necessary

In summary, the use of energy models in a planning process should always be based on a good communication between modeller and decision-maker, and all assumptions, including theoretical choices and the limitations of the model need to be made explicit (Luukkanen 1994). Yet, in reality, is rarely the case, and dominant assumptions tend to prevail over emerging aspirations. Energy modelling is always limited by the boundaries of thinking as well as numerous political, societal and economic obstacles (See also: Schmidt 2008). With models, one can get only a partial, and possibly biased representation of a complex reality, and most importantly, the two should never be confused (Luukkanen 1994). Most energy models are tools based on a positivist approach and its philosophical premises. Energy modellers might struggle in adequate interdisciplinary engagement within the scientific field, or in the communication of results across societal actors or sectors (transport, constructions, households).

In the worst case, narrowly framed practices of energy modelling may end up legitimating decision-making. Such decisions may struggle to gain acceptance of citizens whom inevitably have knowledge as well as versatile opinions about energy choices. While the model user can acknowledge some of these boundaries with the adjustment of assumptions in the use of the energy model; the society as a whole can benefit when the challenge, limitations and different suggestions for energy solutions are made explicit.

### **Energy scenarios**

Energy scenarios are used to assess the impacts of different developments under assumptions of certain outcomes. Scenarios should not be confused with policy prescriptions or the likelihood of outcomes, rather they can be used as an aid in the mapping of different energy futures. Based on energy models (read: chapter above), different types of energy scenarios can be constructed, using the techniques of forecasting and backcasting.

### Forecasting scenarios and the role of influential energy outlooks

The first type of scenario prediction is based on the methodology of *energy forecasting*. Energy forecasting describes a series of events from the present state leading to a certain state of future, following prevailing trends of the society. Based on different assessments of the trends and by changing the parameters of the system, a series of possible states of future, or scenarios, can be described (Luukkanen 1994). Energy forecasting can be conducted based on *quantitative data* such as econometric models that mainly use historical data, or *qualitative data* such as expert interviews and Delphi method or market research.

Energy outlooks that are based on forecasting can include a calculation of the most probable future to present policy-makers a business-as-usual case as well as display alternative scenarios <sup>17</sup>. An elaboration of different scenarios provides different framings and imagined futures what could happen, if there are changes in certain key market variables (global energy demand, different fuels, trade, or investment) or political issues that force the energy system to adapt its functioning in a particular way. Therefore, risk and uncertainty are central components of forecasting predictions. Forecasting scenarios feature in numerous influential policy publications such as IEA World Economic Outlook, BP Energy Outlook, Shell Energy Scenarios (cf. Table 3.2). The table below elaborates different predictions about future world primary energy demand, as suggested by the IEA, BP, Shell and the United Nations.

Table 3.2. List of forecasting scenarios (adapted from Luukkanen et al. 2009)

Forecasting scenario	Main characteristics
1 orecasting sections	Main characteristics
IEA World Energy Out-	New Policies scenario: +3.6°C global warming trajectory: However, even with
look (IEA 2013)	already adopted policies, energy-related emissions will rise 20% by 2035.
IEA World Energy Out- 1	1. New Policies scenario: +3.6°C global warming trajectory: Shift away from
look (IEA 2012)	oil, coal (and, in some countries, nuclear) towards natural gas and renewables.
	China, India and the Middle East account for 60% of increase in energy demand.
2	<b>2. Efficient World scenario</b> : +3°C global warming trajectory. CO <sub>2</sub> emissions
2	and oil demand both peak by the year 2020.
BP Energy Outlook	Global energy trends: World primary energy consumption is 18 billion toe
2035 (BP 2014) (	(2035). Main factors: limited sustainability efforts, new energy sources, efficiency
i	improvements, and some progress in the area of energy security.
Shell Energy Scenarios V	World primary energy demand in 2050:
2050 (Shell 2008)	1. Scramble scenario: Over 900 EJ. Main concerns: energy security and energy
S	supply. Increasing energy demand met with coal, renewable energy and biofuels.
2	2. Blueprints scenario: Under 800 EJ. Carbon price to give clean energy
S	stimulus. Primary sources of energy: efficiency measures, coal and renewables.
UN Global Environ-	World primary energy demand in 2050:
mental Outlook (UN 1	1. Markets First scenario: Over 1 000 EJ.
2008)	<b>2. Policy First</b> : 800-900 EJ.
3	3. Security First: 800-900 EJ.
4	4. Sustainability First: Around 600 EJ.

To read more about the assumptions of global energy scenarios, see e.g. Koljonen (2008) and Koljonen et al. (2008).

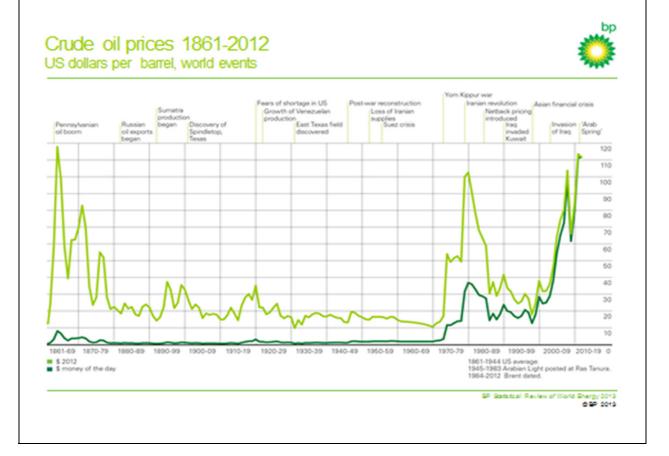
Econometric models, which assume an economic and technology perspective, have often been employed for forecasting. Market analysis and the prediction of energy prices are other concrete examples of the energy forecasting business that have considerable influence about energy-related decision-making (cf. Box 3.4). Yet, there are often large differences in the views of the different energy analysts, when they are predicting future energy prices such as the price of oil, gas, coal or renewable energy. Conservative or progressive views may also tell about the motives of energy forecasting and of the visions what could, or should be a plausible future.

### Box 3.4. How will the price of oil evolve?

World politics has often influenced the price of oil and the energy market. Crude oil prices remained relatively steady in the 1900s. A major spike was experienced in the 1970s with the oil crisis, and several countries sought measures to reduce their oil dependency. In the 1980s, the price of oil dropped again. In the 2000s, the rise of oil prices has increased rapidly, as the war on Iraq and the Arab Spring have caused instability in the Middle East region. Production costs have also increased because of an increased difficulty to find easily accessible oil. In contrast, the production of oil and gas from unconventional resources brings higher costs.

Different energy reports can give highly varying projections on the future development of the price of oil. For instance, World Economic Outlook 2012 by the International Energy Agency predicts oil price to rise to USD 120 per barrel by 2020, and USD 125 per barrel by 2035. Yet, an OECD research paper, published in 2013, suggests that prices could go up to as high as between USD 150-270 only by 2020. Such an increase could represent a ten-fold increase to the prices in the 1960s. Because empirical estimates of key driving parameters are highly uncertain, this results in a wide range of plausible future price paths.

Sources: BP (2013), Fournier et al. (2013), IEA (2012)



The drawback of forecasting scenarios is that they can be affected by numerous biases. Another consideration is the fact that even if business-as-usual scenarios do not necessarily equate with societal good, conservative scenarios may still become baselines to energy debate in the political sphere. Forecasting with the use of historical data may rather reinforce the *status quo*, rather than seek ways to address flaws in the energy system, as portrayed earlier. Modelling and forecasting do not only contribute to rational decision making, which is their alleged purpose, but also define reality, shape political debates. Forecasting can even legitimate political decisions and future investments in the profit for the modeller and exclude other development paths (Luukkanen 1994).

As discussed earlier (See: section about top-down energy models), the scenarios above tend to exercise scenario thinking from a perspective of cost optimisation. Another potential problem of energy outlooks and scenario-building is the dominance of forecasting outlooks by large energy policy actors that yield considerable power. The views of the International Energy Agency (IEA) as an intergovernmental organisation, which analyses matters related to global primary energy and especially oil supply, are key to the formulation of national policies in the OECD states and of commercial policies adopted by industry (Miller 2011). However, the IEA was established in 1974 as a response to the 1973-74 oil crisis and initially to meet the needs of countries in *that* particular era. Large commercial actors in the energy industry such as BP and Shell, in turn, primarily follow the incentive of profit-making. Institutional settings restrain the filtration of ideas into energy forecasting, and many organisations are also bound by the constitutional mandates.

Also, actual technological development may occur (and has occurred) differently to the predictions of forecasting models. A recent example is the relatively rapid fall in the production costs of solar panels, which has taken many energy experts by surprise. In Germany, supportive policies for renewable energy have considerably changed the national and regional energy landscape. Forecasting scenarios ignore or only narrowly discuss the significance of power relations in energy policy. In contrast to traditional energy forecasting, foresight methodology has been employed in futures studies to investigate longer-term developments and what alternative futures and development pathways could also emerge.

### Energy backcasting and low-carbon scenarios

In energy backcasting (Box 3.5), the point of departure is a view of a possible and wanted future, which is expressed as a goal or a target. Contrary to forecasting scenarios, computation is conducted backwards – from the future to the present day – in order to reveal what different activities and steps are needed to reach the envisioned goal (Lovins 1977; Luukkanen 1994). As a normative approach to create future-oriented scenarios, energy backcasting can be employed as a strategy tool under different assumptions and competing objectives. This way, backcasting can also reveal what obstacles there are to a certain future (ideal) state of being. Compared to forecasting, which predicts future based on the prevailing state of society, backcasting is "like playing with open cards, not hiding the policy preferences of the modeller" (Luukkanen 1994, 192).

#### Box 3.5. Six steps of energy backcasting

- J.B. Robinson, a developer of backcasting methodology, has identified six steps to backcasting:
  - 1. Policy goals and constraints are determined and specified;
  - 2. Description of current energy consumption and production is mapped;
  - 3. End-point as well as suitable mid-point dates of the analysis are chosen (usually 30-50 years in the future)
  - 4. The type of energy used and the efficiency of use are specified (including demand management measures and the costs of measures);
  - 5. Supply analysis; supply policy measures, and their costs are specified;
  - 6. An analysis of the social, environmental, economic, and technological implications of the scenarios is performed to assess the implications of the scenario.

Source: Robinson 1982.

Energy backcasting is closely policy-oriented as it explicitly focuses upon policy implications. This makes it useful for the optimisation of future energy demand. Typically, energy backcasting depicts a low-demand society that seeks to conserve and minimise the use of non-renewable energy and other resources seeking to allow it to rely entirely, or very nearly, on renewable energy flows (Luukkanen 1994, 191). Luukkanen (ibid., 193) argues that energy backcasting allows the consideration of many factors, which are obscured in traditional energy supply and demand (economic equilibrium) forecasts.

Due to the climate change threat, there is a need to explore different pathways to sustainability, and to-day, the formulation of low-carbon scenarios using backcasting methodology is increasingly common<sup>18</sup>. To give an example of a backcasting scenario produced by a non-governmental organisation, Greenpeace has since 2005 published its *Energy [R]evolutions* series (Table 3.3). Examples of global energy backcasting scenarios have also been recently produced by the IEA in the shape of the *Blue Map scenario* or 450 scenario. An example of a regional level scenario is the EU Energy Roadmap 2050 of the European Commission.

**Table 3.3.** Samples of backcasting scenarios (IEA reports, Greenpeace 2012, EC)

Backcasting scenario	Main characteristics
Energy [R]evolutions	Target: Low-carbon and zero-nuclear energy world future
(Greenpeace 2012)	Pathway: No nuclear energy, no unconventional oil resources, efficiency gains,
	increase in electricity demand, large RE technology investment (1% of global
	GDP), creation of 12 million jobs. Primary energy consumption in 2050: 481 EJ.
	(N.B. A similar logic is applied in the country-level editions of the ER report.)
450 scenario (IEA 2012)	Target: Limit global temperature increase to 2°C and the concentration of
	greenhouse gases in the atmosphere to around 450 parts per million
	Pathway: Carbon pricing, removal of fossil-fuel subsidies, support for renewa-
	bles and CCS, national policies for renewables and nuclear
BLUE Map scenario	Target: Least-cost means of halving CO <sub>2</sub> emissions by 2050
(IEA 2010)	Pathway: Nuclear energy deployment: 32 large reactors annually until 2050
EU Energy Roadmap	Target: Least-cost means of halving CO <sub>2</sub> emissions by 2050
2050	Pathway: Carbon pricing, efficiency, increase in electricity supply, major scal-
	ing-up of renewable energy plus large changes in technology, networks, man-
	agement, transport, et cetera

To assume an outcome-oriented perspective, in low-carbon scenarios a emissions limit is typically fed into the equation.

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Backcasting scenarios that *take into account* scientific understanding about climate change can show that radical changes are needed in energy infrastructure from supply to demand. Basically all backcasting scenarios indicate a future price on carbon, the eradication of fossil-fuel subsidies, a major scaling-up of renewable energy, and significant increases in energy efficiency. A shift away from fossil fuel energy also implies an increase of electricity supply of non-fossil fuel resources. Many low-carbon backcasting scenarios also deploy nuclear energy as a part of the energy mix, aiming for high amounts of electricity and little carbon emissions. Yet, a vision of the widespread deployment of nuclear energy globally has also been criticised as techno-utopian. Noting the previously known risks, recently nuclear energy has lost popularity due to its costs and the change in public opinion as a result of the Fukushima incident<sup>19</sup>.

Notably, most IEA or other influential backcasting scenarios take little stand on limiting energy demand and changing consumer behaviour. A criticism of energy backcasting scenarios is that they mainly describe technology changes and assume costs such as estimates of the implications to the GDP; their assessment of social, economic and market implications is more limited. Another challenge of backcasting scenarios, especially as alternatives to business-as-usual policy scenarios, is for them to achieve a credible and detailed vision to achieve policy relevance. Achieving a high level of detail in a backcasting model (elaborating changes and trends, including possible technological shifts demands skilled and detailed analysis) demands resources from the producing institution, and particular skills in the drafting of alternative energy scenarios. Understandably, the production of forecasting scenarios or market research based on existing market energy system is somewhat easier, also because they are intuitively considered to be credible.

### What is the role of energy policy for sustainability?

Scenarios should never be confused with energy policy-making. Backcasting scenarios are able to *explore* policy targets and how the energy system should change to enable a discussion about possible policy options. In turn, forecasting scenarios provide insight what *may* happen if current trends continue, or if certain factors push future trajectories towards a certain direction. Different scenarios can help decision-makers as they provide a range of scientific evidence and minimise uncertainty. The task of decision-makers, then, is to choose based on the best possible evidence and act – make responsible decisions as well as be critical of the nature of information, and of the premises upon which different "facts" are based.

It should be noted that sometimes even the best possible knowledge and scenarios may fail in their visions or to anticipate changes. For instance, the global economic crisis since 2007 has changed the economic landscape to such an extent that forecasting and backcasting scenarios that do not take it into account are practically of little use today. What decision-makers should at least remember – as economists or non-economists – is that in energy modelling the paradigm of neoclassical economics does remain dominant. This means that the evidence used to 'evidence-based reasoning' can be argued to suffer from a possible bias towards economic goals in the expense of ecological targets. In turn, information about climate change

World Energy Outlook 2011 explores a *lower-nuclear case scenario* that predicts a strong demand of natural gas and an increase in the use of fossil fuels.

has consistently accumulated to show a very high scientific certainty about climate change and its potential impacts (IPCC 2013; 2007; 2001). Fortunately, political decisions can shape both legislation and policies, and guide both markets and citizens towards more sustainable paths. Public policy can bind, enforce and incentivise actors of the society towards sustainability by using a multitude of options.

## 4. CASE STUDIES

## Towards low-carbon futures and openness in Finnish energy modelling and scenario-building

## Economy and energy landscape in Finland and its particularities

During a few decades, the Finnish economic structure has considerably changed – from an industrial into a service-based economy. At the same time, the industrial structure has also changed; lighter industrial branches have employed more people than traditional energy intensive pulp and paper, base metal and chemical industries. This shift is also reflected in the number and even volume of industrial investments. The role of ICT has rapidly increased in the last two decades. In this change, the role of only one company, Nokia, has been significant. More recently, the search of further new innovations has been identified as an opportunity to transform the old economic structures. However, the uptake of cleantech solutions in Finland has been fairly slow (Peura and Hyttinen 2011).

Annual greenhouse gas emissions in Finland (see Figure 4.1) have altered following a change in economic activities, but are also affected by the fluctuations in the availability of hydropower and the use of coal-fired condensing power plants. Finland has fulfilled its share in the EU Kyoto target, reducing GHG emissions to the 1990 level during the period 2008-2012. However, in some comparisons on climate policy, such as *the Climate Change Performance Index CCPI*, Finland performs fairly poorly when the country is compared to other Nordic countries and the EU Member States (Burck et al, 2014).

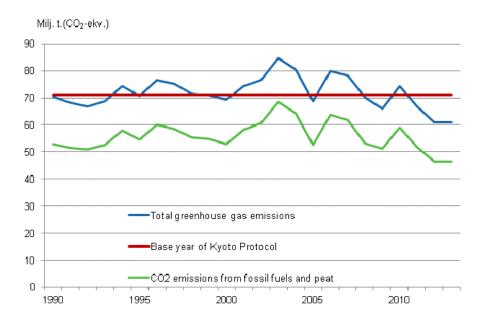


Figure 4.1. Greenhouse gas emissions in Finland 1990–2013. Source: Statistics Finland (2014).

Energy consumption in Finland, measured either per capita or per unit of GDP, is one of the highest among industrial countries. Basic factors to explain this include a cold climate by geographical location in the North and an industrial structure, which still includes many energy intensive branches. Also, on average, the standard of living in Finland is relatively high, in a country, which is very sparsely populated. The fragmentation of regional structure and related long distances are also often referred to when the high level of energy consumption in Finland is explained. The Finnish energy mix (cf. Figure 4.2) is based on several energy sources. Nevertheless, two thirds from total primary energy supply is based on imported fossil fuels.

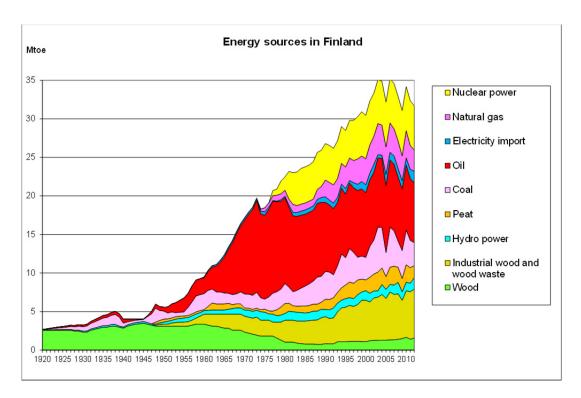


Figure 4.2. Primary energy supply in Finland by energy source 1920–2012.

## Nuclear energy and Mankala-principle

Contrary to most European countries, Finland has planned to expand its nuclear capacity, which already includes four operating reactors in two different sites, Loviisa (Loviisa 1–2) and Olkiluoto (OL1–2). If a third Olkiluoto reactor (OL3) under construction will be completed, and two additional nuclear plant projects with a decision-in-principle granted by the Government in 2010 (Fennovoima and OL4) will be built in the planned schedule, the nuclear capacity in Finland could more than double by 2025.

OL3 has been under construction since 2005. The OL3 reactor, a 1600 MW<sub>e</sub> EPR ordered by Teollisuuden Voima (TVO) from Areva NP, created expectations of a "nuclear renaissance" because it was the first Western order since 1993. However, the OL3 has faced several difficulties from the very beginning of the project. Challenges are related to, for instance, (1) the quality of the base construction work and some materials, (2) process automation of the power plant and its safety systems, (3) implementation of the nuclear safety requirements set by the Finnish Radiation and Nuclear Safety Authority (STUK), and (4) general management and coordination of the work with a large number of international subcontractors. Steve Thomas has described the situation by saying: "The UK government asked me what they could learn from what went wrong at Olkiluoto and I said 'nothing because everything went wrong'." (Nuclear News 2013).

The original schedule suggested that OL3 would be in operation in 2009. In March 2014, the completion rate was still only at 82%, as informed by Areva NP in the company's OL3 webpage. In 2012, TVO announced that the company is preparing to the possibility that this new unit may not start operating until 2016. In December 2013, TVO requested a detailed schedule from Areva NP for completing the remaining work. At the time of the writing of this report, the schedule had not been provided and a new estimate of the timetable was still pending. Due to the considerable delay and the listed problems, the construction costs have heavily overrun the budget, and so far the estimates of the total cost of the project have increased up to 8.5 billion euros. The turnkey contract of 3.2 billion euros is also subject of a dispute between Areva NP and TVO.

Another Finnish nuclear project, Fennovoima, has also been widely debated in the media. This project, planned at Pyhäjoki in the north-western coast of Finland, will probably need a new decision-in-principle from the Government, because the type and size of the selected reactor are different from the granted decision-in-principle, and the shareholders of Fennovoima are now largely different from those in 2010. This is more of a political problem because the Government has changed after 2010, and the current Government's programme does not include new nuclear facilities. Moreover, the German E.ON has given up all business in Finland including Fennovoima, and the new reactor is supposed to be delivered by the Russian Rosatom.

A typical Finnish power company delivers the produced electricity to its shareholders in relation to their ownership rates without making any profit. This kind of cooperation ensures the availability of electricity and enables sharing the economic risk of (large-scale) electricity production. This arrangement is known as the "Mankala-principle", which is quite a unique characteristic of Finnish energy policy. Interestingly, this principle probably also explains at least partly why capital-intensive nuclear power is still in a favorable position in Finland (Vehmas 2009). The name comes from a Supreme Administrative Court decision (1963), when a hydropower company Mankala Ltd. was not found guilty for distributing *hidden dividends* when the shareholder companies received the produced electricity against covering all fixed and variable costs, both in relation to their shares as stated in the articles of association of Mankala Ltd. After 1963, similar companies (e.g. TVO) became very common in the Finnish electricity supply system. Companies operating under the Mankala-principle have invested not only in nuclear power but also in coal-fired condensing power and even in renewable energies such as wind power production.

## Lessons from the energy history in Finland

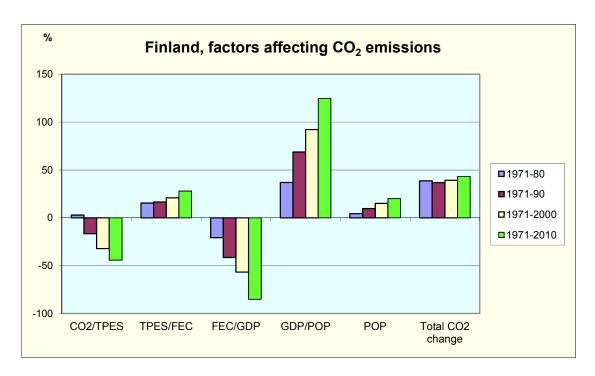
Up to the 1960s, the Finnish energy supply was mainly based on renewable energy sources such as fuel-wood, wood-based industrial fuels and hydropower. Since then, the consumption of oil increased very rapidly in the 1960s and early 1970s. The use of coal in separate electricity production and in CHP production has increased too, and natural gas and nuclear power were introduced in the 1970s. As reaction to the oil

shocks in the 1970s, the use of peat, a domestic fuel, was also increased. The use of renewable energies has been only modestly promoted when compared to other European countries (see Reiche 2005). Finland was a forerunner in introducing a CO<sub>2</sub> tax in 1990, but thereafter, energy and environmental policies have not strongly favoured the use of renewable energies. On the other hand, wood-based energy has traditionally been used largely in the processes of the forest industry, and even peat has been classified as slowly renewing biomass in Finland. Relatively large CHP production has been used as an example of high energy efficiency, although CHP production is largely based on fossil fuels.

The energy history in Finland shows that before the 1973 oil crisis, energy demand was assumed to increase hand in hand with economic growth, and no specific energy demand estimates were made by the state administration. At that time public discussion, related to the building of big power plants, often reflected a wondering whether such large amounts of electricity would ever be needed, as was the case with the planning of Imatra hydropower plant in the 1920s and when the first nuclear facilities were discussed in the 1960s. Big power plants seemed to create a considerable overcapacity. Largely with state-supported industrialisation and the on-going rural electrification, industry and households needed to be lured into the use electricity (Myllyntaus 1991; Vehmas 2002).

Later on, the 1970s oil crises led to the optimisation of certain low-hanging fruits in terms of efficiency in Western countries. In the late 1970s and early 1980s, four nuclear reactors were taken into use in Finland. During that period the forest industry, key to Finnish economic success, invested significantly in electricity-intensive mechanical pulping, and electric heating was promoted actively as the heating system of new buildings.

In a decomposition analysis of the drivers of the Finnish CO<sub>2</sub> emissions from fuel combustion (Fig. 4.3; see Annex 3 for the methodology) we can see that from 1971 to 2010, fuel switch to in the primary energy mix (factor CO<sub>2</sub>/TPES) has decreased CO<sub>2</sub> emissions considerably. The shift to lower efficiency of the energy transformations processes (Factor TPES/FEC) has increased the emissions while the reduction of energy intensity of economic production (factor FEC/GDP) has reduced the emissions. The growth of GDP per capita (factor GDP/POP) has increased the emissions considerably. In addition, the population growth (factor POP) in Finland has slightly increased the emissions. To summarize, in Finland the growth of GDP per capita has been the main driver increasing energy demand while the decrease in energy intensity of production has been the main driver decreasing energy demand and CO<sub>2</sub> emissions from fuel combustion (cf. Figure 4.3).



**Figure 4.3.** Factors affecting CO<sub>2</sub> emissions fro fule combustion (energy use) in Finland in different time periods.

## Out of renewable energy technologies, sustainable use of biomass has main interest

Finland has a commitment to increase the use of renewable energy sources such as bioenergy, wind and solar energy up to 38% of total energy consumption as well as increase the use of transport biofuels by 2020 fulfilling the Finnish share of the EU target (Lindroos et al. 2012). Bioenergy could have a significant potential especially in the rural areas (Peura and Hyttinen 2011). With significant forest resources in the European scale, the particularity of Finland is related to biomass. Therefore, bioenergy is planned to play a central role in meeting renewable energy targets. The pulp and paper industry has already begun the exploration of new technologies around biomass as an energy source and sustainable forestry, such as biorefineries (Näyhä 2012).

On a county level, there is interest for low-carbon solutions (Hinku 2014) because efficiency savings typically make economic sense. However, development in the use of other renewable energy technologies such as wind or solar has been slow (ibid.) due to lack of specific policy targets, active promotion policies and proper incentives for the potential users. In addition, especially wind energy has met *nimby* (not-in-my-backyard) resistance, and arguments relate to noise and conservation of the archipelago area and landscape in general. In solar energy, Finland is one of only three EU countries with no policy target for electricity production by solar energy. Neither is its production statistically recorded. On the other hand, southern Finland where most of the population lives, receives a comparable amount of solar hours to Northern Germany and Denmark. Research polls, though, have usually shown that Finnish people are more supportive of renewable energy technologies than nuclear power (see e.g. Talouselämä 2014).

## Box 4.1. How can the renewable energy sector in Finland be developed?

According to the Finnish renewable energy business, high technology and educational skills could give Finland a competitive advantage to make the country a forerunner in clean technology development. Nevertheless, in their view, despite the recognised potential of solar energy or biomass, the development of the renewable energy business has been slow (Peura and Hyttinen 2011). The business argues that most Government actions have mainly been reactions to the policy targets set by the European Union, rather than to have aimed to proactively develop and support the growth of the domestic industry.

In their view, the development of domestic RE markets, enabled by smart and supportive policies would likely increase demand for renewable energy (Auvinen 2014). In the past, lack of investment security and policy incentives have withheld consumer interest in RE technologies (Auvinen 2014). Small-scale producers in Finland have complained about the difficulty of permits, a rigid subsidy scheme as well as low awareness of the economic, ecological and employment benefits of renewable energy.

One example is the production subsidy for small-scale producers to individually generate RE and sell it to the national electricity grid, which is granted to 100 kVA and bigger facilities only, which has excluded all household-size facilities from the subsidy. On the other hand, investment subsidy can be granted also to small-scale producers. In Germany, a lower limit for production subsidy has encouraged investments in RE technology and more citizens to view electricity generation from renewable sources in the as a business opportunity.

## Characteristics of Finnish energy policy

Finnish energy policy is coordinated and largely prepared by the Energy Department of the Ministry of Economy and Employment (see: Box 4.2). Other ministries participate in the energy policy planning in energy-related sectors such as transport (Ministry of Transport and Communications); land-use planning, construction, waste management and environmental permits (Ministry of the Environment); and biomass (Ministry of Agriculture and Forestry).

The main energy policy goals are the promotion of renewable energy and energy efficiency, development of energy markets, and securing the availability of energy at a reasonable price<sup>20</sup>. In Finnish energy policy, the European Union (EU) targets on greenhouse gas emissions, renewable energy and energy efficiency have been influential. These policy initiatives have included the EU 2020 Climate and Energy targets, EU 2030 Framework for Climate and Energy, and the EU Emissions Trading Scheme (EU ETS). Targets for EU member states are binding, but individual countries are able to make their own more ambitious targets that can be more ambitious than the bottom-line set by the EU policies.

Ryden (2010a) lists ten energy challenges in the Nordic countries: implementing the EU energy and climate policy (20/20/20 package), tapping into renewable energy, energy efficiency, making electricity CO<sub>2</sub> free, balancing between politics and markets, integrating electricity markets in the Northern Europe, district heating, changes in industrial structure, security of energy supply; and using energy models in an appropriate manner. The International Energy Agency (See IEA 2013) has recommended Finland to pay attention to energy efficiency, particularly in the transport sector, and to develop the regional integration of the natural gas market.

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In climate policy, Ministry of Economy and Employment has a shared responsibility with the Ministry of Environment. The Ministry of Environment is responsible for EU and international climate negotiations, and the Energy department of the Ministry of Economy and Employment coordinates the implementation of national climate policy with other ministries (Government of Finland, 2003).

#### Box 4.2. Civil society views of Finnish energy debates: the opening of energy policy

Contrary perhaps to the Government's view, where Finland is represented as a forerunner of climate change action; civil society groups, activists and also ordinary citizens have over the years been rather critical towards the way Finnish Government and the Ministry of Economy and Employment have prepared energy policy. Also the representatives of the renewable energy sector see that electricity production has mainly been a centralised playing field of big power plants and large companies, a well-working arrangement where citizens have no role (Auvinen 2014).

In political studies, the decision-making culture of Finland has been described as corporatist and centralised. In climate and energy matters, environmental non-governmental organisations (NGOs) have tended to see Finnish energy policy as cautious and hierarchical, and have noted how it has been based on close personal relationships between the Ministry of Economy and Employment, large energy companies and the energy-intensive industry. This has also been shown by researchers a long time ago (e.g. Ruostetsaari 1989). Different incidents over the recent years may exemplify that such claims are relevant even today:

Preparation of the Long-Term Climate and Energy Strategy. The first comprehensive Government strategy to steer the Government to reach towards climate change has been characterised described by some energy experts as a sensitive process. The Government prepared the National Energy and Climate Strategy, with technical support of the Ministry of Economy and Employment, and brought it for parliamentary debate. Civil society actors feel that this top-down process granted experts, civil society and citizens with very few entry points to join the debate to deliberate the assumptions that were taken in the Government policy (and the dominant parties). This closed approach could have made the eventual strategy more conservative than needed to be.

New permits for nuclear power. In 2010, the Government granted a decision-in-principle for two companies, TVO and Fennovoima, for constructing new nuclear facilities in spite of strong citizen opposition. Green-peace sued the Government because it did not share the background documentation, including assumptions about energy demand that it had used as basis for decision-making with citizens. The Government eventually shared the documents – after the decision-in-principles were granted and public debate had ceased.

There was also speculation about possible disqualification of the Director of the Energy Department regarding his close ties to Outokumpu Ltd (one of the Fennovoima shareholders) and his central position in the preparation of decision-making. The conclusion made by Attorney General was that the Director was not disqualified. However, the documentation admits the double role of the Director and the possibility to risk the neutrality of decision-making, and highlights that similar double roles are not possible any more. End of cheap oil? In 2014, a NGO called Peak Oil Finland suggested that the Ministry of Employment and the Economy are too limited in their scope of risk management and when estimating necessary changes in the economic structure. Referring to the possibility of an end of the so-called cheap oil, the Government was encouraged to diversify its energy options and better prepare itself for a possible future oil price hike. The organisation also encouraged the Government to reduce its reliance on IEA advocacy (Partanen et al. 2014).

Energy as a cost factor for industry. In the past, the heavy industry has argued that low energy prices are needed to support 'competitiveness'. However, typically energy costs make a small proportion of total costs in an industrial branch. Even in an energy intensive sector like the Finnish pulp and paper industry, energy costs alone do not determine investment decisions. Rather, raw material costs make a more significant share of the costs.

## Energy models and scenarios as a tool of Finnish energy policy

In Finland, the Energy Department of the Ministry of Economy and Employment has quite a long tradition in providing energy scenarios in the preparation phase of Finnish energy policy. Other ministries responsible for relevant sectors are also involved by e.g. providing input and data for the scenarios. Scenarios are included in national climate and energy strategies, which have been used as a basis for more detailed policy-making since the beginning of 1990s. The Energy Department was established in 1975 and quite soon started developing an energy model for preparation of energy policy in Finland. By using this model, the Department of Energy has produced energy scenarios for Finnish Energy Strategies published in 1991 and

1997 as well as long-term Climate and Energy Strategies published in 2001, 2005, 2008 and 2013. Typically each of these strategies is based on a baseline trend of energy consumption where individual alternatives in relation to a proposed policy or implementation of a planned investment (such as a nuclear power plant) are varied. Strictly speaking, a baseline scenario is the starting point, and other scenarios are constructed by varying selected elements of the baseline scenario. The most important scenario-specific assumptions are published within the strategy report, and more detailed assumptions can be found in the background reports (the most recent one: National Climate and Energy Strategy, background report 2013). However, the model used for calculating the scenarios is not widely described.

To the general public, the Energy Department's energy model appears as a "black-box" model. Despite some requests, the Department has not in the past allowed any outsiders to use or even see the model. The Ministry has replied to the requests by arguing that the model is very complicated and difficult to use, and can therefore not be delivered even if requested. The Ministry has also stated that the energy model is not a public document (the type of document that typically must be available for the public). This indicates that the model includes confidential data, i.e. data on individual companies, for example.

In 2009, the Prime Minister's Office published a Foresight Report on Long-term Climate and Energy Policy (Prime Minister's Office 2009). This report includes mostly qualitative scenarios, which cover many other sectors than energy. Finland Futures Research Centre facilitated the process of scenario construction (see Lauttamäki & Heinonen 2010) and Gaia Consulting provided the quantitative part to the above-mentioned scenarios and analysed the economic, environmental, and social impacts (see Vanhanen et al, 2010). All these scenarios were based on a target of 80% reduction in greenhouse gas emissions by the year 2050. Gaia Consulting analysed also the impacts of the Energy Vision 2050 provided by the Finnish Energy Industries (2009; see below)

As a follow-up, Low-Carbon Finland 2050 -platform was introduced by state-owned research institutes operating in different sectors such as VTT (Technical Research Centre), VATT (Government Institute for Economic Research), METLA (Finnish Forest Research Institute) and GTK (Geological Survey of Finland), coordinated by VTT. The platform has provided e.g. energy scenarios, which have the 80% reduction of greenhouse gas emissions as a target (see VTT 2012).

Traditionally, VTT and VATT have employed models in their energy-related research activities quite widely. VTT has used the Markal and Times energy models for constructing energy-related scenarios, and general equilibrium models Vattage and Verm have been developed by VATT (e.g. Honkatukia 2009; Honkatukia 2013). These models have been used to study macroeconomic and regional effects of different energy scenarios and policy applications, e.g. the economic impacts of using specific economic instruments of environmental and climate policies which cannot be dealt with the Ministry of Economy and Employment's energy model used for scenario construction.

The Finnish Energy Industries, which represents energy producers in Finland, has also provided their own national energy vision of a carbon neutral future for the year 2050. In this vision, reduction of CO<sub>2</sub> emissions is similar to the Prime Minister's Office's scenarios, but nuclear power plays a key role (see Finn-

ish Energy Industries 2009). In an annex of the original Finnish version this report, also other scenarios provided by Finland Futures Research Centre (cf. Luukkanen et al 2009), have been included.

Over the years, envisioning alternative energy futures against existing decision-making structures has not been easy. In the preparatory process more unconventional scenarios for the long-term periods up to the year 2050 have been proposed, but these have not really surfaced in the eventual outcome documents. Critics of the official energy scenarios in Finland have especially criticized the assumption of the continuous growth of energy consumption. Some scenarios have also been designed under assumptions to acknowledge the necessity of nuclear power. Such assumptions, assumed of the industry and its advocacy bodies, delimit and control the range of public debate.

#### Box 4.3. Obstacles of model-based learning with alternative scenarios

In 2007, the World Wildlife Fund (WWF) commissioned an energy scenario for Finland (WWF 2007), in which primary energy demand needed to start falling by 2020, energy efficiency would have a major role, and also renewable energy was envisioned to play a significant part. The energy scenario raised interest, and energy experts involved in the scenario-building were asked to debate this scenario in universities and schools.

At this time, the EU 2020 climate targets had not yet been introduced and neither were the EU Emissions Trading Scheme in place. What is more, this was the time when the heavy industry was planning on advocacy for an increase of energy supply through nuclear power. The main economic newspaper (Kauppalehti) in Finland ran a front-page story, which suggested that the scenario calculations performed by the WWF expert group are wrong and misguided.

This case is an example of successful industry lobby, which "kills" the debate of alternative energy choices.

## Economic and energy transformation are challenging the old industries

Energy production based on renewable energy sources is becoming an increasingly recognised energy solution, which is slowly integrating into national policies. In a scenario, where also other renewable energy technologies than biomass, i.e. wind and solar energy, would play a more significant role in the Finnish energy system, also new elements are needed. The intermittent nature of solar and wind energies pose new challenges to the electricity system, including smart grids, demand-side management, regulation of demand by e.g. peak cutting, electricity storage, and improved battery technology. In addition to the development of new renewable energies, energy efficiency will continue play a major role, as transport, housing, construction and food, are all major CO<sub>2</sub> sources of the Finnish economy. New renewable energies and energy efficiency increase also energy self-sufficiency under a low-carbon scenario and decrease reliance on imported energy sources (Halme et al. 2014). Nuclear power, into which the Finnish economy has committed since decades, remains a controversial option for citizens, perceived as low-carbon for some, but a technology with high costs and risks as well.

So far, transition of energy system towards sustainability has been focused on bioenergy and resulted of the policy development of the European Union. However, openness and participative working structures, stimulated by the digital revolution, are emerging trends of the Finnish political and economic life. This is also challenging past corporatist and centralised decision-making patterns. From a business perspective, a lack of domestic markets is an often-recognized problem of renewable energy technology development in Finland, even if a strong domestic market for renewable energies would likely also improve the competitiveness of Finnish companies in a growing international market (Lindroos et al. 2012). For new economic opportunities, the business model needs to be solid, and at an early stage, the infant industry would benefit from appropriate incentives. The strategic leveraging of technology skills through the Finnish engineer-oriented educational system was a major factor behind the ICT revolution in Finland. Something similar could be expected also in relation to renewable energy technology, which is currently a largely export-oriented industry in Finland.

## A case of Thai energy planning with a household and alternative view

The second case study of the report discusses the Thai energy planning and compares the Thailand Power Development Plan 2012–2030 (PDP2010: REVISION 3) and the assessment of it by Greasen and Greasen (2012) as well as how the Thai energy system has been analysed using ThaiLinda model (see discussion of the LINDA model in Luukkanen et al. 2012a).

## Thailand Power Development Plan 2010-2030

Thailand Power Development Plan 2010 - 2030 (PDP2010), which is prepared periodically by the state-owned Electricity Generating Authority of Thailand (EGAT), was approved by the Nation Energy Policy Council (NEPC), and then endorsed by the Cabinet in 2011. According to the Plan, the PDP2010 themes focus on security and adequacy of power system along with the policies of the Ministry of Energy (MoEN) on the aspects of environment concern, energy efficiency and renewable energy promotion to be in line with the 15-Year Renewable Energy Development Plan (REDP 2008–2012). Parenthetically, cogeneration system was recognized to promote as the efficient electricity generation.

According to the PDP in 2010, the recorded actual power demand (*peak*) of the country increased significantly higher than the forecast and tended to grow continuously. Additionally, the new power plant construction of Independent Power Producers (IPP) as plan has been delayed causing power system security to fall at risk influencing power reserve margin (RM) into the level of lower than the setting criteria or standards. Accordingly, the MoEN set a framework for a short-term urgent relief (2012–2019) by revising the power development plan (the PDP 2010) to be the one so-called PDP2010.

According to the PDP the Cabinet called for an Alternative Energy Development Plan: AEDP 2012–2021 and also 20-Year Energy Efficiency Development Plan 2011–2030 (EE Plan 2011–2030). It was seen that the scope of the new government policies and the variation of the economic situation induce changes and fluctuation in both power demand and power supply. It was said that therefore, to have clear vision on power supply acquiring, Thailand Power Development Plan 2010–2030 (PDP2010: Revision 3) was developed along the following issues:

Forecasted power demand results which were approved by the Thailand Load Forecast Subcommittee (TLFS) 2012 were adopted within frameworks as the following.

- Refer to the projected Thai Gross Domestic Products (GDP) and projected Gross Regional Products (GRP) estimated by the Office of National Economic and Social Development Board (NESDB), covering the economic stimulation policies and flooding effects at the end of 2011
- Refer to the approved 20-Year Energy Efficiency Development Plan 2011–2030 (EE Plan 2011–2030) proposed by the MoEN
- 2) Alternative Energy Development were regarded according to Alternative Energy Development Plan: AEDP 2012–2021 to use renewable energy and alternative energy by 25 per cent instead of fossil fuels within the next 10 years.
- 3) Energy supply security was taken into consideration of fuel diversification and suitable power reserve margin level.

## Critical assessment of the Thailand Power Development Plan

According to Greasen and Greasen (2012), PDP is the master investment plan for power system development. It determines what kind and what quantity of power plants get built, where and when. The PDP has wide-reaching implications, shaping not just the future of Thailand's electricity sector and its social and environmental landscape, but also that of Thailand's neighbouring countries. According to the criticism, the official PDP document reflects a planning process in crisis. By selecting excessive amounts of controversial, expensive, risky, and polluting power plants over cheaper, cleaner, and safer alternatives, the PDP is at odds with both Thai energy policy as well as the interests of the vast majority of Thai people. (Greasen and Greasen 2012)

Greasen and Greasen (2012) call their plan simply "PDP 2012", which they claim to be more consistent with Thai policy and the interests of Thai people than the Electricity Generating Authority of Thailand's (EGAT)'s most recent power development plan, the PDP 2010. The intention of Greasen and Greasen is not for the PDP 2012 to be the "only" PDP, but rather one to be considered in comparison to other plans. They hope that all candidate plans be presented to the public in a way that emphasize the values and assumptions embedded in different future scenarios, and that ultimately an optimum PDP is selected that reflects excellent science, consistency with government policy objectives, and coherence with the desires of the Thai public.

Greasen and Greasen (2012) claim that in previous years, "energy security" has been a trump card used to justify official government PDPs and to discount proposed alternatives without serious discussion. The Thai government energy policy guidelines stipulated in the Energy Industry Act do include the four dimensions of energy security (Availability, Affordability, Energy and Economic Efficiency and Environmental Stewardship), but it is claimed that there has been little or no linkage between power sector planning practice and the multi-dimensions of "energy security" as enshrined by the law (see Box 4.4).

## Box 4.4. Policy objectives for the power sector by Thai Government

Energy security: procuring sufficient energy supply to meet demand

Energy reliance: reduced dependency on imports

Promotion of renewable energy: increasing renewable energy share

Efficient use of energy: reducing energy intensity

Diversifying fuel risks Reducing CO<sub>2</sub> emissions

Minimizing impacts from energy procurement

Fair and reasonable costs of energy service to consumers

Greasen and Greasen (2012) suggest to use a framework of indicators of the four dimensions of energy security to enable the comparison of the different Power Development Plans. Table 6.2 shows the proposed indicator framework.

Table 4.1. Indicator framework to assess energy security (Greasen and Greasen 2012).

4 dimensions of energy security	Energy Industry Act 2007	Indicators
Availability	<ul><li>Resource Adequacy</li><li>Min. dependency on imports</li><li>Diversification</li></ul>	<ul><li>Reserve margin ≥15%</li><li>% energy imports</li><li>Shares of fuels</li></ul>
Affordability	<ul><li>Affordable cost of service</li><li>Min. exposure to price volatility</li></ul>	<ul><li>- Electricity cost (B/mo.)</li><li>- % exposure to oil price</li></ul>
Efficiency	- Energy & economic efficiency	<ul><li>Energy intensity (GWh/GDP)</li></ul>
Environment	- Min. environmental impacts	- GHG emissions - SO2 emissions

The proposed efficiency indicator does, however, not tell necessarily of the efficiency of the production because its value depends very much on the production structure in the country (the share of value added in different economic sectors). The production equipment and processes can be very energy efficient but if the production structure is energy intensive (e.g. lot of heavy industry) this indicator would show that the efficiency is low. This will be shown later with the scenarios in the Thai case (Base case and Industrial scenario).

One critic by Greasen and Greasen (2012) of the load forecast in the EGAT PDP is that it is based on GDP growth that is estimated to be too high. It is claimed that in the real GDP growth the "Black Swan" events have considerably decreased the growth e.g. in 1997, 2009 and 2011. It is claimed that such unexpected events, though hard to predict, are part of the reality of the economy and their effect has been to throw growth trajectory toward a path that has ended up being more linear or logistic-shaped than exponentially growing.

In practice, this type of claim includes the idea that the economic growth is continuously slowing down in the future – linear growth means that the annual percentage growth will be always smaller and smaller in the future.

The emphasis on the GDP growth and its form (linear or exponential) is, however, a little bit misleading in the energy analysis. The structure of economic growth is normally much more important for the energy demand, as will later be shown with the ThaiLinda model scenarios.

The "Black Swan" events are problematic from the point of view of scenario building and planning. In practice they increase the unpredictability (stochasticity) of future development and this should lead to the increase in the reserve margin in the planning. Logically, if we think that, in most cases, the "Black Swan" events reduce the economic growth, we should, however, increase the reserve margin in order to be on the safe side.

Greasen and Greasen (2012) claim that what is needed is for Thailand is a move away from load fore-casting based on econometric regression (top-down approach) and an investment instead in the capacity to undertake rigorous bottom-up forecasting that understands what the actual growth in electricity consumption will be sector by sector, industry by industry, end use by end use. This is data intensive and requires much more detailed understanding of exactly how electricity is being used by all customer classes, and how these usage trends are affected by changing technology, appliance efficiency improvement rates, adoption rates, prices, domestic and international economic climate, and changing demographics. It is claimed that though a formidable task, user surveys and data gathering and analysis are likely to be a much better investment than mistakenly building unneeded power plants. Here we have to bear in mind, however, that when we try to construct a very comprehensive model the task of energy scenario building will be directed more and more to the very few energy experts who can understand the model structure and its use. This effectively reduces the possibilities for democratic use of the energy model and can be seen as a step towards the model competition mentioned in chapters above.

Demand Side Management (DSM) is seen by Greasen and Greasen (2012) as one important factor to improve energy efficiency. They say that the EGAT PDP 2010 did take into account savings from energy efficiency but the only program incorporated was the T5 light replacement program which is estimated to yield a savings of 0.3% of total load by 2030. This amount is extremely small compared to the real potential and to what has been done elsewhere in the world. The report refers to a study by Foran et al. (2010) which studies the energy efficiency improvement potential in households in Thailand for the main electricity consuming devices (refrigerator, air conditioning, fans, light bulbs, rice cookers) and results in considerable figures for saving potential.

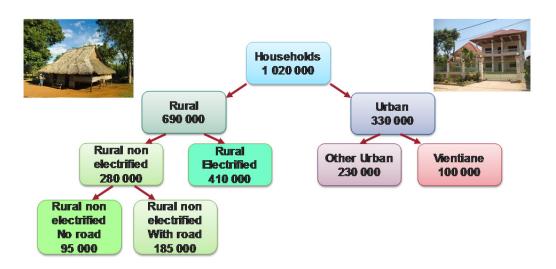
When thinking of the potential of reducing the demand by DSM or other energy saving measures we have to take into account possible rebound effects (Jackson 2009). The rebound effect can easily eat up part of the energy savings achieved through the reallocation of saved money to other activities which increase energy consumption. This should be taken into account in the planning process by trying to direct the activities to low energy intensive consumption.

When discussing of household energy consumption the changes in household incomes, behaviour, equipment that are used, their use intensity, et cetera have to be taken into account and this requires the use of energy models in order to coherently construct scenarios for future. The data intensive household modelling normally requires large amount of survey data to be able to capture the many folded aspects of

household energy use. The LEAP model forms one usable framework for household energy modelling, even if the data requirements are considerable.

## Modelling household energy consumption with the LEAP model

When we think of the household energy use modelling, we have to divide the households into suitable categories in order to be able to model them meaningfully. First, the division can be made between rural and urban households because their energy use profile is usually very different. The next division can be made between those households which have access to electricity grid and those without access, because also this has a considerable impact on energy use profiles. In some cases we have made a distinction within the non-electrified between households between those which have access to road and those without access to road. Figure 4.4 indicates the categorisation of the households in one study in Laos.



**Figure 4.4.** Categorisation of the households in a study in Laos based on rural/urban and electrified/non-electrified distinction.

In addition to the distinction shown in Figure 4.4 it is important to make a distinction within these categories based on household income since also this has a determining impact on household energy use profile. Figures 4.5 and 4.6 show this division in the Lao case.

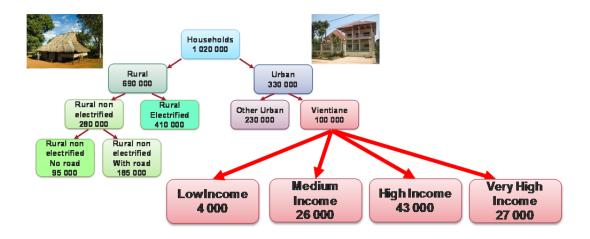
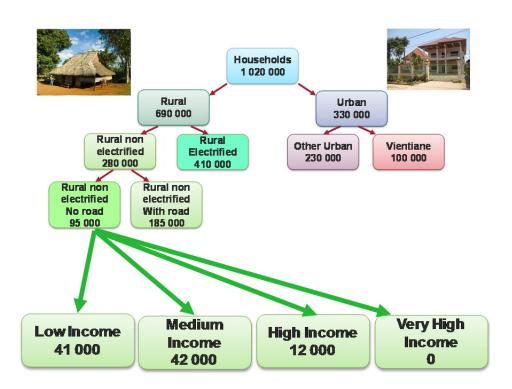


Figure 4.5. Allocation of the Vientiane households in different income categories.



**Figure 4.6.** Allocation of rural non-electrified household with no access to road in different income categories.

The allocation of households in different income categories is a dynamic process since the changes in GDP also change these allocations as households shift to higher (or lower) categories. In scenario building, these changes in the categories are one important part of the scenario construction.

For each household income category we also need information of the electrical equipment and their usage. Figure 4.7 illustrates the information that is required for calculating the electricity use of different equipment in a household within a certain category. For scenario building we have to construct trends in the use of different equipment and their nominal consumption. The change in nominal consumption (pow-

er kW in the Figure 4.7) is just one variable which has to be taken into account in the scenario building the others being the penetration of the equipment and the usage hours. These all change as a function of time and the scenarios have to be built based on these changes. To capture all these potential changes from household distributions to nominal consumption of different equipment and usage hours it is necessary to have a calculation framework to coherently carry out the changes in the scenario building process. The LEAP model provides a good framework for this type of bottom-up household energy modelling.

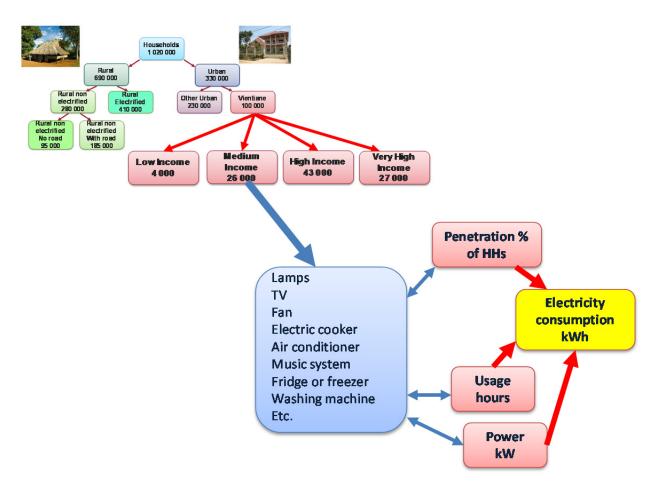


Figure 4.7. Calculation of the electricity consumption of certain equipment within a household category.

### Studying Greasen and Greasen's analysis

Greasen and Greasen (2012) say that the opportunities for energy saving in industry and commercial buildings are much higher than in the residential sector. These savings opportunities are captured in the Thai Government's 20-year Energy Efficiency Development Plan, which targets an annual energy savings of nearly 70,000 GWh by the year 2030. Of this 70,000 GWh, the residential figure of about 19,000 GWh/year is roughly commensurate with the projection for year 2026 by Foran et al. (2010). The criticized EGAT PDP2010 made no mention of the 20-year Energy Efficiency Development Plan because the latter was approved after the PDP2010 was issued.

The political issues related to constraints in renewable energy development are quite difficult to take into account in the modelling work. However, it is possible to create different scenarios with different assumptions of policy options and their impacts on renewable energy development. This means that normally it is not enough to create one scenario but you should develop alternative scenarios which take into account different aspects of the energy sector development.

One important aspect that the Greasen and Greasen (2012) report emphasize is the potential role of cogeneration – not only in providing heat but also providing cooling. This has quite a large potential in the Thai case and should be analysed in more detail. Cogeneration provides good possibilities for energy saving since the overall production efficiency is much higher than in condensing power production due to the use of "waste" heat energy for heating or cooling.

As was mentioned earlier the structure of economic development has a determining role in the future energy demand. Energy demand does not only depend on the growth of GDP but on the changes in the structure of GDP, i.e. the growth of different economic sectors and changes in their technologies. This is because the different economic sectors have considerably different energy intensities. Figure 4.8 shows the changes in historical sectoral energy intensities in Thailand and Figure 4.9 the changes in electricity intensity. The energy intensities within the sub-sectors of the economy vary even more and these should be taken into account in the modelling work if there is data available for the model construction.

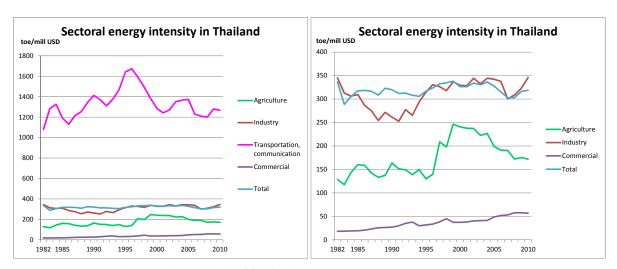


Figure 4.8. Sectoral energy intensities in Thailand.

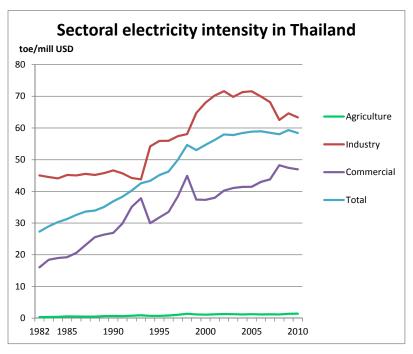


Figure 4.9. Sectoral electricity intensities in Thailand.

## Alternative energy scenarios for Thailand

Next, energy use related to some possible scenarios are shown in order to illustrate the impact of different drivers and their changes. The scenarios are produced with ThaiLinda model constructed by Jyrki Luukkanen (see Luukkanen 2012a). The LINDA model (Long-range INtegrated Development Analysis) is an easy to use Excel-based model, where the user gives the future annual sectoral growth rates and changes in energy intensities. Different modules describing e.g. the labour demand, details of industrial sub-sectors etc. can easily be added in order to make the model (accounting framework) more integrated. The model produces information of energy use and emissions in different scenarios.

## Base case scenario

If we construct a base case scenario with the ThaiLinda model for Thailand with the GDP growth rates for different sector given in Table 4.2 we will end up with the scenarios indicated in Figures 4.10 and 4.12 – 4.14 if the electricity intensities of the sectors change according to Figure 4.11.

**Table 4.2.** Historical and future annual growth rates of value added in different economic sectors in Thailand according to the Base case scenario

	1982-90	1990-94	1994-98	1998-2001	2001-06	2006-10	2010-15	2015-20	2020-30
Agriculture	3.2 %	-1.1 %	5.0 %	-2.2 %	7.7 %	6.9 %	5.0 %	3.0 %	2.0 %
Industry	11.6 %	8.5 %	-0.1 %	4.0 %	7.3 %	3.7 %	4.0 %	3.5 %	2.5 %
Transportation, communication	9.8 %	8.5 %	2.5 %	7.4 %	2.6 %	1.1 %	3.0 %	3.5 %	3.0 %
Commercial	7.7 %	10.8 %	-0.2 %	4.3 %	4.5 %	2.2 %	6.0 %	6.5 %	5.5 %
Total	8.4 %	8.5 %	0.5 %	4.6 %	5.1 %	3.2 %	4.9 %	4.8 %	4.0 %

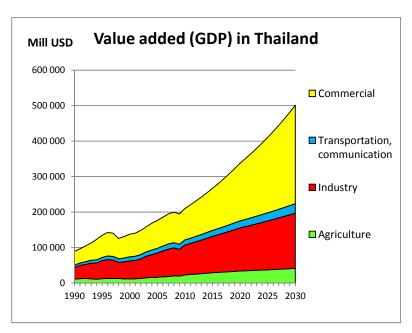


Figure 4.10. Value added in different sectors in Thailand in the Base case scenario.

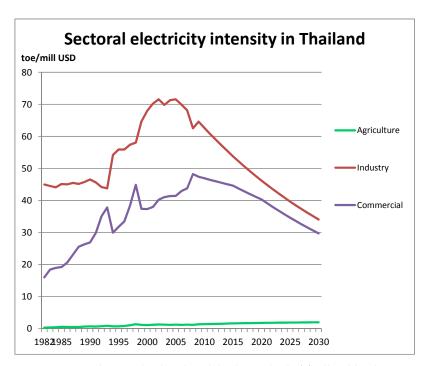


Figure 4.11. Changes in the electricity intensity in Thailand in the Base case scenario.

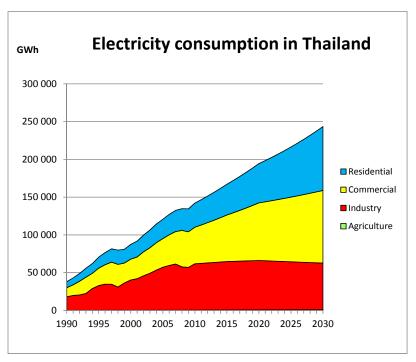


Figure 4.12. Electricity use in different sectors in Thailand in the Base case scenario.

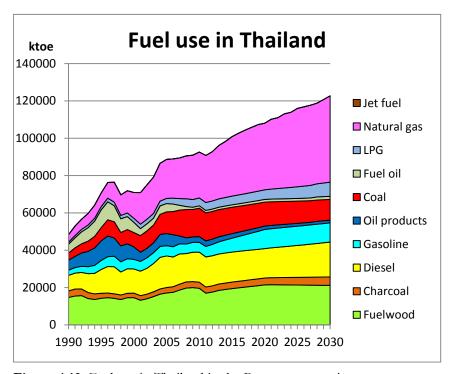


Figure 4.13. Fuel use in Thailand in the Base case scenario.

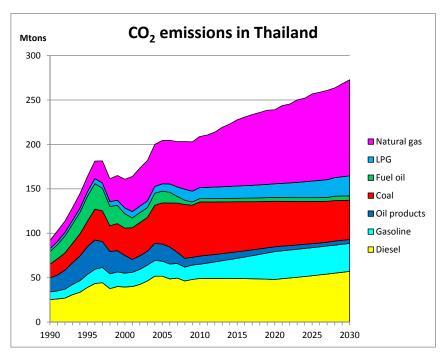


Figure 4.14. CO<sub>2</sub> emissions from fuel combustion in the Base case scenario.

#### Industrial scenario

In the industrial scenario the growth rates in the industrial sector are assumed to be higher than in the Base case scenario. The GDP growth rate is, however, same in this scenario in order to illustrate the differences resulting from different economic structure. The sectoral growth rates of the industrial scenario are given in Table 4.3.

**Table 4.3.** Historical and future annual growth rates of value added in different economic sectors in Thailand in the industrial scenario.

Agriculture	3.2 %	-1.1 %	5.0 %	-2.2 %	7.7 %	6.9 %	5.0 %	3.0 %	1.0 %
Industry	11.6 %	8.5 %	-0.1 %	4.0 %	7.3 %	3.7 %	5.5 %	6.0 %	5.2 %
Transportation, communication	9.8 %	8.5 %	2.5 %	7.4 %	2.6 %	1.1 %	3.0 %	3.5 %	2.5 %
Commercial	7.7 %	10.8 %	-0.2 %	4.3 %	4.5 %	2.2 %	4.7 %	4.3 %	3.5 %
Total	8.4 %	8.5 %	0.5 %	4.6 %	5.1 %	3.2 %	4.9 %	4.8 %	4.0 %

In the industrial scenario the total electricity consumption in 2030 is about 30 TWh higher (more than 12 %) than in the Base case scenario requiring much larger production capacity. In the Industrial scenario the residential electricity consumption is assumed to be similar to the Base case scenario.

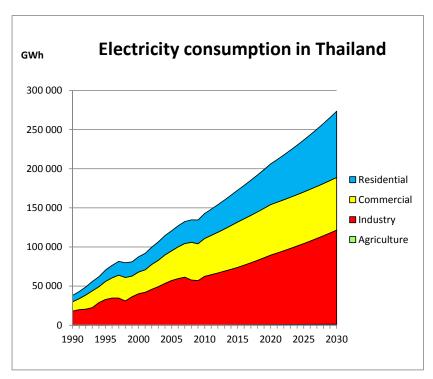


Figure 4.15. Electricity consumption in the Industrial scenario in Thailand.

In the Industrial scenario the fuel use (see Figure 4.16) would be higher than in the Base case scenario due to the increased power production and increased fuel demand in the industrial sector.

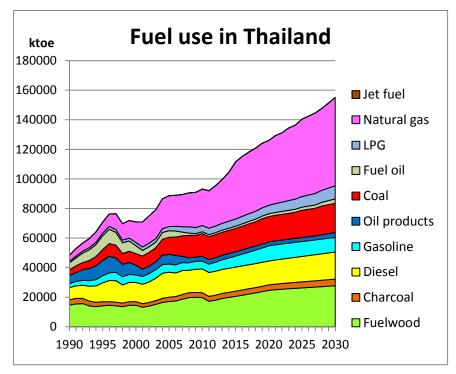


Figure 4.16. Fuel use in the Industrial scenario in Thailand.

Due to the increased fuel use also the CO<sub>2</sub> emissions from fuel combustion would be 28 % higher in the Industrial scenario than in the Base case scenario (cf. Figures 4.14 and 4.17)

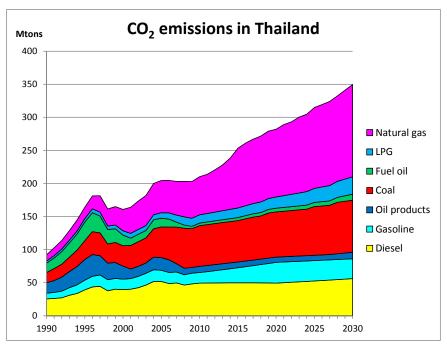


Figure 4.17. CO<sub>2</sub> emissions from fuel combustion in the Industrial scenario.

## High growth scenario

If we construct a scenario with higher GDP growth we can compare the inpacts on energy demand. Table 4.4 shows the annual growth rates for the high growth scenario. In this scenario the GDP in 2030 is 27 % higher than in the Base case scenario (cf. Figures 4.10 and 4.18)

**Table 4.4.** Historical and future annual growth rates of value added in different economic sectors in Thailand in the High growth scenario.

	1982-90	1990-94	1994-98	1998-2001	2001-06	2006-10	2010-15	2015-20	2020-30
Agriculture	3.2 %	-1.1 %	5.0 %	-2.2 %	7.7 %	6.9 %	5.0 %	4.0 %	4.0 %
Industry	11.6 %	8.5 %	-0.1 %	4.0 %	7.3 %	3.7 %	4.0 %	4.0 %	4.0 %
Transportation, communication	9.8 %	8.5 %	2.5 %	7.4 %	2.6 %	1.1 %	3.0 %	3.5 %	3.0 %
Commercial	7.7 %	10.8 %	-0.2 %	4.3 %	4.5 %	2.2 %	7.5 %	7.5 %	7.5 %
Total	8.4 %	8.5 %	0.5 %	4.6 %	5.1 %	3.2 %	5.6 %	5.6 %	5.8 %

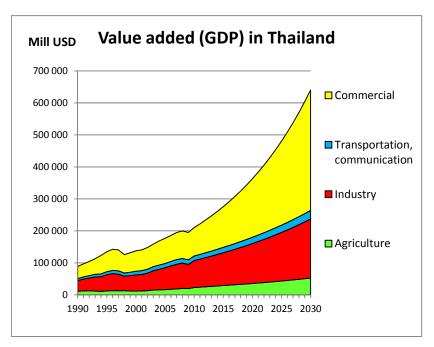


Figure 4.18. GDP growth in Thailand in the High growth scenario.

The electricity consumption in the High growth scenario (Figure 4.19) is not much higher than in the Industrial scenario even though the GDP is 27 % higher due to the lighter (less energy intensive) production structure.

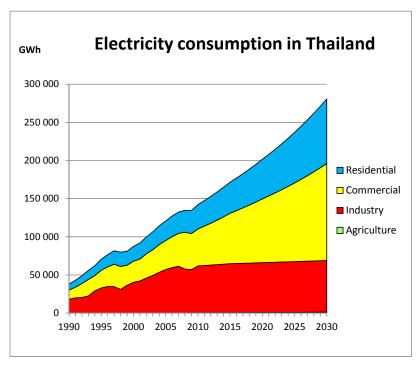


Figure 4.19. Electricity consumption in Thailand in the High growth scenario

## Summary

The Thai case and these scenario examples have been given to indicate the some impacts of changes in some variables in the energy-economic system. The Thai case signifies how different plans can have different types of motives, aims and consequent weighs and that the benefits of energy-related planning can be assessed from multiple perspectives. The examination of assumptions in energy policy matters because without a proper understanding of expected benefits or drawbacks, it is difficult to assess and imagine energy policy alternatives and how they could be constructed. In contrast to top-down figures (see Chapter 4.3 about energy use in Kenya), the use of LEAP model has been portrayed to illustrate the reader how bottom-up type of energy analysis can be employed to escape the dilemma of aggregation. Different scenarios for Thailand were eventually provided based on historical and future sectoral growth figures, using the LINDA model where the user can make estimations about sectoral growth rates and changes in energy intensities. Such features are useful in understanding of the energy system and the structure of the economy.

## Competing drivers of energy scenarios in Kenya

In the final case study, Kenya and its potential energy futures have been discussed from the point of view of renewable energy, fossil fuel findings and access to energy. The case study exemplifies some of the challenges related to future energy choices and climate change.

## Factsheet: Economy and energy landscape in Kenya

For Kenya's population of almost 45 million, energy access is still low, at not more than 16% (World Bank 2013). Wood fuel and other biomass account for 68% of total primary energy consumption. Most of energy in Kenya (petroleum and electricity) is consumed in manufacturing, commercial, transport, residential, power generation, and street lighting. Transport is the largest consumer of petroleum products followed by the manufacturing sector and other sectors (agriculture, tourism and power generation) (Institute of Economic Affairs 2013). In 2011, total electricity consumption was 6,273.6 GWh. There has been consistent growth in demand for electricity in Kenya estimated at an average of 7% per annum over a decade (ibid.). Kenya imports both crude and refined petroleum products.

At the same time, over half of the households in Kenya continue to use kerosene for lighting, and 60% of households use biomass for cooking, with especially the dependence on wood aggravating deforestation (Mugo and Gathui 2010). Less than 20% of Kenyan households, or approximately 1.5 million customers are connected on the electricity grid. Also, connectivity to electricity varies from region to region; whereas the capital area of Nairobi consumes over half of the energy (700 MW or 53.5% of total consumption), connectivity in other areas (Central 42.4%, North Eastern 14.5% and Western 14.7%) is low, and especially so in rural areas where access is less than 8% (ERC 2014).

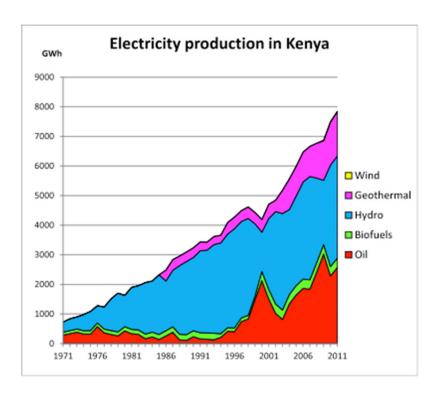


Figure 4.20. Electricity production in Kenya per energy source (IEA database)

The energy system in Kenya has operated through a national grid, which has covered only 25-30% of the country, with separate mini-grids also existing (KREP 2011, 5). The installed grid-connected electricity capacity is 1,741 MW, with a national peak demand recorded at 1,334 MW: 812 MW is a result of hydropower, 646 MW of thermal (fossil fuel), 251.8 MW of geothermal, 5.1 MW of wind, and 26MW from cogeneration (Kiva 2013)<sup>21</sup>. According to IEA statistics, about 5 % of electricity was imported up to 2006.

In addition to the low supply, problems and challenges to solve are related to over-dependence on hydropower with its unreliability of hydro-generation<sup>22</sup>; maintenance and the frequency of system losses, weak transmission and distribution network; system failures and transformer failures; vandalism of equipment; and high cost of rural electrification projects (GoK 2013; Kisero 2014). Low voltages are also contributing to energy tariffs, which are perceived as relatively high. Therefore, the national energy policy envisions to provide "affordable quality energy for all Kenyans" due to perceived high energy costs (up to 21 US cents per kWh), at least when the government compares its figures to countries like India and China where rates have been at approximately 6 US cents per kWh.

### Renewable energy in the Kenyan energy mix

In Kenya, there is an impetus to develop renewable energy: geothermal power, wind, and solar energy with the assistance of public-private partnerships, World Bank and EU-support (see also UNEP 2012). Kenya expects to generate more geothermal power as well as gain smaller increases in generation capacity from

<sup>&</sup>lt;sup>21</sup> Installed capacity of mini-grids has accounted for less than 20 MW (Kiva 2013)

<sup>&</sup>lt;sup>22</sup> Due to variations in hydrology and possibly accentuated by climate change

wind energy and solar energy (cf. Box 4.5). Feed-in tariffs have provided investment security and spread the decentralized production of renewable energy to encourage potential independent power producers (IPPs) to carry out feasibility studies on renewable energy generation, based on which to negotiate Power Purchase Agreements (PPAs) (WFC 2009; Gok 2012a; Kiva 2013). In Lake Turkana Wind Farm Project (310 MW), the largest single wind farm in sub-Saharan Africa, Kenya Power will buy the electricity generated at a fixed price over 20 years in accordance with a power purchase agreement (PPA) (Okoth 2013).

#### Box 4.5. Government initiatives to develop the renewable energy sector in Kenya in 2000s

- Feed-in Tariff Policy (2008; amendments in 2010 and 2012)
- Wind Atlas developed in 2003; installation of Data Loggers and Wind Masts
- Program for Solar PV installations in public institutions in Arid and Semi-Arid Land areas
- Regulations for Solar Water Heating developed
- Developed Solar Photo Voltaic Systems Regulations
- Carrying out feasibility studies for small hydro power sites
- Promotion of improved cook stoves
- Establishment of Geothermal Development Company
- Green Energy Facility to be set up to finance development of clean energy projects

Source: SREP (2011)

There is an estimated potential for 7 000 MW to 10 000 MW of geothermal energy; 3 000 MW to be generated with small-hydro generation (at the moment only 30 MW has been installed); and also potential for solar, wind, biomass and biogas generation are high (Institute of Economic Affairs 2013). Yet, there remain various challenges to develop the renewables sector. The high capital costs to develop the renewable sector are high for the state to consider them as budgetary requirements. In Lake Turkana, the costs are projected to reach up to 625 million € (or USD 800 million) and project implementation in a remote location is not without challenges (LTWP 2014; Okoth 2013). Furthermore, to implement all earmarked geothermal projects, Kenya may need to spend massively, according to press reports, up to USD 4.5 billion between 2014-2016, and to generate the targeted 5 000 MW by 2030, the country is reported to be lacking about USD 20 billion). Also, low awareness of opportunities and related economic benefits have constrained the uptake of RE technologies.

## The policy environment and ambitious future economic visions

In Kenya, the energy sector was liberalised in the 1990s, creating semi-autonomous companies dealing separately with generation and supply, following a prevalent trend in developing countries. In 2003, Kenya also began to actively develop renewable energy (RE) sources, geothermal power as well as wind energy, and adopted its first Feed-in Tariff (FiT) policy in 2008 (with amendments in 2010 and 2012) (cf. Box 4.6). In geothermal energy, the government has set its own Geothermal Development Company to develop the sector. The process of devolving power to counties and a new constitution (2010) are making the country

review its national energy policy<sup>23</sup>. Other influential policies include the Least Cost Power Development Plan (LCPDP), Rural Electrification Master Plan. Also, Kenya published Kenya National Climate Change Response Strategy in 2010.

### Box 4.6. Strategic objectives in the Kenyan energy sector

- Up-scaling power generation by increasing the capacity
- Increasing access and connectivity to electricity and in particular increasing access in rural areas
- Reducing power losses
- Increasing use of new and renewable energy sources
- Securing fossil fuel resources

Source: Institute of Economic Affairs (2013)

Simultaneously, under its economic blueprint Vision 2030, the government envisions large and ambitious infrastructure projects for modernisation, to transform Kenya into a newly industrializing, "middle-income country providing a high quality life to all its citizens" between 2008 and 2030 (cf. Box 4.6). The government is planning to radically raise the current electricity generation capacity, from 1 713 MW to 17 000 MW by 2030 (Kiva 2013)<sup>24</sup>. It is seen that energy supply needs to supply increased energy for the use of manufacturing, agriculture, services, public facilities and households (GoK 2013). "Affordable, sustainable and reliable supply of energy" is seen to be able to stimulate high and sustained economic growth, which will catalyse higher incomes, increased employment and reduced poverty (Institute of Economic Affairs 2013).

#### Box 4.7. Scenario of growth in energy demand

By 2017, to make electricity generation reach an expected 5,500 MW: renewable energy sources (geothermal 1,646 MW; wind 630 MW; hydropower 24 MW; cogeneration 18 MW) are expected to contribute less than non-renewable resources (coal 1,920 MW, liquefied/compressed natural gas (LNG/CNG) 1,250 MW; diesel plants 250 MW).

By 2030, to reach an estimated a capacity of 15 000-18 000 MW, electricity is expected more from *renewable energy sources* (geothermal 5,110 MW; wind 2,036 MW; hydro 1,039 MW; others (Solar, MSW, Cogeneration 3,000 MW) than *non-renewable resources* (thermal ie. fossil fuel 3,615 MW, coal 2,420 MW, imports 2,000 MW).

Sources: Kiva (2013); Government of Kenya (2013), Sambu (2014)

## Analysis of the drivers of energy demand and CO<sub>2</sub> emissions

The drivers of Kenyan energy demand have been analysed using decomposition analysis (see Annex 3). The results of the analysis are shown in Figure 4.21. The first component (CO<sub>2</sub>/TPES) indicates a shift to increasing share of fossil fuel use between 1971–2010. The second component indicates slight decrease in the

<sup>&</sup>lt;sup>23</sup> In 2000s, Sessional Paper No.4 (2004) and Energy Act, No. 12 (2006) restructured the energy sector. Other key legislation has included the Geothermal Resources Act No. 12 (1982) and the Petroleum (Exploration and Production) Act, Cap 308.

The peak load is projected to grow to about 2,500MW by 2015 and 15,000 MW by 2030. To meet this demand, the projected installed capacity should increase gradually to 19,200 MW by 2030.

efficiency of the energy transformation process. The reduction in energy intensity of the economic production (FEC/GDP) has decreased, to an extent, the energy use in Kenya while the growth in GDP per capita has increased the energy use. This factor has, however, been considerably low, and indicates almost no economic growth per capita during the 40-year period (compare this with the Thai case in 4.2). The population growth in Kenya has been very fast increasing the energy demand considerably.

In Kenya, the main driver for increase in energy demand has been the growth of population. The growth of GDP per capita has been very slow in Kenya during 1971-2010 having only a slight increasing impact on energy use. The energy intensity of economic production has had quite a small decreasing impact on energy demand. The planned industrial development can increase the GDP per capita in the future and it can also lead to more energy intensive production structure. The development of these two components is crucial for future energy demand in Kenya.

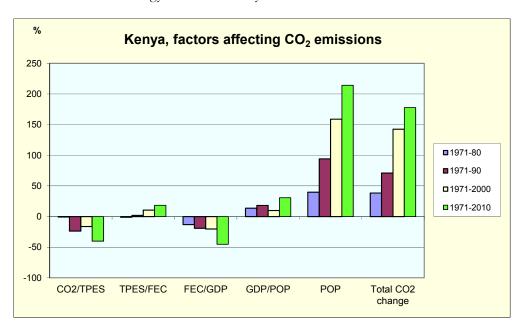


Figure 4.21. Factors affecting CO<sub>2</sub> emissions (and energy use) in Kenya in 1971–2010.

#### Industrialisation aspirations gaining strength from new fossil fuel findings

For long, Kenya had no known commercial petroleum reserves. Not until 2012, when oil was discovered in Northern Kenya, which soon attracted the interest of international investors. The government has been quick to react, and has set out to map its natural resources more in detail. Already the following year, in 2013, a bilateral agreement was conducted between Kenya and China for the mapping of natural resources. Energy provision and ambitious infrastructure projects are becoming increasingly linked with talks of coal, gas-fired plants, and nuclear power plants.

In order to develop the fossil fuel sector, government has identified as challenges the outdated refinery and pipeline system; inadequate storage infrastructure for strategic reserves of the petroleum products, volatility of international crude oil prices, and weak legal and regulatory framework for energy resources exploration, exploitation and development (GoK 2013). Development of the extractive industries would also increase energy demand heavily. Kenya Electricity Transmission Company (KETRACO), has already been

mandated to construct new transmission lines with government funding, is now involved with transmission lines of plans on coal-plants (Lamu and Kitui) and natural gas plants (Dongo Kundu in Mombasa). Despite an increasing interest in industrial activity, attention into improving and resourcing access to energy has been more limited given the largely unequal opportunities of access to energy. Fossil fuel discoveries are also making the government see its domestic resources to bring an reduction to the fuel bill, which in 2012 stood at almost USD 4 billion to release finances available for other areas. Rising prices of petroleum products have fuelled inflation, pushing poverty levels up by making basic commodities more costly (Institute of Economic Affairs 2013).

## Lack of electricity access and unreliable grid as pertinent challenges

The majority of people who rely on biomass and lack access to electricity are in the rural areas. Connecting households to the national grid is expensive and grid expansion can also be stalled due to land issues that are sensitive for local people. In 2013, the Kenya Power and Lighting Company (KPLC) announced that it is able to operate only on commercially viable connections. Because of the high costs of improving rural energy access, KPLC is deferring this responsibility to the state. In Kenya, this means mainly the Rural Electrification Agency (REA), established in 2006, which is responsible for providing power connections to rural Kenya (African Review 2012; Ayiebo 2011)<sup>25</sup>.

Rural electrification has increased from 4% in 2003 to 22% in 2012, this has happened mainly in major economic centres and public institutions: trading centres, health centres and schools, following the agency's (REA) Strategic Plan Phase I (2008-2012)<sup>26</sup>. Phase II (2013–2022) aims to triple the national electrification rate from 22% to 65% by 2022. Phase III (2022-2030) targets universal access by 2030 (Ayiebo 2011; Kiva 2013). In the two coming decades, attention to the broadening of energy access now is supposed to be a priority for REA.

An alternative to improve energy access, also in a more sustainable manner, is the introduction of renewable energy technologies at a household and village level. Under the 2<sup>nd</sup> Medium-Term Plan (2013–2017), the government has initiated a pilot of eco-communities in eight counties. There remain certain obstacles, though. A key problem related to the scaling up of renewable energy is financing arrangements that would enable citizens to buy such technologies. Equipment is rather costly, awareness limited, and interest rates provided by banks in Kenya perceived too high by the poorest and even the middle-class. In comparison to large-scale renewable energy schemes where the state is able to seek international loans from financial institutions such as the World Bank, neither companies nor consumers have access to such consumerscale financial mechanisms or supportive policies.

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<sup>&</sup>lt;sup>25</sup> In the acceleration of electricity access, REA has listed nine potential drivers: lead in Government Commitment, lead in local funding, support from development partners, establishment of committed lead agencies, passion by stakeholders, community involvement, bulk purchase of materials, use of labour and transport contractors, and promotion of organized settlement (Ayiebo 2011)

<sup>&</sup>lt;sup>26</sup> Access means households within 1.2km of M.V/L.V line (Ayiebo 2011)

One option would be the creation of institutions that enable to citizens or companies to buy the equipment through funding schemes with low interest rates and long payback periods. This is because conventional institutions (banks, investors, existing state institutions) do not have mechanisms that would incentivize locals for RE and could wait for a longer return on their investment. Off-grid systems that would provide household-level systems of solar, wind or biogas, or cogeneration between these technologies, and related batteries are few, and mostly initiated through non-governmental organisations and development actors.

Some areas of rural Kenya are especially vulnerable to marginalisation, including nomadic pastoralists. In the past, when government plans and development projects have been designed, this might have taken place without sufficient involvement of the locals, disadvantaging them (Anderson et al. 2012; IIED 2014). In spite of the will to expand energy supply, the enforcement of top-down development approaches and centralised systems may contradict peoples' lifestyles, needs and priorities. Although an increasing amount of climate financing projects is to be implemented in the local level, this raises some concerns about the appropriateness of their governance frameworks. Without a careful consideration of the business models around these new technologies, there is a threat that externally-led projects exacerbate aid dependency in already marginalised areas (see also Anderson et al. 2012).

### Conclusions

Under its economic vision, Kenya has taken a determined approach to develop its energy sector, also trying to learn from some resource-wealthy countries that have failed to benefit of their natural resources. In the past, interest in resource rents has been associated with fear, based on examples of economies in which resource use has had limited, or hindered, development outcomes (Sachs and Warner 2001). Understandably, developing countries view development to follow industrialisation. Following this logic, it seems that the Kenyan energy policy mainly derives from conventional macroeconomic models based on aggregate growth. Positively, electrification schemes have also sought to enhance local economic opportunities.

In spite of its ambition, there are certain downsides of this strategy. Following the cost optimisation strategy, in 2013, the Government of Kenya, suspended the issuing of new licenses for renewable energy until 2017. An increasing interest to prioritise the fossil fuel industry development could jeopardize existing, relatively progressive policy arrangements and the interest to develop them further. Also, the growth of GDP does not equate with economic development. Another concern is related to the need to improve the quality of energy supply in Kenya, which is a recognised challenge. An interest in industrialising activities and related policies could also overlook the urge to develop access to electricity and its positive returns in terms of poverty reduction.

Crucial aspects of an economic transformation include questions related to the structure of the economy, what employment effects growth can create, and what education and skills are needed to harness those potential jobs. While Kenya is addressing to seek economic gains from its fossil-fuel resources and is undergoing a review of its energy-related policies, the total economic assessment in terms of the amount of value addition and how it is divided locally is not yet known. Instead of a GDP-based assessment, a sector-

based energy model, as provided for instance by the LEAP model, could better elaborate what sectoral linkages there are between energy supply and different economic activities (see 4.2). Some questions are also posed about the future demand predictions, and whether energy consumption will actually increase the way the government has projected. An article in Daily Nation in 2014 doubted current energy demand projections and stated that "electricity consumption in Kenya cannot possibly jump from the current 1,600MW to 5,000MW in 40 months" (Kisero 2014). This poses questions over the urge and timing to construct power plants.

Developing countries, which typically import technology, have had limited participation in the clean-tech sector. From a local business perspective, this makes the harnessing of such technologies locally limited. Especially in developing nations, commercial renewable energy industry is still in its infancy, and the electricity markets in developing parts of the world remain almost completely untapped (Makoni 2011). This could be addressed with the promotion of relevant skills; entrepreneurial culture; industry collaboration; financial support; and supportive state policies. Problematically, some claim the power purchasing agreements (PPAs) for renewable energy to undermine government plans to reduce the price of power – a 23% reduction is envisioned by 2017. Even so, relatively much has already been put underway in Kenya to scale up the renewable sector. This underlines the imperative to continue this work. In addition, Kenya, typically characterized as the driver of East African economy, tends to set a model for its neighbouring countries. This could also highlight possible spill-over effects for benchmarking and opportunities of regional market development within the East African community (EAC).

A broader question concerns the seemingly inevitable future "lock-in effect" to a carbon-intensive development path not only in Kenya, but in all developing countries that are seeking to increase their energy supply. Ironically, a developing country like Kenya seems poised to increase its engagement in a fossil-fuel economy that will exacerbate climate change whose effects will likely most severely be felt in the Sub-Saharan African region. While fossil fuel based economic activity can create economic output and may provide certain positive economic outcomes, climate change impacts will become increasingly visible in the medium- and long-term future. Such energy hooices could also further undermine the national productivity in the agricultural sector, and of the global economy.

# 5. CIVIC ENGAGEMENT, DEMOCRACY AND ACCESS TO ENERGY POLICY

In energy policy, large oil and gas companies, owned by the state or international actors, have traditionally provided energy infrastructure. In certain regional energy initiatives, it may have been difficult for a single country to even plan for energy structure that could collectively benefit a range of stakeholders without the industry presence. This aggregate perspective has driven the implementation of large energy projects as well as top-down energy modelling. A reference to advanced mathematical and technical properties maybe used as an important political argument by groups possessing a model monopoly (Luukkanen 1994). Unfortunately, this can also silence critical questions and challenges from groups that do not possess access to models. Therefore, citizens and civil society often have legitimate concerns of the bias of decision-makers towards the industry and their networks. Concerns of non-organised or marginalised groups or individual citizens with lesser advocacy skills and power may feel that their concerns are secondary to more influential advocacy networks and coalitions, and marginalised by the political system.

#### Box 5.1. Think before counting – the 'governmentality' effect of calculations

The notion of governmentality, or the art of government, emerges from Michel Foucault's writings. Governmentality refers to the organised practices through which subjects are governed through dominant discourses and different 'technologies' (Foucault 1978; see: Burchell et al. 1991). When statistical information is connected to decision-making machinery, this information can become 'a technology of power', (Foucault 1982, 1978).

Statistical information and quantification have brought "an avalanche of printed numbers" (Hacking 1990). Using mathematical formulas, numbers are able to synthesise, summarise and visualise information that otherwise would be unattainable. Michel Foucault studied the knowledge of the state, and how it subjects citizens under its decision-making. Albert Einstein famously noted that, "everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted". In science, this is recognised as the quantitative-qualitative divide.

In spite of the potential of technology, technocratic narratives can also undermine certain values that economic models struggle to quantify, including culture, heritage, human rights or ecological diversity. Open data, which may bring new knowledge resources, is also bound to increase the penetration of numbers. In the digital era, organising information and presenting it in an understandable manner is even more important for both civic engagement and accountability. Sartori (2004) has demanded individuals and groups to *think before counting*; and to use *logic* in thinking. Foucault (1966), in turn, originally emphasised the significance of the order of things. Foucault referred to the way issues and numbers are organised because it bears a major influence in how the world is presented to and perceived by the public.

Public administration coordinates its expertise with particular language and technical terminology, which may also manifest as a potentially unconscious means of exclusion. An example in energy modelling is, when forecasting results are taken from their producers to wider public. Often times, an implicit transformation from uncertainty to certainty takes place, and the results stand out as authoritative in spite of ambiguous data, elasticities that are difficult to estimate, ceteris paribus assumptions, and so on (Luukkanen 1994, 180-191). Reality may soon be defined as the situation represented by the models instead of the lived reality of those who are directly concerned with a political choice (ibid.). Conflicts and arguments are easily

shifted from the *political* to the *technical* field and so the discussion of problems is limited to those who are fluent in this technical discourse (ibid.).

Authoritative institutions and their policy-networks that inform decision-making (Sabatier 1998; Sabatier and Jenkins-Smith 1999) can undermine the opportunity of weak actors to contribute to knowledge production. Making alternative views heard can be difficult, and in setting terms in energy policy, the industry often has had an upper hand. Representatives of established industries might arrange frequent meetings with ministry officials, which may impose a *psychological bias* of their stronger voice. For smaller actors, the exercise of professional advocacy may be more unfamiliar. Even within the private sector, renewable energy companies compete against the advocacy resources of the fossil-fuel industry. In turn, scientific bodies with their vast knowledge resources may hesitate to assume an advocacy role, leaving their views unaccounted for, or undermined by competing needs. Notably, when non-governmental organisations construct their alternative models, they may be forced to adhere to baseline data and assumptions of the state and industry they would not necessarily want to endorse, but are unable to change. Civil servants, in their part, may adhere to economically motivated arguments and expect careful demonstrations of costs and benefits of alternative solutions. The public administration holds considerable power in inviting certain experts for consultations and hearings, and choosing not to hear other opinions.

## Opening the decision-making process with deliberative democracy

The scepticism of citizens in political matters across countries has been interpreted as a criticism of the way political systems are designed. Therefore, complementary means of participation have been proposed to overcome this democracy deficit. According to John S. Dryzek (2000), the essence of democratic legitimacy is in the authentic deliberations on the part of those affected by a collective decision. Also, the deliberative turn has challenged established institutions and models of democracy (ibid.). This can also be considered true for energy policy. As long as there is little discussion about the guiding assumptions that shape energy policy, it seems that there is also little room for democracy.

Although state institutions do have a focal role in public policy, institutionalist democracy theories have tended to overtly focus in the functionings of the state and rationalistic worldviews, to the detriment of ignoring the communicative aspects of public decision-making. However, in order to achieve its full potential, democracy should be reflexive in its questioning, transnational, dynamic in its openness to prosper for opportunities for democratization, critical of established power, and also emphasize issues of community, rights, equity (rather than self-interest) and ecological limits (see Dryzek 2000). Deliberative democracy allows non-violent techniques of communication, verbal conflict and rhetoric to improve the quality of decision-making to strive for best possible arguments (ibid.).

In the energy sector, one feasible step towards the enabling of democratic participation and a diversity of views could be the opening of all assumptions that guide energy policy and energy modelling. In this regard, certain countries are already more advanced than others. Certain different scenarios and the key parameters of the energy model such as guiding assumptions, climate change, sectoral growth could be opened for citizens for them to discuss and evaluate the predictions. Participative practice could increase

awareness and opportunities for citizens in agenda-setting even if this does not yet guarantee a change in the outcome of decision-making. This could be organised with experts of discursive facilitation, open communication processes. Also, for instance, the Department of Energy and Climate Change in the United Kingdom organises large energy-related consultations and is involved in digital and social media platforms.

## Open government and big data: revolutionising the knowledge basis

The availability to real-time data to anyone is becoming an increasingly vital tool for the government to improve its operations and increase citizen participation and awareness in a world of online collaboration, participation and open access. A vision of an open government (Lathrop and Ruma 2010; Tauberer 2010) is already re-imagining and re-shaping the relationship between citizens and their governments, especially at the local level (Goldstein and Dyson 2013). Open data is seen as a new defining feature of a state and an opportunity because the state has a large incentive to improve its knowledge resources for more informed decision-making. The buzzword of "big data" (Mayer-Schönberger and Cukier 2013; Schmarzo 2013) refers to the ability to crunch vast collections of information, analyse, and draw surprising conclusions from it<sup>27</sup>.

However, civic participation into unleashing the potential of open data between electoral cycles is an essential element of the democracy potential of access to information. Therefore, in addition to a mere publishing of information, active networks are important for an equitable circulation of data (Peixoto 2013). Unfortunately, it has been already noted that the potential for mediation with open data is closely related to the political freedoms and civil rights in place. In the absence of free media, governments might publish data, which is irrelevant and does not advance accountability in essential matters<sup>28</sup>. Therefore, information must also be opened for it to be challenged and evaluated by experts as well as ordinary citizens. Essentially, open data is a potential tool of enlarging the sphere of evidence-based discussion to the broader civil society. Also, the contesting of discourses is always necessary for a critical and constructive orientation towards better decisions. Only this way can open data genuinely spark innovation and drive efficiency and fulfil the potential of this information to drive change in the society.

#### Conclusions

Alternative scenario modelling under the precautionary principle could benefit societal risk management and complement the traditional administrator-citizen relationship. It has been argued that because democracy, solidarity, development and global warming are linked, the task of science is to demonstrate those links and provide credible lessons and recipes for change to fellow citizens (Hirst 2002). The ministry in charge, on the state part, should ensure that citizens understand their 'energy model', the assumptions they follow and have the ability to question it. This demands appropriate communication and the facilitation of the participation of experts and citizens.

According to Mayer-Schönberger (2013), the so-called "big data" is expected to transform ways of thinking and change blueprints in economy, learning, politics and innovation

Institutions themselves need to be participatory, and secondly, also a set of certain technical skills, hardly accessible for to most citizens, is required (Peixoto 2013)

Like experts and politicians, citizens also try to make informed judgments about energy policy. This includes questions about controversial energy issues such as fossil fuel dependence, the emergence of new technologies (carbon capture and storage, fracking), the question of nuclear energy, and so forth. In the past – and even if political science literature – citizens have been treated as passive subjects of decisions rather than actors whose interests and opinions form the basis of a legitimate democratic process.

Because citizens have concerns about decisions influencing their lives and localities, this makes citizens important stakeholders in decision-making and "experts" of their own communities. Without the involvement of citizens in major societal debates and concerns such as climate change, it may be difficult for the society to act decisively and collectively. In a deliberative approach to energy policy, new avenues and pathways may be provided through the openness of argumentation, an ability to listen, and the capability to challenge historical assumptions. An equal involvement of all stakeholders can enhance meeting this goal.

## GENERAL CONCLUSIONS

This briefing report has examined how energy models are constructed and the assumptions under which they operate. Energy models and scenarios may aid planning activity to analyse system, system controllability and seek policy alternatives (Luukkanen 1994), *but* only when the transparency of assumptions and the limitations of models and scenarios are well understood. Problematically, in scenario-analysis forecasting techniques and economic-driven energy modelling have supported historical assumptions rather than attempted to solve future challenges. Also, in the communication process with decision-makers, strong networks between the state and industry following the industrial era have prevailed to impose change resistance into the political system.

Consequently, the established 'elites' have been accused across countries of using forecasting to provide political legitimacy for traditional energy developments, with little regard to the informative and explorative aspects of forecasting. The energy establishments, in turn, have accused the ecological movement of unreal-istic zero-growth and "soft" forecasts. These arguments reflect differences in worldviews, positioning and available information as well as the industry-driven nature of the energy sector. In energy policy, the voice of large energy companies has typically been louder than actors whom are endowed with more limited resources. Citizens, in their part, rarely have similar awareness about the premises of energy policy, access to information, or entry points into energy-related decision-making to ensure its democratic nature.

Future-oriented models can benefit political decision-making. Future-oriented models can assess the dynamics of the energy and economic system in the context of climate change, needs of particular groups and articulate what role behaviour change could play in future energy solutions. The decentralisation of energy systems and the liberalisation of energy markets have already lead to more diverse energy supply approaches across countries. However, policy-wise several changes are likely needed in order to transform societies into low-carbon paths. Because the mitigation of climate change is an intellectual as well as a political challenge, institutional settings and decision-making systems need re-examination. A deeper understanding about present decision-making models and their limitations could enable the formulation of decisions that openly acknowledge the need to adapt into a changing energy future.

#### Key messages for alternative energy models and scenarios

• Provide and reveal model assumptions clearly to citizens, not experts only. Rather than a neutral tool to help decision making, modelling wields power and the results obtained with the model are often decisively affected by the choice of variables. Assumptions behind the parameters that are decided when a study is commissioned highly shapes the produced energy scenarios. Energy models should express their level of detail and uncertainty, and also visualise data clearly and in an appropriate manner. Most energy scenarios endorse simultaneously the goals of economic growth and climate change mitigation, *but* do not elaborate how these goals might be in conflict with one another due to the present fossil fuel-based energy system.

- Energy scenarios can help thinking, but are not policy recommendations. By changing different parameters that influence the energy model, different scenarios can be sketched to map different future pathways. Most low-carbon energy scenarios are able to consider what could happen, if a price was put on carbon. Scenarios can aid decision-makers in the mapping of relevant parameters, but they are not policy recommendations. Decision-makers ultimately make changes in policies, which is why advocacy matters.
- Provide accountability with tangible issues and timelines through backcasting. Backcasting can envision a plausible future, the steps required to achieve this future and obstacles in the way to realise the vision. The more detailed and realistic this vision is made economically and in terms of policy changes, the more useful and credible it is as a discussion paper for policy-making. Energy models and scenarios can *help* in solving what decision-makers are seeking answers to, make problems comprehensible, and create meaningful dialogue. For instance, *Energy [R]evolutions* report series of Greenpeace has caught the attention of decision-makers and been publicly debated.
- ergy models are not integrated assessment models (IAMs) that acknowledge the whole earth system. Top-down energy modelling struggles to acknowledge ecological constraints or household-level needs because it is based on a macroeconomic view that focuses on cost optimisation and a techno-rationalistic logic. Reference or business-as-usual scenarios that suggest increases in energy demand also assume that economic growth must follow increases in energy demand. Many influential energy outlooks such as those provided by International Energy Agency and British Petroleum endorse such values implicitly. This can mislead the decision-making process and drive them into seemingly pre-determined paths, even when alternative political choices can or should be proposed.
- Open the energy model for the public, researchers and stakeholders. The promotion of transparency and openness in energy modelling also demands other modellers to follow the same principles. In certain countries, a comprehensive overview of the model construct and its assumptions is already provided. The opening of energy modelling also encourages model-based learning to a broader group of stakeholders, and can enhance the deliberative aspect in decision-making.
- Emphasize the long-term impacts of decision-making. Long-term impacts of ecological, social and economic nature need to be made visible because short-term economic impacts are almost always measured. Because energy infrastructure is built for decades, long-term assessments can show a more relevant picture than short-term assessments. Cost-benefit analysis that measures short-term economic gains can lead to negative impacts in the long-term. Even if economists are allowed to debate about the specifics of an appropriate social discount rate, this is well elaborated in the Stern Report (2006).
- Energy models may have limited interdisciplinary linkages. Energy models do not investigate in detail the key emitting sectors such as the transport, constructions or food sector. Energy models also have limited connection with urban planners, even if cities are major sources of CO<sub>2</sub> emis-

- sions. Energy models also limitedly deal with normative issues such as political culture or dynamic issues such as consumer behaviour.
- Consider also the likelihood of unlikely events and the possibility of random events. Chernobyl and Fukushima disasters had a major impact in decision-making in energy policy across countries. What other "black swans", unforeseen events could lie in energy-related decision-making that have not been considered?

#### Key energy policy messages towards a low-carbon world

- The absolute changes needed are vast, and needed fast. World is increasingly investing in fos-sil-fuel infrastructure, while carbon emissions are growing at an unprecedented rate. This trajectory is unsustainable. IEA warned about a "lock-in effect" by 2017 already some years ago. Over 80 % of global energy consumption is fossil-fuel based, and around 75% of electricity production as well. From the climate change perspective, it is crucial to demonstrate the urgency and rate of change as well as the difference between absolute and relative figures.
- Use country case studies to demonstrate necessary steps towards an energy transition. Positive examples can be found from Germany (*Energiewende*), the rise of solar industry (China), legislation changes (California in the U.S.), waste to energy solutions (Austria), the employment of minihydro power plants with small environmental impacts (Chile), wind energy (Denmark), or the uptake of electric cars (Norway). Also, it should be noted that individual policy approaches in different countries do not exclude one another, but could rather prove complementary.
- Outline a list of necessary policy changes and their potential benefits. The scaling up of the renewable energy sector needs market development and visionary thinking. The RE sector would likely benefit from a comprehensive and supportive policy framework to create stability for the industry and incentives for the consumers. Modelling and understanding the impacts of policy choices beforehand as well as what obstacles need to be tackled is useful.
- Connect visions with structural changes, timelines and responsibilities. Local politics brings abstract issues close to citizens and makes them visible in cities and counties. Across European countries, campaigns are calling cities and counties for carbon-neutrality, demanding them to initiate an energy transition for a low- or no-carbon energy future. Visions can be made tangible in order to help local areas achieve and seek ways through which they can collaborate or compete with one another. Counties and cities are leaders in many climate change initiatives because of potential economic gains and an employment effect locally.
- Translate technical issues into common language. Bureaucratic language is an obstacle that can limit the ability of citizens to understand energy choices. For instance, notions such as public procurement or the technical details of energy choices are not a direct concern of citizens unless their actual significance is made understood. However, often these connections remain hidden. For instance, the creation of a coal-based power plant may seem like an appealing option before it is understood that in the long-term, fossil-fuel based energy generation can lead to other problems.

- Focus on market development. In Germany, the state has provided affordable low-interest loans with long payback periods for consumers, households and institutions to invest in renewable energy technologies as a part of *Energiewende*. In both developed and developing countries, the development of the domestic renewable energy market is important. Renewable energy solutions could be incentivised through schemes set by the government to stimulate demand *and* to address the needs of the poorest. Marketing and the provision of support services are important to make new products familiar to future consumers.
- Learn from past mistakes. In the past, countries failed in their renewable energy policy because of the uncertainty about future policies or costs. Feed-in tariffs (FiT) should be interpreted to signify only as the first policy step towards an energy transition. Predictability of the policy environment can safeguard investments into renewable energy and build trust for the renewable energy industry, surrounding industries and end-consumers.

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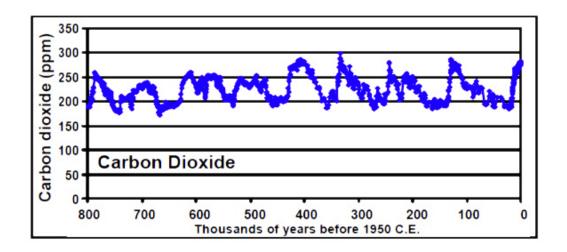
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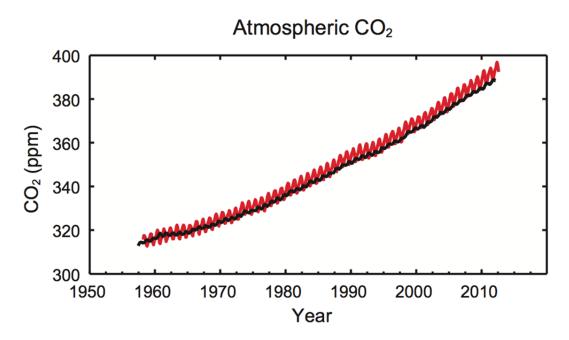
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# ANNEX 1: CLIMATE CHANGE: CO<sub>2</sub> CONCENTRA-TIONS IN THE ATMOSPHERE



Natural factors caused the carbon levels to fluctuate between 170ppm and 300ppm (parts per million) for over 800 000 years, as indicated by ice-core data. Source: Dome C 800,000-year record: European Project for Ice Coring in Antarctica (EPICA), D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, and T.F. Stocker, Figure available at: <a href="http://cdiac.ornl.gov/trends/co2/ice\_core\_co2.html">http://cdiac.ornl.gov/trends/co2/ice\_core\_co2.html</a>.



Carbon dioxide (CO<sub>2</sub>) concentrations have increased rapidly, resulting from the use of fossil fuels in the world economy, rising above any previously measured levels. Source: IPCC (2013, 11-12, Figure SPM.1), Figure available at: http://www.climatechange2013.org/.

## **ANNEX 2: LIST OF ENERGY MODELS**

Adapted from Herbst et al. 2012 and Unger 2010.

Model Used by Characteristics and geographical area Bottom-up energy models Partial equilibrium models **POLES** Prospective Outlook on Long-term Energy System model, by Enerdata, European Commission, analyses the international energy markets based on a simulation WEC process to react to international price changes, and technological and economic trends. POLES depicts 7 world regions, 11 subregions, 32 countries, and 40 technologies of power, including the final energy sectors. In 2014, POLES published energy scenarios until the year 2035. **WEM** World Energy Model is a mathematical model on a global and region-IEA al level. WEM can generate medium- and long-term sectoral and regional projections of energy demand and power generation. The model can also estimate investments, calculate CO2 content factors for coal, oil and gas for different sectors and regions as well as make demand projections for three scenarios. **PRIMES** PRIMES consists of 11 sub-models (demand- and supply-side European Commission modules) and can analyse the impacts of carbon emission trading and of renewable and energy efficiency policies on energy markets. PRIMES can simulate market equilibrium for energy demand and supply up to 2030 within each of the EU Member States. Compared to many other energy models, certain functions of PRIMES are not publicly documented. Optimisation models MARKAL MARKAL models the entire energy system (energy demand and Throughout in Western supply) with a bottom-up, dynamic modelling approach, employed countries on a country level, regionally and globally. Global TIMES models the entire global energy system (stationary and transports). MARKAL-Nordic is applied for Nordic countries. The model can be used to identify a least-cost energy system with cost-effective responses to emissions restraints. **EFOM** The Energy Flow Optimization Model is a supply-side energy model for Europe energy forecasting that simulates/optimises primary energy requirements and investments to meet a given energy demand. EFOM has been employed in Europe since the 1980s. TIMES The Integrated MARKAL-EFOM System (TIMES) is an evolution of European Commission

the MARKAL model with special features such as climate equations, commodity related variables, data decoupling, flexible processes, flexible time periods, and process generality. Global TIMES models like TIMES Integrated Assessment Model (TLAM) include a full

representation of the climate equations.

**MESSAGE** 

Model for Energy Supply Strategy Alternatives and their General Environmental Impact, developed by IIASA, can compute the evolution of the energy sector up to the year 2100. The model identifies socioeconomic and technological responses to energy challenges, and aggregates the world into 11 regions.

European Commission, IPCC, WEC

DIME

Dispatch and Investment Model for Electricity markets in Europe model is a linear optimisation model for medium- and long-term forecasting of the European electricity generation market. DIME covers 13 Central and Western European countries and 11 technologies.

Europe

#### Simulation models

**LEAP** 

Long range Energy Alternatives Planning System, developed at the Stockholm Environment Institute, is a widely-used software tool for energy policy analysis and climate change mitigation assessment. LEAP can be employed both from a bottom-up (households) and a top-down (energy consumption, production and resource extraction in all sectors of an economy) approach.

More than 190 countries, research institutions

LINDA Wilmar Long-range INtegrated Development Analysis, developed by Finland Futures Research Centre, is an Excel-based model, where the user gives the future annual sectoral growth rates and changes in energy intensities. Different modules describe labour demand, details of industrial sub-sectors et cetera. LINDA model is an accounting framework to produce information of energy use and emissions in different scenarios.

Lao PR, Thailand

REEPS

Residential End-Use Energy Planning System is a forecasting model of residential energy patterns capable to evaluate the impacts of a range of energy conservation measures (appliance installations, operating efficiencies, and utilization patterns for space heating, water heating, air conditioning, and cooking).

United States

#### Top-down energy models

#### Input-output models

**EEA** 

Environmental-Economic Accounting for Germany is provided from four topics: energy, raw material, emissions; private households and environment; transport and environment; and cross-section publications. The energetic input-output (I/O) analysis is used in the analysis of the energy sub-system. EEA is linked with the German national strategy for sustainable development and national sustainable development indicators.

Germany

**UNIO** 

*United Nations Input-Output Table Compilation* provides an analysis of industries and products. UN IO makes a breakdown of the production account, the goods and services account, and the generation of income account.

United Nations

**UN SEEA** 

The System of Environmental-Economic Accounting (SEEA) sets internationally agreed concepts, definitions, accounting rules and tables for internationally comparable statistics on the relationship of environment and the economy. Within SEEA, SEEA-Energy part accounts for the energy sub-system.

United Nations

#### Econometric models

E3ME

E3ME is a macro-econometric model (employment, gross value added, prices plus other economic, energy and environmental variables) that simulates GDP for all EU Member States.

Cambridge Econometrics

**NEMS** 

National Energy Modelling System is a regional economic and energy model, which models the U.S. energy markets 25 years into the future. NEMS is used to produce the Annual Energy Outlook, by projecting the energy, economic, environmental, and security impacts on the U.S. of alternative energy policies and different assumptions about energy market. Major assumptions influencing energy markets include economic growth and oil prices.

U.S. Department of Energy

#### CGE (Computable general equilibrium) models

**GTAP** 

Global Trade Analysis Project is a multi-region, multi-sector, computable general equilibrium model that models the entire macro-economy globally, based on input-output data. GTAP Consortium includes institutions such as ADB, European Commission, OECD, UNCTAD, World Bank and WTO

Intergovernmental and research institutions

GEM-E3

GEM-E3 simulates interactions of the economy, the energy system, the environment and the macroeconomic effects of environmental policies (taxes, standards, tradable permits).

European Commission

#### System dynamics models

**TIMER** 

The IMAGE Energy Regional Model analyses long-term trends in energy demand and efficiency and investigates a possible transition towards renewable energy sources. TIMER is based on an earlier TIME (Targets IMage Energy) model of long-term structural developments within the worldwide energy system.

The Netherlands

# ANNEX 3. METHODOLOGY OF DECOMPOSITION ANALYSIS.

Decomposition analysis of a change in CO<sub>2</sub> emissions explains the underlying causes of change. The decomposition approach for economic time series was introduced in the 1950s and from the 1980s. Decomposition analysis has been applied to especially in the field of energy economics. In recent years, decomposition analysis has been increasingly applied to explaining change in energy-related greenhouse gas emissions such as CO<sub>2</sub> emissions.

The objective of decomposition analysis in this article is to divide an observed change in CO<sub>2</sub> emissions into contributions of different factors of interest identified in Equation (1):

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP$$
(1)

In Equation (1), CO2 refers to carbon dioxide emissions from fuel combustion, TPES is total primary energy supply, FEC is final energy consumption, GDP is real gross domestic product, and POP is the amount of population. The contributions of the factors on the right hand side of Equation (1) will be calculated as shown in Equations (2a-2e):

$$\frac{CO2}{TPES} = (TPES_0 + \lambda_1 \Delta TPES_{t0}) \times \Delta \left(\frac{CO2}{TPES}\right)_{t0} (2a)$$

$$\frac{TPES}{FEC} = \left(\left(\frac{CO2}{TPES}\right)_0 + (1 - \lambda_1) \Delta \left(\frac{CO2}{TPES}\right)_{t0}\right) \times (FEC_0 + \lambda_2 \Delta FEC_{t0}) \times \Delta \left(\frac{TPES}{FEC}\right)_{t0} (2b)$$

$$\frac{FEC}{GDP} = \left(\left(\frac{CO2}{TPES}\right)_0 + (1 - \lambda_1) \Delta \left(\frac{CO2}{TPES}\right)_{t0}\right) \times \left(\left(\frac{TPES}{FEC}\right)_0 + (1 - \lambda_2) \Delta \left(\frac{TPES}{FEC}\right)_{t0}\right) \times (GDP_0 + \lambda_3 \Delta GDP_{t0}) \times \Delta \left(\frac{FEC}{GDP}\right)_{t0}$$

$$(2c)$$

$$\frac{GDP}{POP} = \left(\left(\frac{CO2}{TPES}\right)_0 + (1 - \lambda_1) \Delta \left(\frac{CO2}{TPES}\right)_{t0}\right) \times \left(\left(\frac{TPES}{FEC}\right)_0 + (1 - \lambda_2) \Delta \left(\frac{TPES}{FEC}\right)_{t0}\right) \times (DP_0 + \lambda_4 \Delta POP_{t0}) \times \Delta \left(\frac{GDP}{POP}\right)_{t0}$$

$$POP = \left(\left(\frac{CO2}{TPES}\right)_0 + (1 - \lambda_1) \Delta \left(\frac{CO2}{TPES}\right)_{t0}\right) \times \left(\left(\frac{TPES}{FEC}\right)_0 + (1 - \lambda_2) \Delta \left(\frac{TPES}{FEC}\right)_{t0}\right) \times \left(\left(\frac{TPES}{TPES}\right)_{t0}\right) \times \left(\left(\frac{TPES}{TPES}\right)_{t0}\right) \times \Delta POP_{t0}$$

$$\left(\left(\frac{FEC}{GDP}\right)_0 + (1 - \lambda_3) \Delta \left(\frac{FEC}{TPES}\right)_{t0}\right) \times \left(\left(\frac{GDP}{POP}\right)_0 + (1 - \lambda_4) \Delta \left(\frac{POP}{EMP}\right)_{t0}\right) \times \Delta POP_{t0}$$

$$(2e)$$

In Equations (2a-2e), parameters  $\lambda_1$ ,  $\lambda_2$ ,  $\lambda_3$  and  $\lambda_4$  refer to shares of corresponding joint effects (residuals) allocated to the two factors in each of the chained two-factor decompositions. Subscript 0 refers to the base year value and subscript t0 refers to a deduction of the base year value from the value at year t (target year).

The effect of CO<sub>2</sub>/TPES refers to the contribution of the change in CO<sub>2</sub> intensity of primary energy use to CO<sub>2</sub> emissions. In practice, change in CO<sub>2</sub> intensity is a result of several things. One of the most obvious is fuel switch, i.e. change from the use of one energy form to another with different carbon content (if any). Examples of significant switches include changes from fuels with a high carbon content such as coal or oil, to energy sources with a lower or zero carbon content such as nuclear power, renewables, or natural gas – and vice versa.

The effect of TPES/FEC refers to the efficiency of the energy transformation system, i.e. efficiency in transforming primary energy into different energy carriers such as electricity or heat. This can be influenced by e.g. a switch from fuel use to electricity use, or vice versa, or technological changes in fuel combustion such as a shift from separate heat and electricity production to combined heat and power production (CHP) or vice versa.

The effect of FEC/GDP refers to the energy intensity of the whole economy. This can be influenced by several factors, such as changes in the industrial structure from energy intensive to less energy intensive industrial branches, a shift from industrial production towards services in terms of GDP shares, or technological development inside energy-consuming fields of the economy.

The effect of GDP/POP refers to the amount of economic activity per capita which is influenced by economic growth and changes in the amount of population.

The effect of POP refers to changes in the amount of population brought about by changing birth and death rates as well as changes in international migration.

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