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THE ROLE OF ENERGY EFFICIENCY IN GLOBAL ENERGY SCENARIOS

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LIST OF SYMBOLS AND ABBREVIATIONS

BAT	Best available technology
CCS	Carbon capture and storage
CHP	Combined heat and power generation
CO_2	Carbon dioxide
EREC	European Renewable Energy Council
GHG	Greenhouse gases
Gt	Gigatonne
GtC	Gigatonnes of carbon
Gtoe	Gigatonnes of oil equivalent
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LED	Light-emitting diode
Mtoe	Million tonnes of oil equivalent
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoule
R&D	Research and development
RD&D	Research, development, and demonstration
SD	Sustainable development
TWh	Terawatt-hour
WEC	World Energy Council

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1 INTRODUCTION

Scenarios are stories about possible future development. They help to understand the future better and describe what kind of future we could have based on today's experiences and historical development. Some scenarios contain predictive elements, but usually the purpose of the scenario is not to forecast. (International Energy Agency 2003, 14-20). Scenario planning is used in many branches of science, for example, energy scenarios are used to explore future energy issues and things that could possibly affect the energy sector (Blomgren et al. 2011, 792; International Energy Agency 2003, 3; Nakićenović et al. 2000, 335). Many energy scenarios are created with the help of certain assumptions and theories, but some scenarios are more descriptive and thus more or less based on intuition (Nakićenović et al. 2000, 335).

Energy efficiency can be defined as 'an amount of energy used to produce some specified useful output through a process, product or service'. When energy efficiency increases, the same benefit can be achieved with a lower amount of energy. (Viinikainen et al. 2009, 56.) Efficient energy use has many advantages: it helps to reduce emissions, energy intensity and costs in energy sector (International Energy Agency 2010, 596; Teske et al. 2010, 181). Energy efficient technologies require less energy. For example, energy efficient washing machine uses less energy and water. (Teske et al. 2010, 181.) Without energy efficiency improvements, today's energy use would be much higher in many countries (International Energy Agency 2010, 596). Energy efficiency can also have an important role in different energy scenarios (Nakićenović et al. 2000, 334). It is especially important to scenarios with sustainable development targets because it can show the potential for energy demand and emission reductions (Jochem et al. 2000, 176; Nakićenović et al. 2000, 334).

The purpose of this thesis is to assess the role of energy efficiency in energy scenarios. This study focuses on global energy scenarios because global scale is more commonly used in energy scenarios than local scale and there are abundant documents available for analysing global energy scenarios. Many scenarios deal with energy issues by concentrating on energy related emissions and their reductions, but in this thesis the scenarios will be compared and assessed from energy efficiency's perspective. Specifically, the aim is to find out why energy efficiency is important to energy scenarios; how energy efficiency is presented in different scenarios; what kinds of scenarios include energy efficiency improvements; and what factors in scenarios can affect efficiency improvements. This thesis is related to the Cluster for Energy and Environment (CLEEN) Research Program on Efficient Energy Use (EFEU). It serves as supplementary background information for the Program's further research.

The paper is organised as follows. Chapter 2 describes the methodology of this study. Chapter 3 explains the most important types of scenarios. Energy efficiency and ways to increase it in different sectors are presented in Chapter 4. This chapter focuses on the sectors that are often mentioned in different energy scenarios such as; buildings, appliances, transportation, industry and power production. Chapter 5 presents the energy scenarios developed by different organisations and assesses the role of energy efficiency in those scenarios. Chapter 6 is a general discussion about the scenarios and Chapter 7 summarises the study and makes conclusions.

2 METHODOLOGY

There are different kinds of scenarios that can be used for various purposes, for example energy scenarios, emission scenarios, policy scenarios, global scenarios and scenarios for different countries or regions. This thesis concentrated and utilised global energy scenarios taken from various documents and reports from different organisations. Documentary collection and analysis were followed systematically and accordingly as follows:

2.1 Identification of suitable scenarios

From the array of different global energy scenarios developed by different organisations, nine scenario groups were considered as suitable for the study. The main sources of those scenarios were either publicly available on-line or printed reports from each considered organisation. The nine scenario groups were initially considered as candidate scenarios as they appeared to indicate some keywords or issues on energy efficiency. After thorough and careful reading of the nine scenario groups, bearing the purpose of finding answers to the set objectives, selection of the final and suitable scenarios were done accordingly.

2.2 Selection of the scenarios for analyses

Out of these nine groups of energy scenarios, five groups were selected as the main scenarios for analyses. These five scenario groups were:

- Two groups of scenarios by International Energy Agency (IEA): two scenarios from their publication *Energy Technology Perspectives – Scenarios and Strategies to 2050* and four scenarios from their publication *Energy to 2050 – Scenarios for a Sustainable Future*
- Scenarios by International Institute for Applied Systems Analysis (IIASA) and World Energy Council (WEC)
- Scenarios by European Renewable Energy Council (EREC) and Greenpeace International
- Scenarios by Shell International

Four scenario groups were not chosen for inclusion in the analysis for one reason or another. Scenarios by Intergovernmental Panel on Climate Change (IPCC) were left out because these scenarios mainly concentrate on emissions and are often called emission scenarios rather than energy scenarios. World Energy Outlook scenarios developed by IEA were left out due to unclearness in energy efficiency issues. Renewable energy scenarios by EREC were also left out because other scenarios that EREC has developed together with Greenpeace International present energy issues in more detail. Energy policy scenarios by WEC were left out because these scenarios concentrate too much on regional energy issues.

2.3 Analysis of the selected scenarios

The five scenario groups formed the main focus of analysis in terms of their importance, contents, role of energy efficiency and various factors for improving energy efficiency as well as factors that affect those efficiency improvements. The main purpose was to find out how energy efficiency is shown in those scenarios and to look for factors that affect the efficiency improvements. During the analysis, two important things were noticed. Firstly, there are different types of scenarios, for example business-as-usual type. Secondly, most of the scenarios focus on certain areas of energy efficiency such as efficient buildings or vehicles. Hence, different scenario types and energy efficiency in different sectors were presented in this thesis. Tables and graphs were given when necessary in order to ensure a better understanding and clarified description and characterisation of a given scenario.

3 SCENARIO TYPES

There are several ways to classify different scenarios types. This section presents the most common types of scenarios. Many of them are commonly used in energy scenario development but some less frequently used scenario types are also presented.

3.1 Qualitative and quantitative scenarios

Scenario analyses are often classified into qualitative or quantitative. The main difference between these two types is their emphasis on technology and economy and the development of social, political and cultural issues. Qualitative scenarios are developed with the help of creativity and intuition. (Söderholm et al. 2011, 1106.) These scenarios can also be called descriptive or narrative because they are based on storylines rather than numbers and modelling. Quantitative scenarios, however, are usually based on models and formal analyses. (Nakićenović et al. 2000, 335; International Energy Agency 2003, 22.) The development of different scenario sections, for instance energy demand, is usually presented numerically (International Energy Agency 2003, 22). Quantitative analysis is commonly used in energy scenarios, but sustainable energy scenarios are often qualitative because their storylines have many assumptions about the future and sustainability. Some energy scenarios contain features of both qualitative and quantitative analysis. (Nakićenović et al. 2000, 335-336.)

A significant benefit of qualitative analysis is that it underlines the strengths and weaknesses of scenarios. It also emphasises the difficulties in reducing emissions and is commonly used to supplement quantitative scenarios. (Söderholm et al. 2011, 1113.) Quantitative scenarios interest decision-makers more than qualitative scenarios because their description of policy actions is more credible and reliable (International Energy Agency 2003, 24). Quantitative scenarios also pay closer attention to economic issues and technology. However, an old fashioned approach to politics, institutions and governance is one of the major drawbacks of low-carbon quantitative energy scenarios. The other disadvantage of qualitative analysis is that, despite the detailed discussion of possible future development, the resulting futures often seem to be too similar to current situation. (Söderholm et al. 2011, 1107-1113.)

Quantitative scenarios are usually based on either top-down or bottom-up models (Söderholm et al. 2011, 1106). Bottom-up scenarios are technology driven, whereas economy and costs are the driving forces behind top-down scenarios. Because bottom-up models analyse different technologies in detail, they can describe energy system accurately. Unlike top-down scenarios, bottom-up scenarios do not pay attention to economic issues. Top-down models typically optimise the energy costs and try to find the cheapest combination of different energy forms. Technology and fuel costs, for example, have a huge impact on future energy system in top-down scenarios. Top-down models do not describe different technologies in detail. (Teske et al. 2010, 19.) The combination of the bottom-up and top-down models can also be used to form a mixed model (Söderholm et al. 2011, 1106).

3.2 Predictive, explorative and normative scenarios

Scenarios can also be classified into predictive, explorative and normative scenarios. Predictive scenarios answer the question ‘What could happen?’. The target of predictive scenarios is to forecast what is likely to happen in the future. These scenarios can help to prepare for future events and problems that could possibly arise. Predictive scenarios investigate how things could turn out if some specified event or development likely affects the future. These scenarios often assume that present trends could continue in the future and the role of historical development is also important. (Börjeson et al. 2006, 725-726.) Predictive analysis is not usually the best option for energy scenarios because the functionality of the scenario is typically poor in predictive approach (Söderholm et al. 2011, 1106).

Explorative scenarios answer the question ‘What can happen?’. These scenarios are often created in sets of several scenarios. Every scenario explores possible future events and development from its own point of view. Many global energy scenarios are explorative but such scenarios can also be created for different companies or organisations. Explorative scenarios can help to find out what could result from alternative developments or decisions. Explorative scenarios often give a useful basis for policymaking and strategies. (Börjeson et al. 2006, 727-728.) These scenarios also explore the way our actions affect the future (Söderholm et al. 2011, 1106). A major advantage of explorative scenarios is that they do not usually assume the continuity of present and historical trends but still help to prepare for possible future events (International Energy Agency 2003, 21).

Desirable future situations provide a framework for creating normative scenarios (International Energy Agency 2003, 16). Normative scenarios define exact goals for the future and describe how these goals could be reached (Börjeson et al. 2006, 728). Sustainable energy scenarios are often normative because they discuss how to achieve sustainable development goals, for example, lower greenhouse gas concentrations in the atmosphere (International Energy Agency 2003, 22; Nakićenović et al. 2000, 336). There are two types of normative scenarios: the first tries to reach the goals cost-efficiently without changing current system structure and the other is used if structural changes are needed in order reach the goals. The latter is often called backcasting mode. (Börjeson et al. 2006, 728-729.) Backcasting means 'working backwards from desirable future' and developing ways to find that future (Söderholm et al. 2011, 1106). The future targets cannot be reached if the current development continues (Börjeson et al. 2006, 729). Backcasting scenarios are the most common type of normative scenarios. Normative scenarios describe policy measures and other actions needed to achieve the desirable goals. (International Energy Agency 2003, 16-22.) One drawback of backcasting approach is that the targets can change and it therefore takes more time to achieve those targets (Börjeson et al. 2006, 729).

3.3 Business-as-usual type

Business-as-usual scenarios are also called baseline scenarios or reference scenarios (Nakićenović et al. 2000, 335; International Energy Agency 2003, 15). It is very usual to start creating energy scenarios by developing a business-as-usual baseline (Nakićenović et al. 2000, 335). This kind of scenario supposes that current policies and system structure remain unchangeable. Technological and behavioural development also stays on present state. Business-as-usual scenarios give a good background for discussion and a baseline for developing other scenarios. (Nakićenović et al. 2000, 335; Bourdaire 1999, 29.)

Business-as-usual scenarios estimate future development by assuming that historical trends will continue. It is possible that in short-term or medium-long -term scenarios this estimation will hold true quite well. But when time horizon grows longer the continuation of historical trends is more and more unlikely. Therefore long-term future plans should not be based on business-as-usual scenarios alone. (International Energy Agency 2003, 15.)

3.4 Global and regional scenarios and their time horizons

Energy scenarios can be used to examine local, regional or global energy development. Regional and global scenarios typically have different kind of time horizons. It is usual that long-term scenarios are global and short-term scenarios are either national or regional. Energy scenarios usually have long time frames because changes in energy sector happen slowly. The time horizons of energy scenarios can vary from few decades to a century or more. (Nakićenović et al. 2000, 334-352.)

4 ENERGY EFFICIENCY IN DIFFERENT SECTORS

Technologies, processes and services are more energy efficient if they use less energy to produce the same products or services (International Energy Agency 2011). Efficient energy use has many advantages: it reduces the amount of greenhouse gas emissions; helps reduce energy intensity and is cheaper than producing new energy (International Energy Agency 2010, 596; Teske et al. 2010, 181). Energy efficiency helps to reduce the fuel costs and need for investments in energy sector (International Energy Agency 2012). Energy efficiency can be increased in every part of energy value chain: energy production, distribution, use and end-use sectors (World Business Council for Sustainable Development 2011). End-use efficiency means efficient use of final energy in different sectors (Jochem et al. 2000, 175).

Most of the scenarios in this thesis mainly concentrate on end-use efficiency and sometimes on power production efficiency because information about those sectors is readily available. Hence, the thesis focuses on end-use efficiency and power production efficiency. For end-use efficiency, four energy intensive sectors are considered such as; buildings, appliances, industry and transportation. These sectors are commonly discussed in different scenarios and also have lots of opportunities for efficiency improvements. However, all sectors are not necessarily included in every energy scenario.

4.1 Energy efficiency in buildings and appliances

Buildings consume a great deal of total energy use. Heating, cooling, lighting and different kinds of appliances all consume energy in buildings. Energy efficiency of the buildings has a significant impact on the building sector’s energy consumption. Energy efficient buildings require less energy and help to reduce emissions from building sector. Lower energy consumption also means lower costs. Energy efficient buildings are well insulated and use efficient technology. (International Energy Agency 2008, 7-11.)

There are still problems in taking advantage of energy efficiency in building sector. Lack of information makes it more difficult to increase energy efficiency in buildings. Building owners, tenants, architects and engineers may not have enough knowledge of energy efficiency and thus fail to take advantage of it. People are often reluctant to spend money on expensive efficiency improvements, especially in rented buildings. (Jochem et al. 2000, 203.) They are unwilling to buy new, more efficient household appliances if the old ones are still functioning. (International Energy Agency 2010, 604).

Energy efficiency can be improved in many ways in the building sector. For example, heat transfer through windows, walls and roofs has a significant effect on the energy efficiency in buildings (Bekkeheien et al. 1999, 105). Energy demand can be reduced by installing better insulation of the building and a great increase in energy efficiency can be achieved by improving windows. Similarly, triple-glazed windows reduce heat losses. (Bekkeheien et al. 1999, 105; Teske et al. 2010, 183). Heat pumps also have quite an important role in increasing energy efficiency. Heat pumps can utilise the energy from air, water or ground with the help of refrigerant and use it for heating. (Bekkeheien et al. 1999, 106.) Cooling by heat pumps is a good way to improve the efficiency of air-conditioning. Another option is to change the refrigerant of the air-conditioner which improves the efficiency of the equipment. Inefficient household appliances should be taken out of use because these appliances produce a lot of waste heat which increases the need for cooling. Smart ventilation and efficient appliances reduce the need for air-conditioning and make it more efficient. (Teske et al. 2010, 189.)

Efficient lighting and appliances help to reduce the energy need of buildings and households (Teske et al. 2010, 181). Utilisation of daylight and smart use of additional lighting can easily increase the energy efficiency of a household. Inefficient light bulbs should be replaced with compact fluorescent lamps, which use 75% less energy and last much longer. Another efficient lighting alternative is LED-lamps. If more people used household appliances with energy label A++, significant amounts of energy could be saved and household efficiency would improve. Computers are often left on day and night, which is one reason for high energy consumption in offices. The efficiency of the building would improve a lot, if power managed computers and efficient monitors were used more. (Teske et al. 2010, 186-187.)

Technical standardisation would suit well for different energy consuming appliances and equipment (Jochem et al. 2000, 209). Strict and compulsory efficiency standards would take inefficient appliances out of use and evolve together with technical development. In addition, energy labels, for example EU energy label for household appliances, should be used more because the labels help people to choose more efficient appliances. (Teske et al. 2010, 210.) EU energy label classifies the appliances on a scale of A-G according to their energy use and uses colours from dark green (high energy efficiency) to red (low energy efficiency) to indicate the efficiency of devices (European Committee of Domestic Equipment Manufacturers 2012).

4.2 Energy efficiency in transportation

Fuel efficiency improvements play an important role in increasing the energy efficiency in transportation. A problem is that most people do not pay attention to fuel efficiency issues and only a few countries, for example Japan, have fuel efficiency standards for transportation. (Jochem et al. 2000, 181-204.)

Engine design, weight, aerodynamics and air-conditioning are the main factors affecting the fuel efficiency of cars. Vehicle’s energy efficiency decreases because of the heat losses in the engine and frictional losses in the power-train. (Bekkeheien et al. 1999, 101.) Reduction in vehicle weight increases fuel efficiency. There are also many technologies that can be used to improve fuel efficiency. Hybrid vehicles consume less fuel than ordinary cars. Electric vehicles, fuel cell vehicles and plug-in hybrid electric vehicles (combinations of hybrid and electric vehicles) are also efficient options for energy efficient transportation. (Teske et al. 2010, 198-203.) Engine preheating and heat retention, higher air content and higher compression ratio can also improve vehicle efficiency (Bekkeheien et al. 1999, 102).

Fuel consuming driving habits, inefficient engines and consumer’s preference for big cars make efficiency improvements more difficult (International Energy Agency 2010, 606-608). Ideally, people should travel more by train and bus because these modes of transportation are more efficient than cars and air transport. Efficiency standards would have a significant impact on technology improvements and making smaller vehicles more popular (Teske et al. 2010, 196-210.) Governments should regulate efficiency standards for cars, airplanes and other vehicles in order to increase energy efficiency. Old and inefficient vehicles often end up being sold in developing countries where many people cannot afford new vehicles. This makes it more complicated to improve energy efficiency in transportation sector. Vehicles should not be transported to developing countries, if they are more than five or six years old. (Jochem et al. 2000, 205-211.) Better logistics and route planning can also be a solution to energy efficiency improvements, especially in air travel (International Energy Agency 2010, 291).

4.3 Energy efficiency in industries

Industrial sector uses a great deal of energy in many countries, usually 30-40 % of the total energy consumption (Eichhammer 2004, 383). Industrial energy efficiency has increased a lot in recent decades but there is still a great potential for additional improvements (International Energy Agency 2010, 161). Energy efficiency can be increased by production improvement, optimisation of processes and using new, more efficient technologies and equipment (Watanabe 1999, 135). Significant efficiency improvements can be achieved by using best available technologies (BATs) (International Energy Agency 2010, 161). The European Commission has published BAT reference documents for many industries. Such documents help to find BAT solutions for industrial systems. (European commission 2008.)

Many industries are very energy intensive. That is why it is very important to use energy efficiently. Heat losses can be reduced by using heat recovery and better insulation materials reduce the need for cooling. Using light and less energy-intensive materials, for example plastic and wood also requires less energy. Combined heat and power production (CHP) has a lot of potential for primary energy savings, especially in the chemical industry, in the pulp and paper industry and in the food industry sector. Efficient industrial appliances such as boilers and motors help to improve the overall energy efficiency. Another option is to improve the maintenance and operation management so that existing technologies can function efficiently. (Eichhammer 2004, 388-393.)

There are still some problems in implementing of energy efficiency measures in the industrial sector. For example, lack of knowledge and technical skills makes improving energy efficiency more difficult because people do not understand the advantages of it. Even if a company has enough knowledge on energy efficiency, it might not have enough money for investments. Likewise, installing energy efficient devices may be difficult if a company lacks properly trained staff. For CHP, high costs for maintenance is a primary disadvantage. (Eichhammer 2004, 389-391.) Increasing industrial energy efficiency is also more difficult in developing countries where machineries and equipments are, in many cases, less modernised if not obsolete and environmental regulations are less strict compare to developed countries (International Energy Agency 2010, 180-181).

4.4 Energy efficiency in power production

New power plants are usually more efficient than the old ones. Power production efficiency can therefore be increased by improving older plants. Sometimes inefficient power plants can even be closed down in order to increase energy efficiency. Installation of new efficient devices also increases energy efficiency. (International Energy Agency 2010, 115.) For example, more efficient boilers, turbines and other equipment help to save energy and reduce the amount of waste heat in power plants (Hordeski 2011, 172).

A good design of the power systems and use of efficient technologies help to achieve higher efficiency in power production. For example, the efficiency of a gas turbine power plant can improve significantly if the hot exhaust gases are utilised in steam production. Efficient combustion technologies such as fluidised beds burn the fuel more efficiently. Fluidised bed combustion is also suitable for CHP. Moreover, cogeneration of heat and electricity increases the total efficiency of the plant. (Hordeski 2011, 172-174.)

Energy demand affects the power production because more energy needs to be produced in the daytime and less in the night when energy demand is lower. If energy demand were more constant around the clock, power plants would be able to produce energy at more efficient capacities. (Hordeski 2011, 160.) Smart grids increase the flexibility of energy distribution and help to find balance between energy generation and demand. Therefore these grids can help to achieve energy efficiency targets. (International Energy Agency 2010, 141.)

5 ENERGY EFFICIENCY IN GLOBAL ENERGY SCENARIOS

5.1 Scenarios by IEA

The IEA publication *Energy to 2050 – Scenarios for a Sustainable Future* presents two types of energy scenarios: three explorative scenarios and one normative scenario. The three explorative scenarios are called Clean but not sparkling, Dynamic but careless and Bright skies. The total primary energy demand will increase in all scenarios despite of the energy efficiency improvements. The scenarios differ in the attitude towards environment and in the pace of technological change. The normative scenario is called SD vision scenario, where SD stands for sustainable development. (International Energy Agency 2003, 3-112.) The last two scenarios forwarded by IEA are called the Baseline scenario and the Blue map scenario. These scenarios were presented in IEA publication *Energy Technology Perspectives* 2010 and are based on earlier IEA scenarios presented in *Energy Technology Perspectives* 2008 and *World Energy Outlook 2009*. (International Energy Agency 2010, 70.)

5.1.1 Clean but not sparkling

In this scenario, technological change is slow and concern for the environment is high. Both public and policymakers are worried about environmental issues, but they do not think that the problems can be solved by technological change. Although concern for the environment leads to increasing demand of clean and efficient technologies, the pace of technological development is slow. Existing technologies improve only a little, but energy efficiency improvements can be achieved with the help of policy measures and more efficient lifestyles. Because of the slow technological development, environmental targets can only be achieved through behavioural changes. (International Energy Agency 2003, 65-67.)

Between years 2000 and 2035 people will start to pay more attention to environmental issues in developed countries. Their concern for climate change will encourage the governments to develop more ambitious climate and energy policies. Policy measures include emission trading, taxes on fuel use or energy consumption and different standards or regulations. Demand for environmentally friendly products will encourage businesses and industries to improve energy efficiency and reduce emissions. Energy conservation, low-carbon fuels and the use of efficient technologies will have a great importance in this scenario. (International Energy Agency 2003, 67-68.)

Lifestyle changes and reductions in energy intensity during the first 35 years in the scenario will help developed countries to achieve significant environmental benefits. Efficiency standards on appliances and vehicles will help to improve energy efficiency in households and transportation. A significant amount of energy will be saved in households due to environmentally friendly behaviour and energy efficiency. Inefficient vehicles will be taken out of use and fuel efficiency standards will help to improve vehicles' performance. A great improvement in aircraft fuel efficiency will be achieved by using lighter construction materials. More renewable energy and natural gas will be used in the power sector and investments for research and development (R&D) of their efficiency will be made. The price of the energy will increase because of the expensive efficiency improvements in power productions systems. Coal fired power plant will become better in developing countries. (International Energy Agency 2003, 68-76.)

Between years 2035 and 2050 productive activity will become less energy intensive in developing countries. Energy demand will decrease in developed countries, mainly due to efficient end-use technologies. Efficient diesels, hybrids and fuel-cell vehicles will consume less oil and most people will use public transport. Because of efficient technologies and behavioural changes, the amount of greenhouse gas (GHG) emissions will start to decrease in 2040. (International Energy Agency 2003, 76-77.)

These IEA scenarios do not contain much numerical information. That is why it is hard to know how much energy can be saved through energy efficiency improvements or how much energy efficiency can be attained per year. However, these scenarios tell how energy efficiency is affected by technological development and the people's attitude towards the environment. Efficiency improvements in this scenario result from strong will to protect the environment by reducing energy consumption and GHG emissions. Energy efficiency increases through policy measures and lifestyle changes. Because technological development is slow, new and efficient technologies cannot easily be used to improve efficiency. However, the slow rate of technological change does not prevent efficiency improvements from happening. People use existing technologies, take inefficient devices out of use and pay attention to their own behaviour to improve energy efficiency.

5.1.2 Dynamic but careless

In this scenario, technological change is very active but the concern for the environment is low. People think that rapid technological development will solve all problems without any policy measures. Both developed and developing countries concentrate on economic growth. Climate change and other environmental problems are not left aside but actions to prevent them are only taken at the local level. People have more money to spend because of the economic growth, which results in energy consuming lifestyles. (International Energy Agency 2003, 78-79.)

In the first decade of this scenario, energy generation is mostly based on fossil fuelled power plants in both developing and developed countries. Demand for fossil fuels grows. People have inefficient lifestyles: households usually have only one or two members, apartments are bigger and people have lots of energy consuming electrical equipment. Cars become faster and bigger and their fuel efficiency increases at the same time. However, more and more people favour small city cars because these cars are easier to handle and park. Small cars are also much more efficient than bigger cars. Air travel increases in developing countries and fuel efficiency improves in both developing and developed countries. (International Energy Agency 2003, 78-83.)

Between years 2015 and 2030 oil supply will become more and more difficult. Because of the strong oil demand, the oil industry will try to find new ways to extract oil cost effectively. Some countries will be strongly dependent on imported gas and oil. The most important technology options to reduce energy dependence in this scenario will be coal gasification and liquefaction, technologies to use oil from deep deposits or from unconventional sources and efficiency improvements in energy transformation and end-use sectors. (International Energy Agency 2003, 84-85.) Unconventional oil sources will include oil shales, heavy crude oil and tar sands (Rogner et al. 2000, 141). Most of the energy efficiency improvements will concentrate on technologies that use oil products, gas or electricity. Eventually, efficiency will start to increase in all demand sectors. By 2025, fuel-cell cars will be commonly used in developed countries and fuel-efficiency of the hybrid vehicles will improve. (International Energy Agency 2003, 86.)

Reliance on fossil fuels will result in increasing levels of GHG emissions. Environmental issues, for example air pollution, will start to concern people. The use of renewable energy will evolve more and nuclear power will offer a solution for energy production without local pollutants. Fuel-cells will also be a rather clean option for electricity or heat production, but more efficient ways to produce and store hydrogen for them would be needed. Energy efficiency will start to increase rapidly after 2025 and great improvements are foreseen to be achieved by 2040. Although the emissions will be much higher in this scenario than in the first one, rapid technological development will be seen to help reduce emissions quickly. (International Energy Agency 2003, 88-90.)

In this scenario, people and policymakers are seen not to be caring about energy efficiency until the problems with oil supply arise. Energy efficiency improvements are just unavoidable measures to reduce dependence on gas and oil. Fast technological development makes efficiency improvements possible. Energy efficiency cannot be increased by behavioural changes because people are not worried about the environment and continue their energy consuming lifestyles. When people start to pay more attention to environment and emissions, they also realise that efficiency improvements can help to reduce emissions and energy consumption.

5.1.3 Bright skies

Bright skies is a scenario of fast technological development and strong concern for the environment. Both public and the governments pay attention to climate change and other issues concerning the environment. Developed countries agree to start fighting against climate change and developing countries will join the process later. Environmentally friendly behaviour and demand for products with low environmental impact are some of the main characteristics of this scenario. (International Energy Agency 2003, 90-91.)

New policies in developed countries will be created to spur emission reductions and technological development. These policies will include short-, mid- and log-term actions. The aim of the short-term policies will be to reduce energy consumption and increase energy efficiency with the help of taxation, emission trading and efficiency standards on buildings, vehicles and appliances. Mid-term measures will tighten the regulations, encourage the shift to more environmentally friendly fuels and improve existing technologies. The most important long-term policy target will be the reduction of GHG emissions. (International Energy Agency 2003, 90-93.)

In this scenario, people prefer products and services that have low emission levels and that are not material or energy intensive. This will encourage businesses to manufacture efficient devices and cars and to design more efficient buildings. The market for environmentally friendly products will be blooming. Low or zero carbon fuels will increasingly be used in power production. GHG emissions from the power production will increase, despite the efficiency improvements in fossil fuel use. At first, energy demand will also increase, although the efficiency of electric devices will significantly improve in both households and industry. Efficiency improvements in transportation sector will be achieved because more and more people choose to walk or use bicycle and do not necessarily have a car of their own. In addition, improvements in fuel efficiency and vehicle efficiency will have a significant impact on the overall efficiency improvement. As a result of all these measures, both energy demand and emission levels will finally start to decrease. (International Energy Agency 2003, 93-95.)

Developing countries will also agree to reduce their emissions. Old, polluting power plants will be replaced with more efficient ones. Renewable energy will be utilised increasingly and extremely efficient power plants will be used, if coal is the only fuel available. Market for efficient and clean technology will spread to developing countries and people will learn how to take advantage of the technology improvement. Economic growth will lead to growing emission levels and energy demand. (International Energy Agency 2003, 96-97.)

Between years 2025 and 2050, technological development will continue. Developed countries will lead the actions to reduce global emissions and start to develop more low and zero emission options for electricity production and transportation. Efficient power production will be very important especially when electricity is increasingly used as a source of energy. Renewable energy will become cheaper and more efficient. CO_2 emissions from transportation will decrease thanks to significant efficiency improvements in fossil fuel powered vehicles. Hydrogen fuel cells will develop a lot in this scenario and the development of efficient ways to store hydrogen continues. By 2050 many countries will be industrialised, which makes new efficient technologies affordable to more and more people. (International Energy Agency 2003, 98-100.)

In this scenario, energy efficiency is a part of everyday life. Assumptions about rapid technological change and strong concern for the environment lead to policy measures and lifestyles that improve energy efficiency right from the start. Environmental awareness is high and people know that they can reduce emissions and energy consumption by choosing efficient devices, cars and buildings. The rate of efficiency improvements is higher in this scenario than in the other explorative scenarios because it contains the characteristics of sustainability.

5.1.4 A normative scenario: SD vision scenario

SD vision scenario is a normative scenario with sustainable development targets. The main targets of this scenario are to mitigate climate change, to give access to electricity to 95 % of the world's population and to increase energy security (International Energy Agency 2003, 111-119). Energy security means that different forms of affordable energy are continuously available to use (Khatib et al. 2000, 112). This scenario mitigates climate change by setting a target of 60 % zero carbon energy sources in the world by 2050. Policy measures and technological development guarantee energy security. (International Energy Agency 2003, 114-120).

Both public and the government have a strong will to achieve the goals in this scenario. Policy measures and energy efficiency improvements in everyday life will lead to decreasing energy demand. In the SD vision scenario, global energy intensity falls about 1.5 % per year. Emission reductions will be important part of the policy measures. One way to reduce emissions in this scenario will be the implementation of carbon capture and storage. CO_2 emissions will start to decrease in 2030 and the in 2050 emissions will be at the same level as in 2010. Economic growth will be rapid in this scenario, especially in developing countries. Both environmental and energy policies will be developed in such way, that the policy measures will not slow down the economic growth. (International Energy Agency 2003, 123-138.)

The best way to increase power production efficiency in this scenario will be to improve fossil fuel usage in power plants. Because energy efficiency levels for such plants are usually below 40 %, it would be important to increase energy transformation and end-use efficiency to reduce energy demand and the need for fossil fuelled power plants in the first place. Power plant efficiency will be increased in many ways in this scenario. Gas turbines, combines cycles and pulverised coal power plants are very efficient. Technologies that use fossil fuels as a source of energy will also improve in industries, buildings and transportations. Environmental and energy policies, standards, taxes and other measures mentioned in the three explorative scenarios will help to reduce the use of fossil fuels in the industrial sector. For the building sector the SD vision scenario suggests efficiency standards and better building design. Additionally, solar energy and stationary fuel-cells will be used to replace fossil fuels in heat and energy production of the households. In the transportation sector the efficiency of public transport will increase. Other ways to increase energy efficiency in transportation are similar to those in other scenarios. (International Energy Agency 2003, 148-152.)

The SD vision scenario is target oriented and the main target is to reduce global energy related emissions. Energy efficiency is used to reduce emissions and it helps to achieve sustainable development targets. Global energy efficiency will increase because energy intensity improves. Efficiency improvements will be achieved in different sectors. The SD vision scenario does not highlight the importance of energy efficiency, but it is clearly one of the best ways to reduce emissions, especially in fossil fuelled power plants.

5.1.5 The Baseline scenario

The Baseline scenario is a business-as-usual scenario and works as a baseline for the Blue map Scenario. It describes what will happen in the future if current energy and climate policies remain unchangeable. The Baseline scenario also has two variants: one for industry and one for transportation. Both scenarios are called High Baseline, since these scenarios assume higher growth in industrial production and vehicle ownership in developing countries, vehicle travel and freight transport. (International Energy Agency 2010, 68–70.)

In the Baseline scenario energy related CO_2 emissions in 2050 would be 57 Gt, which is almost twice the level they were in 2007. Primary energy need will rise totally by about 84 %. Energy efficiency gains in technology will slow down the growth in energy use, but primary energy need still rises. The demand for fossil fuels will grow significantly. Final energy demand in 2050 will be about 14500 Mtoe in the Baseline scenario, which is around 45 % higher than in Blue map scenario. However, final energy demand would be notably higher without energy efficiency improvements. Energy efficiency will improve 0.7 % per year in the Baseline scenario. (International Energy Agency 2010, 48–90.)

Energy demand in buildings will rise by 60 % in the Baseline scenario. Efficient use of biomass will decrease the demand for energy in the building sector. Industrial energy use will increase and in transportation sector energy use almost doubles between years 2007 and 2050 because of the growth in transport activity. Fuel economy will improve by 25 %. In addition, aircraft efficiency will improve by 30 % and truck efficiency will increase. Because the transport activity will grow, energy use will increase despite the efficiency improvements. Electricity demand will increase from 16 999 TWh to 42 655 TWh between 2007 and 2050, regardless of great efficiency improvements. (International Energy Agency 2010, 81–265.)

The Baseline scenario only gives information about certain values and numbers, for example the growth in energy demand or increases in CO_2 emissions. It is created to form a baseline for the Blue map scenario and only used for comparison. This is the reason why the Baseline scenario does not give detailed information about energy efficiency improvements and other things that affect the scenario results. The result itself is more important for the comparison than the way how to get to the result. The Blue map scenario describes energy efficiency and such in more detail because it needs to show how to get better scenario results than the Baseline scenario.

5.1.6 The Blue map scenario

The Blue map scenario is target oriented and its main goal is to halve global energy related CO_2 emissions by 2050. Blue map scenario has several variants: four for the electricity sector, three for buildings, two for transportation and one for industry. (International Energy Agency 2010, 47-69.)

In the Blue map scenario, global energy related CO_2 emissions in 2050 will be 14 Gt, which is 43 Gt less than in the Baseline scenario and about half of the emission level in 2005. Energy efficiency will have a significant role in the emission reductions. New and efficient technologies in different sectors and end-use efficiency improvements especially in fuel use, industry and power sector will be the most important factors affecting the emission reductions. In the Blue map scenario, end-use efficiency improvements will help to reduce CO_2 emission by 38 % between years 2007 and 2050. Figure 1 presents the CO_2 emission reductions by technology area. (International Energy Agency 2010, 48-76.)

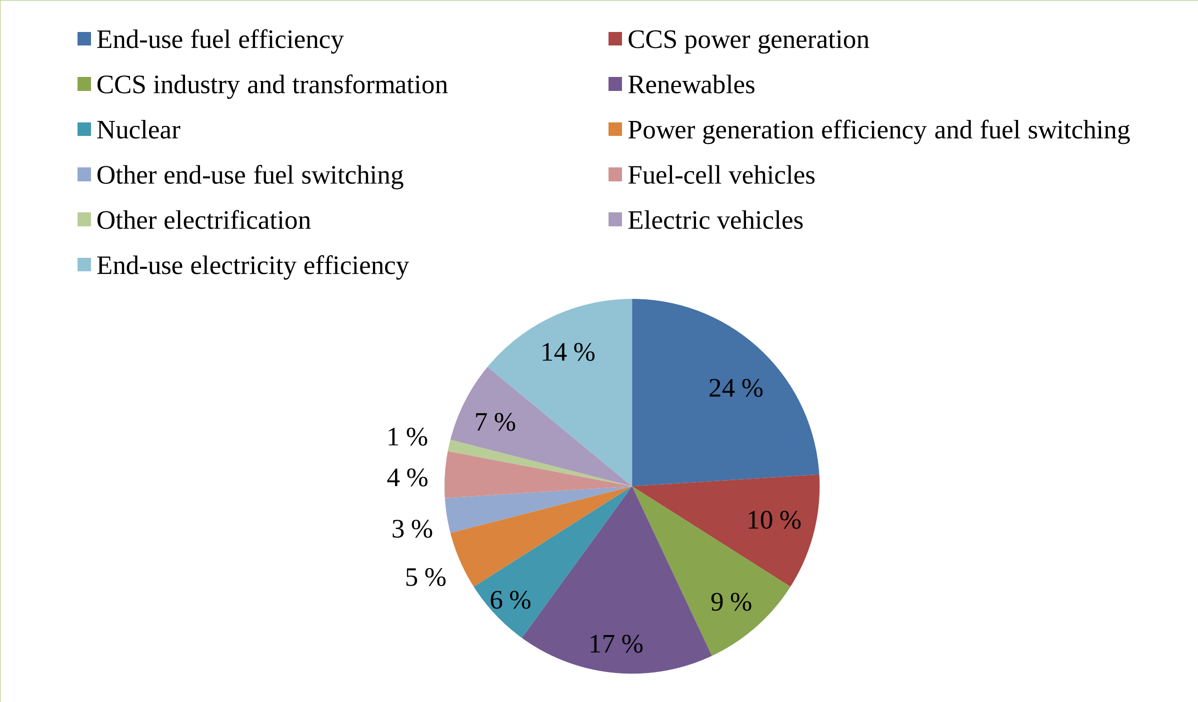

Figure 1. CO2 emissions reductions in the Blue map scenario (International Energy Agency 2010, 76).

Primary energy demand will be significantly lower in the Blue map scenario than in the Baseline scenario. CO_2 emissions from the power sector, buildings and industry will fall significantly and energy efficiency will be one of the most important contributors to reductions. In supply and demand sector, energy efficiency improvements will have the main role in reducing emissions. Final energy demand will be 31 % lower in the Blue map scenario than in the Baseline scenario. The most of the reductions will occur in the buildings and transport, where potential for energy efficiency improvements is high. Globally energy efficiency will improve 1.5 % per year in the Blue map scenario. (International Energy Agency 2010, 48-89.)

In the Blue map scenario, emissions from the building sector will be 83 % lower than in the Baseline scenario. Energy efficiency, along with low-carbon electricity and technologies, will have a significant effect on the emission reduction. Building efficiency will improve because of high efficient technologies, air-conditioning and ventilation systems, lighting and efficient use of electricity. Improvements in insulation and building shell design will account for 22 % of the total emission reduction from building sector. Efficient lighting and appliances will account for 32 % of the emission reduction. The Blue map scenario assumes the introduction of tight energy efficiency standards for buildings. It also assumes that appliance and lighting efficiency standards will become better. Heating equipment and air-conditioners will be efficient and not too expensive. In the Blue scenarios efficient heat pumps will be commonly used for both heating and cooling. A Blue map scenario variant, Blue Heat Pumps, assumes the use of extremely efficient heat pumps for cooling. Efficient heat pumps can reduce emission from building sector by 22 %. Efficient water heating systems, such as solar energy, CHP and heat pumps, will also help to reduce emissions and increase the energy efficiency of buildings in the Blue map scenario. Table 1 shows the potential for energy efficiency savings and the need for policy actions in building sector in the Blue map scenario. (International Energy Agency 2010, 205-231.)

Table 1. Potential for efficiency savings and the need for policy actions in the building sector (International Energy Agency 2010, 219).

	Overall energy efficiency savings potential	Policy urgency
Lighting	Medium	Average
Appliances	Large	Average
Water heating systems	Medium to large	Urgent
Space heating systems	Medium to large	Urgent
Cooling/ventilation systems	Medium to large	Urgent
Cooking	Small	Average

Energy efficiency improvements and reduction in electricity demand will account for approximately one third of the emission reductions in industry. Although industrial energy efficiency will improve a lot, industrial energy use will still rise. Compared to 2007, industrial energy use will be 31 % higher in the Blue map scenario and 48 % higher in the Blue scenario variant, the Blue high-demand scenario. Use of carbon capture and storage (CCS) will reduce emissions, but will also reduce energy efficiency and offset some savings that otherwise would have been achieved. Both the Blue map scenario and the Blue high-demand scenario will achieve energy efficiency improvements in iron, steel and aluminium industries, cement industry and chemical sector. (International Energy Agency 2010, 167-194.)

Efficiency improvements will help to reduce emissions also in transportation sector by reducing the energy demand of the vehicles. New vehicle technologies, such as fuel-cell vehicles, electric vehicles and hybrids, will become more efficient. One of the Blue scenario variants for transportation, the Blue Shifts scenario, assumes a shift towards more efficient travelling options, for example rail transport. In truck transport energy efficiency will improve by 40 % and in rail transport by 25 %. Passenger transport efficiency will increase more than freight transport efficiency. Air-transport efficiency will improve by 43 % between years 2007 and 2050. Energy efficiency improvements in the power sector and all end-use sectors will be equally important in the Blue map scenario. Electricity demand will reduce due to end-use efficiency improvements. Power production efficiency improvements, lower electricity demand, fuel switching and low-carbon technologies will reduce the emissions from power sector by 1.9 Gt. Because new power plants are often more efficient than the old ones, the Blue map scenario assumes the closure of the most inefficient old plants. (International Energy Agency 2010, 55-277.)

In the Blue map scenario, successful implementation of efficiency improvements will require policy measures and initiatives and R&D of energy efficiency technologies. Standards, regulations, energy labelling and information campaigns will help to improve efficiency and will be especially useful for end-use efficiency improvements because policy measures can lead the consumers to choose energy-efficient technologies. (International Energy Agency 2010, 71-602.)

The Baseline and the Blue map both focus on energy related CO_2 emissions and how to reduce these emissions. In these scenarios energy efficiency improvements are used to reduce energy consumption and especially emissions. The scenarios tell how much emission reductions can be achieved by increasing energy efficiency. The Blue map scenario also includes detailed information about energy efficiency improvements in different sectors, especially in transportation sector and buildings. The Blue map scenario contains a lot more numerical information about energy and emissions than the other IEA scenarios. It tells how much energy efficiency improves in different areas of end-use efficiency. The Blue map scenario highlights the importance of energy efficiency, because most of the CO_2 emission reductions are achieved with the help of efficiency improvements.

5.2 Scenarios by IIASA and WEC

IIASA and WEC have developed three scenario cases with the help of top-down and bottom-up models. The three cases are called Case A (high growth), Case B (middle course) and Case C (ecologically driven). Scenario variants for cases A and C have also been developed: scenarios A1, A2, A3, C1 and C2. All scenarios have some common features. The time horizon of the scenarios starts from the year 1990 and extends to the year 2100. Energy efficiency will increase steadily and energy intensity will improve all over the world due to technological development. End-use efficiency improvements will decrease energy intensity and have a significant role in emission reductions. (Grübler et al. 1996, 237-257; Nakićenović et al. 1998, 1-35.) Better fuels and power plants, lower energy consumption and behavioural changes will also have a positive effect on energy intensity. Changing inefficient energy forms for commercial energy will improve energy intensity in developing countries. Historical development and different circumstances will have a significant impact on energy intensity improvements in different countries. (Nakićenović et al. 1998, 35-42.) Primary energy need will increases in all cases, Case A having the highest growth rate (Grübler et al. 1996, 249). Economic growth is the driving force behind the improvement on energy intensity. The development of new, efficient technologies will require investments in research, development, and demonstration (RD&D). (Nakićenović et al. 2000, 340-348.) The following chapters present the different scenario cases and their characteristics.

5.2.1. Case A

Case A scenarios are characterised by high economic growth and fast technological development. High economic growth will accelerate the energy efficiency improvements and technological change. (Grübler et al. 1996, 239.) Efficient technologies will help to improve energy intensity (Nakićenović et al. 1998, 71). Case A includes three scenario variants called A1 (clean fossils), A2 (dirty fossils) and A3 (bio-nuc). (Grübler et al. 1996, 239-241.) The three variants are similar to each other in energy end-use but different in energy systems (Nakićenović et al. 1998, 71).

Scenario A1 (clean fossils) does not rely on coal or nuclear power. Rapid technological development will enable the use oil and gas from both conventional and unconventional sources. Fossil fuels will dominate, accounting for a half of primary energy consumption in 2100. (Grübler et al. 1996, 239-253.) Because there are enough oil and gas resources left, the energy structure can easily be shifted to nuclear power and renewable energy over the next century (Nakićenović et al. 1998, 8). Scenario A1 also assumes that technological change helps to reduce emissions and improve energy efficiency. Scenario A2 (dirty fossils), has very low concern for the environment. Oil and gas resources are running out, which will lead to increasing use of coal. However, problems will start to arise as deep and remote coal resources are difficult to exploit. (Grübler et al. 1996, 239-253.) Coal production will become more and more expensive and new technologies will be needed so that coal can be mined and refined. Scenario A2 will have severe environmental impacts. (Nakićenović et al. 1998, 73-125.) Because fossils fuels are commonly used in scenarios A1 and A2, energy related emissions will be high in these scenarios (Nakićenović et al. 2000, 334).

Scenario A3 (bio-nuc) is a technology intensive scenario that favours renewable energy and new generation nuclear power. The use of fossil fuels will start to decrease early in this scenario. (Nakićenović et al. 1998, 73-76.) Technological development will accelerate the transition to a time when fossil fuels are no longer used. (Grübler et al. 1996, 241.) Clean and efficient fossil fuel technologies and the implementation of CCS will be the main contributors of this change (Nakićenović et al. 2000, 347). Natural gas will be the most important transitional fuel. By 2100, fossil fuels will account for 30 % of primary energy consumption. (Grübler et al. 1996, 239-253.) Renewable energy, technological development and economic growth together will help this scenario achieve sustainable development goals. Policy measures, lifestyle changes, end-use efficiency and reduction of CO_2 emissions will all help to protect the environment. Energy efficiency will reache very high level in this scenario. (Nakićenović et al. 2000, 334-364.)

Energy intensity will improve 1.0 % per year in the Case A (Grübler et al. 1996, 244). Energy intensity will improve, because energy efficiency will increase and inefficient technologies will bee replaced with more efficient ones (Nakićenović et al. 2000, 343). In Case A energy efficiency will improve when inefficient power plants will be taken out of use. New technologies will increase the efficiency of gas-fired power plants to 50 % and thermal efficiency of coal-fired power plants will improve to 40 %. (Nakićenović et al. 1998, 87.) Energy production from hydrocarbons, nuclear power, hydrogen and renewable sources will develop and end-use technologies will become more efficient. Primary energy growth will be the highest in Case A and lower in Cases B and C. In Case A, primary energy demand will be 25 Gtoe in 2050 and 45 Gtoe in 2100. (Grübler et al. 1996, 238-249.) CO_2 emissions will be 9-15 GtC (gigatonnes of carbon) in 2050 and 7-22 GtC in 2100, depending on scenario variant (Nakićenović et al. 2000, 338).

Concerns for the environment and the rate of technological development have a significant effect on energy efficiency improvements in IIASA-WEC scenarios. If technological development is rapid, more efficient technologies will be developed and higher levels of energy efficiency can be achieved. IIASA-WEC scenarios do not tell how much energy efficiency improves but the improvement in energy intensity reveals that energy efficiency must also increase. Scenario A3 has a very high level of energy efficiency. Strong concern for the environment and characteristics of sustainability accelerate the technological development and policy measures that help to increase energy efficiency. Consumers favour environmentally friendly technologies which help to increase end-use efficiency in Scenario A3. In Scenario A1, energy efficiency increases only due to fast technological development. Scenario A2 does not mention energy efficiency at all because technological development concentrates on the utilisation of coal resources and concern for the environment is low.

5.2.2 Case B

Scenario B works as a reference scenario for cases A and C (Nakićenović et al. 2000, 334). Economic growth and technological development are slower but also more realistic than in the other scenarios. Energy system structure and end-use are also similar to today’s situation. (Nakićenović et al. 1998, 9.) Scenario B fails to achieve sustainable development goals (Nakićenović et al. 2000, 334). It favours fossil fuels, even though it is not as coal intensive as Scenario A2. Oil and gas from conventional and unconventional resources will be the main energy sources up to 2070. In 2100, renewable energy and nuclear power will be used in addition to fossil fuels. (Nakićenović et al. 1998, 9-73.) Moderate technological development will complicate the utilisation of decreasing fossil fuel resources and there will also be problems with financing the use of unconventional oil. Technological development is less rapid than in Case A due to less advanced research and development. Existing technologies will improve but new technologies for energy production will not be developed. Environmental problems start to arise because of the use of fossil fuels. Global energy intensity will also improve in Scenario B, but the improvement rate is quite low: 0.8 % per year. Primary energy demand will be lower than in Case A, being 20 Gtoe in 2050 and 35 Gtoe in 2100. (Grübler et al. 1996, 238-253.) CO_2 emissions will be 10 GtC in 2050 and 14 GtC in 2100 in this scenario (Nakićenović et al. 2000, 338).

Because technological development is quite slow and energy intensity does not increase a lot, energy efficiency improves only a little in this scenario. Because Case B is a reference scenario, it does not concentrate on efficiency improvements that would help to reduce emissions and improve energy intensity.

5.2.3 Case C

Ecologically driven Case C includes two scenarios with sustainable development targets (Nakićenović et al. 2000, 363). The rate of technological development is high and new innovations are made to solve the environmental problems (Grübler et al. 1996, 241). Case C assumes that strong international cooperation helps to protect the environment. Carbon emission reductions will be achieved through taxes and other political measures. (Nakićenović et al. 2000, 346-347). Thanks to policy measures and new technologies, energy producers and consumers will start to take notice of more efficient use of energy (Nakićenović et al. 1998, 9). Emissions will be controlled locally and regionally and a global control system will be established. The world will start shifting away from fossil fuels. Renewable energy and low-carbon fossil fuels will be used to produce energy and end-use efficiency will be high. By 2100, renewable energy will account for more than 80 % of world energy use. (Grübler et al. 1996, 246-255.) Case C scenarios concentrate on environmental protection, energy efficiency improvements, energy conservation and environmentally friendly technologies. Efficiency improvements and the use of renewable energy will be accelerated by taxation in both scenario variants (Nakićenović et al. 2000, 334-339). Efficiency requirements will be high and energy will be stored and transformed efficiently to the consumers (Grübler et al. 1996, 255).

Energy demand will be lower in Case C than in Cases A and B (Nakićenović et al. 1998, 2). Primary energy demand will be 14 Gtoe in 2050 and 21 Gtoe in 2100. Case C has a target to reduce global CO_2 emissions to 2 GtC per year with the help of environmental policies, emission control and technological development. Carbon emission will be 5 GtC per year in 2050 and 2 GtC per year in 2100. (Grübler et al. 1996, 238-241.) Case C will not have significant environmental impacts because it favours renewable energy and invests in energy efficiency improvements (Nakićenović et al. 1998, 125). Global energy intensity will improve 1.4 % per year in Case C (Grübler et al. 1996, 244).

Case C includes two scenario variants with different visions about nuclear energy. Scenario C1 assumes that nuclear energy is taken out of use by 2100. (Grübler et al. 1996, 241.) C1 will meet the most of the requirements of sustainable development because it focuses on all kinds of environmental problems and energy efficiency improvements. (Nakićenović et al. 2000, 364.) Scenario C2 assumes the use of new small-scale nuclear reactors (Grübler et al. 1996, 241). Nuclear power and renewable energy will be used in this scenario as the environmental policies prefer to produce energy without using fossil fuels. Both C1 and C2 will have low environmental impacts and energy demand due to energy conservation and efficiency improvements. (Nakićenović et al. 2000, 337-347.)

Case C scenarios will reach very high level of energy efficiency because of the rapid technological development and characteristic of sustainability. Both scenarios concentrate on efficiency improvements to reduce emissions and energy demand, similarly to IEA SD vision scenario and the Blue map scenario. Energy intensity improvement rate is higher in Case C than in Cases A and B, which means that energy efficiency also increases more.

5.3 Scenarios by EREC and Greenpeace International

5.3.1 Reference scenario

The Reference scenario is based on IEA World Energy Outlook 2009. It assumes that energy policies remain unchangeable and current development continues as before. The Reference scenario provides a baseline for the Energy Revolution scenarios. (Teske et al. 2010, 10-48.)

Global CO_2 emissions will increase more than 60 % in the Reference scenario. Primary energy demand in 2050 will be 783458 PJ/a which is almost twice the level it was in 2007. Final energy demand will increase from 305095 PJ/a in 2007 to 531485 PJ/a in 2050. Figure 2 shows energy demand growth by sector. Other sectors include agriculture, forestry, fishing, residential, commercial and public services. (Teske et al. 2010, 10-214.)

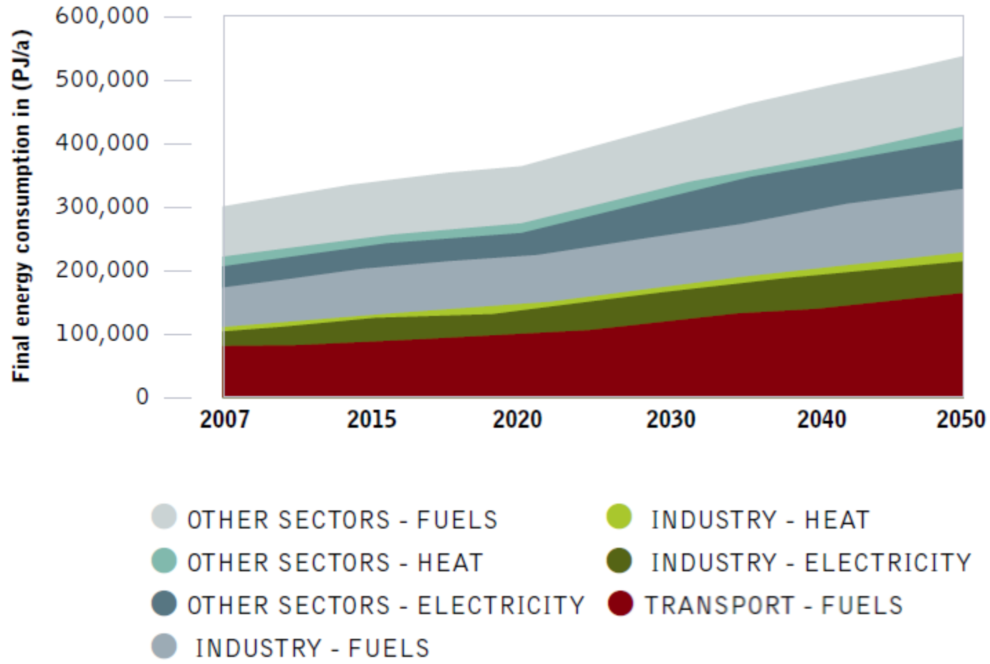

Figure 2. Energy demand growth under the Reference scenario (Teske et al. 2010, 181).

The Reference scenario assumes that energy intensity for car transport, air travel and rail transport decreases by 2050. Travelling by train is the most efficient option, while freight transport intensity also falls. Global energy intensity will decrease 1.25 % per year in the Reference scenario. (Teske et al. 2010, 65-196.)

The Reference scenario is similar to the IEA Baseline scenario because both have been developed to form a baseline for other scenarios. Because the Reference scenario is used for comparison, it does not give much information about its own efficiency improvements. However, improvements in energy intensities reveal that energy efficiency improves in the Reference scenario.

5.3.2 Energy revolution scenario and Advanced energy revolution scenario

The Energy revolution scenario has two main goals: to halve global CO_2 emissions by 2050 and to phase out of nuclear energy. Energy efficiency improvements and the use of renewable energy will be the main contributors to achieve these goals. The Advanced energy revolution scenario has the target for reducing CO_2 emissions by 80 % by 2050. Emissions must decrease faster in this scenario than in the basic Revolution scenario. Therefore the Advanced energy revolution scenario assumes the lifetime of coal fired power plants to be 20 years instead of 40 and the growth rate of renewable energy to be higher. Otherwise the scenario assumptions are the same in both Revolution scenarios. Energy efficiency improvements will also be similar in both scenarios except for transportation sector. The Advanced energy revolution scenario assumes 15-20 % lower energy demand in transportation sector because people will drive less, use public transport and have more efficient vehicles. (Teske et al. 2010, 10.)

The success of the energy revolution will require different policy measures and actions. Firstly, both Revolution scenarios assume the phase out of fossil fuels and nuclear energy. Economic growth will not rely on fossil fuels in these scenarios. Secondly, use of renewable energy will increase with the help of policy measures and prise support mechanisms. Renewable energy will be produced near consumers and transformed efficiently. Energy efficiency improvements in all end-use sectors will play an important role in Energy revolution scenarios. Both scenarios assume technical and political support for energy efficiency and strict efficiency standards for appliances, buildings and vehicles. Energy efficiency improvements will lead to decrease in energy intensity (Teske et al. 2010, 11-206.)

Global CO_2 emissions in the Revolution scenario will decrease from 27408 million tonnes in 2007 to 10202 million tonnes in 2050. In the Advanced revolution scenario the emissions will decrease even more: emissions in 2050 will be 3267 million tonnes CO_2. Emission reductions will be achieved with energy efficiency and renewable energy. Figure 3 presents global CO_2 emissions by sector in the Revolution scenarios. The white section shows the savings from energy efficiency and renewable energy.

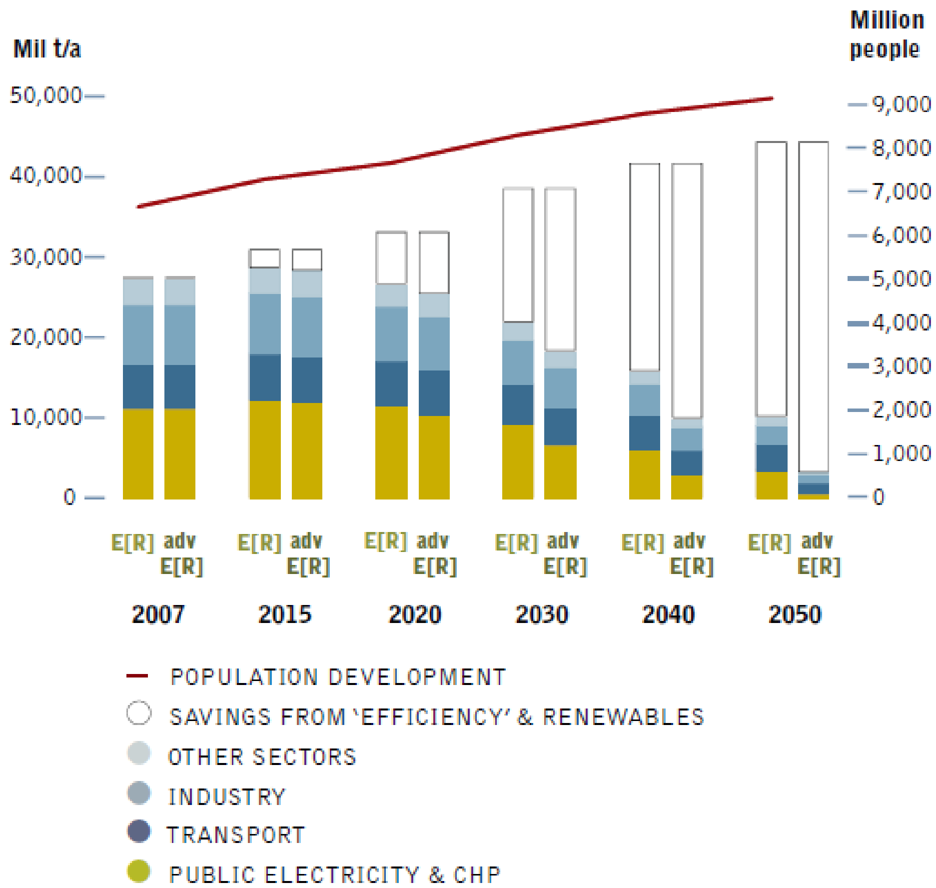

Figure 3. CO2 emissions by sector in the Energy Revolution scenarios. (Teske et al. 2010, 73).

Although overall demand for power will be high in the Advanced revolution scenario, it will still have lower electricity demand than the Reference scenario. Electricity demand in 2050 will be 31795 TWh/a in the Energy revolution scenario, which is 8549 TWh/a lower than in the Reference scenario. The reduction will be achieved by energy efficiency improvements in all sectors. Final energy demand will increase from 305095 PJ/a in 2007 to 340933 PJ/a in 2050 in the Advanced revolution scenario. Thanks to efficiency improvements, final energy demand in 2050 will be much lower than in the Reference scenario. Total final energy demand by sector in different scenarios is presented in Figure 4. 'Efficiency' shows the reduction compared to the Reference scenario. (Teske et al. 2010, 10-73.)

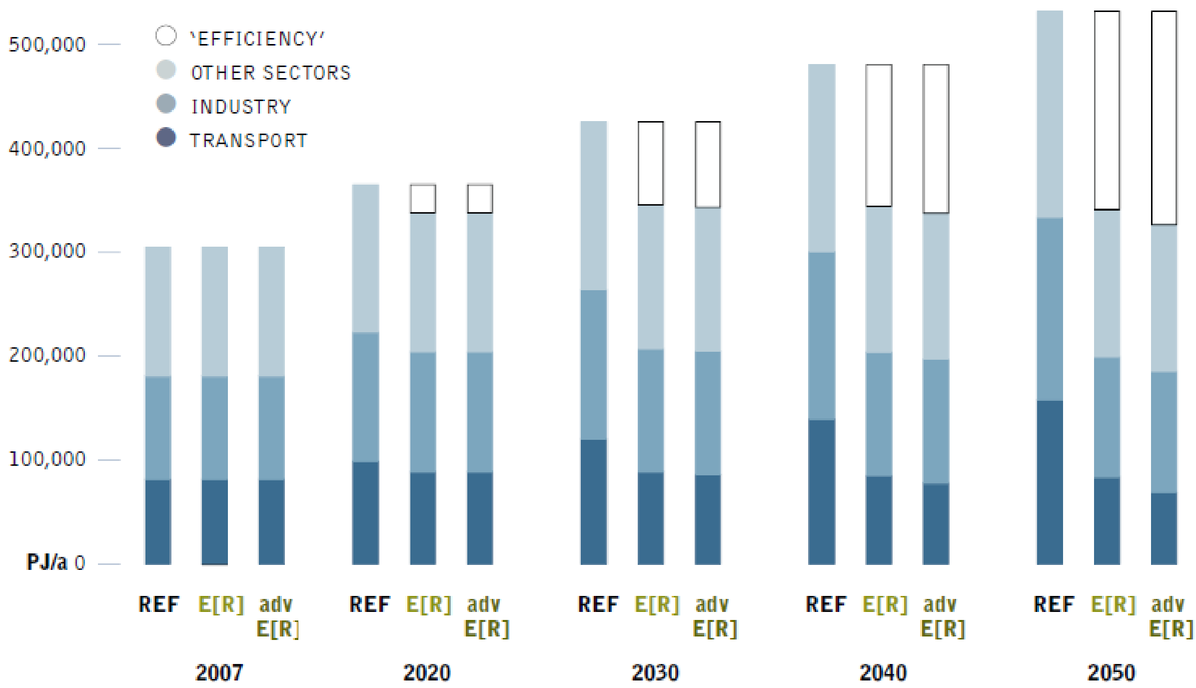

Figure 4. Final energy demand by sector in different scenarios. (Teske et al. 2010, 66).

Energy can be saved in households by building new houses that use energy more efficiently, by renovating old buildings and by using more efficient appliances. Energy efficiency measures will also decrease the demand for heating. The Energy revolution scenario assumes that all new buildings in OECD countries will be low energy buildings. In developing countries, energy efficiency will improve 1.4 % per year in the building sector. Better windows and insulation will decrease the demand for heating by more than

50 % by 2050. Many appliances require a standby power which can consume 4-10 % of total electricity use in building sector. The Revolution scenarios assume an efficiency improvement of 3.1 % per year in stand-by power consumption. Behavioural changes, efficient lamps and taking advantage of daylight are assumed to reduce energy consumption in lighting by 70 % by 2050. Energy efficiency improvement for cold appliances will be 2.5 % per year in the Energy revolution scenario. Energy savings for computers and servers will be 55 % by 2050 and the same amount of energy will also be saved by using efficient air-conditioners. (Teske et al. 2010, 71-189.)

Travelling by bus and train and the development of smaller and lighter vehicles will improve energy efficiency in the transportation sector. The development of hybrid and electric vehicles will also accelerate the increase in energy efficiency. However, electricity demand in the transportation sector will grow due to increased use of electric cars and production of hydrogen for fuel cell vehicles. Electricity demand in the Advanced energy revolution scenario will be 43922 TWh/a by 2050, which is 16 % higher than in the basic Revolution scenario but still 5 % lower than in the Reference scenario. Energy demand will be 83507 PJ/a in the Revolution scenario, which is 47 % lower than the demand in the Reference scenario. The Advanced energy revolution scenario assumes energy demand to be 15-20 % below the basic Revolution scenario. To achieve this goal people need to travel less and workplaces need to be placed near living areas. In addition, efficient ways to storage energy needs to be developed for electric and hybrid vehicles. (Teske et al. 2010, 11-71.)

Both Revolution scenarios assume that energy efficiency improvement for passenger rail transport will be 1 % per year and for freight rail 2.5 % per year. Efficiency improvement for marine transport will also be 1 % per year. The Revolution scenarios assume that the fuel intensity in air transport will decrease 60 % by 2050. Buses and minibuses will also improve their fuel efficiency. The Revolution scenarios assume a fuel saving of 50 % for medium duty trucks and a saving of 39 % for heavy duty trucks by 2050. Efficiency improvement for passenger cars will be 3 % per year. Energy efficiency improvements will help to reduce emissions and energy demand from transportation sector. (Teske et al. 2010, 196-210.)

Power generation from renewable energy sources will increase rapidly in both Revolution scenarios. By 2050, approximately 95 % of electricity and 80 % of primary energy will be produced from renewable energy. CHP production will use renewable fuels or natural gas and increase the efficiency of the production system. Efficient technologies will be developed to replace fossil fuel technologies. Efficiency improvements will be vital for the success of the energy revolution because the improvements will reduce the demand for energy. When the demand is lower, it will be easier to cover it with renewable energy alone. Electricity demand will be high in both Revolution scenarios. New renewable energy capacity and efficient gas-fired combined cycle power plants will be built to meet the increasing demand. Standardisation and closure of inefficient power plants will also increase the energy efficiency in power sector. (Teske et al. 2010, 11-210.)

Although the main goal of the Energy revolution scenarios is to reduce global CO_2 emissions, the scenarios concentrate more on energy savings than emission levels. The scenarios give a lot of information about energy consumption, energy savings and energy efficiency improvements in different sectors. Energy savings or efficiency improvement rates especially in buildings and transportation sector are presented in detail. Energy efficiency is used to reduce emissions, but unlike the IEA Blue map scenario these scenarios tell how much efficiency improves rather than how much emission reductions can be achieved by improving efficiency.

5.4 Scenarios by Shell International

These scenarios developed by Shell International are both explorative (Felder et al. 2011, 57). The two scenarios called Scramble and Blueprints describe the development of global energy system during the next 50 years (Shell International BV 2008, 7).

5.4.1 Scramble scenario

Scramble scenario concentrates on guaranteed national energy security. Because of the growing energy demand, the governments will focus on economic growth and securing the energy supply. International cooperation between different countries will be poor. Developing countries will struggle with energy production and economic growth while developed countries will try to answer to the increasing energy demand. Policy makers will not pay attention to energy efficiency improvements or emission reductions before serious problems on energy supply and environment arise. (Shell International BV 2008, 13-15.)

Coal will be a commonly used fuel is this scenario and the coal industry will double during the first 25 years of this scenario. In 2050, the size of the coal industry will be two and a half times larger than it was in 2000. The use of coal will cause many environmental problems, but the governments will be reluctant to act because they do not want anything to slow down the economic growth. The use of biofuels will start to increase early in this scenario and they will account for 15 % of the worlds primary energy mix in 2007. Nuclear power and renewable energy will decrease the demand for coal and the governments will finally start to act to increase energy efficiency. But their actions will not be as effective as they could. Because of the huge pressure to decrease the energy demand, the policy actions will often be unconsidered and can even make it more difficult to improve energy efficiency. Meanwhile, CO_2 emissions will keep increasing and climate policy will still be at a trial stage. In addition, volatile energy prises will temporarily slow down the economic growth. (Shell International BV 2008, 13-21.)

Finally, energy efficiency will start to increase rapidly mainly because of the demanding efficiency standards. Efficiency improvements, renewable energy sources and decreasing use of fossil fuels will start to reduce the amount of GHG emissions in the atmosphere. When economic growth will start to heal again, countries will be in the same situation than before – high energy consumption will lead to increasing emissions. The governments will finally realise that they should have started the emission reductions and efficiency improvements much earlier to avoid serious consequences and high costs. (Shell International BV 2008, 22.)

The Shell scenarios describe energy issues quite shortly and do not give any numerical information about energy use or efficiency improvements. In the Scramble scenario, energy efficiency improvements are pushed into the future until serious problems arise.

This makes the Scramble scenario very similar to IEA Dynamic but careless. In both scenarios, energy efficiency is just a necessity evil. Because the Scramble scenario focuses on economic growth, energy efficiency improvements are not used to reduce emissions or energy demand in the beginning of the scenario. The Scramble scenario tells that efficiency starts to improve eventually, but that is all. It does not give detailed information about efficiency improvements in different sectors.

5.4.2 Blueprints scenario

This Shell scenario focuses not only on economic development and energy security but also environmental issues and emissions. At first, different cities and regions and then the national governments will start to pay attention to these issues. In the beginning the governments will be unsure about the environmental and energy policies. Nevertheless, the share of renewable energy and policy actions related to taxes and emission reductions will start to take root quite early in this scenario. (Shell International BV 2008, 25-26.)

In the beginning of 21st century, many cities will invest in renewable energy and energy efficiency improvements. Developed countries will also invest in emission reduction projects in developing countries. Emission trading programs will begin and people will start to believe that economic growth is possible without high emission levels. The U.S. will concentrate on fuel efficiency, the CO_2 allowances will become tighter in the Europe and both China and India will invest in efficient power production. Energy intensity will improve in both developed and developing countries. Electric vehicles will become very efficient and reduce the energy demand in transportation. End-use efficiency improvements will result in lower primary energy demand and more affordable energy prices. (Shell International BV 2008, 27-31.)

By 2050, economic growth will be possible without increasing the use of fossil fuels. More and more energy will be produced from renewable sources and almost all fossil fuelled power plants will implement carbon capture and storage. Although CCS will be important to emission reductions, it will also reduce the efficiency of the power plant. International cooperation between different countries will work better in this scenario than in the

Scramble scenario and make new technologies spread around the world easily. Meaningful carbon pricing will be the main contributor to emission reductions, efficiency improvements and effective energy and environmental policies. (Shell International BV 2008, 32-37.)

Because people in this scenario are aware of environmental problems, actions to reduce emissions begin at once. Energy efficiency is once again one of the most important measures to reduce emissions and energy demand. The Blueprints scenario does not include any numerical information about energy efficiency improvements. It just briefly describes some efficiency improvements that are achieved in different sectors and tells that energy intensity improves all over the world. The lack of detailed descriptions and numerical information reduces the plausibility and usefulness of the Shell scenarios.

6 GENERAL DISCUSSION

Different kinds of energy scenarios make people think about the future and how it might turn out. The most believable scenarios are not too optimistic about sustainable development targets, for example emission reductions and the use of renewable energy. The Blue map scenario and the Energy revolution scenarios are very optimistic about the future and the Revolution scenarios even assume the phase out of nuclear energy. However, these scenarios feel more believable than scenarios that do not contain any numerical information, for example Bright skies scenario. Calculations and figures can show how scenario targets are supposed to be achieved. Fossil fuel intensive scenarios seem to be formed to show bad and undesirable options for the future.

The Energy revolution scenarios are clearly the best of these scenarios from energy efficiency's point of view. These scenarios include detailed information about energy efficiency in different sectors; tell how much energy efficiency improves globally and how much reduction in emission levels and energy demand can be achieved with energy efficiency improvements. However, phasing out of fossil fuels and nuclear energy raises some doubts. Is it really possible to achieve those targets by 2050? Another good scenario is the Blue map scenario because it tells what can be achieved with energy efficiency: it reduces CO_2 emissions by 43 %. The Blue map scenario also contains a lot of information about energy efficiency in different sectors and presents how many percents energy efficiency can be improved between years 2007 and 2050. The IEA publication *Energy Technology Perspectives – Scenarios and Strategies to 2050,* which includes the Baseline scenario and the Blue map scenario, has more than 700 pages and such a lot of figures, tables and numbers that all of the useful and interesting information cannot possibly be included in this thesis.

Other scenarios that just descriptively present efficiency or briefly mention it are not as useful as scenarios that describe energy efficiency also numerically. If scenarios are used for future planning, it is more difficult to decide which part of the emission reductions should be covered with energy efficiency improvements or how much energy efficiency can increase in different sectors. Lack of numerical information is the main disadvantage of the Shell scenarios, IIASA-WEC scenarios, SD vision scenario and the three explorative scenarios by IEA. However, these scenarios can tell how different factors, for example technological development, affect the efficiency improvements. Scenarios by Shell International are not very useful since they are rather short and not as clear as other scenarios analysed in this thesis. They also describe energy efficiency improvements very briefly.

The best option for energy scenarios would be to use both numerical information and verbal description to discuss energy efficiency. Scenarios should also present the efficiency improvement rates for different end-use sectors and power production and tell how much overall efficiency improves globally. Target oriented scenarios could tell how energy efficiency affects the achievement of the target.

7 SUMMARY AND CONCLUSIONS

Energy scenarios are used to explore the possible future development of the energy sector. Energy efficiency often has an important role in different energy scenarios. Several global energy scenarios developed by different organisations were discussed in this thesis. Table 2 provides the summary of all these scenarios highlighting the role of energy efficiency.

Table 2. Energy efficiency and the characteristics of different scenarios.

	ENERGY EFFICIENCY			
SCENARIOS	Is not discussed in detail	Is ignored until problems with emissions or energy supply arise	Is used to reduce emissions	Improves due to rapid technological development
IEA				
Clean but not sparkling			x	
Dynamic but careless		x		x
Bright skies			x	x
SD Vision scenario			x	
Baseline	x			
Blue map			x	
IIASA-WEC				
A1				x
A2				
A3			x	x
B	x			
C1			x	x
C2			x	x
EREC and Greenpeace				
Reference scenario	x			
Energy Revolution scenarios			x	
Shell International				
Scramble	x	x		
Blueprints	x		x	

The first three explorative scenarios (Clean but not sparkling, Dynamic but careless and Bright skies) developed by IEA are characterised by the rate of technological development and low or high concern for the environment. Lifestyle changes and environmentally friendly behaviour help to increase energy efficiency if the concern for the environment is high. Rapid technological change accelerates the development of efficient technologies and appliances and increases energy efficiency. The normative scenario by IEA is called SD vision scenario that aims to mitigate climate change and emphasises energy efficiency improvements to reduce global GHG emissions. The Baseline and the Blue map scenario focus on energy related CO_2 emissions. Efficiency improvements are considered to reduce emissions and energy consumption especially in the Blue map scenario.

IIASA and WEC have developed three scenario cases that include totally six scenarios. Case A (high growth) contains three scenarios, Case B (middle course) has a single scenario and Case C (ecologically driven) includes two scenarios. Energy intensity improvements are affected by economic growth, the rate of technological development and characteristics of sustainability. Energy revolution scenarios developed by EREC and Greenpeace include detailed information about efficiency improvements. On the contrary, scenarios developed by Shell International (Scramble and Blueprints) describe energy efficiency improvements very briefly.

Energy efficiency improvements are important especially for energy scenarios that have sustainable development targets because energy efficiency helps to reduce greenhouse gas emissions and energy consumption. If energy scenarios assume strong concern for the environment, people have energy efficient lifestyles and the governments support the efficiency improvements with different policy measures. If technological change is assumed to be fast, energy efficiency improves more and achieves a higher level. Economic growth also affects energy efficiency in different ways. If scenario concentrates on economic growth, policy makers have no will to start efficiency improvements or environmental protection. Economic growth can also help to increase energy efficiency. It speeds up the development of new technologies in IIASA-WEC scenarios, which leads to improvement in energy intensity.

Energy efficiency improvements can be described either briefly or in detail in different scenarios. The reference scenarios do not usually describe energy efficiency improvements in detail and by sector because these scenarios are only created for comparison. The scenarios that are compared with the reference scenario usually offer more detailed information about energy efficiency and other things affecting the scenario results. Some scenarios just briefly mention that energy efficiency will increase. SD Vision scenario, IIASA-WEC scenarios and the three explorative scenarios by IEA do not tell how much efficiency improves per year but describe efficiency improvements in other ways. Lack of detailed and numerical information affects the plausibility of the scenarios. Scenarios having more detailed information about energy efficiency usually contain numerical information, tables and figures. These scenarios also discuss efficiency improvements in different sectors. Energy revolution scenarios and the Blue map scenario are good examples of scenarios that include more detailed information about energy efficiency.

Many energy scenarios are rather unclear when describing energy efficiency and there is not much information available about the role of energy efficiency in energy scenarios. Therefore it was necessary to find out how energy efficiency is presented in global energy scenarios. Energy efficiency has the most visible role in energy scenarios describing future with low emissions and more renewable energy. Scenarios that include only minor energy efficiency improvements often describe undesirable futures because these scenarios are usually fossil fuel intensive and have high emission levels. The analysis of global energy scenarios confirms that energy efficiency has a major role in achieving sustainable development targets.

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