Turun yliopisto
University of Turku

BACKCASTING ENERGY EFFICIENCY FUTURES OF THE EUROPEAN UNION

Case studies of Finland and Germany

Master's thesis in Futures Studies

Author:
Ellinoora Leino-Richert

Supervisors:
Adjunct professor Jyrki Luukkanen
Professor Petri Tapio
Adjunct professor Jarmo Vehmas

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Turku

Turun kauppakorkeakoulu • Turku School of Economics

Table of contents

List of figures

List of tables

1 INTRODUCTION

1.1 Importance of energy efficiency

"Energy is the life blood of our society" (European Commission 2010.) The future of energy is a hot topic around the world. Global mega trends such as climate change, population growth and resource scarcity are strong drivers in energy policy. In addition to global agreements related to climate and energy issues (UNFCCC 2015) and regional energy policies and strategies (European Parliament 2012; European Commission 2016d), nations have their own interests in energy politics. The EU Member States have made National Energy Efficiency Action Plans (NEEAPs) about energy reduction targets as well as suitable energy sources (European Commission 2016g) and also Intended Nationally Determined Contributions (INDCs) as part of the global climate agreement (UNFCCC 2014). Energy efficiency – using less energy to achieve the same benefit – is one of the important goals for the European Union (European Commission 2011a). It is an essential matter, because the global energy demand is increasing extremely fast due to growing population and higher living standards. Also, the traditional energy sources – fossil fuels – are becoming scarce and therefore expensive. Burning non-renewables is also harmful for the environment, because they produce CO_2 emissions and cause global warming. (European Commission 2016d.) Extensive changes are needed in the whole energy production process, use and supply (European Commission 2010). Energy efficiency is considered as one of the most cost effective ways for society to enhance security of energy supply and at the same time reduce emissions of greenhouse gases and other pollutants. All EU countries are required to use energy more efficiently at all stages of the energy chain. (EUFORIE 2015, 13.) Also, energy efficiency has many positive affects to the EU citizens: lower energy costs, increased energy security due to decreased oil and gas import and better environmental quality (European Commission 2016a).

The EU energy goals have been set in 2020, 2030 and 2050 strategies (European Commission 2010, 2011b, 2014a, 2014c), Europe's Energy Efficiency Plan (European Commission 2011a) and Energy Efficiency Directive (2012/27/EU) (European Parliament 2012), and they are guiding the way to more energy efficient futures of the EU. The 2020 climate and energy package (European Commission 2010) sets targets for the EU to improve energy efficiency by 20% from 1990 levels, while the Energy Efficiency Directive (European Parliament 2012) helps to reach those targets. To reach the EU's 20% energy efficiency target by 2020 and 27% efficiency by 2030 (European Commission 2014b), individual EU countries have set their own indicative national energy efficiency targets. Depending on country preferences, these targets can be based on primary or final energy consumption, primary or final energy savings, or energy intensity. Each Member State has set the absolute level of energy consumption (Mtoe) for the year 2020 and the target is reported by Member State in 2013, in the NEEAP in 2014 or in a separate notification to the European Commission in 2015. (European Commission 2016b.)

Even though European countries are trying to follow the efficiency targets set by the EU, it is not absolutely certain that those can be reached. This thesis is linked to the EUFORIE[1] project by first exploring the possible energy efficiency futures of Finland and Germany, and then studying how well these scenarios fulfil the EU targets. These two countries were chosen to this thesis due to their interesting, but different energy policies. Germany has been globally leading the transition to more decentralised renewable energy system by increasing wind and solar power capacity [Energiewende[2]], whereas in Finland, the energy production has been centralised to large companies using wood-based renewables and hydro power.

Through using a target-orientated backcasting method (Robinson 1982c) for researching, the possible energy scenarios with desired future state can be identified. Earlier, future energy requirements were derived from energy-demand forecasts with a top-down approach involving variables, like GDP and population. Nowadays economic and political conditions are changing faster and decreasing the accuracy of these forecasts. (Robinson 1981, 627.) In this thesis, LINDA scenario model is used to construct both forecasts and backcasts for Finland and Germany. First, business-as-usual BAU scenarios are made for these countries, and by changing the structure of the economy (industry vs. service scenarios) and energy sources (non-renewable vs. renewable scenarios), four other alternative scenarios per country are also created. In addition, three intensity (backward) scenarios are created for both Finland and Germany. The aim is to see, how well these different scenarios reach the EU's energy efficiency targets for 2020 and 2030, and how much the structural changes of the economy and different energy sources change energy consumption and efficiency figures. GAP analysis is applied to count the differences between the scenarios. In GAP analysis the point is to compare, how far the scenarios are from the efficiency targets. In addition, de-linking energy consumption from GDP growth as well as Environmental Kuznets Curve (EKC) – dealing with the same phenomenon – are explored in the BAU scenarios. The EKC hypothesis states that environmental degradation increases when economy grows (GDP per capita) up to a level, where the environmental quality starts to improve with the economic growth. In this

[1] EUFORIE – The European futures for energy efficiency project (2015-2018) funded by Horizon2020 program and lead by Finland Futures Research Centre

[2] *'Energiewende'* means a transition to a low-carbon society, where energy is mainly produced with renewables and energy efficiency is valued high for environmentally friendly, secure and affordable energy supply.

thesis, the EKC is explored between energy consumption and GDP per capita to see, whether less energy than earlier is needed to produce the same or more value per capita. De-linking resource use (here energy consumption) from economic growth has been set as a policy goal in the EU (CEC 2001, 3). In this thesis, both the EKC and de-linking processes are related to the development of energy efficiency or intensity, because efficiency is measured in GDP (e.g. $) / energy (e.g. toe) and intensity other way around, energy/GDP. The more energy efficiency proceeds in every areas of society – like in construction, lighting, production and in intelligent solutions – the easier it becomes to use less fossil fuels and to increase the amount of renewables (Halme et al. 2015, 26).

1.2 Objectives and research questions

The research problem of this study is to find out if there is a gap between the forward BAU and the backward desirable energy efficiency scenarios. The aim is to research, how well the actual energy efficiency situation now and in the future (2030) relate to the energy efficiency targets in Finland and Germany. The study also aims to find out what needs to be changed in the current system to be able to achieve the desired energy futures. This is done by researching both EU and country specific political targets, plans (like NEEAPs) and visions effecting the energy production and consumption in Finland and Germany. Also, ideas and suggestions are given and pathways are offered to get to the desired future state. In addition to this, the study aims to find out, whether de-linking happens and EKC occurs in Finland and Germany, and what kind of policy implications are needed to support this development, and what is the role of energy efficiency in this process.

The following objectives have been chosen for reaching the stated aim:

1. Examine the energy policy and energy efficiency situation in the EU in general and especially in Finland and Germany.
2. Construct forward energy efficiency scenarios for Finland and Germany for the year 2030.
3. Analyse the differences and correlations between the scenarios separately in Finland and Germany (by carrying out GAP analyses) and compare the results between the countries.
4. Construct backward energy efficiency scenarios for Finland and Germany for the year 2030.
5. Identify and critically evaluate the reasons behind the future energy efficiency scenarios and propose suggestions for pathways to the desirable energy futures (visions).

These are the research questions based on the presented research problem:

1. What are the possible energy efficiency futures for Finland and Germany that could fulfil the EU 2020 and 2030 targets?
2. How the structure of the economy and different primary energy sources affect the possibilities to reach energy efficiency targets in Finland and in Germany?
3. How well forward scenarios and the targets correspond each other (GAP analysis) and what is needed for the backward scenario?
4. What should be changed in the economy (with policy support) that would enable de-linking and EKC to occur and what is the share of energy efficiency in this change?

The overall motivation for my thesis is to help EUFORIE project in its mission to produce knowledge for the European Union and its Member States and to help EU to reach its ambitious energy efficiency targets. The importance of the study is that by achieving energy efficiency targets, nations as well as individuals are able to save money, protect the environment and enhance security of energy supply.

1.3 Thesis outline

The structure of this thesis is as follows: after the introduction (chapter 1), energy efficiency is properly defined, energy policy in the EU is opened up for a closer look, and a set of existing global and national (Finnish and German) energy plans and visions are described in chapter 2. Chapter 3 outlines the wide, theoretical framework of the thesis, and chapter 4 focuses on the LINDA methodology. Chapters 5 and 6 are dealing with the scenario construction for both Finland and Germany. The results are presented in chapter 7. Chapter 8 answers the research questions, and concludes by giving ideas for further research.

2 ENERGY EFFICIENCY

In this chapter, energy efficiency is explored in many angles: definitions are offered from multiple sources (2.1), the EU targets and visions for energy efficiency are opened up (2.2), and other existing visions and scenarios on energy efficiency futures are presented (2.3) in order to offer a wide view of the meaning and aim of energy efficiency. In addition, national energy plans of Finland and Germany are opened up (2.4).

2.1 Definitions

According to the Energy Efficiency Directive (EED) of the EU, 'energy' means *"all forms of energy products, combustible fuels, heat, renewable energy, electricity, or any other form of energy --- "*. The directive determines 'energy efficiency' as *"the ratio of output of performance, service, goods or energy, to input of energy"*. Increased efficiency is a result of technological, behavioural, and/or economic changes. (European Parliament 2012.) The International Energy Agency (IEA) explains energy efficiency as more output produced with the same energy input or the same output with less energy (IEA 2016b). The EU's Energy Efficiency Plan makes a separation between 'energy efficiency' and 'energy saving', where energy efficiency is about using less energy inputs while economic activity (GDP) stays the same, and energy saving means reducing overall consumption (European Commission 2011a). According to Herring (2006), 'energy efficiency' means the ratio of energy services out to energy input, or getting the most out of every unit of energy one buys. 'Energy conservation' then means reduced energy consumption through energy services, e.g. lower heating levels and standardized consumption limits on appliances influenced by regulation, consumer behaviour and lifestyle changes. (Herring 2006, 11.) Despite the differences of these terms, they are often understood and thus used as the same. Murray (1996) defines a simple ratio for energy efficiency:

Useful output of a process / Energy input into a process, or

GDP (e.g. $) / Energy (e.g. toe)

The question is, how to define the useful output and the energy input? Murray divides the energy efficiency indicators into four groups: thermodynamic, physical-thermodynamic, economic-thermodynamic and economic. These indicators can be applied to product, sectoral or national levels. (Murray 1996, 377-378.) In this thesis, the economic-thermodynamic indicators are applied, where the energy input is being measured in thermodynamic units (toe) and the output in terms of market value ($). Energy efficiency can also be defined as inverse to 'energy intensity' (energy/GDP) that describes how much energy is needed for production of one million dollars (Luukkanen 2014). In the LINDA model used in this thesis, energy intensity (like 'Energy use ktoe/Value added Mill. USD' including fuel, electricity and heat use) is used to look at the development in sectors ('Industrial energy intensity').

Proskuryakova and Kovalev (2015) analyse the energy efficiency indicators (EEI), and the disparity between the concepts of energy efficiency and energy intensity. The challenge of using these concepts as alike, is that energy efficiency is more of an engineering concept whereas energy intensity is more commonly used at macro level in statistical data. However, the authors suggest that thermodynamic indicators of energy efficiency for example at the company, sectoral or national levels without economic variables could complement energy intensity indicators. (Proskuryakova & Kovalev 2015, 450, 452.)

Especially Herring (1999; 2006) has challenged energy efficiency as a tool for reducing national energy consumption and specifically whether the promotion of energy efficiency at the micro level reduces energy consumption at the macro level. Even though efficient use of energy has been associated with decreased energy use, the issue is more complicated. He states that improved energy efficiency lowers the energy price, and by making energy more affordable, leads to a greater use of energy (*rebound effect*). According to Greening et al. (2000), a rebound effect refers to an increase in the energy service supply, like fridges due to more efficient energy use and higher demand of these services in response to lower prices. This kind of development can diminish (technological) energy efficiency gains. Greening et al. conclude that market mechanisms, like fuel taxes, are needed to gain energy savings by efficiency technologies, and avoid rebound effects. (Greening et al. 2000, 389.) Herring (1999; 2006) continues that improved efficiency has also been related to a structural shift to more dematerialized economy rather than reductions in energy consumption. He argues that instead of energy efficiency, energy sufficiency (or conservation) is needed to limit energy consumption. According to Herring, energy efficiency is rather a means, not an end, and concludes that *"The aim of energy efficiency should not be to reduce energy consumption but to produce a higher quality of life and enable us to fund the transition to a green and sustainable future"* (Herring 2006, 19).

According to the study by Kaivo-oja & Luukkanen (2004, 1518), the intensity effect of energy use has not changed in Finland, which means that the energy efficiency in Finland has not really been improved during the analysed time period 1960-1998. In 1960 less energy was used to produce one FIM of GDP than in the year 1998. One reason for the un-improving energy efficiency in Finland has been re-industrialization in the 1990s. In his paper, Lund (2007) investigates the future role of energy efficiency and renewable energy in Finland by 2020, and especially the decision-making criteria in the energy policy. Even though Finland differs as an energy-intensive economy from the rest of the EU, it does provide an interesting case to the other Member States to discuss about their future energy directions. All the EU Member States are confronted with similar energy challenges related to emission reduction, energy security, growing demand for electricity, and overall cost-efficiency. The study shows that an integrated approach consisting of renewable energy sources and energy efficiency measures would be a competitive alternative to consider. However, this option did not match with the preferences of the Finnish parliament in 2002, but instead the new nuclear power plant got accepted. This shows that meeting the “3 Es” (Environmental, Energy security and Economical requirements) for energy may not be enough, but a much wider range of criteria is needed to assess politicians’ priorities.

2.2 Energy policy in the European Union

Targets, strategies, plan and directive. The European Union has several strategies and targets, which are guiding the way for more energy efficient future of the EU. The three key drivers steering EU’s general energy policies are secure energy supply, competitive environment and sustainability. In addition to these, dependency on energy imports, increasing global demand of energy, scarcity of fossil fuels and global warming are challenges that the EU has to tackle. (European Commission 2016d.)

2020, 2030 and 2050 strategies. The 2020 strategy focuses on five priorities, the first one concentrating on achieving energy efficient Europe. According to the European Commission (2010), the EU is not achieving the 20% energy savings target by 2020 (Council of the European Union 2007; European Parliament 2009). *“While we are broadly on track for the 20% target for renewable, we are a long way from achieving the objective set for energy efficiency”* (European Commission 2010). The 2020 strategy calls for stronger political commitment among EU Member States as well as regional and local authorities to make full use of objectives and indicators, like the NEEAPs (2.4) for reaching the stated target. The aim of the 2020 strategy is to decouple the use of energy from the economic growth. (European Commission 2010.) The EU has been able to answer to the paradigm of future growth with less energy and lower costs. Since 2006, the EU has started to decouple economic growth from energy consumption through increased energy efficiency. (European Commission 2014b, 2.) The 2020 strategy points out that efficiency efforts should be embedded on the whole energy chain, from production, transmission and distribution, to final consumption. Transport sector and buildings have the largest potential to make efficiency gains, but also industry sector needs to take advantage from new energy solutions. The growing ICT sector is also important, because the sector is changing the economic structure to less energy intensive.

The public sector should however lead the whole process showing example for others. New ways of taxation and pricing should be explored and investments to energy-efficient technologies are encouraged. (European Commission 2010.) The 2030 climate and energy framework continues the progress towards a low-carbon economy based on the earlier 20/20/20 targets (Council of the European Union 2007, European Parliament 2009). This framework sets a 27% energy saving target for the EU Member States by 2030 compared to business-as-usual scenario (European Commission 2016c). Investors and funds are needed to finance research and to enhance new innovations done in energy efficiency. For example, the EU's Horizon 2020 fund invests in innovation for energy efficiency (see EUFORIE 2015). The 2030 strategy considers whether energy intensity improvements, absolute energy saving or a mix of the two would frame the 2030 objective. (European Commission 2014a.) The 2050 low-carbon economy strategy states that the EU needs to be extremely more energy efficient to meet the new energy system. Wider context of resource efficiency should contribute in meeting the energy efficiency goals faster and more cost-efficient way. (European Commission 2011b.)

Energy Efficiency Directive EED. Energy Efficiency Directive sets binding measures to reach the 20% target by 2020. In 2007 (Council of the European Union 2007), a projection of the primary energy consumption in 2020 was made for the whole EU (1,842 Mtoe). A 20% energy reduction target by 2020 was then counted based on the projection: *"---the Union's 2020 energy consumption has to be no more than 1 474 Mtoe of primary energy or no more than 1 078 Mtoe of final energy---"* (European Parliament 2012, 12). In order to reach this target, all Member States are required to set national targets (in NEEAPs) and to indicate, how to achieve them. A shift to more energy-efficient economy will speed the development of technological innovations, create new jobs in many sectors and boost economic growth. (European Parliament 2012.) **Energy Efficiency Plan.** Energy Efficiency Plan proposes strict measures without binding national targets related to the role of public sector, energy sector, buildings, eco-labelled devices and appliances and transport (European Commission 2011a). The **Green paper on energy efficiency** aims at promoting energy savings especially in energy production, transport and building sectors. In energy production 40-60% of energy is lost in the process. Transport represents a third and heating and lighting buildings counts for 40% of energy used in the EU. (European Commission 2005.)

Nilsson (2007) argues that the goals represented in the Green Paper about increased competitiveness, environmental targets, and security of supply are best reached with the direct energy efficiency measures especially designed for each goal. The Energy Efficiency Watch project assessed all National Energy Efficiency Action Plans NEEAPs (2.4) to find out the current efficiency situation of the EU. According to that research, almost all plans met the 9% savings target between 2007-2016, and public sector was showing the exemplary role within its buildings and transport infrastructure. The conclusion of the project was that even though the minimum requirements were fulfilled, more effort needs to be put into the plans. (de Vos 2010.) Chang (2014) investigates the energy use efficiency of the EU Member States, and suggests an indicator for measuring the difference between the energy intensity target and the actual intensity. The traditional energy intensity indicator (energy use / GDP) has an incomplete affect on energy use efficiency. The author concludes that improved energy efficiency does not completely derive from a decrease in energy intensity.

Scenarios and visions. In addition to the energy efficiency strategies, EED and the related plan, the European Union has also compiled energy scenarios and visions for the future. The **Energy Roadmap 2050** includes seven scenarios from which one is called 'High Energy Efficiency' scenario with political commitment to very high energy savings. This appears for example as stricter minimum requirements for appliances and high renovation rates of buildings leading to a 41% decrease in energy demand by 2050 as compared to 2005-2006. (European Commission 2011b, 4.) *"Primary energy demand drops in a range of 16% to 20% by 2030 and 32% to 41% by 2050 as compared to peaks in 2005-2006. Achieving significant energy savings will require a stronger decoupling of economic growth and energy consumption as well as strengthened measures in all Member States and in all economic sectors".* (European Commission 2011b, 7.) According to the Energy Roadmap 2050, the main focus should remain on energy efficiency, when moving from 2020 to 2050 (European Commission 2011b, 9).

The **EU reference scenario** is an important analysis tool for the European Commission as it projects the impact of current EU policies on energy and transport trends. The scenario provides projections for indicators and energy efficiency for the EU as a whole and for each Member State. According to the reference scenario, there will be remarkable improvements in energy efficiency driven by policy before 2020 and by market and technology trends after 2020, and primary energy demand and GDP will continue to decouple (European Commission 2016e). According to the recent study made for the EU, the energy efficiency levels in industry are expected to improve overall up to 2050 (ICF Consulting Limited 2015). Figure 1 shows that GDP is increasing quite strongly while the use of primary energy consumption is decreasing.

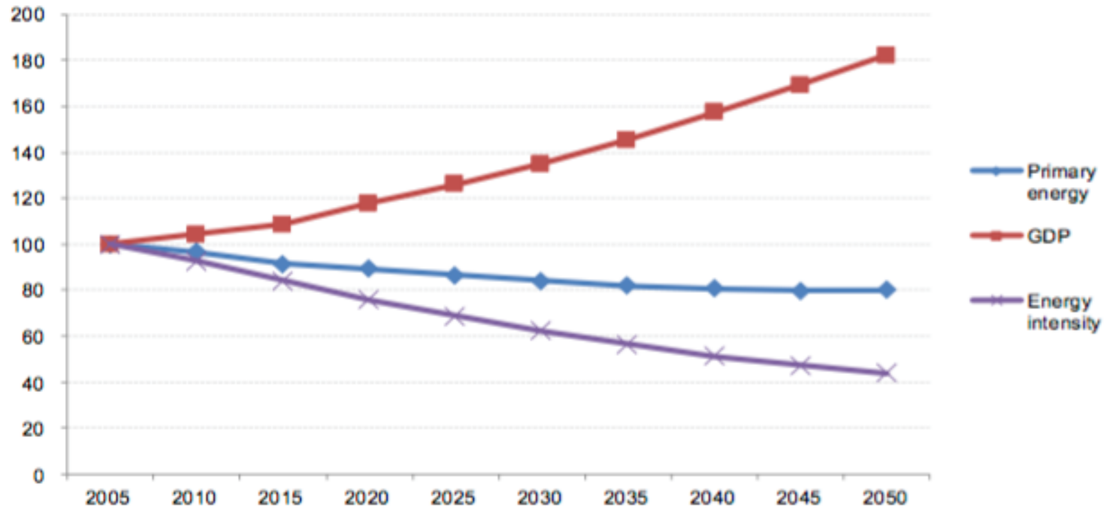

Figure 1. Decoupling energy production from GDP in the EU reference scenario. Source: European Commission 2016f.

The above mentioned EU targets talk about 20/27% improvement in energy efficiency by 2020/30 but the actual set targets are presented in energy amounts, not in efficiency or intensity. Efficiency and intensity are taking GDP development into account as well. The overall assumption behind these targets is that there is an approximately linear trend is GDP growth. Since GDP growth affects energy efficiency a great deal, it could be argued that more attention could be put to explore various ways of GDP growth and its effects to efficiency. Do to multiple scenarios constructed for this thesis based on economic structure and fuel sources, it was decided to keep GDP growth same in all the scenarios of Finland and Germany. The exploration of energy efficiency scenarios with various assumptions of GDP growth (fast, slow, very fast, very slow, uneven etc.) would again give different results for the research.

2.3 Global energy visions and scenarios

This chapter deals with a set of existing energy scenarios and visions made by other authorities than the EU. The point here is to give a broader overview of the energy efficiency situation worldwide, and reveal the trends and drivers affecting the possible energy (efficiency) futures. Some indirect effects affecting energy efficiency, such as forecasts of GDP, technological development and visions of the economic structure, are offered in addition to different energy efficiency scenarios. The preliminary scenario sources are based on the global energy scenarios review by Luukkanen et al. (2009), from which three most suitable sources were chosen. The main points of these three energy scenario sources – done by World Energy Council, Greenpeace International and Royal

Dutch Shell – are presented here and later used for comparison with the scenarios created with LINDA model. It is worth noticed that these scenarios draw pictures of the global energy futures instead of domestic ones. Also, the purpose of these scenarios is not to predict the future and therefore show probable or even preferable futures, but instead offer possible futures to consider and to take into account in policy and decision making processes.

World Energy Council (2013) presents two global energy scenarios to 2050 called 'Jazz' and 'Symphony'. The first one focuses on equal access to affordable energy by individuals and the latter on achieving environmentally sustainable energy future through global energy policies. In Jazz, the GDP growth is higher (3.54%) than in Symphony (3.06%) due to e.g. lower environmental constraints. In Jazz, the markets are growing the renewable energy options, whereas in Symphony those are promoted actively by governments. Even though fossil fuels – coal, oil, gas – will still dominate in absolute amounts, the growth rate of renewables will be increasing strongly. The share of fossil fuels will be 77% and the share of renewables 20% in Jazz, and 59% and 30% in Symphony. Nuclear energy will account for 4% of the total primary energy supply in Jazz and 11% in the Symphony scenario. Future electricity generation will increase a lot from 2010 to 2050 (in Jazz 150% and in Symphony 123%), and especially generating electricity from renewable sources will increase around five times. Energy efficiency increases greatly in both scenarios, but more in Symphony than in Jazz, because of the strong policy constraints. Primary energy intensity (energy use / GDP) will decrease by 50% in Jazz and 53% in Symphony compared to 2010, which means that only half the energy is needed to get the same GDP growth. The WEC's scenarios do show that energy efficiency and energy conservation are both highly important in maintaining the energy balance. They both also require behavioural change among consumers and some financial investments. (World Energy Council 2013, 13-18.)

Energy scenarios made by **Greenpeace International** are often seen as alternatives to the scenario projections done by *International Energy Agency* presented yearly in World Energy Outlook publications (e.g. IEA 2014). Energy [R]evolution (2015) by Greenpeace presents a energy scenario, in which 100% of the energy is produced by renewables. Even though most of the countries in the world have set targets to increase the use of renewable energy and improve energy efficiency, there is still much to do to to achieve sustainable energy for everyone. Therefore, there is a need to double the amount of renewables – especially in heating and transport – as well as the level of energy efficiency by 2030. Energy [R]evolution offers some valuable ideas of what still needs to be done to reach the 100% target, and thus works as an important tool in global energy discussion.

(Greenpeace International 2015, 4-5.) According to the *Reference* scenario[3], energy intensity will decrease 1.85% per year, which means 51% reduction between 2012 and 2050 in final energy demand per unit of GDP. In the *Basic* Energy [R]evolution scenario, intensity will decrease 3.45%, and in the *Advanced* Energy [R]evolution even more, 3.55 % per year, which counts for 75% improvement in energy efficiency by 2050. When combining energy intensity results with the projections of population and GDP growth, we will get the future pathways of the final energy demand of the world. In the Reference scenario, final energy demand increases 65%, but in Basic it decreases 12% and in Advanced even more due to higher share of e-cars. Even though intensity is decreasing in both Energy [R]evolution scenarios, electricity demand is still growing in all sectors, because of GDP growth and electrification of transport. Still, the highly efficient electronic devices can hinder the demand especially in industry, residential and service sectors. However, in the Advanced scenario, electricity will further increase due to the fact that electricity will become the major renewable 'primary' energy also for the generation of synthetic fuels to replace fossil fuels. Compared to electricity sector, energy efficiency will increase even more in heating sector, because of low-energy standard houses, energy-related renovations in existing residential buildings, and highly-efficient warming and cooling systems. (Greenpeace International 2015, 83-84.)

Royal Dutch Shell – one of the contributors to the development of scenario method – has created two comparable energy scenarios for 2050. In the first scenario, 'Scramble', national governments are the main actors that are concentrating on energy supply levels, while ignoring total energy consumption, and thus energy is used inefficiently. The lack of international cooperation leads to various domestic and local energy supplies. In the second scenario, 'Blueprints', local actions by individuals, cities or companies are taken to lower environmental harm and to raise energy security. The scenario draws a picture of the dynamics – like supply and environmental concerns as well as new venture possibilities – behind new alliances and their actions. In addition, financial policy instruments are used to steer the development to more energy efficient measures. (Royal Dutch Shell plc 2008, 14, 25.) When comparing the scenarios, there are rise of biofuels in 2022 and solar expansion in 2028 in Scramble, while in Blueprints EVs enter mass market in 2023 and nuclear revives in 2026. In 2033, nuclear will come important again in Scramble and biofuels account for 30% of liquid fuels in 2050, whereas in Blueprints electrification takes over transport sector in 2036 and decoupling happens between world GDP and energy growth in 2043. In 2050, Blueprint scenario needs 13% less primary energy than Scramble. Efficiency technology mandates in Scramble and efficiency behaviour is necessity, whereas economic standards and incentives play a bigger role in

[3] Based on the IEA World Energy Outlook 2014 (IEA 2014).

energy efficient technology in Blueprints and efficiency behaviour is designed in. (Royal Dutch Shell plc 2008, 38-41.) Table 1 gathers the data presented in this chapter.

Table 1. Documents used for scenario comparison.

DOCUMENT	INPUT	ENERGY SCENARIOS
The Energy Roadmap 2050 by the EU	Political commitment to high energy savings Requirements for appliances and buildings Energy savings Energy efficiency	7 scenarios, from which one called 'High Energy Efficiency'
World Energy Council	GDP Markets vs. government Renewables vs. fossils Nuclear Electricity generation Energy intensity/efficiency	Jazz Symphony
IEA World Energy Outlook 2014	Energy intensity/efficiency Final energy demand	Reference
Greenpeace International	Double the use of renewables (esp. heating and transportation) Energy intensity/efficiency Electricity demand Heating	Basic Energy [R]evolution Advanced Energy [R]evolution
Royal Dutch Shell plc	National governments vs. local 'grass root' actions & new alliances Energy supply vs. energy security & environmental reasons Biofuels, solar power, nuclear Transport sector & EVs Decoupling Efficiency technology Efficiency behaviour	Scramble Blueprints

2.4 National energy plans and visions for Finland and Germany

The chapter presents an overview of the energy (efficiency) situation in Finland and in Germany. Several national energy policies, plans and scenarios are offered to give a holistic picture of the field. First, some recent energy statistics are presented by Odyssee-Mure project and EUROSTAT. After that, the most relevant plans and visions of Finland and Germany are shortly viewed. These data sources are utilized later in this thesis when analysing and comparing the results.

Odyssee-Mure project gathers energy efficiency data from all the EU Member States and Norway. Odyssee internet database concentrates on energy efficiency indicators, and Mure database on policy measures and their impacts. The key indicators or sectors in Odyssee are Industry, Transport, Households, and Services. According to their statistics in 2014, Finland had the highest total energy intensity of the countries, whereas Germany had the 5th lowest. Due to the traditional heavy industry in Finland, the country had also the highest energy intensity of Industry, Germany being the 7th lowest. In Transport sector, Finland had the 9th lowest efficiency gains (base year 2000) 11.3 % and Germany the 4th highest, 17.7 %. In Households, the numbers were 8.1 % for Finland and 24.0 % for Germany, Finland having the lowest energy efficiency gains in Households of all the EU countries. Finland also had the 3rd highest electricity intensity in Service sector, Germany the 4th lowest. Final energy intensity adjusted to GDP structure in Finland was two times bigger than in Germany. Energy intensity of industry of Finland adjusted to the same value added structure of Germany was more than three times larger in Finland than in Germany. Figure 2 shows, how Finland positions with Germany in overall energy efficiency. (Odyssee-Mure project 2017b.)

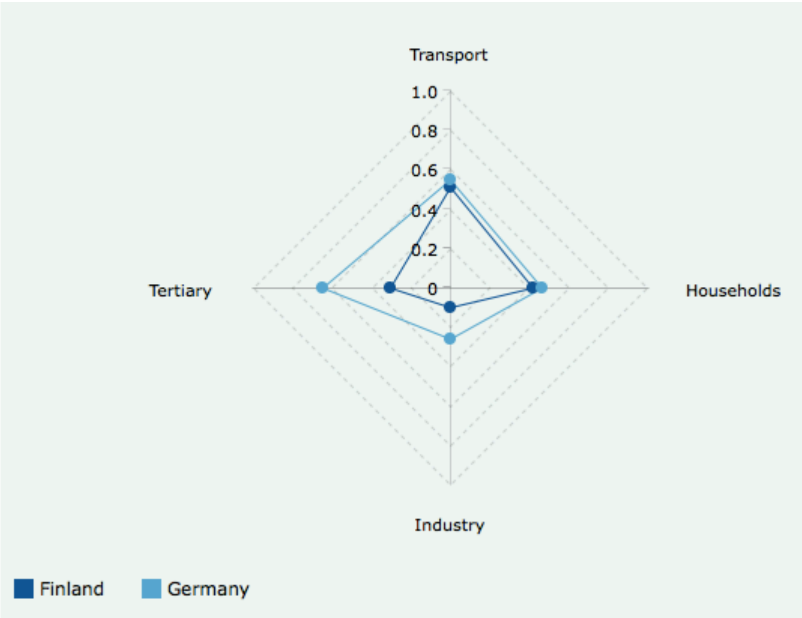

Figure 2. Finland positioning with Germany in energy efficiency of four sectors. In the graph 1.0 corresponds to the three best countries and 0 to the three countries with the lowest performance in the Odyssee-Mure study. Source: Odyssee-Mure 2017a.

According to the European Statistics by European Commission EUROSTAT, energy intensity of the Finnish economy (measured in Gross inland consumption of energy divided by GDP) was 214 (kg of oil equivalent per 1,000 EUR) in 2004 and 186 in 2014. In Germany the numbers were 143 and 114. The median for the whole EU-28 were quite similar to Germany's: 152 in 2004 and 122 in 2014. (EUROSTAT 2017.)

2.4.1 The official plans and scenarios for Finland

The Energy Efficiency Law of Finland (Finnish Government 2014) grounds in the Energy Efficiency Directive EED. The purpose of the law is to enhance energy efficiency in several ways (e.g. presenting energy audits) in energy companies, other big companies as well as district heat and cooling networks.

The 3rd National Energy Efficiency Action Plan for Finland **NEEAP-3** (Finnish Government 2014) describes the implementation of the EED and the national energy efficiency measures and their impacts on energy consumption up till 2020. The action plan aims to stop the growth of energy consumption and thereby includes the national energy consumption targets for 2020 (see also Finnish Government 2016), which are very similar to the current consumption figures (Table 2). The action plan improves the energy performance of buildings, e.g. by setting a long-term strategy for mobilizing investment in the renovation processes. Other measures to enhance efficiency gains are for example development of energy audits and promoting heat pumps in detached houses. The plan also sets other measures to energy end-use efficiency divided into five sectors: public sector, services/private sector, industry, transport, and agriculture. (Finnish Government 2014.)

The Annual Report on the EED 2016 for Finland (Finnish Government 2016) determines the indicative national energy efficiency target for 2020 and the used indicators to measure that target. Some statistical information on Combined Heat and Power CHP and overview of energy savings are presented as well. The efficiency and savings targets are the same as in previously presented NEEAP-3 plan since they are part of the same political process. The national energy efficiency targets are closely connected to the Climate and Energy Strategy of Finland (see TEM 2013b). There are all together 24 indicators measuring annual energy consumption in Finland. The indicators indicate annual total energy consumption (both primary and final) and consumption in sectors (industry, transport, households, services). Also, total GDP and growth in sectors are measured in addition to electricity and heat generation. Some more indirect variables, such as population, number of households, and average household income, are also taken into account to get holistic view of the energy system. (Finnish Government 2016.)

The goal of the **Energy and Climate Strategy 2013** of Finland (TEM 2013b) is to ensure the actions being taken for 2020 to reach the long-term energy and climate targets of the EU (Table 2). As a part of the long-term vision, Finland has created a roadmap for 2050 (see TEM 2014a) to increase energy efficiency, enhance the use of renewables and to aim carbon-neutral society. The strategy states that Finland is one of the internationally leading countries in many energy saving activities and efficient use of energy. Combined electricity and heat production, systematic execution of energy audits and coverage of voluntary energy efficiency agreements are great examples of successful energy savings.

However, in some sectors, like in transport and agriculture, these actions have not been applied that much. (TEM 2013b, 13, 15.)

Energy and Climate Roadmap 2050 (TEM 2014a) states that the long-term carbon-neutrality goal of Finland is possible but challenging to achieve. The roadmap works as a strategic guidance towards this goal, and it evaluates the means to build up a low-carbon society. The energy system has to be transformed nearly emission-free by 2050 and therefore the use of fossil fuels and peat needs to be dropped and replaced with mainly forest biomass. The roadmap is based on four low-carbon scenarios for 2050 (created in Low Carbon Finland project) that are called 'Continuous growth', 'Stop', 'Saving' and 'Change'. In addition to these, two other scenarios – 'Baseline' and 'Base-+80%' – were developed that are close to the current economical structure. All the scenarios fulfilled the set emission targets, if the technological development is as assumed in the scenarios. (TEM 2014a, 9-10, 18.) The same six scenarios were also utilized in the study by Korenoff el al. (2014), where current energy efficiency was reviewed and future energy efficiency paths – the six scenarios – were created with TIMES-VTT energy system model. Also Kara (2001) developed three different energy scenarios for Finland 2030 (Table 2), and according to his study, it seems more economical for the society to allocate money to technological development than to raise taxes to achieve same environmental benefit. (Kara 2001, 11.)

The new **Energy and Climate Strategy 2016** of Finland was released at the end of 2016 (TEM 2016b). The strategy concentrates on increasing the use of renewables and energy self-sufficiency, cutting half the oil imported, giving up of coal by 2030, encouraging the use of wood-based energy, and promoting bio gas production and use. Since the new strategy was recently released, the older strategy (TEM 2013b) has mainly being used as a primary source when creating scenarios with LINDA. As a part of the new Energy and Climate Strategy 2016, a study of a 100%-renewable energy system was done (TEM 2016a). The challenges and possibilities of a totally renewable society were studied in electricity, heating and cooling, transport, and industry sectors. The conclusions were that the fast development of renewable technologies such as wind and solar power, and the improvement of their competitiveness will create possibilities towards a 100%-renewable energy system. In addition to new energy systems, the current energy production system would need to be strengthened, flexibility and safety would be needed on the whole level, and the efficient use of energy and resources would need to be more emphasised. (TEM 2016a.) Table 2 gathers the documents reviewed here.

Table 2. Official energy scenario documents for Finland.

DOCUMENT	CONTENT
The Energy Efficiency Law of Finland (1429/2014)	Grounds in the EED
NEEAP3 Finland	Implementation of the EED The national energy consumption targets 2020: 310 TWh (26.6 Mtoe) for final energy consumption 417 TWh (35.86 Mtoe) for primary energy consumption
The Annual Report on the EED 2016	The national cumulative energy savings target 49 TWhcum during 2014-2020 and the cumulative energy saving impact 87.6 TWhcum by 2020.
Energy and Climate Strategy 2013	Energy saving target 2020 (base year 2008) 37 TWh from which 5 TWh is electricity and the rest heating energy and transport fuels.
Energy and Climate Roadmap 2050	Emission- and carbon-free energy system by 2050 4 + 2 energy scenarios for 2050 (developed with TIMES-VTT energy system model)
”Energy visions for Finland for 2030”/VTT (Kara, 2001)	3 energy scenarios for 2030: Kyoto (baseline), Save (strong savings) and Techno (technological development)
Energy and Climate Strategy 2016	> 50% of energy consumption coming from renewables in 2020s
100%-renewable energy system study	Energy used in society 100% renewable

2.4.2 The official plans and scenarios of Germany

The 3rd National Energy Efficiency Action Plan for Germany **NEEAP3** (German Government 2014) documents the efforts made and progress achieved in energy efficiency policy in Germany. Even before the EED (chapter 2.2), Germany had already managed to decouple energy consumption from GDP growth. The country is trying to continue on this positive development path by increasing energy efficiency and gaining energy savings as part of the ‘energy transition’. The German Government is encouraging its citizens to save energy in multiple ways and businesses to innovate more efficient technologies and services. The NEEAP3 plan provides a summary of the expected future energy savings as well as an overview of the growing market of energy services, including energy audits and building renovations. Also, many providers from energy companies to engineering and architectural firms are adding to the lively competition of the energy market. Table 3 presents some of the set goals for Germany by NEEAP3. (German Government 2014, 5-7.)

The projected energy consumption estimations for 2020 (base year 2008) are described in **Energy scenarios 2011** (BMWi 2011a; see Table 3). The targeted annual energy efficiency is 2.3-2.5 % and the share of renewables at least 18% in final energy consumption by 2020. After the nuclear disaster of Fukushima in Japan, Germany decided to phase out nuclear power within a decade. (BMWi 2011a.) Due to this, the country has had to maintain ‘dirty’ coal as part of the energy mix together with ‘clean’ renewables, like biomass, wind, solar and hydro, which together count in 2014 already a third of the power generated. However, the government is considering to end coal burning by 2040 or 2050. (Climate Home 2016.)

In addition to Germany’s NEEAP-3 (German Government 2014), the **National Action Plan on Energy Efficiency NAPE** (BMWi 2014b) was compiled for Germany. NAPE describes many immediate measures and forward-looking processes for using energy more efficiently and at the same time environmentally friendly and cost-effectively. The areas of action in NAPE are "Energy efficiency in buildings", "Energy conservation: a business and earnings model", "Empowerment for energy efficiency" and "Transport". Also **the Annual Report on the EED 2016** for Germany (German Government 2016) concludes some main indicators during 2011-2014 on the progress in meeting the national efficiency targets. The **Renewable Energy Sources Act EEG** (BMWi 2014a) promotes green electricity by systematically steering the expansion of renewable energy (Table 3). The new **Renewable Energy Sources Act EEG for 2017** (BMWi 2016) starts a new era of energy transition based on the idea that markets, rather than government, will determine the funding of renewables by auction schemes. The act gives a definition to a "citizens' energy company" and provides participation in the auctions.

Energy concept by 2050 (FVEE 2010) introduces an energy efficient and 100% renewable energy vision covering energy supply, distribution and consumption, a high supply security and profitability. The described, new energy structure refers to a transition from a centralized system to a decentralized, intelligent and supply-oriented energy system. The mix of all renewable energy from wind and hydro power to photovoltaics, from solar plants and biomass waste to geothermal and wave energy, will cover a firm energy supply system. Electricity demand is increasing thanks to electrified transportation sector and heat demand is decreasing by efficiency efforts. In the Energy Concept 2050, power is mainly produced by wind and photovoltaics supplemented by combined heat and power plants powered by biogas. Table 3 gathers the data sources mentioned in this chapter.

Table 3. Official energy scenario documents for Germany.

DOCUMENT	CONTENT
NEEAP3 Germany	Reducing primary energy consumption 20 % by 2020 and 50 % by 2050 compared to 2008. An annual increase of 2.1 % in energy productivity and 1.1 % in GDP from 2008 to 2020, which results in a reduction in primary energy consumption from 314.3 Mton in 2008 to 276.6 Mtoe in 2020 and in final energy consumption from 220.7 Mtoe to 194.3 Mtoe.
’Energieszenarien 2011’	Estimations for 2020, base year 2008: Primary energy consumption (PEC) 250.1 Mtoe, and Final energy consumption in: Private households 52.8 Mtoe, Commerce, trade and services 27.2 Mtoe, Industry 54.2 Mtoe, and Transport 57.6 Mtoe
NAPE	Immediate measures and forward-looking processes
The Annual Report on the EED 2016	Measures of main indicators during 2011-2014
Energy concept by 2050	100% renewable by 2050
The Renewable Energy Sources Act (EEG) 2014 and 2017	In 2014, 25% of electricity produced with renewables In 2015, 32% of the energy from renewables In 2025, possibly the share will rise up to 45%

3 THEORETICAL FRAMEWORK

The theoretical framework of the thesis consists of three research approaches: backcasting, Environmental Kuznets Curve (EKC) and de-linking. Backcasting method (see Robinson) is about defining a specific target and then finding ways to achieve it. It is about reaching a preferable future by effective means. There are many possible ways to reach that end point, and therefore many backward scenarios can be conducted. The relationship between economic growth and environment has interested researchers for a long time (Meadows et. al 1972). Environmental concerns, like resource scarcity and emissions have increased basically at the same time with GDP growth in many countries. De-linking environmental degradation from the GDP growth (de Bruyn 2000) and the related EKC hypothesis (Panayotou 1993), are dealing with this phenomenon. De-linking explores, whether environmental stress (ES) and GDP starts to de-link at some point. The EKC hypothesis states that first both ES are GDP are growing at the same pace, but at a certain GDP level per capita, ES starts to decline. This particular level or point, where de-linking happens and the EKC starts curving down, can be seen as a positive turning point for environmental harm. The preferred level of environmental harm then lays somewhere below this end point level depending on the case (like the EU energy efficiency target). Backcasting method then aims to find the right kind of path and needed actions to e.g. minimize environmental harm and to get its level below the set maximum target. Hence, it can be stated that the three theories applied in this thesis have a *complementary relationship* with each other (Figure 3). All of them are related to normative scenarios with embedded values, especially respect to environment. In this thesis, energy intensity has been chosen for indicator to measure environmental stress and improvement in energy efficiency. The aimed targets are set by the EU for 2020 and 2030.

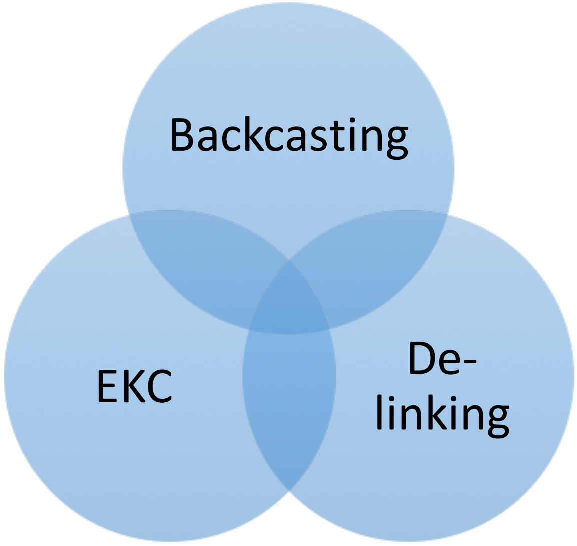

Figure 3. The complementary relationship of the research approaches.

Backcasting method, EKC hypothesis and de-linking approach were particularly chosen for this thesis for three reasons: 1. With LINDA model it is possible to conduct both forward and backward scenarios, 2. Improving energy efficiency is related to the larger picture of improving environmental condition by using less energy resources and producing less emissions, and 3. A research combining these three theories has not been done before, which adds a new and interesting perspective to this research. In the research, the three theories are utilized in a different way: backcasting and scenarios are related to the research approach, and EKC and de-linking are more content related.

The outline of this chapter is following: First, scenario approach is presented highlighting normative scenarios and preferable futures, followed by backcasting theory and its comparison to forecasting. Then, the EKC hypothesis is stated continuing to the theory of de-linking. Finally, decomposition approach is presented to open up the theory behind the LINDA model. All the subsections follow the similar structure: first, history and researcher(s) behind the theory are outlined, then development of the theory described, and finally several studies using that particular theory are presented.

3.1 Scenarios

A scenario is a basic concept of futures research that was introduced well by Kahn and Wiener (1967). Later, several scenario types and techniques have been developed for better understand the field of futures research (e.g. van Notten et al. 2003; Börjeson et al. 2006; Bishop et al. 2007). Despite the different typologies, scenarios are descriptions of possible, probable and/or *preferable futures* as categorized by Amara (1981), and they reflect different perspectives on the past, the present and the future. Dreborg (2004) suggests three modes of futures thinking that are predictive, eventual and *visionary*, and provides forecasting, external scenarios and *backcasting* as methodologies for those.

Van Notten et al. (2003) divide scenarios into three themes that are project goal (why?), process design (how?) and scenario content (what?) (Figure 4). The *project goal* can be exploration or decision support. In the latter case, the scenarios are used to examine pathways to desirable futures representing concrete strategic goals. *Decision-support scenarios* are characterized with *values*, which make them preferable, optimistic or pessimistic, utopian or dystopian. Often both exploration and decision support are exploit in defining the strategic goal. First, exploration is performed to get multiple future visions, and then new scenarios are created based on the exploration phase, and the relevant aspects of the strategic goal. (Van Notten et al. 2003, 426-427.) At Royal Dutch/Shell, global scenarios are first developed at a corporate level, and then used as input for strategic scenarios in the individual Shell companies (van der Heijden 1996).

The second scenario theme by van Notten et al., the *process design* includes intuitive and formal dimensions. The *formal approach* means that the scenarios are developed in a more rational and analytical way, and that quantitative data and computer simulation are used in the process. These are for example macro-economic computer simulation models that can be applied to energy, transport and environmental policy. The third theme, the *scenario content* is divided into complex and simple scenarios. *Complex scenarios* take into account multiple actors, factors, and sectors, and use many time or spatial scales. Simple scenarios are more limited with a narrow focus or a short-term perspective. (van Notten et al. 2003, 427-428.) The scenarios produced by LINDA model are more complex, since they have longer time-perspective, and the energy economy is being analysed on macro level with several sectors and primary energy sources.

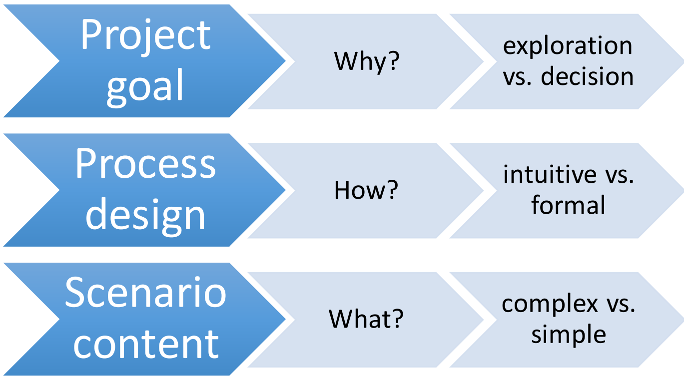

Figure 4. Scenario typology. Source: van Notten et al. 2003, 426; modified by the author.

The scenario typology presented by Börjeson et al. (2006) is similar to the one introduced earlier by Amara. Börjeson et al. divide the types into predictive, explorative and *normative scenarios*. Forecasts and what-if scenarios are predictive scenarios; external and strategic scenarios explorative; and preserving and transformative scenarios are normative. According to Börjeson et al., the World Energy Outlook (e.g. IEA 2014) publication is an example of predictive forecasts. Two types of energy models – Reference and OECD Alternative Policy Scenarios – are created to explore the possible evolution of energy markets. The scenarios are based on historical trends and values, but also expected structural changes are taken into account. In normative scenarios, the focus is on the specific target, and how it could be reached. When the target seems to be reached in the current situation, the preserving scenario approach is used. In *transforming scenario studies*, such as *backcasting*, the starting point is some high-level target (e.g. the EU 2020 target), which can not be reached in the current system. In this case, several target-fulfilling images of the future and a proposal of changes are needed in order to reach the target. Backcasting scenarios focus on finding options for long-term targets. A problem with backcasting is that it can result in decisions that are expensive in the short term and that the long-term target could be changed. (Börjeson et al. 2006, 725-730.)

3.2 Backcasting vs. forecasting

For a long time, the future of energy demand has been an important subject to investigate for the secure energy supply. Traditionally, forecasting techniques have been exploit to estimate the future energy demand and supply based on previous trends (extrapolation). However, these techniques have been criticized in producing inaccurate and unreliable results. This has lead to the development of new kinds ways for energy estimation, such as the *backcasting* method. (Robinson 1981; 1982b.)

Especially John Bridger Robinson has criticized energy forecasting and proposed backcasting technique for energy policy analysis in several research articles (Robinson 1981; 1982a; 1982b; 1982c; 2003). Robinson (1982b) argues that the unreliability of the energy forecasts can not be eliminated even by developing better forecasting techniques. According to him, backcasting is about how *desirable* futures can be achieved, not how probable those futures are. This means that backward scenarios are *normative* starting from a certain end-point in the future, and from there, moving to the present to determine the needed policy measures to reach that point (Figure 5). The purpose of backcasting is to explore and suggest policy implications for a chosen, *preferable* future, like for an energy efficient future. (Robinson 1982c, 337.) According to Vergragt and Quist (2011, 747), backcasting is about visioning and analysing future alternatives followed by pathways and strategies to reach the preferred target.

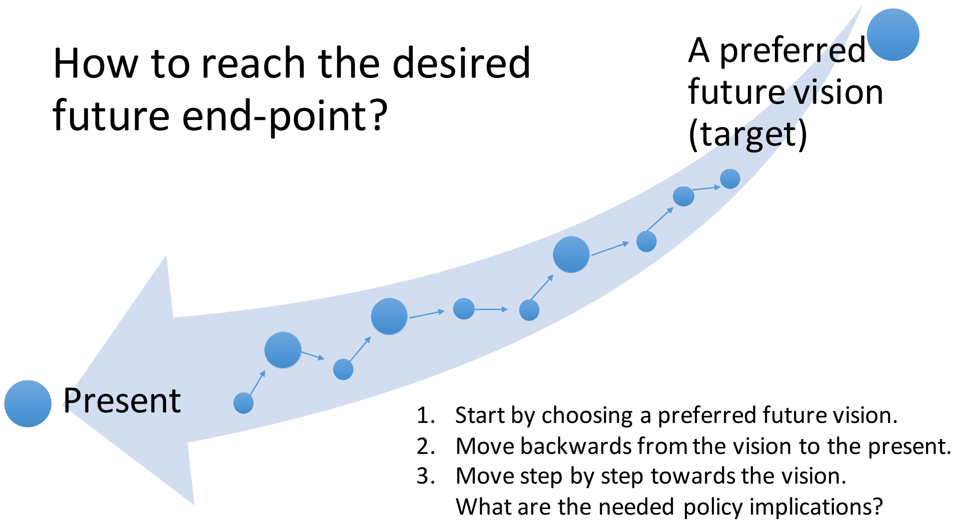

Figure 5. The idea of backcasting.

Energy backcasting is closely related to the policy process, more than forecasting is (Robinson 1982c, 338). Forecasts are about discovering the underlying features possibly affecting future energy demand and supply, and backcasts are about determining the action needed to get to that future. Forecasts show us where we seem to be heading, while backcasts indicate the possible directions. (Robinson 1981, 629.) Like Robinson claims (1990, 822), the increased environmental targets, like improvement in energy efficiency, indicate a strong need for more normative, goal-oriented analysis. The methodological approach has changed from a top down to a *bottom up analysis*. While a top down analysis takes aggregate energy demand as a dependent variable, a bottom up analysis takes a *disaggregated approach* instead. Bottom up analysis or *end-use approach* is based on the idea that the future energy demand is estimated through tasks or end-uses. The bottom up analysis presents clearer picture of the energy use and allows more detailed analysis of alternative efficiencies. Bottom up analysis requires a detailed examination of the whole consumption process and takes into consideration structural changes. (Robinson 1981, 628.)

On the basis of a detailed end-use analysis, backcasting involves specific future goals for energy consumption and analysis on how to reach that future. Energy backcasts can not be used for justifying policy decisions, like a need for a nuclear power station, but to indicate the policy implications of different energy futures. (Robinson 1981, 629.) Backcasts are better suited for long-term problems, because of their normative and problem-solving character (Quist & Vergragt 2006, 1030). Also Dreborg (1996, 814) argues that backcasting is especially important approach in complex problems, such as long-term sustainability problems.

Energy backcasting studies have been associated with *soft energy path* analysis used for energy conservation and renewable energy development. (Robinson 1981, 629.) In his paper, Robinson (1982a) introduces the *'hard'* and the *'soft'* energy paths. The hard paths are based on extrapolation of the past energy trends, increasing energy supplies and growing use of nuclear power. The soft path refers to efficient use of energy, renewable energy transition and initiatives against nuclear energy. Traditionally, scenario analysis has relied on qualitative research and forecasting on quantitative models. However, backcasting has its roots in *quantitative analysis* involving some modeling. The modeling system is able to simulate alternative scenarios to reach a desirable future target. This kind of modelling is called a *design approach*, and it requires building bottom up models. (Robinson 2003, 344-345.)

There are various ways of doing backcasting. Robinson proposed a six-step energy backcasting method (Robinson 1982c). This backcasting method has been utilized for instance in the study by Anderson (2001) about the electricity industry. Robinson's (1982c, 339-344) *six-step method* is presented in the Table 4. Later, Robinson introduced a 'second generation' form of backcasting, where the desired future is not decided in advance of the analysis, but instead in the social learning process (Robinson 2003, 839).

Table 4. Robinson's six-step method (1982c, 339-344).

The main 6 steps	The sub-steps
1. Specification of goals and constraints	Determination of policy goals and constraints
2. Description of current energy consumption and production	Primary source, secondary fuel, sector, type, and end-use. Primary, secondary and tertiary consumption. Primary and secondary production.
3. Outline of future economy	1) Choose end-point date 2) Construct a model of the end-point economy 3) Choose mid-point dates 4) Derive a demand scenario
4. Demand analysis	1) Derive tertiary and secondary consumption profiles 2) Determine demand management measures 3) Specify the costs
5. Supply analysis	1) Develop an inventory of supply sources and fuel 2) Match supplies to consumption profile 3) Derive energy supply industry requirements 4) Develop primary energy requirement profile 5) Determine supply policy measures 6) Specify the costs
6. Implications	An analysis of the social, environmental, economic, political, and technological implications of the scenarios.

Backcasting can be *pathway-orientated* or *action-orientated*. The former is interested in how change can happen by identifying e.g. policies and the latter who can make it happen by identifying stakeholders. (Neuvonen et al. 2014, 69.) Tuominen et al. (2014) propose a method for *pluralistic backcasting*, where – instead of a single normative vision – multiple visions of the future are developed in a participatory and interdisciplinary process. In their paper, Vergragt and Quist (2011) present a broad overview of the current state of backcasting studies, methodologies, and results. They argued that more comparative studies are needed to better understand and improve the method. They also elaborated research questions for further study, such as do systemic changes need coordinated action by many stakeholders. (Vergragt and Quist 2011, 753.) In addition, Neuvonen et al. (2014, 69) argue that backcasting theory, where social structures would be included as change objects, is still missing. The backcasting method that I will use in my thesis is based on Robinson's six step framework combined with Linda accounting framework model (see Chapter 4).

3.3 Environmental Kuznets Curve

The Kuznets curve is based on economist Simon Kuznets work about the relationship of income and economic inequality (Kuznets 1955). The hypothesis states that the income growth and inequality in income distribution over time forms an upside down U-shape Kuznets curve (Figure 6). In the case of Environmental Kuznets Curve, the income inequality is replaced with environmental stress. The hypothesis states that the environmental degradation increases when economy grows up to a level, where the environmental quality starts to improve with the economic growth. (Vehmas et al. 2007, 1665.)

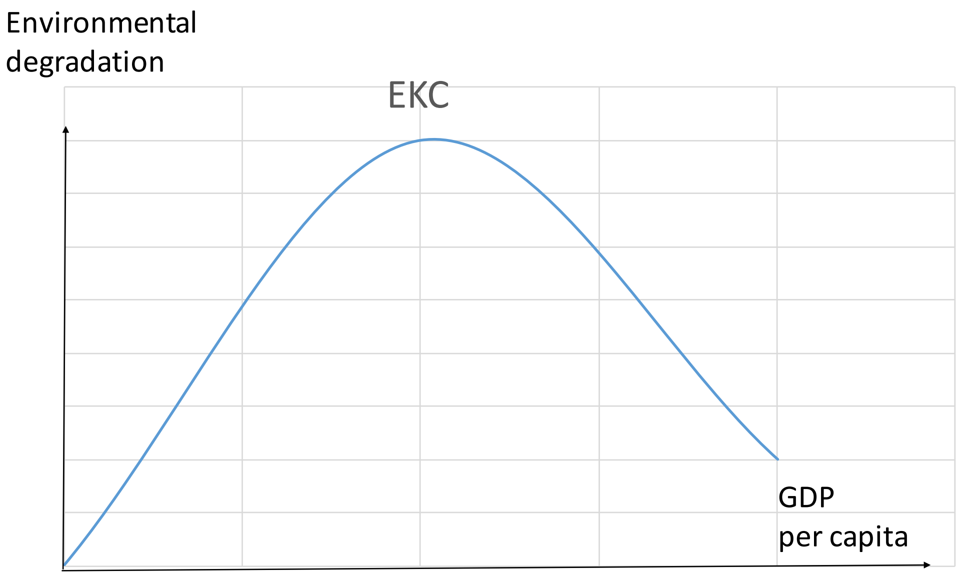

Figure 6. An inverted U-shaped Environmental Kuznets Curve.

Since 1970s', the relationship between economic growth and environmental quality has been an important research object (see Meadows et al. 1972). Theodore Panayotou (1993) was one of the first ones actually introducing the Environmental Kuznets Curve (EKC). According to him, the type and level of pollution and resource exhaustion depends on *the sectoral structure of the economy*. The economic development (measured by GDP), the share of industrial sector in GDP and the structure of industry have a close relationship. As an example, in developed countries, the share of the industry stabilizes and the more advanced technology industries and services are dominating the sectoral structure. Later, the share of the industrial sector begins to decline while the share of information technologies and services continues to rise. According to Panayotou, the structural changes in industry can alone explain the inverted relationship between pollution and the level of economic development. (Panayotou 1993, 2.)

Grossman and Krueger (1991) and Grossman (1995) write about three ways – *the scale of economic activity, the composition of economic activity* and *the techniques of production* – on how income growth affects the quality of the environment. First, growing economy with increasing output (products) needs more input (resources), and also delivers by-products (emissions, pollution). Then structure of the economy changes from heavy industries to technologies and services. Finally, a country can afford to cleaner technologies to improve the quality of the environment. If the changes in the production structure in developed economies are not accompanied by similar changes in the composition of production, the EKC might still occur due to a displacement of dirty industries to developing countries. (Grossman and Krueger 1991; Grossman 1995.)

As stated before, the impact of industrial growth on the level of environmental degradation depends on the stage of industrialization. While the general trend for industrial emissions is first to grow and then to decline, *government policy* can affect the process by postponing or accelerating structural change and technological development, and thus modifying the relationship between emissions and economic development. As GDP grows, environmental regulations become stricter and people can afford to be *more environmentally conscious*. (Panayotou 1993, 3-4.) As Dinda (2004, 431) states, the development of the economy from agrarian to industrial finally to service, and wealthier people having more interest in environmental quality, are the possible explanations for the EKC to occur. According to Grossman (1995, 43), the demand for a cleaner environment and supportive policies are the main theoretical support for the EKC. Panayotou writes that the hypothesis between environmental degradation and GDP is reasonable, because the size of the economy, the change in economic structure, the polluted technology, the demand for environmental services and the level of environmental expenses have all an effect on the level of development (Panayotou 1993, 5). He concludes that the idea that things may have to get worse before they get better could be more generalized. (Panayotou 1993, 1).

The idea of whether economic growth is a benefit for the environment rather than a harm is intensively analysed by Rothman & Bruyn (1998). Initial studies about the EKC (Grossman & Krueger 1991 and 1994, Panayotou 1993) showed that some pollutants follow the EKC with respect to income, and that economic growth can be compatible with environmental improvement. These studies have been then criticized by many due to limited environmental indicators and causes taken into account. The original studies have been applied *reduced-form models* (see Grossman and Kruger 1994) that consider only GDP per capita as explanatory variables. However, by using different indicators and more explanatory variables, the studies could lead to more accurate and reliable results of EKC. (Rothman & Bruyn, 1998, 143-145.) Suri and Chapman (1998) argue for using energy consumption as an indicator for measuring environmental degradation. They state that in addition to income, also import and export of manufactured products are important variables. A high share of manufacturing in total GDP refers to higher energy consumption. (Suri and Chapman 1998.)

Also Ekins (1997), Borghesi (1999) and Dinda (2004) have written reviews dealing with the EKC studies. Generally, the EKC discussion have concentrated on the macro level and on production instead of consumption, and neglected the important fact that increasing efficiency might lead to increasing consumption directly or indirectly. This phenomenon is called *rebound effect*, and it happens at the micro level in energy consumption (Herring 1999; Greening, Greene & Difiglio 2000). However, de Bruyn and

Opschoor state that *environmental macro economy* is related to *'I = PAT' formula* (where *I* means environmental impact, *P* population, *A* affluence and *T* technology) by Ehrlich and Holdren (1971). This formula is often used in calculations of environment degradation in alternative scenarios related to population or economic growth. (de Bruyn and Opschoor 1997, 256.)

In his paper, Borghesi (1999, 5) presents a critical review of the EKC literature to find out, how well EKC is empirically tested and have these studies affected on policy work. As Grossmann and Krueger (1994, 19-20) state, well-tested and formulated EKC could help policy makers to create better environmental policy. However, there exists limitations, such as data problems on environmental indicators (lack of data and using estimates) that can have an effect on the validity and reliability of the EKC studies (Borghesi 1999, 14-18). Many EKC studies are made by using *a cross-country approach*, but Borghesi recommends *a single-country approach*, because of the individual differences in each country. The EKC studies utilize several indicators (like water, air and other environmental indicators) for measuring environmental degradation, since there is no agreement of one universal indicator. This automatically leads to different versions of the curve. (Borghesi 1999, 8-14.) According to the studies, only some air quality indicators show the evidence of the EKC (Dinda 2004, 431). Also, the choice of the scaling factor (per capita emissions, total emissions or emission intensity) in the model has an affect on the shape of the curve (Borghesi 1999, 17-18).

As Borghesi writes, the main reason behind the decreasing EKC in the literature is *the income elasticity of environmental demand*. As income grows, also environmental awareness grows, and the consumers demand for more environmental-friendly activities and policies. This shifts the economy towards less polluting sectors and technologies. (Borghesi 1999, 7.) However, there is no agreement on the income level at which environmental degradation starts declining (Dinda 2004, 431), and thus no clear evidence to support the environment-income relationship. This is why more research is needed to get better understanding of the Environmental Kuznets Curve. (Borghesi 1999, 21.)

In this thesis, the relationship between energy consumption (TPES) and GDP per capita is explored in Finland BAU and in Germany BAU scenarios to to see, if the EK-Curve appears, and how the changes in energy efficiency affect this development.

3.4 De-linking / Decoupling

De-linking or *decoupling*[4] environmental degradation from economic growth, and the EKC hypothesis dealing with the same phenomenon, have become important in scientific

[4] '*Decoupling*' is more commonly used in transportation studies (see Tapio 2005).

debate since they were introduced in 1990s. Also, de-linking resource use from economic growth has been set as a policy goal in the EU (CEC 2001, 3). According to the analysis of International Energy Agency (IEA 2016a), global CO_2 emissions and economic growth have been de-linking recently due to increase of renewable energy and improvements in energy efficiency. The largest emitting countries, China and the USA, have declined their emissions. However, this decline has been offset by increasing emissions in Asia and middle East as well as in Europe. (IEA 2016a.). As Proskuryakova & Kovalev (2015, 452) state, de-linking GDP growth from energy use is the direct result of decreasing energy intensity and improved energy efficiency.

The linking process looks at the trends of economic development and environmental degradation and their relationship during a determined time period. De-linking happens, when economic activity increases but environmental stress (ES) decreases during specific time or increases slower than economic activity. de Bruyn and Opschoor (1997, 263-264) have defined five different phases in the linking process, called *N-shaped curve*. If the last re-linking phase does not happen, an inverted *U-shaped curve*, the EKC appears. de Bruyn (2000) has separated weak and strong de-linking in the growing economy. *Weak de-linking* means that the ES intensity of the GDP decreases over time. Environmental stress can still increase, but at a lower rate than economic growth. *Strong de-linking* means that ES decreases over time. (Vehmas et al. 2007, 1665.)

Weak de-linking
Δ (ES/GDP) < 0

Strong de-linking
Δ ES < 0

The EKC hypothesis states that GDP first increases ES (weak de-linking), but at a certain income level, ES starts to decrease (strong de-linking). The reasons for de-linking to happen are technological progress and shift towards less energy intensive sectors. Dinda (2004) lists the most important factors behind the EKC and de-linking that are demand for environmental quality; scale, technological and composition effects; international trade; market mechanism; and regulation. However, empirical identification of these factors is not easy, and de-linking or the EKC can not alone explain them. (Vehmas et al. 2007, 1665.)

In the future, it might be that weak or strong de-linking conditions do not hold anymore, because environmental quality may have a technological or economic upper limit. Then, economic growth becomes more dominating, and ES and GDP will be re-linked again until new technical solutions. In *re-linking*, ES intensity of the GDP increases over time. Environmental stress can decrease, but only if the economy also decreases (*weak re-linking*). In *strong re-linking* environmental stress increases over time. (Vehmas et al. 2007, 1665.)

Weak re-linking
Δ (ES/GDP) ≥ 0

Strong re-linking
Δ ES ≥ 0

The de-linking and re-linking are dealing with the changes in environmental stress (Δ ES), in environmental stress intensity of GDP, (Δ ES/GDP) and in GDP (Δ GDP). There are eight possible combinations of these three changes, assuming linking happening in both directions. However, only six combinations are logically possible. The six combinations show the different degrees of the linking process (Figure 7). (Vehmas et al. 2007, 1665.)

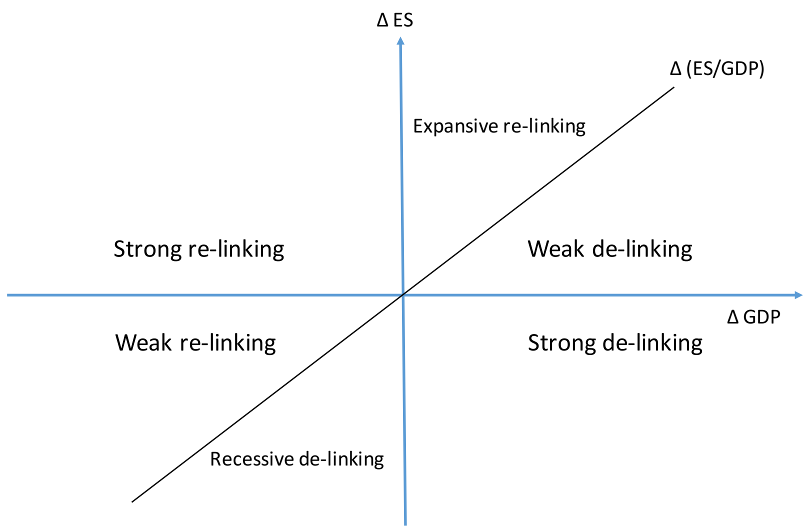

Figure 7. Degrees of de-linking and re-linking. Source: Vehmas et al. 2003b, 31.

When the change of ES intensity of GDP (Δ ES/GDP) is negative, de-linking emerges in different degrees. Strong de-linking happens, when GDP is positive, ES negative and change in ES/GDP negative. More efficient technology reducing environmental degradation while generating economic growth would explain this. Weak de-linking appears, when both changes in GDP and ES are positive and Δ ES/GDP negative. Environmental degradation would increase with economic growth despite of the technological improvements. In the third, *recessive de-linking* case, decrease in GDP would cause also decrease in ES with some improvements in efficiency. (Vehmas et al. 2007, 1665-1666.)

If the change of ES intensity of GDP (Δ ES/GDP) increases, re-linking appears. Strong re-linking emerges, when change in GDP decreases and in ES increases, while ES intensity is positive. Negative changes in both GDP and ES and a positive change in ES/GDP can be determined as weak re-linking. When all the three variables are positive, *expansive re-linking* appears. This would mean that economic growth would be achieved by more inefficient technology and rising environmental harm. (Vehmas et al. 2007, 1666.)

The different degrees of de-linking and re-linking also indicate weak and strong Environmental Kuznets Curves (Figure 8). In weak EKC, environmental intensity of the economy (ES/GDP) is chosen for the vertical axis. Environmental stress or ES per capita is chosen in the vertical axis in strong EKC. In both cases, GDP per capita or GDP as such, is chosen for the horizontal axis. (Vehmas et al. 2007, 1666.). Often, per capita figures have been chosen for the EKC studies. However, this might lead "too positive" results from the environmental perspective, because ES per capita decreases when population grows, but the total ES stays the same or increases. The problem is same between GDP/GDP per capita figures. The curve could become flatter with GDP per capita values than with total GDP. (Vehmas et al. 2007, 1664.)

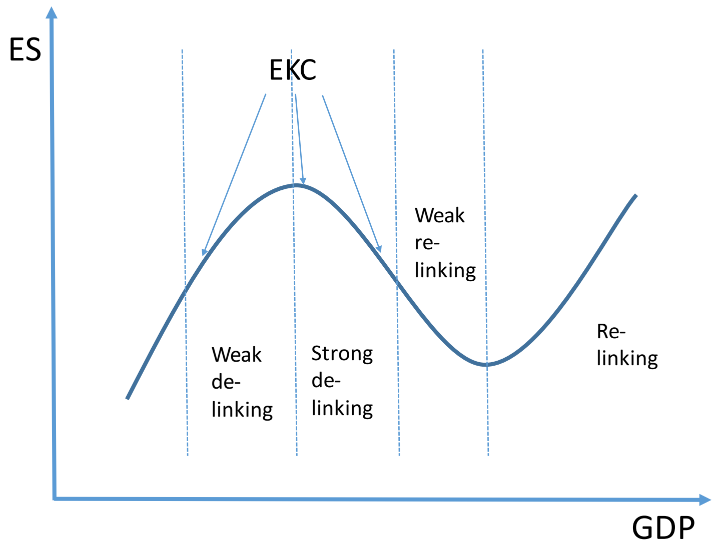

Figure 8. De-linking (and re-linking) and EKC. Source: de Bruyn 2000, 64; modified by the author.

The indicators chosen to describe environmental stress, like different emissions and energy consumption, end up in different results as demonstrated well in many empirical EKC studies (de Bruyn 2000; Borghesi 1999; Dinda 2004; Ekins 1997). Therefore, environmental policy can not be based on the analysis of a single indicator, but of several ones (Vehmas et al. 2007, 1666). As de Bruyn and Opschoor state, there are many studies that do indicate decreasing material and energy intensities (for example energy studies by Bossanyi 1979; Chesshire 1986), but each of those have only taken single pollutants and materials into account (de Bruyn & Opschoor 1997, 259). In the study by Vehmas et al. (2003a), both de-linking analysis was done and the EKC hypothesis tested. The conclusion was that any certain trend related to the de-linking process and the EKC could not be found, and the results vary from country to country, from time period to another, and between the environmental indicators. (Vehmas et al. 2003a.)

In the research by Luukkanen et al. (2005), the sharing of CO_2 emission burden was studied by using the *Contraction and Convergence* framework. In this approach, all countries take part in CO_2 reduction with per capita emission permits converging to equal per capita levels. (Luukkanen et al. 2005, 17.) The study utilizes a quantitative *Advanced Sustainability Analysis* (ASA) developed in Finland Futures Research Centre. ASA analyses changes in ES using different indicators. The analysis takes into account the three dimensions of sustainability, and shows the direction towards or away from it. ASA has been used for example in analysing *dematerialization*[5] of production, *immaterialization*[6] of consumption and *rebound effects*. The ASA method utilizes a complete *decomposition* analysis (see 3.5) to divide the total ES change into different factors. Different decomposition techniques have been developed especially in the energy studies for modelling change, like energy intensity (Rose & Casler 1996; Ang & Zhang 2001; Ang 2004). (Luukkanen et al. 2005, 25-26.)

The Contraction and Convergence model requires a decline of emissions in countries which are above the limit of 1.8 tons of CO_2 per capita. This could be achieved in developed countries rather easily by improved energy efficiency, renewable energy and most importantly, by structural changes in the production system. The shift to a lighter production structure happens when service sector increases its share and importance in the economy. According to Luukkanen et al., structural changes are more effective in intensity reduction than technology improvements. However, part of this change comes from the fact that developed societies are relocating heavy industry to developing countries. This – of course – is not a sustainable or preferred way of development. Dematerialization and immaterialization have also affected positively on emission reduction. However, increasing GDP and population growth have replaced the positive effects (rebound effects). Luukkanen et al. conclude that innovations for better material and energy efficiency are called for, and scientifically a need to develop new ways of explaining dematerialization and immaterialization at micro and macro levels. Also, possible rebound effects in new ways of production and consumption should be carefully analysed. (Luukkanen et al. 2005, 119-120, 125-126.)

De-linking adopts both dematerialization and depollution processes by reducing environmental impacts – like materials and energy inputs, or emissions and wastes – at the same time with economic activity. De-linking can result from changes in production processes, product design, and/or consumption. These developments are dealing with *structural changes* in the economy, rather than GDP changes (Simonis 1989; Jänicke et al. 1989). Structural change may be a result of processes operating within the economy, like policy interventions. (de Bruyn & Opschoor 1997, 258-259.) Dematerialization and rebound effects are related to a third ASA concept called *sustainable economic growth*, which means that the level of environmental stress stays constant or decreases by economic growth. (Vehmas et al. 2003b, 39.) In the study by Tapio et al. (2007), the term *'decarbonization'* is used in addition to immaterialization and dematerialization, and it can be defined as the reduction in carbon intensity of the whole economy.

According to Vehmas et al. (2003b), de-linking economic growth from environmental degradation has not been achieved during the research period. In industrialized countries

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[5] Producing larger economic output with less material input.

[6] Consuming more services than material things.

economic growth per capita affects environmental stress more than population growth. This negative effect on the environment exceeds the positive contribution of technological development. (Vehmas et al. 2003b, 9.) Technological development and services can lead to the dematerialization and immaterialization, and diminishing environmental deterioration. However, continuous economic growth can override the positive effect of dematerialization (rebound effect). As an example, people might want bigger cars, which consume more energy, even though cars have in general become more energy efficient. As Vehmas et al. concluded, a reduction in material and energy use per capita levels are needed to prevent environmental stress and rebound effects. (Vehmas et al. 2003b, 21-22.)

In this thesis, de-linking GDP growth from energy consumption (TPES) is explored in Finland BAU and in Germany BAU scenarios to see, if weak/strong de-linking or re-linking happens, and how does that affect the development of energy intensity/efficiency in these scenarios.

3.5 Decomposition analysis

The improvement of energy efficiency depends on the socio-cultural, economic, structural and technological development of the society. Especially the structure of the global industry and development of other sectors is essential: shift of heavy industry from developed to developing countries and increase of ICT and service sector and tourism. (Kaivo-oja & Luukkanen 2004, 1526.) In the study by Kaivo-oja & Luukkanen (2002), the efficiency developments of energy systems in the largest world economies were analysed. The changes in energy production and CO_2 were compared with GDP, and the activity, structural and intensity effects were reported. The method used is based on *decomposition analysis* usually employed in energy sector analyses (Ang 1995; Sun 1998; Sun & Malaska 1998) and in sectoral country level analyses (by Schipper et al. 1992; 1995). The research utilizes a complete decomposition model and dynamic analyses of the changes in the energy sectors and CO_2 emissions. Similar methodology was applied in the papers by Luukkanen and Kaivo-oja (2002a; 2002b).

In the study by Kaivo-oja & Luukkanen (2004, 1511), the decomposition analysis was utilized to model changes in energy consumption and emission production the EU countries. Energy intensity changes were explained by the structural changes and CO_2 intensities by the energy intensity changes and fuel switching. The average GDP growth rate of those countries has decreased after the oil crisis being around 1 %, but Total Primary Energy Supply (TPES) has more than doubled between 1960-1998. However, at the same time energy intensity has been decreasing pointing to growing energy efficiency: less primary energy has been used to produce 1 US dollar of economic output. Improved technology and structural change in the economy are the reasons for improved energy efficiency. According to the study, de-linking energy use from economic growth has taken place in Europe. (Kaivo-oja & Luukkanen 2004, 1512-1513.)

The decomposition method used in the studies by Kaivo-oja & Luukkanen (2002; 2004), is presented here under:

The productivity ratio of energy P(E,Q)

$$P(E,Q) = \frac{\text{economic outcome}}{\text{energy input}} = \frac{Q}{E}$$

The intensity of energy consumption in different sectors (i) as inverse to the previous one

$$eI_i = \frac{E_i}{Q_i}$$

where
eI_i is the energy intensity in sector I,
E_i is energy use in sector i and
Q_i is the value added of sector i.

A formula for decomposing energy use of an economy

$$E = Q \times \frac{E}{Q} = Q \times \sum_i eI_i \frac{Q_i}{Q} = Q \times \sum_i eI_i s_i$$

where the sum is all sectors counted together.

$$s_i = \frac{Q_i}{Q}$$

is the share of sector *i* production of the total production (a structural factor of the economy).

The explanatory variables are the activity level in the economy (Q_{effect}), sectoral intensity (I_{effect}), and structural shift (S_{effect}):

$$\Delta E = EQ_{effect} + EI_{effect} + ES_{effect}$$

The activity effect Q_{effect} shows the effect of GDP growth on sectoral energy use. Growing economic output increases the activity effect. The intensity effect I_{effect} expresses the impact of the technological change and the change in production systems on sectoral energy consumption. The intensity effect decreases, if the increase in economic output is bigger than the increase in the energy input. The structural effect S_{effect} describes the impact of change in the sectoral share on energy consumption. The structural effect of one sector increases, if the share of it in the total economic output increases. (Kaivo-oja & Luukkanen 2004, 1513-1514.)

In the study by Kaivo-oja et al. (2014), both the chained and the sectoral decomposition analyses were made. In the chained analysis, the difference of CO_2 from fuel combustion was decomposed to for example intensity factors. In the sectoral analysis, the change in final energy use in agricultural, industrial and service sectors was decomposed to for example intensity.

Decomposition is a mathematical model that is used to estimate the input of different actors to the energy intensity change. The model can be accompanied with *bottom-up* energy efficiency indicators measuring the change in efficiency. In the *bottom-up* approach the data is collected at lower level followed by aggregation and resulting in composite indicators at higher level. The opposite *top-down* approach is based on the company data from national statistics that is summed up at macro level and then disaggregated to sectoral level. (Proskuryakova & Kovalev 2015, 452.)

4 METHODOLOGY

The methodology of this thesis is based on backcasting approach and particularly Robinson's (1982c) *six-step method* (see 3.2). The actual model used in the research is an Excel based model called LINDA (Long-range INtegrated Development Analysis). The sectoral structure and distribution of different energy sources makes LINDA a very similar to the six-step method. Therefore, it can be stated that the six-step method is in a way build into the LINDA approach. While conducting backcasting scenarios with LINDA model at the same time Robinson's method is utilized. The only difference is that costs are not taken into account in this study (costs are included in some versions of the LINDA model), meaning that the last, sixth step in the Robinson's method is left undone.

The initial FinlandLINDA and GermanyLINDA scenario models were made by the EUFORIE project. For this analysis, time series data on energy supply, energy consumption, energy efficiency and other macro level data were collected from IEA, EUROSTAT and other relevant databases. These LINDA models were then used as a basis for the business-as-usual BAU scenarios and those then used as a basis for other scenarios. Both forward and backward scenarios were conducted in the research. Scenarios were based on varying input data which have direct and indirect effects on energy use. These were EU and country specific political targets and plans on energy efficiency, different economic structures, technological development and economic growth rates in the future. The impacts of energy efficiency changes on energy consumption were counted and analysed. The objective of this macroeconomic analyses is to combine historical energy and energy efficiency trends and their drivers, synergies and trade-offs between different energy efficiency policies, like EU policy targets and conduct forward and backward scenarios based on that data.

LINDA model and backcasting method were specifically chosen for this research, because of the EUFORIE project, where one of the tasks is to research energy efficiency futures in all the EU Member countries by using LINDA method and create backward scenarios. If some other method would have been chosen for this research, it would have not fulfilled the project's research purpose.

4.1 EuroLinda Model

LINDA (Long-range integrated development analysis) model is an Excel based energy system analysis and scenario building tool developed by D. Tech Jyrki Luukkanen. The model is based on the decomposition analysis (3.5), and looks at the development of energy in sectors and concentrates on energy intensity (energy/GDP). The future growth rate for economy (% per year) and energy intensities (e.g. energy intensity decline due to decrease of heavy industry) are given by the model user. Linda is an Accounting Framework model that contains quantitative data and can produce visual outputs. As a relatively simple tool, LINDA can be used in policy making and can offer a detailed description of the sectors, if the needed data is available. (Luukkanen 2014.)

The LINDA model is based on an intensity approach utilizing the Extended Kaya Identity[7] (see O'Mahony 2013). The Kaya forms a framework for LINDA, but the model also takes into account various fuel types and electricity, the electricity production system, and the different sectors. Based on the given input, LINDA calculates future energy scenarios for the specific country. Figure 9 shows the different modules and their linkages in LINDA. The *historical data* is given as *input* in the model. This data consists of *energy data* (fuels and electricity used in each sector, electricity production, power plant capacities), *economic data* (valued added per sector) and *population data*. Different versions of LINDA model include different number of sectors depending on the data availability, some version include even 38 industrial subsectors. The sectors in the LINDA used in this thesis are *Industry, Commercial, Transportation/Communication, Agriculture and forestry*, and *Residential.*

Based on the historical data, expert views on future energy intensities and sectoral GDP growth, the future *energy demand* is calculated. The *economic growth* figures are based on government plans or some expert information. Technological development trends, new investments or other expert information define *future energy intensities* in the model. The plan for new power plants (capacity) are given as input data to calculate the future *electricity* production. The fuel efficiency and plant load factor, in addition to the installed new capacity determine the needed *fuel* input to produce the required electricity demand.

The LINDA model uses yearly averages to calculate the electricity demand. The output is future *energy use* by fuel in different sectors and related CO_2 emissions. The emissions are calculated using the IPCC guidelines. In this thesis, the CO_2 emission are not taken into account. By changing the future economic growth figures in different sectors or the energy intensities, the model user can easily create different scenarios. The shares of different fuels can also be easily varied to illustrate e.g. changes in government policies, like moving to 100% renewable energy. (Luukkanen et al. 2015 869-871.)

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[7] Kaya identity is based on the formula I=PAT (see 3.3).

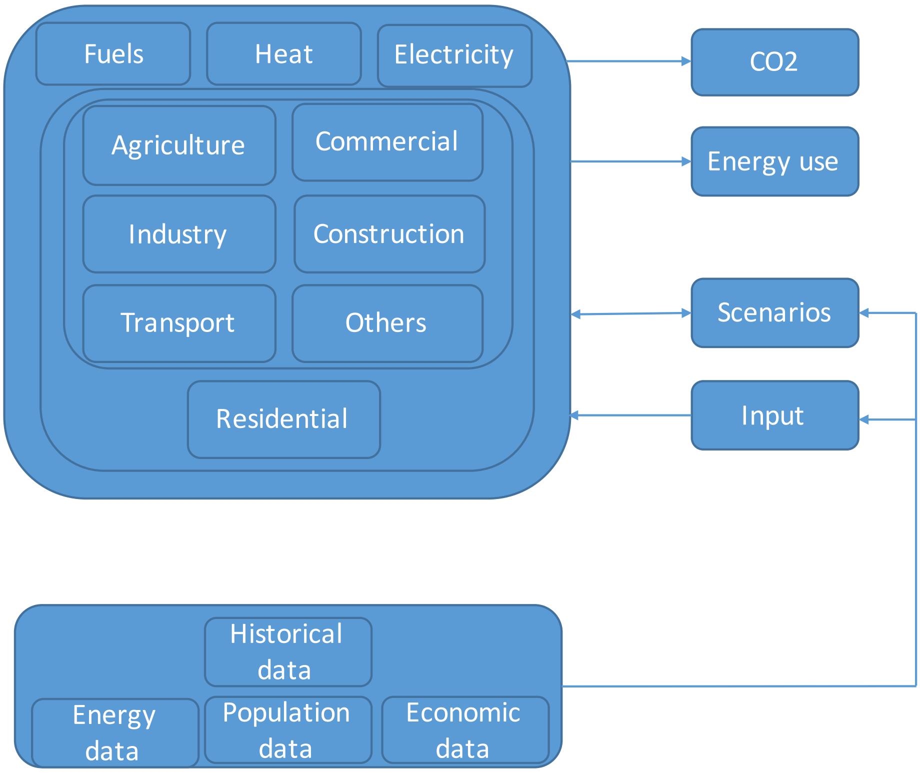

Figure 9. Linkages of different calculation modules in the LINDA model. Source: Luukkanen et al. 2015, 871.

With LINDA model it is possible to make both forward and backward scenarios, and often BAU scenarios are constructed first (Luukkanen et al. 2015 873). Backcasting is carried out by starting with the visions, in this case preferable energy visions based on European Commission's and national energy efficiency targets of Finland and Germany, and finding ways, how to achieve these targets. The LINDA models are usually made separately for each country, like FinlandLinda and GermanyLinda models used in this thesis.

In LINDA it is easy to get too many scenarios. To avoid this, it is recommended to change only one variable at the time and keep the amount of changes reasonable (e.g. industrial vs. service growth). The figures that are used for creating the scenarios are based on my own views and interpretation of the data on what will (BAU) and what should (target) happen in the energy field of Finland and Germany by 2030.

Even though LINDA model is a quantitative method, the interpretation of the results and the analysis is more qualitative and descriptive. This means that even though a lot of numbers are used during the scenario construction, the interpretations of the numbers is playing a bigger role. The overall aim is to find ways and give suggestions, how to better achieve the set energy targets, if they are not been met in the current economic system. During the scenario construction, it is very important to write down and explain explicitly, why a certain number/growth percentage has been chosen, what are the reason for that, what lies behind the numbers. It is important to acknowledge that the reasoning for the particular choices can be in practice somewhat challenging. Still, like in futures research in general, the aim is to present possible images of the energy future, and the related consequences, since there is no one future that we know for sure to come true. Instead, we should consider several options and raise our awareness of the different alternatives to better anticipate to the future and also affect on it.

In addition to LINDA, the differences of the preferable and the probable scenarios are counted for Finland and Germany separately and some comparisons of the results are done for the countries, too. These comparisons are done by using GAP analysis (= to subtract energy intensity and energy consumption figures (%) from each other).

In LINDA model, energy consumption is described by two components: *Total Primary Energy Supply* (TPES) and Final Energy Consumption (FEC or Total FEC). The International Energy Agency IEA defines them as follow:

Total Primary Energy Supply (TPES) = equivalent to total primary energy demand. TPES represents inland demand only and, except for world energy demand, excludes international marine and aviation bunkers (IEA 2016c).

Total Final Energy Consumption (TFEC) = the sum of consumption by the different end-use sectors. TFC is broken down into energy demand in the following sectors: industry, transport, buildings (including residential and services) and other (including agriculture and non-energy use). It excludes international marine and aviation bunkers, except at world level where it is included in the transport sector (IEA 2016c).

According to the EU, *Primary energy consumption* – which can be referred to TPES – means gross inland consumption, excluding non-energy uses, and *Final energy consumption* means all energy supplied to industry, transport, households, services and agriculture. It excludes deliveries to the energy transformation sector and the energy industries themselves. (European Parliament 2012.)

The component TPES/FEC describes the intensity of converting the primary energy to final energy. In LINDA model, *Value added* refers to each sector, and *GDP* is the value added sum of all the sectors and it is measured in millions of US dollars (M$).

In the study by Luukkanen et al. (2015), LINDA modelling was used to evaluate the possibilities to reduce CO_2 emissions and fossil fuel imports in Cambodia and Laos. The purpose was to analyse the energy trends in those countries, compare different scenario methods, like LINDA, construct scenarios with those methods and analyse the future energy demand, emissions and the role of renewables in this process. In addition to detailed scenarios made with combined LINDA/LEAP[8] models, also decomposition scenarios were constructed (see 3.5). The study combines both bottom-up and macroeconomic modelling in a unique way. The scenario showed that there is a rapid growth in energy consumption and CO_2 emissions pushed by rapid GDP growth and industrialization.

In the study of energy visions for Finland in 2030 (Kara 2001), the growth projections for 35 sub-sectors including 25 industrial sectors, were separately estimated. In the LINDA model the main five sectors – Industry, Transportation, Commercial, Residential, and Agriculture and forestry – including 35 sub-sectors in industry. Kara concludes that the most important driving forces affecting energy demand are:

- Changes in economic activity
- Trends in energy prices, taxes and other energy costs
- Technological change
- Social and demographic change, and
- Environmental factors, like climate change.

According to him, the most important driver is however the first point – the development of GDP – and that is why the sectoral growth percentages should be taken into account in the scenario construction. (Kara 2001, 194.)

4.2 Data gathering and scenario framing

The data used in the LINDA scenario modelling were gathered from several sources. All the data were based on trusted sources found in Internet and available for free (except the IEA data). Some of the material was only used for Finland LINDA and some for Germany LINDA, some for both of them. The historical data input – including fuels and energy as well as GDP and population – for Finland and Germany was based on the statistics of the International Energy Agency (IEA) and World Bank (Table 5). The data were macro-economic, country level data that takes sectoral bottom-up analyses into consideration. These data were chosen and fed to the model by Juha Panula-Ontto.

In addition to the national energy strategies and plans for Finland and Germany, the general energy policy of EU was used as input to set the targets for energy efficiency for 2020 and 2030 (Table 5). Some of the data were statistics by energy authorities. Also, some previous energy visions and projects offered valuable information for the scenario construction process and also worked as a comparable images of the energy futures, when evaluating the ready LINDA scenarios. The data collection provided both accurate

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[8] LEAP (long-range energy alternatives planning system) is also Accounting Framework type of modelling tool that is widely used and has low data requirements (Luukkanen et al. 2015, 869).

numeric data and other info, like external drivers that could effect the energy futures. The data material is roughly presented in the 'Energy efficiency' chapter, but more detailed description of the relevant data is done in chapters 5 and 6, where the creation process of Finland BAU and Germany BAU scenarios are presented.

Table 5. The historical data sources used in the scenarios and the data for the EU targets.

DATA SOURCE	INPUT	SCENARIO
International Energy Agency IEA	Fuels and energy data: Energy balances for OECD countries, Energy statistics for OECD countries, CO2 emissions for fuel combustion	Historical data for all scenarios
World Bank	GDP and population data: World Development Indicators	
EU 2020 strategy	20% efficiency target by 2020	Energy efficiency targets
EU 2030 strategy	27% efficiency target by 2030	
EED Finland	TPES = 35.9 Mtoe FEC = 26.7 Mtoe	
EED Germany	TPES = 276.6 Mtoe FEC = 194.3 Mtoe	
NEEAP3 Finland	Total energy saving 51,844 GWh/a = 4.46 Mtoe	
NEEAP3 Germany	PEC = 250.1 Mtoe PEC + non-energy-related consumption = 273.8 Mtoe	

Robinson's (1982c, 339-344) *six-step method* (see 3.2) is in a way embedded to the LINDA model, because the model includes similar phases to the method: description of specific targets, energy consumption and production, economic data, analysis of demand and supply, and related implications. Based on these steps and using different future estimates for the variables, LINDA models alternative scenarios (Table 6).

First, the business-as-usual BAU scenario was created in order to make the other scenarios based on that. Energy-intensive *Industry* scenario and less energy-required *Service* scenario refer to a stronger growth of those sectors in the scenarios. *Non-renewable* and *renewable* means that the energy used is mainly produced with fossil fuels or relying more on climate friendly options, such as solar, wind, hydro and geothermal energy. In these scenarios, nuclear power was decided to give a non-renewable energy status. Therefore, the nuclear energy capacity was smaller in the renewable scenario and bigger in the non-renewable one. In industry and service scenarios the nuclear capacity was the same as in BAU. It is worth noticed that the annual GDP growth was decided to keep almost the same in all the scenarios of Finland/Germany to limit the amount of scenarios produced. The sectoral GDP growth could well have been more varied in industry and service scenarios, and thus producing different total GDPs as well as energy intensities. Since constructing and especially the analysing process of multiple scenarios is too demanding for a Master's thesis, it was decided to only make four scenarios in addition to BAU per country (scenarios marked with grey background in Table 6). There fore the scenarios numbered 5.-8. in the list above are left out. However, it would be interesting to see, how these other scenarios play out and how they differ from the scenarios 0.-4. Constructed in this thesis. This could be a proposal for a further study.

BAU scenarios were based on forecasts and assumptions of total and sectoral GDP growth percentages, as well as power plant capacity changes, but also some country specific energy source targets were taken into account in the scenario creation process. In this way, it can be said that BAU scenario is a mix of forward and backward scenarios. However, in the context of efficiency targets, BAU and other four scenarios are all forward scenarios. That is why pure backward scenarios or *intensity scenarios* for both countries were also created to reach the country specific energy efficiency targets represented by EED by only changing electricity and energy/fuel use intensities. Otherwise these intensity scenarios were the same as BAU. (See chapter 7.3)

Table 6. The main characteristics for the 9 scenarios.

In non-renewable and renewable scenarios, GDP is the same as in BAU, but the power plant capacity differs. In industry and service scenarios, GDPs can be different than in BAU due to sectoral changes.

Production structure	**Emphasis on renewable and non-renewable energy sources**		
	Non-renewable energy	BAU	Renewable energy
High Industry	Industry, non-renewable	Industry	Industry, renewable
BAU	Non-renewable	BAU	Renewable
High Service	Service, non-renewable	Service	Service, renewable

5 ENERGY SCENARIOS FOR FINLAND

5.1 Finland BAU

The historical, input data of Finland LINDA model were based on the statistics of IEA and World Bank, and the future visions on several different data sources presented in this chapter. Fuel shares for each sector were estimated according to the historical development and future plans and visions in the energy field. The (-) sign in the Table 9 means that no changes were done for the future (adding/removing capacity), and the capacity figures were the same as the input data.

Annual total GDP growth %. The future GDP growth percentages for Finland were based on the national energy and climate strategy of Finland (TEM 2013a, 14), which estimates 1.6% annual growth between 2010-2020 and 1.9% 2020-2030. Since the estimated future percentages cannot be placed straight in the LINDA model, the growth percentages in each sector have first to be estimated in able to get the wanted total GDP growth percentages. (Table 7)

Annual GDP growth % per sector. The growth percentages of Agriculture and forestry, Industry and Commercial (= Service) sectors were based on the national energy and climate strategy of Finland (TEM 2013a, 15). The growth percentages for Transportation and communication sector were then estimated, and also some of the other sectoral percentages were still modified in able to get the wanted GDP growth. According to the national strategy, Agriculture and forestry would grow 1.6%, Industry 2.1% and Commercial 1.6% annually between 2010-2020, and 0.8%, 2.1% and 1.8% between 2020-2035. This kind of development is highly relying on industrial growth, and to get the optimal total growth, which enables Transportation/Communication sector also to grow, the growth percentages for the Industry were estimated a little lower than the estimations of the strategy. Both Agriculture and forestry, and Commercial have similar growth percentages as in the strategy. (Table 7) On the whole, The Ministry of Employment and the Economy (TEM) expects much stronger growth of Industry sector compared to Service sector, which is surprising in post-industrial economy. However, recent news in Finland have been in favour of this assumption, since e.g. maritime and car industries are now growing strongly in South-West Finland.

Table 7. Annual GDP changes in Finland BAU in 2013-2030.

GDP	2013-2015	2016-2020	2021-2025	2026-2030
Agriculture and forestry	1.0 %	0.9 %	0.9 %	0.8 %
Industry	1.2 %	1.2 %	1.5 %	1.5 %
Transportation, communication	3.0 %	3.0 %	3.5 %	3.5 %
Commercial	1.6 %	1.6 %	1.8 %	1.8 %
Total	1.6 %	1.6 %	1.9 %	1.9 %

In Finland BAU, Commercial sector would grow faster than Transportation/Communication and Industry sectors. In Agriculture and forestry sector, the growth pace would be similar. GDP would be 100,000 M$ larger in 2030 than in 2000. (Figure 10)

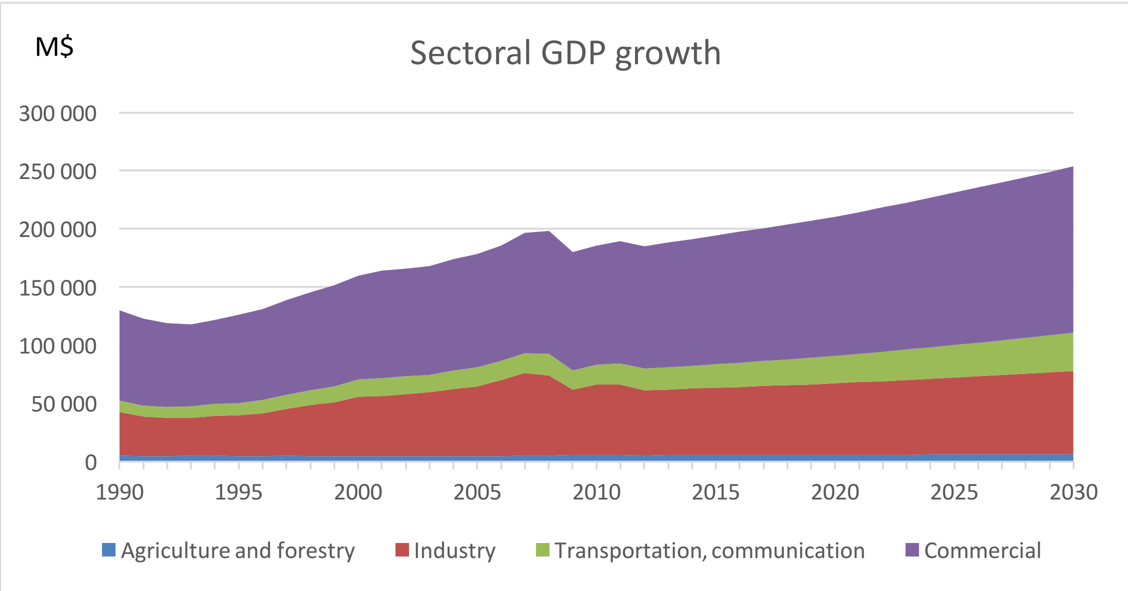


Figure 10. Total and sectoral GDP growth in Finland BAU in 1990-2030.

Energy & electricity intensities. The annual change percentages in the energy and electricity intensities of the LINDA model for Finland were discussed and decided together with prof. Luukkanen for the years 2013-2015 and for 2026-2030. The years between – 2016-2025 – were estimated by the author. (Table 8)

Table 8. Annual electricity and energy intensity changes in Finland BAU (and in Germany BAU) in 2013-2030.

Electricity intensity ktoe/million USD	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**
Agriculture and forestry	-1.0 %	-1.0 %	-2.0 %	-2.0 %
Industry	-1.5 %	-1.5 %	-2.0 %	-2.0 %
Transportation and communication	-1.0 %	0.0 %	1.0 %	2.0 %
Commercial	-0.5 %	-0.5 %	-1.0 %	-1.5 %
Residential electricity use (not intensity)	1.5 %	1.0 %	0.5 %	0.0 %
Energy (fuel use) intensity ktoe/mill. Kip	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**
Agriculture and forestry	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Industry	-3.0 %	-3.0 %	-3.0 %	-3.0 %
Transportation and communication	-2.0 %	-2.0 %	-3.0 %	-4.0 %
Commercial	-2.0 %	-2.0 %	-2.0 %	-2.0 %
Residential use (not intensity)	-3.0 %	-3..0 %	-3.0 %	-3.0 %

Coal. The future data of power plant capacity was based on several sources. In 2015, the Finnish government decided that during 2020s coal will be abandoned as energy source (Prime Minister's Office 2015, 23). This is taken account in the BAU scenario so that by 2030 energy consumption of coal would be 0 MW. This means that the existing coal plants will be shut down gradually and that new plants will not be opened.

Peat. The consumption stays almost the same, just a slight increase was made to compensate the decreased use of coal. However, it is worth mentioned that peat is not a sustainable and renewable energy source, unlike solar and wind, and therefore increasing its production heavily is not encouraged.

Crude oil, Fuel oil, and Other oil products. The consumption of oil fired will be much less in the future due to strengthened climate targets. The Finnish government has also decided to cut half of the oil used during 2020s (Prime Minister's Office 2015, 23). In the Finland BAU the target of oil consumed was taken from the EU reference scenario, and according to that the capacity power would be around 600 MW by 2020, when it was more than 1,500 MW still in 2015 (European Commission 2016e).

Natural gas. The consumption will be growing due to decreased use of coal. The increase was around 3,000 MW (in 2030 more than 5,000 MW), which is an unrealistic goal, but necessary for the equal amount of electricity imported and hence the comparability of the scenarios.

Nuclear power. The nuclear power data was taken from TEM (TEM 2016c). Currently, there are two nuclear power plants and in those four nuclear reactors with total gross capacity of 2,860 MW. The permission to use of the two nuclear reactors (both 520

MW) in Loviisa end in 2027 and 2030, and the two (both 910 MW) in Olkiluoto in 2038. The new, third reactor (1,600 MW) in Olkiluoto is planned to be in use in 2018. Also, the Finnish government will make the decision of building a new nuclear reactor by Fennovoima, (1,200 MW) in 2018. In the BAU scenario of Finland, all of the six nuclear reactors were in use in 2025 with a total capacity of 5,660 MW.

Hydro power. According to the Energy industry (2016), the annual hydro capacity for Finland is 3,100 MW. Since the input data was almost the same, no capacity was added to LINDA.

Solar power. The solar capacity in 2012 was 11.2 MW according the historical data and 12 MW in 2015 according to the EU reference scenario (European Commission 2016e, 158). The new solar power figures were based on the assumption by Lappeenranta University of Technology (LUT) that by 2022, 1% of the electricity used in Finland would come from solar energy. This would mean 330,000 new solar panels (each 3 kW) build by 2022, which equals total of 990 MW. (LUT 2014.) By 2030, the solar capacity was estimated to double from that to total of 2,000 MW.

Wind power. The data for the future plans of wind power was taken from the Finnish Wind Power Association. Finland aims for 6 TWh wind power production for the year 2020 meaning total of 2,000-2,500 MW capacity and 1,000 new wind power plants. For 2025, the production target is set up to 9 TWh, which stands for 3,000-3,500 MW and around 1,500 new wind power plants. (Finnish Wind Power Association 2016a.) According to the association, in 2012 there was 89 MW new wind power capacity build in Finland. From 2016 to 2020, the annual growth was decided to set to 300 MW in LINDA to reach the target of 2,000-2,500 MW by 2020. In this way, the total capacity was 2,438 MW. In a same way, the annual growth was put to 200 MW from 2020 to 2025 to reach the 3,000-3,500 MW target being 3,438 MW in 2025. (Finnish Wind Power Association 2016b.)

Biofuels & waste. The waste incineration capacity for the future were counted from the current and new plants. These figures were then compared to the estimates of the EU reference scenario for Finland, and the similarities were found, like in 2020 2,953 MW in the reference scenario and 3,116 MW in the LINDA model based on the historical data. (Energy industry 2015, 5-6.) In Finland, forests produce a great amount of wood to be used as biofuels. It is anticipated that in the future, wood-based biofuels are produced more to make more environmentally friendly fuel for transportation. For this reason, there will be a great increase in biofuels and waste by 2030.

Load factor. Load factor or capacity factor describes the use of power plant in practice – how much it produces electricity in a year compared to the case where it would produce electricity with full capacity 24 hours a day and 365 days a year. Estimates for load factors were decided upon and put in place by prof. Luukkanen.

Table 9. Data sources for Finland BAU scenario.

VARIABLE	REFERENCE SOURCE	SPECIFIC DATA (INPUT)
GDP growth	Energia- ja ilmastostrategia 2013 [Energy and Climate Strategy 2013]	1.6% annual GDP growth between 2010-2020 and 1.9% 2020-2030
Coal	Valtioneuvoston kanslia [Prime Minister's Office]	During 2020s abandon of coal
Peat	Estimated	-
Crude oil	Valtioneuvoston kanslia [Prime Minister's Office]	Cut half of the oil exported during 2020s
LPG	-	-
Motor gasoline	-	-
Diesel	-	-
Fuel oil	Valtioneuvoston kanslia [Prime Minister's Office]	Cut half of the oil imported during 2020s
Other oil products	Valtioneuvoston kanslia [Prime Minister's Office]	Cut half of the oil imported during 2020s
Natural gas	Estimated	-
Nuclear	TEM [Ministry of Employment and the Economy]	Nuclear power plant capacity
Hydro	Energiateollisuus ry [Energy industry]	Annual capacity 3,100 MW
Geothermal	-	-
Solar	Lappeenranta University of Technology/LUT; EU reference scenario	1% of the electricity used coming from solar energy by 2022 2,000 MW in 2030 (estimation)
Wind	Suomen tuulivoimayhdistys [Finnish Wind Power Association]	6 TWh in 2020, 9 TWh in 2025
Biofuels and waste	Energiateollisuus ry [Energy industry]	Incineration plant capacity

Overall energy consumption would decrease. Decrease has been very strong between 2012-13, quite strong between 2013-21 and would be relatively strong from 2021 onward. In 2030, the total energy consumption would be less than in 1990 (< 20,000 ktoe). Industry sector would use the biggest share of energy, and Commercial sector the second smallest share after Residential. (Figure 11)

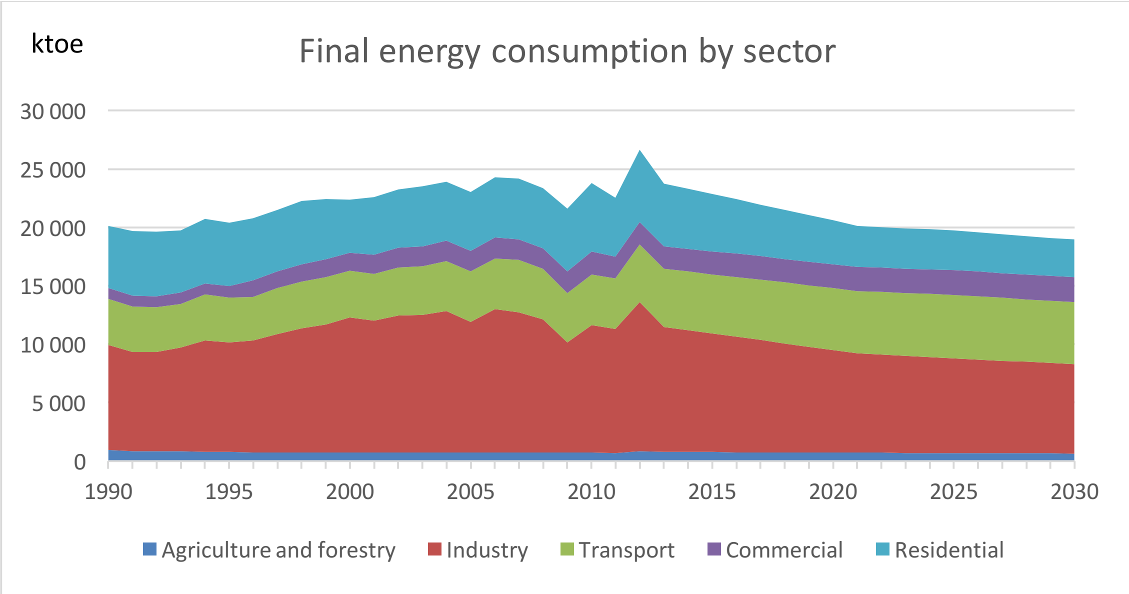


Figure 11. Total and sectoral energy consumption in Finland BAU in 1990-2030.

Power plant capacity would grow very fast: the total amount would double between 1990 and 2030. Nuclear power and natural gas would have the largest power capacities in 2030. Hydro, wind, and biofuels and waste capacities would be similar size sharing the second place in the capacity ranking. Solar and peat would have the third largest capacities. (Figure 12)

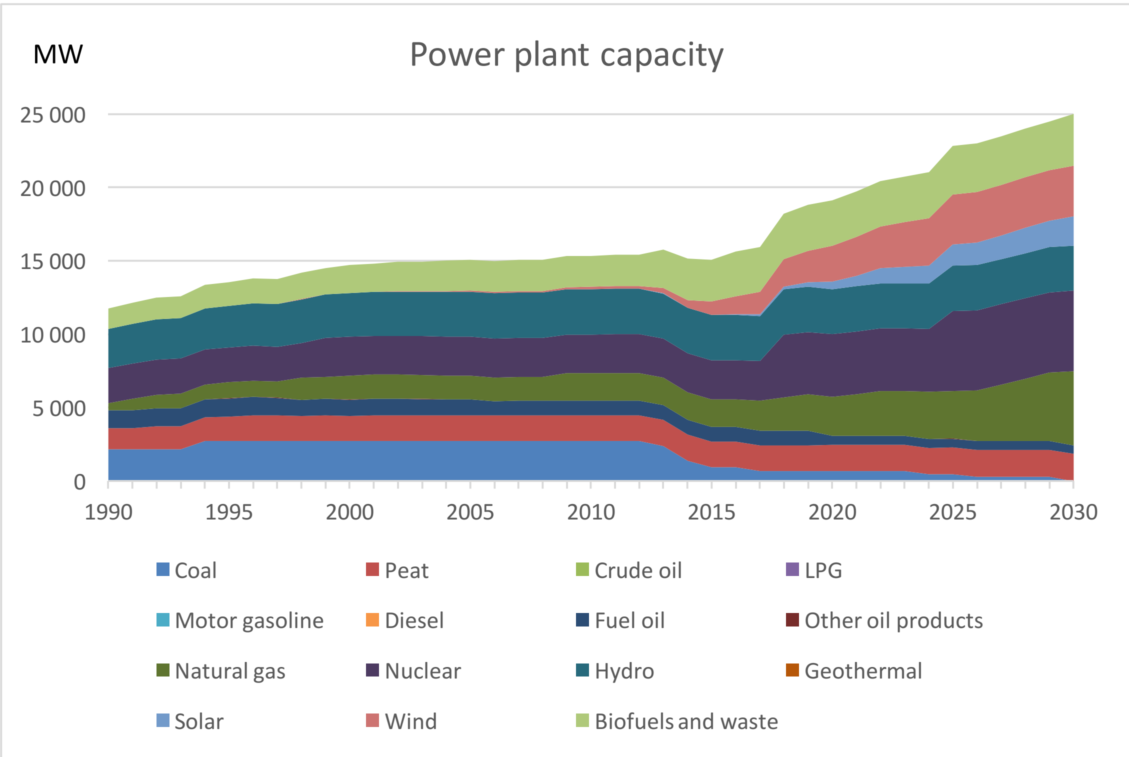


Figure 12. Total power plant capacity in Finland BAU in 1990-2030.

5.2 Structure of economic growth: industry vs. service

Industry. Industry scenario was based on the assumption that industry sector would be growing more than in BAU while the growth of service sector would be less than in BAU. This means that by 2030, the share of Industrial sector of GDP would be higher and the share of Commercial sector of GDP lower than compared to BAU. The growth percentages of the other sectors – Transportation/Communication, and Agriculture and forestry – were kept as in BAU. (Table 10)

Table 10. Annual GDP changes in Finland (industry scenario) in 2013-2030.

GDP	2013-2015	2016-2020	2021-2025	2026-2030
Agriculture and forestry	1.0 %	0.9 %	0.9 %	0.8 %
Industry	1.2 %	2.0 %	3.0 %	4.0 %
Transportation, communication	3.0 %	3.0 %	3.5 %	3.5 %
Commercial	1.6 %	1.2 %	1.0 %	0.2 %
Total	1.6 %	1.6 %	1.9 %	1.9 %

Service. In the *service* scenario, the assumption was exactly the opposite to the previous industry scenario: the less-energy intensive Commercial sector would grow faster than the energy-intensive Industry sector by 2030. Again, the growth percentages of the other sectors – Transportation/Communication, and Agriculture and forestry – stayed as in BAU. (Table 11)

Table 11. Annual GDP changes in Finland (service scenario) in 2013-2030.

GDP	2013-2015	2016-2020	2021-2025	2026-2030
Agriculture and forestry	1.0 %	0.9 %	0.9 %	0.8 %
Industry	1.2 %	0.4 %	-1.3 %	-5.8 %
Transportation, communication	3.0 %	3.0 %	3.5 %	3.5 %
Commercial	1.6 %	2.0 %	3.0 %	4.0 %
Total	1.6 %	1.6 %	1.9 %	1.9 %

Figure 13 shows the total and sectoral GDP development in both industry and service scenarios in 1990-2030. The total economic growth of the scenarios would be almost the same as in BAU. However, the growth of Industry sector would be faster in the industry scenario, whereas in the service scenario, Service sector would grow faster.

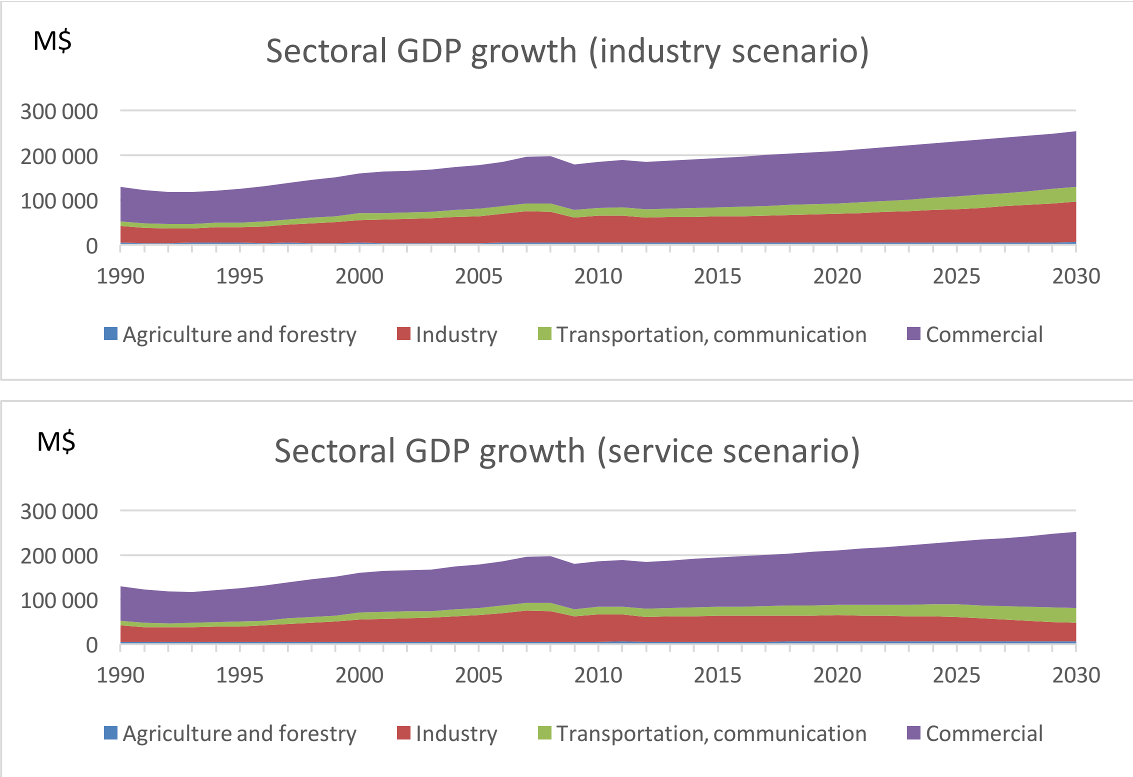


Figure 13. Total and sectoral GDP growth in Finland (industry vs. service scenario) in 1990-2030.

In both scenarios, energy consumption would decrease as is the case also in BAU scenario. However, the decrease would be slightly bigger in service scenario due to decrease of Industry sector that traditionally needs more energy than Service sector. (Figure 14)

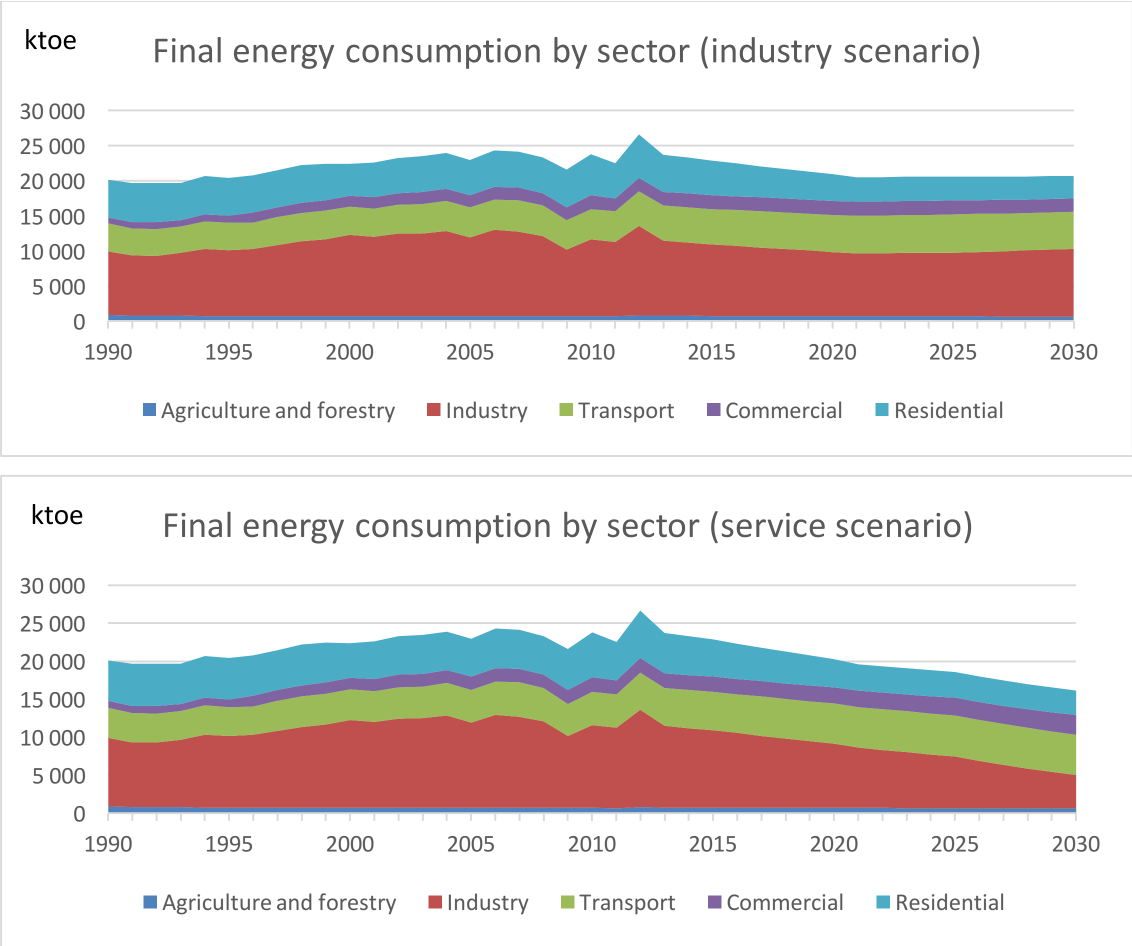


Figure 14. Total and sectoral energy consumption in Finland (industry vs. service scenario) in 1990-2030.

5.3 Energy sources: non-renewable vs. renewable

Non-renewable. In this *non-renewable* scenario, most of the energy used were based on fossil fuels. This can be done by changing *Shares of fuel use* (%) in each sector and also by adding or removing different power plants. It should be noticed that only primary energy sources, like oil, gas and peat, but also biofuels and waste, are counted as fuels in the LINDA model. Wind, solar, hydro, and nuclear power are used in the electricity production and therefore they were not taken into account in the fuel share changes. However, by adding and removing different power plants in the scenario, it was possible to effect the share of renewables and fossils. The sectoral and total GDP growth was kept the same as in BAU. In this scenario, the renewable energy capacity was assumed to increase less than in BAU and the non-renewable capacity (fuel oil, natural gas, and coal) to decrease less than in BAU. The plans of new nuclear power stations were kept as in BAU.

Renewable. The growth in the *renewable* scenario was assumed to be different than in the previous non-renewable scenario: most of the energy would come from renewables: solar, wind, and hydro. This could be done by adding more power plants that use renewable energy and removing plants that rely on fossil energy. Also, growing the share of biofuels and waste in the *Shares of fuel use* (%) added to the idea of renewable energy scenario. GDP structure and volume was again the same as in BAU. Since the energy used was based on renewable energy, more investments to wind, solar and hydro power, as well as biofuels and waste were made to grow their capacity in the future. In this scenario, less fossil fuel capacity was needed in the economy, and therefore no new investments to fuel oil, gas, coal or nuclear power were needed. More likely, some of the old plants, such as coal plants, were shut down, and visions to grow nuclear power capacity were neglected.

Table 12 and Figure 15 present the power plant capacities of both scenarios. In non-renewable scenario, the total capacity would be a bit smaller than in BAU (25,000 MW in 2030). The total capacity of renewable scenario would be even smaller than the capacity of non-renewable scenario. The share of renewables – biofuels and waste, wind, solar and hydro – would constitute around 60% of the total capacity of renewable scenario in 2030. In non-renewable scenario, the amount of renewables would be around 40% in the same year. In non-renewable scenario, the share of natural gas would more than triple compared to renewable scenario. Also the share of nuclear, coal and fuel oil would be larger in the non-renewable scenario than in the renewable scenario.

Table 12. Power plant capacity (MW) in Finland (non-renewable vs. renewable scenarios) in 2030.

Power plant capacity, cumulative MW (for 1971-2006 calculated based on load factor and produced amount of electricity)	Non-renewable scenario 2030	Renewable scenario 2030
Coal	664	0
Peat	1,837	1,837
Crude oil	0	0
LPG	0	0
Motor gasoline	0	0
Diesel	0	0
Fuel oil	795	195
Other oil products	8	8
Natural gas	7,451	1,851
Nuclear	5,465	2,665
Hydro	3,084	3,884
Geothermal	0	0
Solar	15	25
Wind	2,438	4,438
Biofuels and waste	3,116	4,316
Total	24,873	19,219

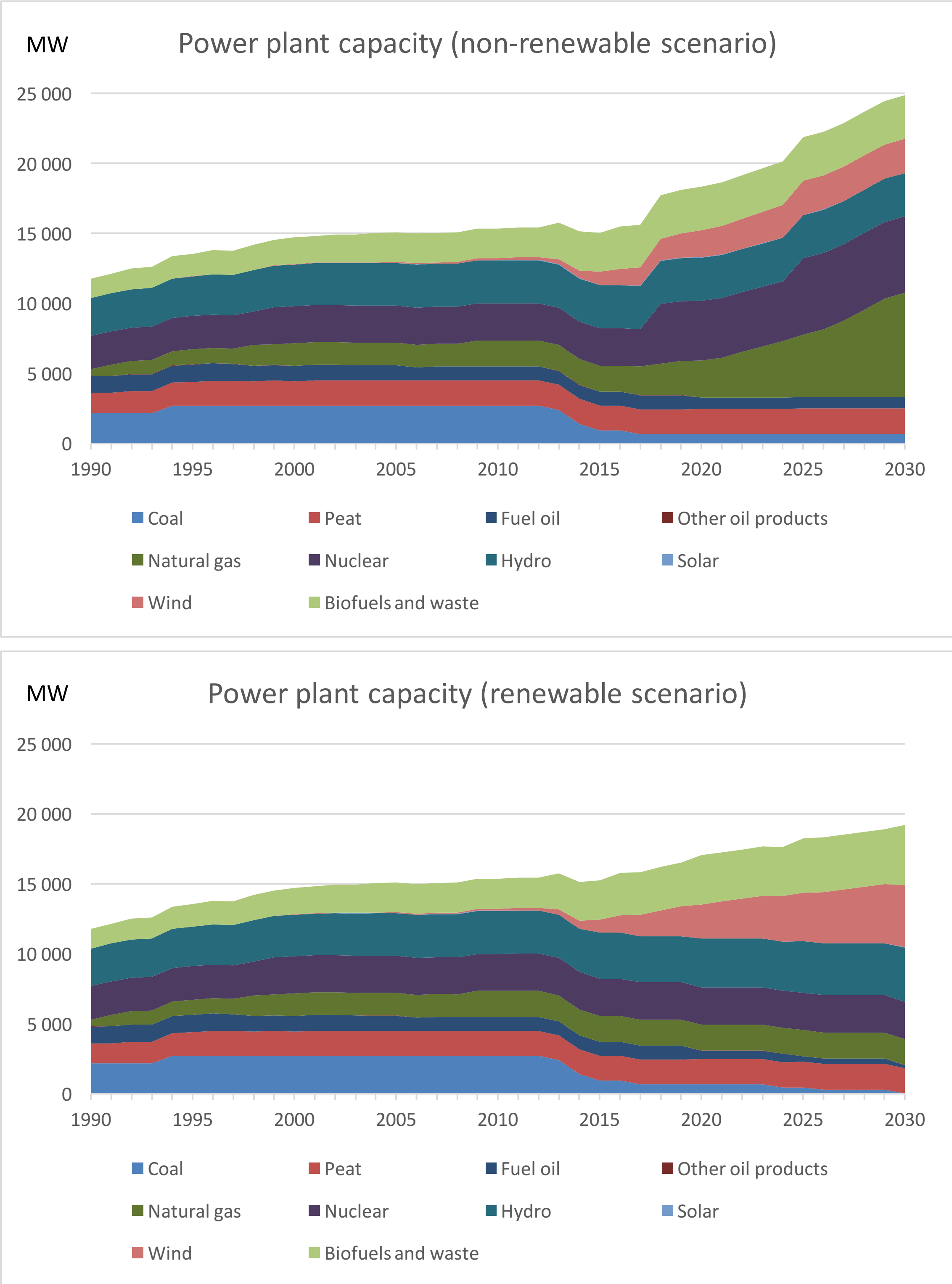


Figure 15. Power plant capacity in Finland (non-renewable vs. renewable scenario) in 1990-2030.

6 ENERGY SCENARIOS FOR GERMANY

6.1 Germany BAU

The historical, input data of Germany LINDA model were based on the statistics of IEA and World Bank, and the future visions on several different data sources presented in this chapter. Fuel shares for each sector were estimated according to the historical development and future plans and visions in the energy field. The (-) sign in the Table 14 means that no changes were done for the future (adding/removing capacity), and the capacity figures were the same as the input data.

Annual total GDP growth %. The future GDP growth percentages for Germany were based on several sources (e.g. Knoema 2016; German Government 2014, 7). Based on these projections, estimations were made for Germany. As an example, the annual growth rate for Germany was said to be 2.4% in 2020 (Trading Economics 2016). The total GDP changes chosen for the LINDA model of Germany were 1.5% between 2012-2015, 2.0% 2016-2020, 2.5% 2021-2025, and 3.0% 2026-2030. Since the estimated future percentages can not be placed straight in the LINDA model, the growth percentages in each sector have first to be estimated in able to get the wanted total GDP growth percentages. (Table 13)

Annual GDP growth % per sector. The growth percentages of Agriculture and forestry, Industry, Transportation/Communication, and Commercial (there Service) were based on assumptions about the economic activity of those sectors in the future. (Table 13)

Table 13. Annual GDP changes in Germany BAU in 2013-2030.

GDP	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**
Agriculture and forestry	-8.5 %	-8.5 %	-7.5 %	-5.0 %
Industry	3.0 %	3.7 %	2.8 %	3.0 %
Transportation, communication	3.0 %	3.2 %	2.8 %	3.0 %
Commercial	0.5 %	0.8 %	2.3 %	3.0 %
Total	1.5 %	2.0 %	2.5 %	3.0 %

In Germany BAU, the economic growth would be very fast: GDP would double between 1990 and 2030. Industry sector would grow a bit stronger than in Finland BAU. Otherwise, the sectoral GDP development of Germany BAU would be rather similar to Finland BAU. (Figure 16)

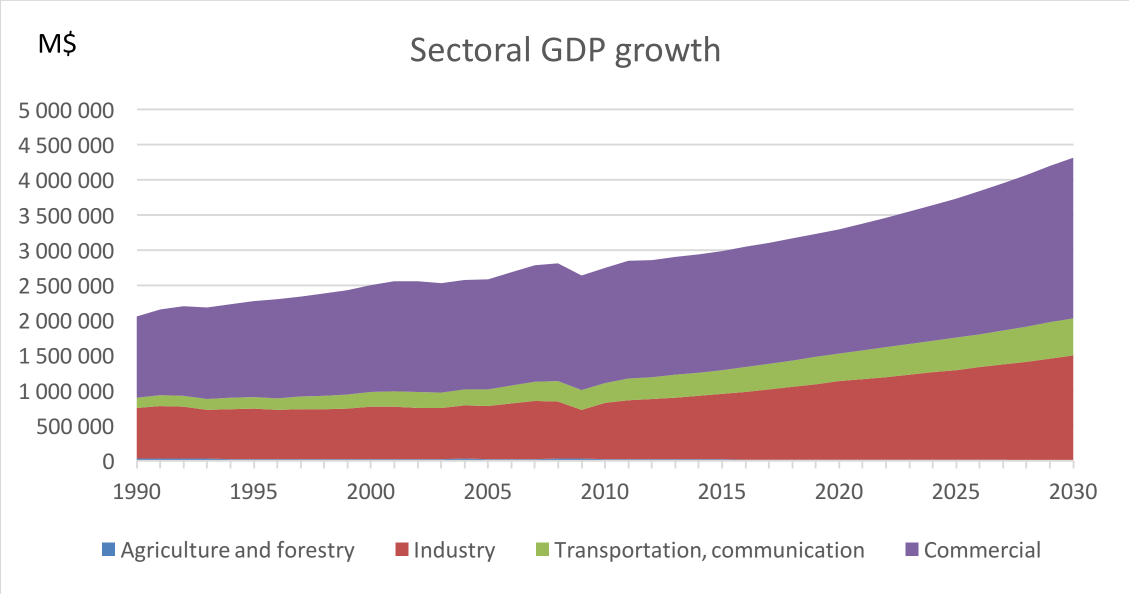


Figure 16. Total and sectoral GDP growth in Germany BAU in 1990-2030.

Energy & electricity intensities. The annual change percentages in the energy and electricity intensities of the LINDA model for Germany were based on the figures of BAU Finland (see Table 8). Overall, Germany has set a target of cutting primary energy consumption 20% by 2020 and 50% by 2050 compared to 2008 level (BMWi 2010, 5). The Energy Concept of Germany states that the country will increase the final energy consumption of renewable energies 18% by 2020 following 30% by 2030, and 60% by 2050. Also, by 2020 electricity generated from renewables is accounted to 35%, 50% by 2030, and 80% by 2050. (BMWi 2010, 5.) Since renewables are not fully covering the total energy demand by 2050, some fossil fuels are still required in the future. However, the Renewable Energy Research Association has made a 100% renewable energy scenario by 2050 for Germany not requiring any fossil fuels (FVEE 2010).

Nuclear power. The future data of power plant capacity was based on several sources. The general attitude towards nuclear power in Germany has changed especially due to safety reasons. Germany has made a decision to stop producing nuclear power by 2022. Eight nuclear power stations have been taken off grid in 2011, and the nine other plants will be shut down gradually by 2022. Since the economy has highly relied on nuclear power, the whole energy system has to be restricted, and the power has to be generated from other sources in less than 10 years. (BMWi 2011b; BMWi 2012, 6.) In the BAU scenario of Germany, the remain nine nuclear plants (total 18,003 MW in 2012 in LINDA) were reduced so that the annual reduction was 2,000 MW between 2012-2022 to reach 0 MW.

Coal and gas. Due to phasing out nuclear power by 2022, new coal and gas power stations will be needed to secure power capacity supply. In addition to new plants under construction, around 17 GW would be needed by 2022 to fulfil the capacity. (BMWi

2012, 8.) In the LINDA model, both coal and gas were estimated to build up half of that, meaning 8,5 GW = 8,500 MW growth for both. According to the EU scenario, the large increase in gas capacity would be only between 2030 and 2035 (from 26,978 MW to 39,096 MW). However, total capacity would have to grow earlier to reach the surplus of 8,500 MW by 2022. (European Commission 2016e, 162.)

Fuel oil. Fuel oil was expected to decrease heavily in Germany. The EU reference scenario estimates that by 2030 the amount is only 1,248 MW being 5,688 MW in 2010. (European Commission 2016e, 162.)

Hydro power. According to the EU reference scenario, there will be only a slight increase in hydro power: from 5,592 MW in 2020 to 5,857 MW in 2030 excluding pumped hydro storage capacity (European Commission 2016e, 162). In 2010, the hydro capacity was 5,407 MW in the EU scenario and according to the input data of LINDA, 11,137 MW. This means that LINDA model takes into account pumped hydro storage capacity as well. When doubling the EU hydro capacity in 2030, we get 11,714 MW, which is almost the current situation in the LINDA meaning that no extra plants were needed.

Solar power. Solar capacity figures were taken from the estimates of the EU reference scenario: 52,803 MW by 2020 and 63,959 MW by 2030 (European Commission 2016e, 162). This means more than to triple the amount of capacity between 2010-2030. The future growth rates were estimated so that in 2020, the solar capacity follows the estimates of EU reference scenario and in 2030, the capacity was anticipated to more than double compared to 2020 to replace the domestic energy production that earlier leaned heavily on nuclear power plants.

Wind power. Due to the high target for renewables, the massive expansion of wind energy, both offshore and onshore, will be a challenge for Germany (BMWi 2010, 7). Offshore wind capacity is aimed to increase by 25 GW by 2030 (BMWi 2010, 8). Also, there is assumption of almost doubling the wind power capacity from 27 GW to 51 GW by 2020 (BMWi 2012, 19). According to the EU reference scenario, wind capacity for 2015 was 44,946 MW, and the growth is expected to be as fast as 61,832 MW in 2020 and 67,214 MW in 2030 (European Commission 2016e, 162). The increase of new wind power plants in the Germany BAU by 2020 follows the projections of the EU. However, the wind capacity was decided to almost double between 2020-2030 due to decreased nuclear power capacity.

Biofuels & waste. In Germany, biofuels are not that important source of energy due to limited amount of biomaterial, like wood. However, energy crops and energy recovery from biomass waste could be used for the production of synthetic fuels for planes and ships. The share of biofules was targeted to be around 10% in 2020 of the total fuel consumption. (FVEE 2010, 5, 33.) The figures in the EU reference scenario are similar to the input data in LINDA (in 2020 7,100 MW / 6,625 MW and in 2030 6,894 MW /

6,625 MW), so there was no need for additional biofuel capacity. (European Commission 2016e, 162.)

Load factors were estimated by prof. Luukkanen.

Table 14. Data sources for Germany BAU scenario.

VARIABLE	REFERENCE SOURCE	SPECIFIC DATA (INPUT)
GDP growth	Traiding Economics (also Knoema and NEEAP3 Germany)	2.4 % annual GDP growth in 2020
Coal	Estimated	8,500 MW by 2022
Peat	-	-
Crude oil	-	-
LPG	-	-
Motor gasoline	-	-
Diesel	-	-
Fuel oil	EU Reference scenario	1,248 MW by 2030
Other oil products	-	-
Natural gas	Estimated	8,500 MW by 2022
Nuclear	'Energieszenarien 2011'/Prognos; BMWi 2011, BMWi 2012	0 MW by 2022 (phasing out nuclear power)
Hydro	EU Reference scenario	5,592 MW in 2020 5,857 MW in 2030
Geothermal	-	-
Solar	EU Reference scenario	52,803 MW in 2020 63,959 MW in 2030
Wind	BMWi 2010; BMWi 2012; EU reference scenario	51 GW by 2020; 61,832 MW in 2020 67,214 MW in 2030
Biofuels and waste	FVEE	10% of the total fuel consumption in 2020

The total energy consumption in 2030 would be bigger (around 30,000 ktoe) than in 1990, so the consumption would increase and be opposite to the decreasing trend of Finland. This could be to do with the growing Industry sector. Industry sector does use most of the total energy Transport sector being the second biggest user. (Figure 17)

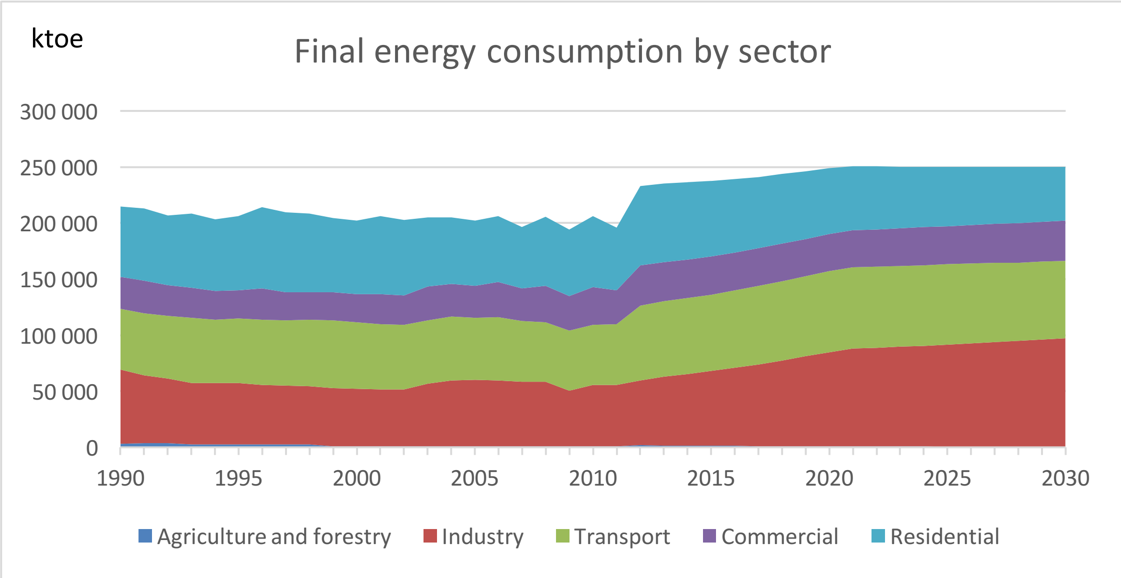


Figure 17. Total and sectoral energy consumption in Germany BAU in 1990-2030.

Solar power capacity would be the biggest wind being the second in 2030. Coal would be the third and natural gas the fourth in the capacity share. The renewables – solar and wind, also hydro – would constitute together 2/3 of the total power capacity in 2030. Total power plant capacity would more than triple from 1990 to 2030. (Figure 18)

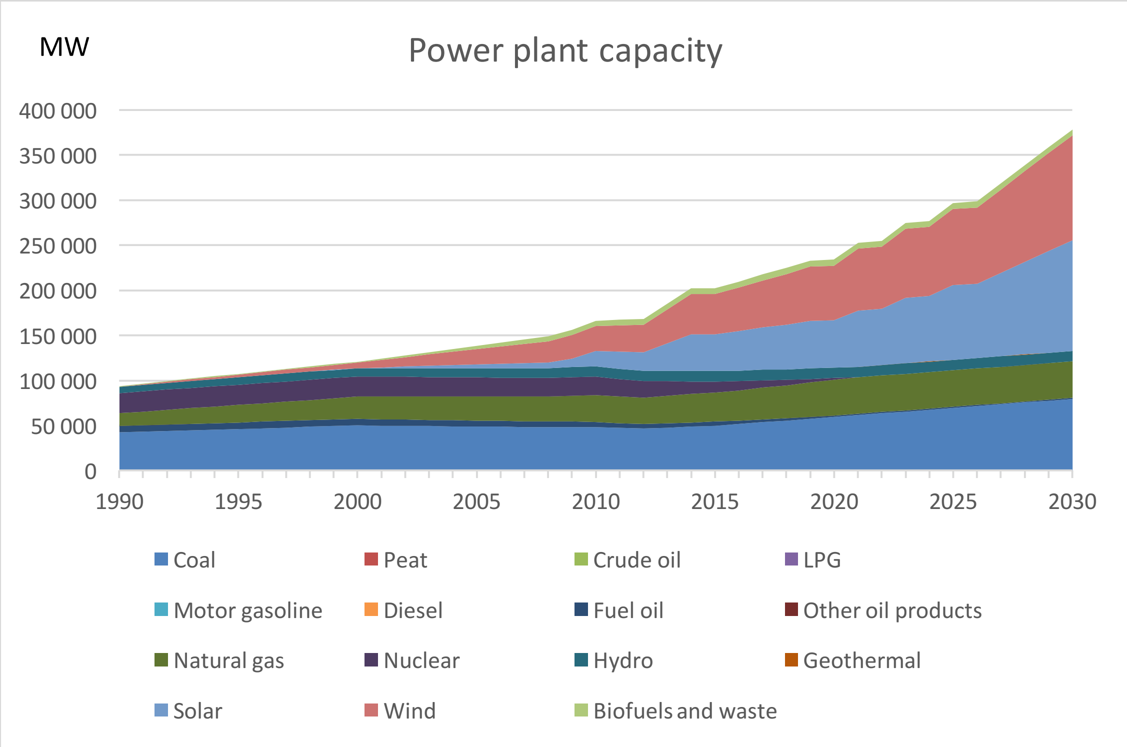


Figure 18. Total power plant capacity in Germany BAU in 1990-2030.

6.2 Structure of economic growth: industry vs. service

The assumptions of these two scenarios of Germany were similar to the scenarios of Finland (see 5.2).

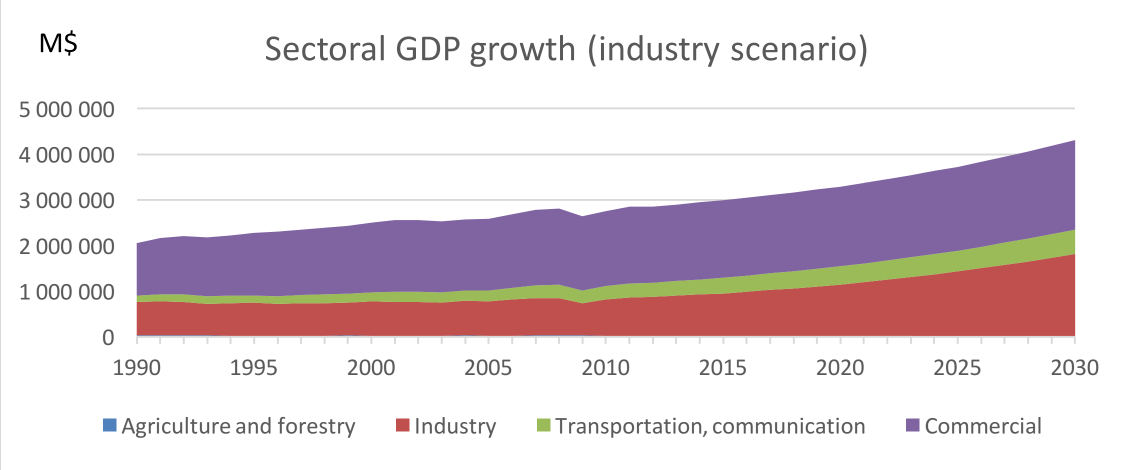
The total economic growth in industry and service scenarios would be very similar to Germany BAU. The growth of Industry sector would be stronger in the German industry scenario than in the industry scenario of Finland. In the service scenario of Germany, the slow growth of Industry sector would be then very similar to the development of Industry sector in the service scenario of Finland. (Tables 15 and 16, and Figure 19)

Table 15. Annual GDP changes in Germany (industry scenario) in 2013-2030.

GDP	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**
Agriculture and forestry	-8.5 %	-8.5 %	-7.5 %	-5.0 %
Industry	3.0 %	4.0 %	4.6 %	5.0 %
Transportation, communication	3.0 %	3.2 %	2.8 %	3.0 %
Commercial	0.5 %	0.6 %	1.0 %	1.3 %
Total	1.5 %	2.0 %	2.5 %	3.0 %

Table 16. Annual GDP changes in Germany (service scenario) in 2013-2030.

GDP	**2013-2015**	**2016-2020**	**2021-2025**	**2026-2030**
Agriculture and forestry	-8.5 %	-8.5 %	-7.5 %	-5.0 %
Industry	3.0 %	1.7 %	1.5 %	0.9 %
Transportation, communication	3.0 %	3.2 %	2.8 %	3.0 %
Commercial	0.5 %	2.0 %	3.0 %	4.0 %
Total	1.5 %	2.0 %	2.5 %	3.0 %



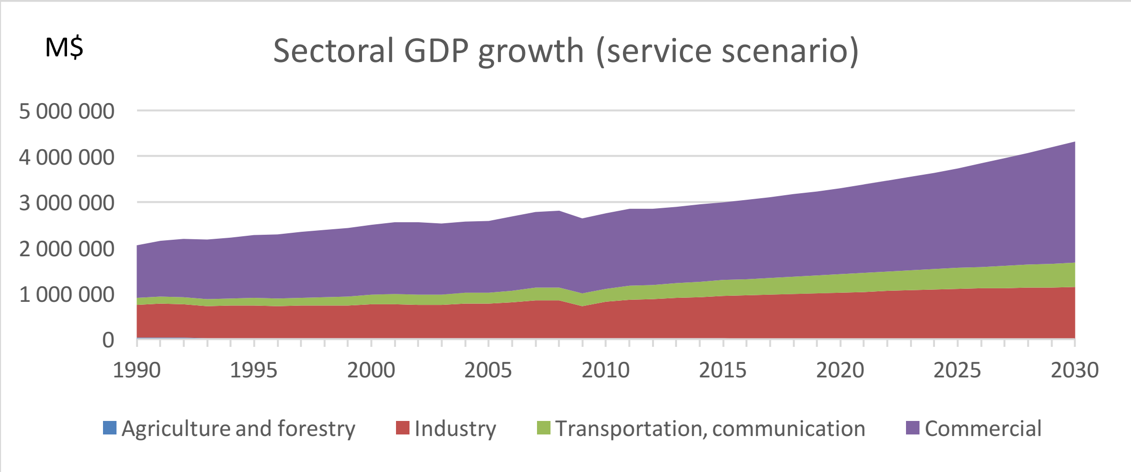
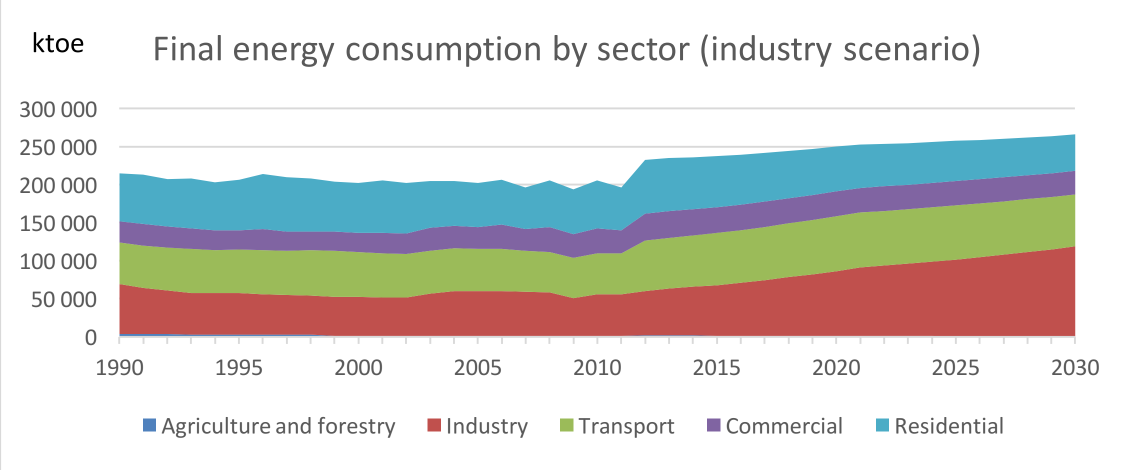


Figure 19. Total and sectoral GDP growth in Germany (industry vs. service scenario) in 1990-2030.

Presumably, the total energy consumption in industry scenario would be bigger, and in service scenario smaller than in Germany BAU. Industry sector would grow fast in industry scenario causing almost half of the total consumption. In service scenario, industry sector would be responsible of a third of the total energy use. (Figure 20)



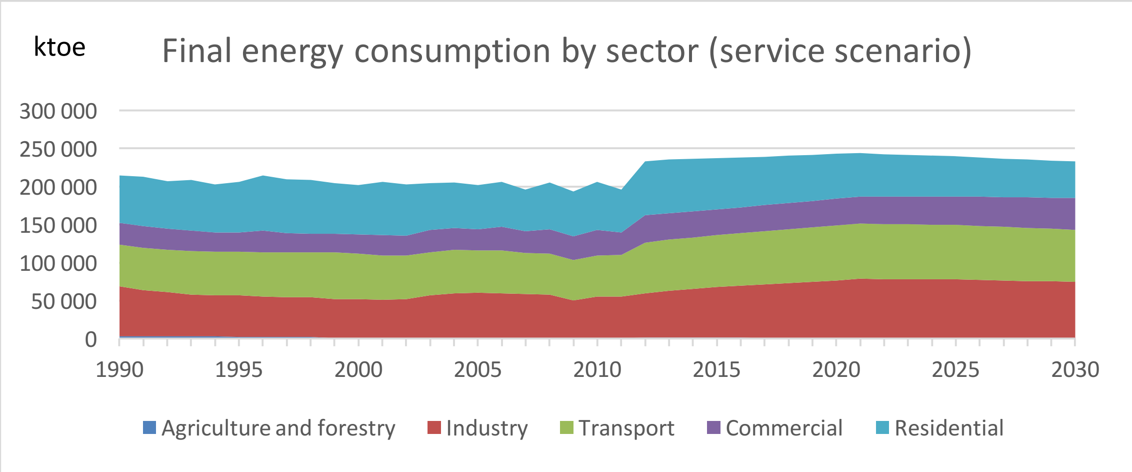


Figure 20. Total and sectoral energy consumption in Germany (industry vs. service scenario) in 1990-2030.

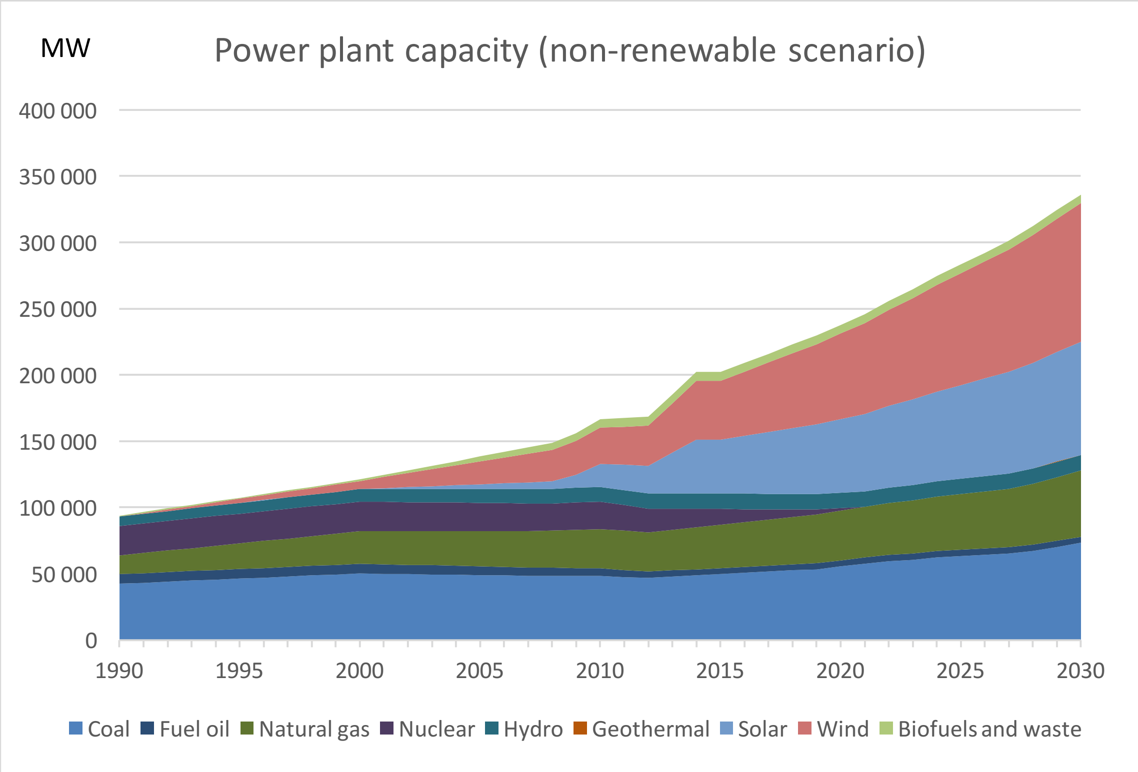
6.3 Energy sources: non-renewable vs. renewable

Non-renewable. In this scenario, the increase of renewable energy capacity was assumed to be less and the non-renewable capacity (coal and natural gas) more compared to BAU scenario. The plans to end nuclear energy production were the same as in BAU. Also, there were no decrease in the fuel oil capacity after 2012, as was the case in BAU scenario.

Renewable. In this scenario, solar and wind power capacities were larger than in BAU and additions to coal and natural gas capacities were less and decrease in fuel oil more than in BAU scenario. The plans to cut nuclear power was the same as in BAU. In non-renewable scenario, the total power plant capacity would be less than in BAU, but in renewable scenario the capacity would be more than in BAU. Even though being non-renewable scenario, the amount of renewables – especially wind and solar – would be around 60% of the total power capacity. However, the share of natural gas and coal would increase in non-renewable scenario, as in renewable scenario the development of gas and coal capacity would be the same as in BAU. In renewable scenario, the amount of wind, solar and hydro power would be around 80%. (Table 17 and Figure 21)

Table 17. Power plant capacity (MW) in Germany (non-renewable vs. renewable scenarios) in 2030.

Power plant capacity, cumulative MW (for 1971-2006 calculated based on load factor and produced amount of electricity)	**Non-renewable scenario 2030**	**Renewable scenario 2030**
Coal	73,164	46,714
Peat	0	0
Crude oil	0	0
LPG	0	0
Motor gasoline	0	0
Diesel	0	0
Fuel oil	4,750	0
Other oil products	0	0
Natural gas	49,907	29,657
Nuclear	0	0
Hydro	11,610	11,610
Geothermal	68	68
Solar	85,650	149,650
Wind	104,403	150,403
Biofuels and waste	6,626	6,626
Total	336,178	394,728



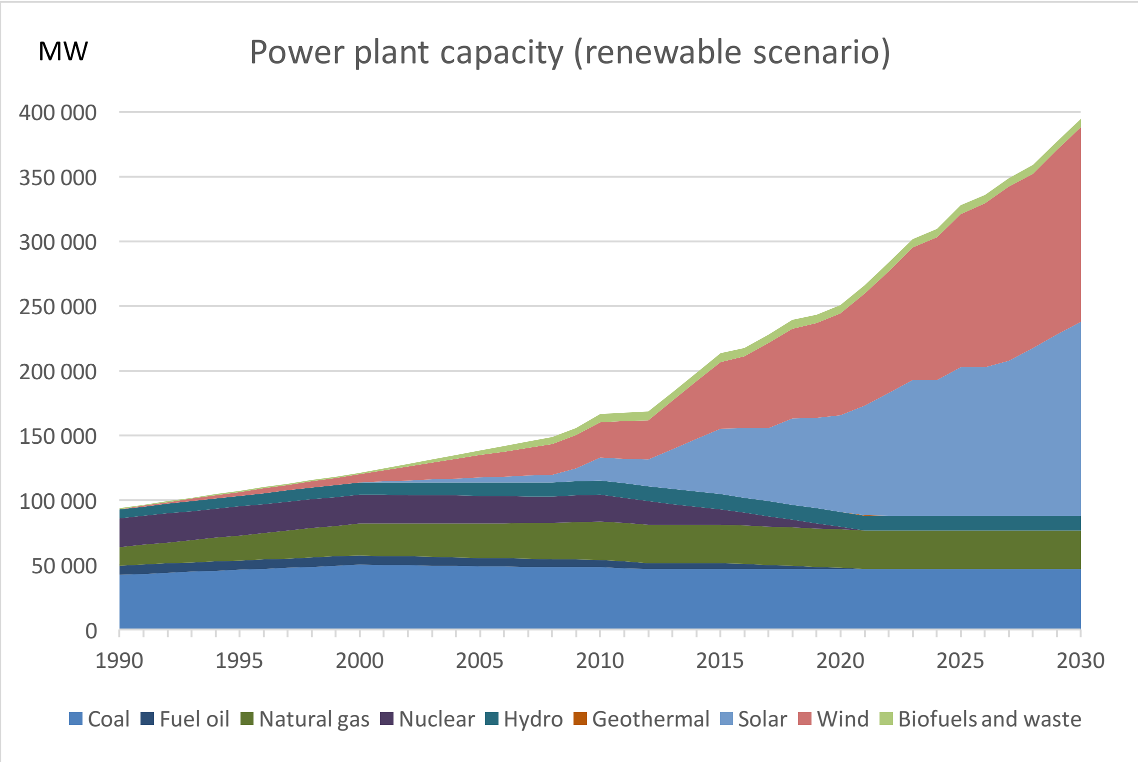


Figure 21. Power plant capacity in Germany (non-renewable vs. renewable scenario) in 1990-2030.

7 RESULTS

This chapter provides the results of energy intensity calculations done for the LINDA scenarios of Finland (7.1) and Germany (7.2). Also, the comparisons of the results and the efficiency targets (GAP analysis) are presented with different figures accompanied with short text analyses. In addition, the curves of EKC and de-linking based on BAU scenarios of Finland and Germany are analysed (7.1.3 and 7.2.3). In the end, backward intensity scenarios are created and compared with BAUs and energy efficiency targets (7.3).

7.1 Finland

7.1.1 Energy efficiency targets vs. Finland BAU

Energy efficiency in Finland were counted through energy intensity. First, intensities and change percentages were counted for the years 1990, 2020 and 2030 based on the Finland BAU scenario. After that, these intensities were compared with the energy efficiency targets of EU 2020 and 2030. Also, energy consumption targets (by the EED and NEEAP3) that are related to energy efficiency, were compared with Finland BAU.

Energy intensities of BAU scenario and change percentages

Energy intensity can be counted as follows:
Energy intensity = Energy input / Value added = Total Primary Energy Supply TPES / Gross Domestic Product GDP

The change (percentage) in energy intensity compared to 1990 level in 2020 and 2030 can be counted as follows:

100 % * (Intensity 2020 – Intensity 1990) / (Intensity 1990), and
100 % * (Intensity 2030 – Intensity 1990) / (Intensity 1990)

The EU 2020 and 2030 targets

The 20% and 27% targets can be counted from the 1990 level:
EU 2020 target: 0.8 * energy intensity in 1990, and
EU 2030 target: 0.73 * energy intensity in 1990

Figure 22 presents both the historical and the possible future development of energy intensity in Finland. Also, the figure shows the intensity differences between Finland BAU and the EU targets. It can be seen that energy intensity of Finland BAU would be the same as the target in 2020 and lower than the target in 2030. Therefore, the Finland BAU scenario would reach the energy efficiency targets.

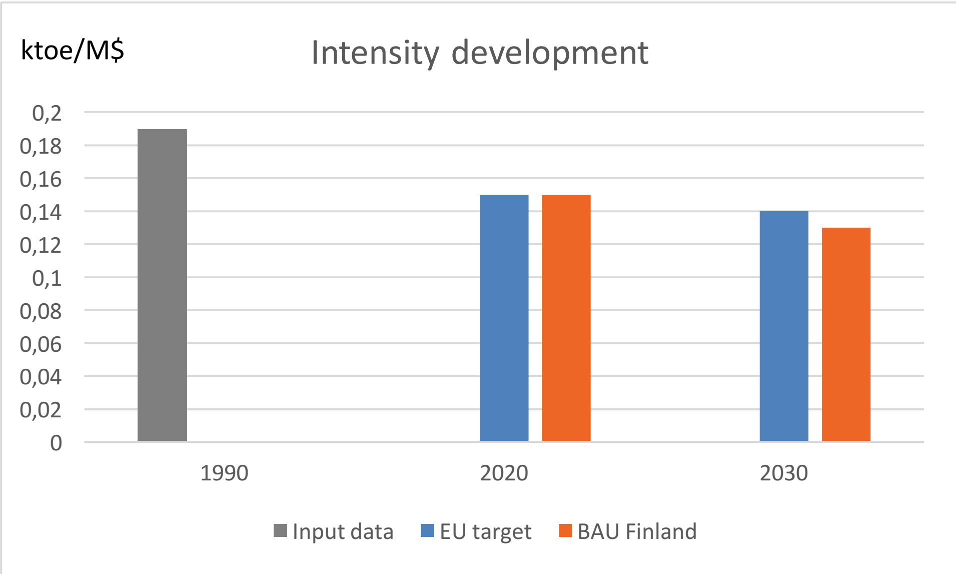


Figure 22. Development of energy intensity in Finland BAU.

The increase in energy efficiency from 1990 to 2020 would be slightly bigger in the BAU scenario compared to the EU 2020 target, i.e. 20 % improvement in energy efficiency by 2020. In 2030, the efficiency would go well over the 27 % EU target. (Figure 23)

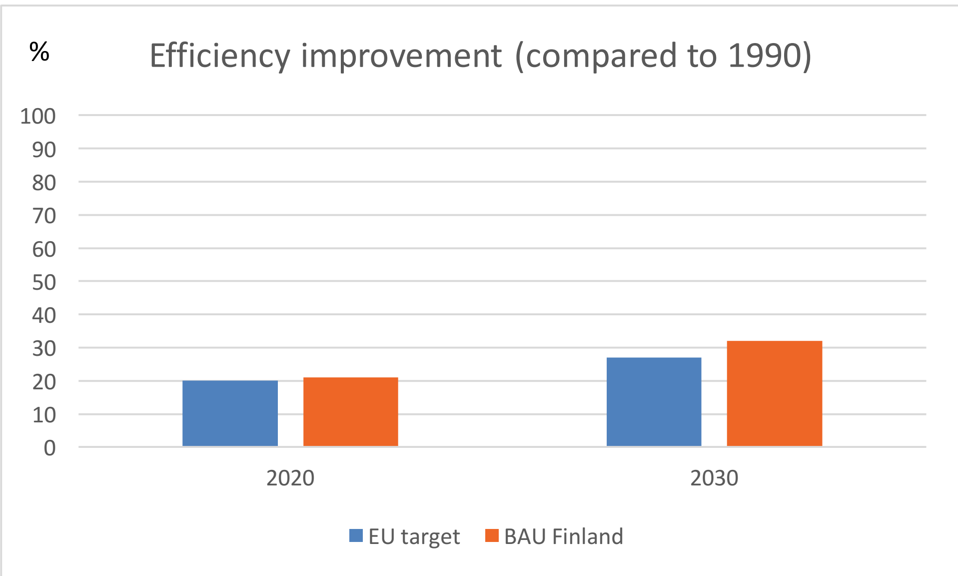


Figure 23. Improvement of energy efficiency in Finland BAU.

The EED targets of Finland

According to Energy Efficiency Directive EED (European Parliament 2012), the set target for Finland for primary energy consumption (= TPES) is 35.9 Mtoe and for final energy consumption (FEC) 26.7 Mtoe in 2020 (European Commission 2016b; TEM 2014b). Figure 24 shows that the consumption would be lower than the maximum in Finland BAU, which means that Finland would save even more energy than expected by the EED.

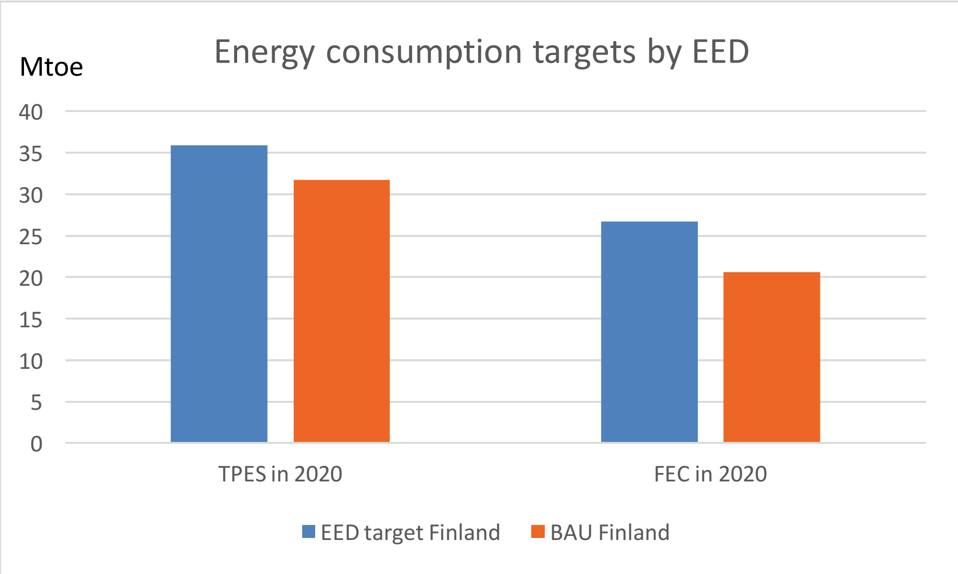


Figure 24. Energy consumption targets and Finland BAU scenario.

The NEEAP3 target of Finland

In the NEEAP3 of Finland, the figures present energy savings, like e.g. estimated *Total Energy Saving All* in 2020 51,844 GWh/a (TEM 2014b, 13). When transforming GWh/a to Mtoe: 51,844 GWh = 4.46 Mtoe. Figure 25 shows that Finland BAU would not reach even half of the saving target. This might be because the total energy consumption in Finland BAU in 2020 is already less than assumed in the NEEAP3, and therefore the savings are also less. (See the actual numbers and calculations in Appendix Finland.)

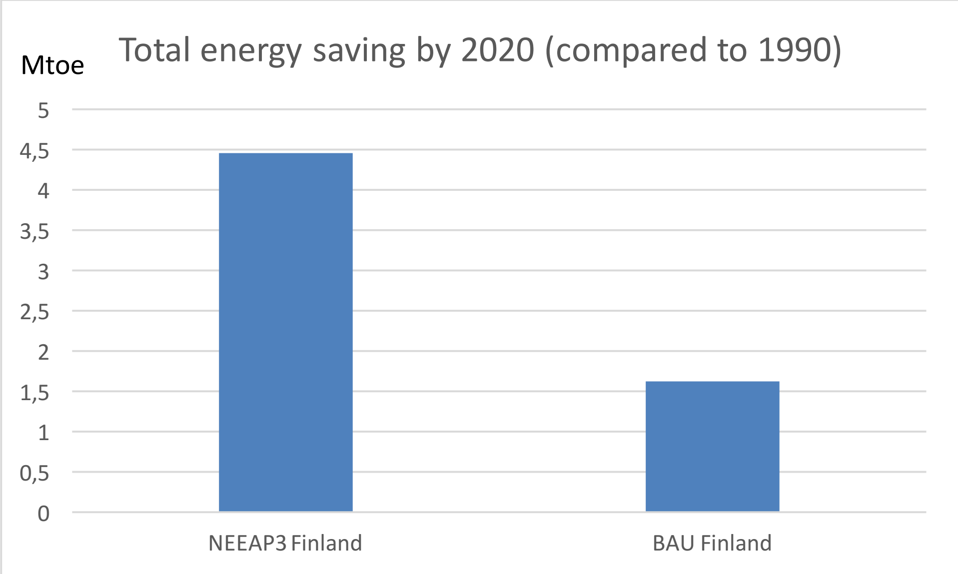


Figure 25. Energy savings by 2020 in Finland BAU.

7.1.2 Energy efficiency targets vs. other scenarios

Intensities of industry vs. services and non-renewable vs. renewable scenarios of Finland are compared with the energy efficiency targets of the EU 2020 and 2030 as well as BAU scenario. Also, energy consumption targets by the EED are compared with the scenarios. Figure 26 presents the differences of these scenarios in 2020 and 2030. In 2020, the intensities would be the same in all the scenarios except the intensity of the renewable scenario would be lower than the others. All the scenarios would still reach the EU 2020 target. In 2030, the situation would differ more: industry and non-renewable scenarios would have the same intensity as the EU target, and the intensities of renewable, service and BAU scenarios would be lower than the target. Despite the differences, all the scenarios would reach the EU 2030 energy efficiency target.

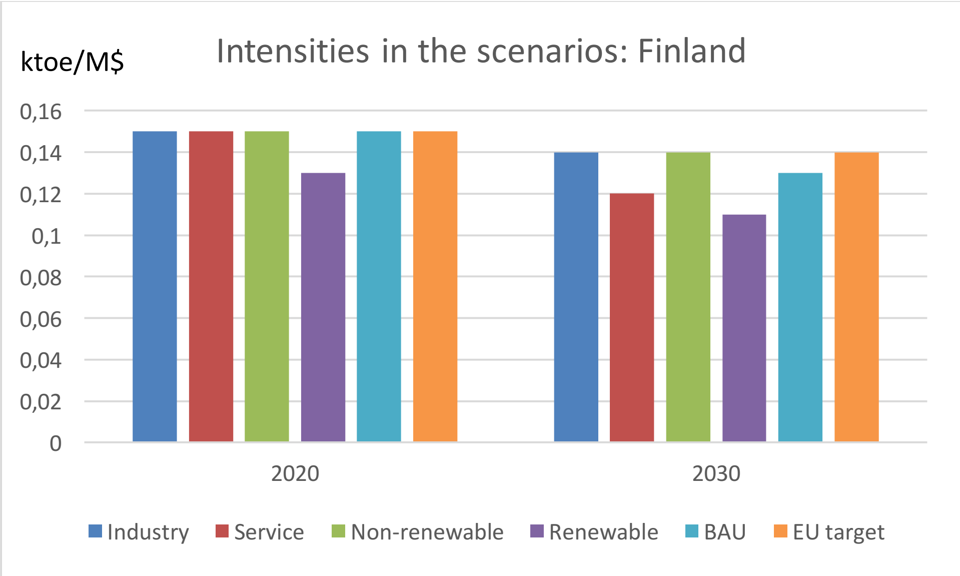


Figure 26. Development of energy intensities in all scenarios of Finland.

In general, energy would be consumed less than the maximum targets set by the EED in all the scenarios. The figures in Total Primary Energy Supply (TPES) differ more than in Final Energy Consumption (FEC). The primary supply would be the same in industry, non-renewable and BAU scenarios, slightly smaller in service and even smaller in renewable scenario in 2020. The final consumption would be the same in all the scenarios except in service the consumption would be slightly smaller. TPES figures in 2030 are also presented in Figure 27 to get a better idea of the energy development in the scenarios.

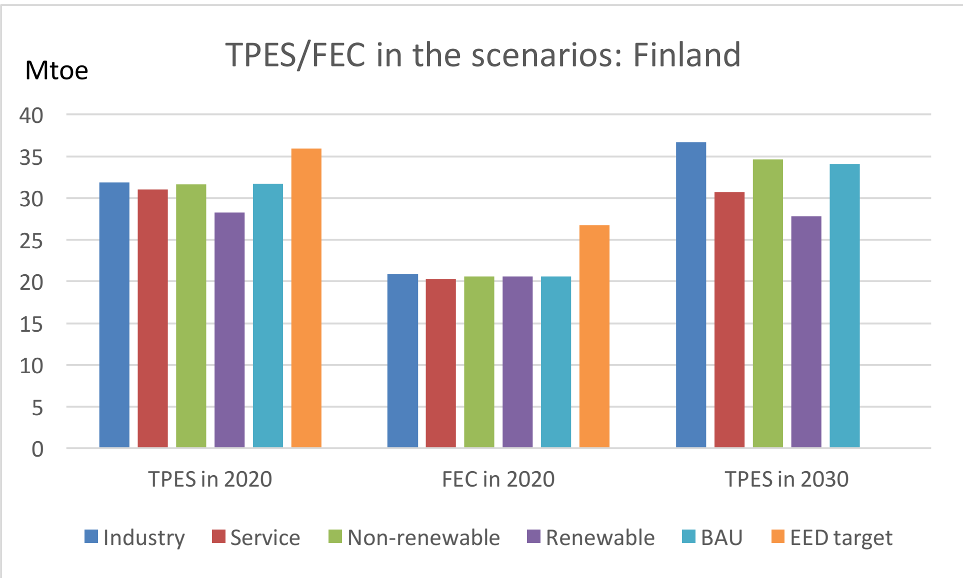


Figure 27. Energy consumption in 2020 in all scenarios of Finland.

7.1.3 EKC and de-linking

The relationship of energy consumption (here Total Primary Energy Supply TPES) and GDP growth (as GDP per capita) in Finland BAU were explored between 1972-2030. Figure 28 shows that energy consumption would grow more slowly in the future than before, while GDP per capita would grow fast. An inverted U-shape curve, Environmental Kuznets Curve (EKC) can not yet be seen in the figure, but if the decreasing trend would continue in the future, the EK-Curve might then occur. Figure 29 shows (weak) de-linking energy consumption from GDP growth. Even though energy consumption would still have a slightly increasing trend line, energy intensity would decrease due to fast economic growth: GDP would grow almost 100% by 2030 compared to 1990.

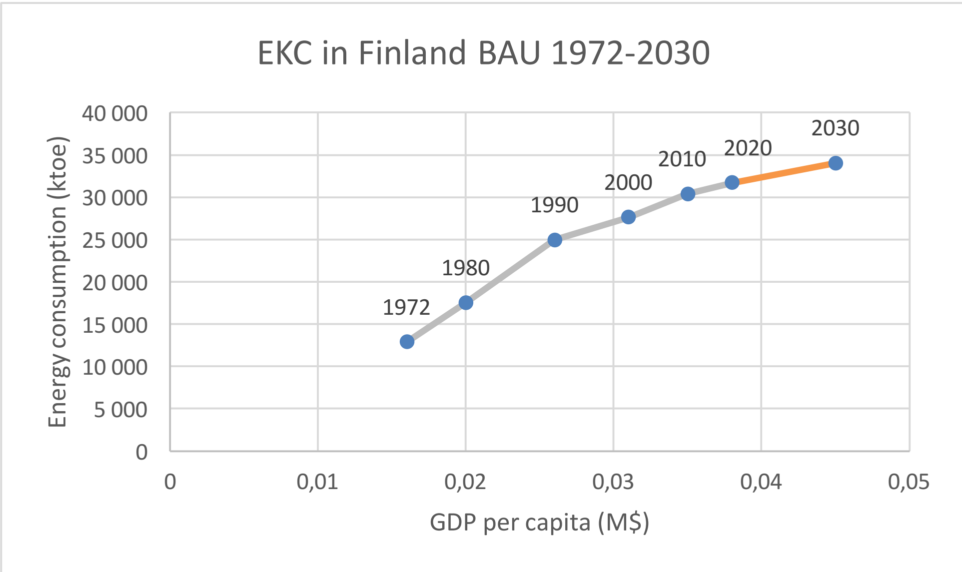


Figure 28. Relationship between GDP and energy consumption in Finland BAU.

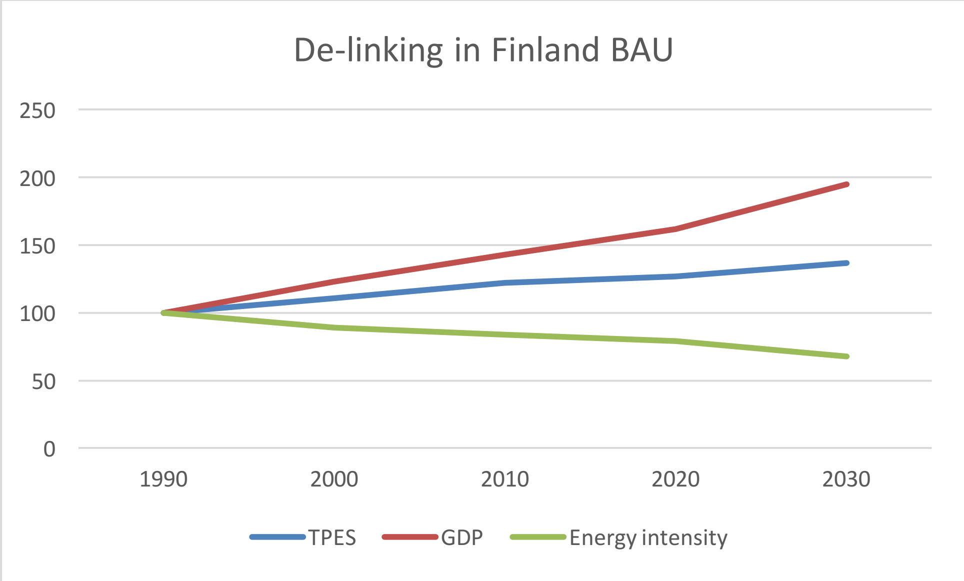


Figure 29. De-linking energy consumption from GDP in Finland BAU.

7.2 Germany

7.2.1 Energy efficiency targets vs. Germany BAU

Energy efficiencies or intensities in Germany were counted similarly to Finland. Figure 30 shows even better development than in Finland BAU: energy intensities of Germany BAU for 2020/2030 are both lower than the EU targets, and energy efficiency would then improve a great deal in Germany in the future.

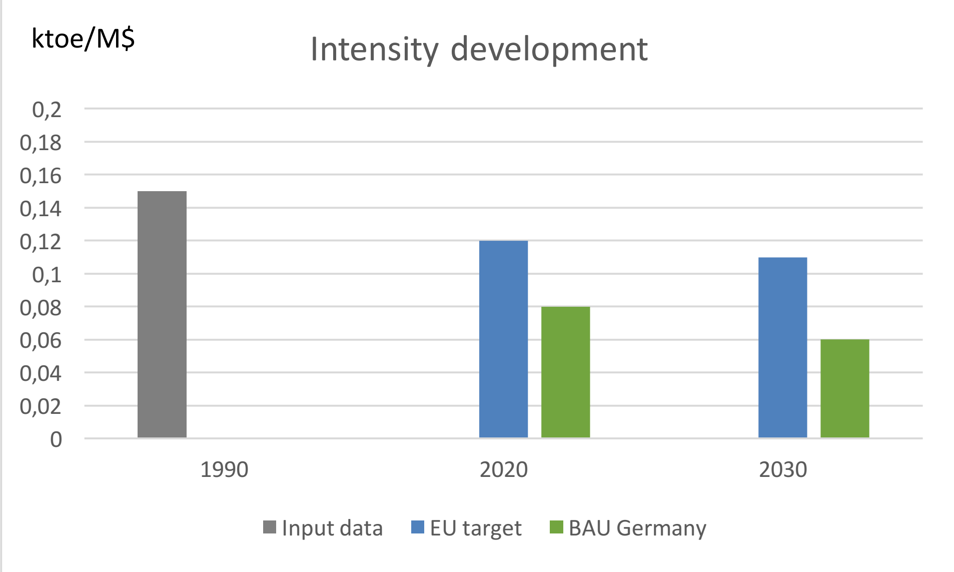


Figure 30. Development of energy intensity in Germany BAU.

Energy efficiency improvement between 1990 to 2020 is almost 50%, meaning that Germany would easily meet its EU 2020 target, i.e. 20 % improvement in energy efficiency by 2020 in the BAU scenario. In 2030, efficiency improvement would be more than double the 27 % target. (Figure 31)

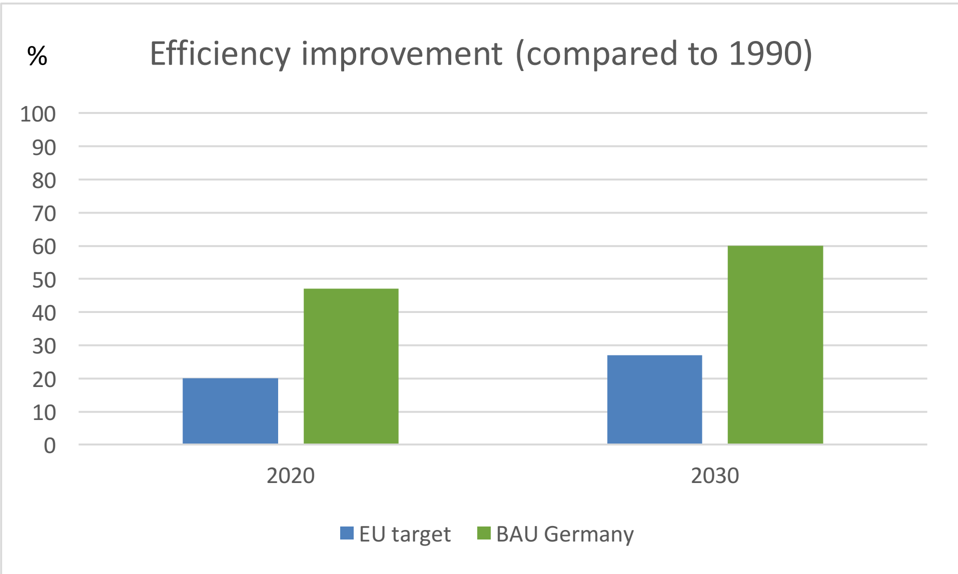


Figure 31. Improvement of energy efficiency in Germany BAU.

The EED targets of Germany

According to Energy Efficiency Directive EED (European Parliament 2012), the set target for Germany for primary energy consumption (= TPES) is 276.6 Mtoe and for final energy consumption (FEC) 194.3 Mtoe in 2020 (European Commission 2016b; German

Government 2014, 7). Primary energy consumption in Germany BAU would be below the maximum TPES target, but final energy consumption would exceed the FEC target by more than 50 Mtoe. This means that even though Total Primary Energy Consumption would be according to the set level, or even lower, Final Energy Consumption would be too high. (Figure 32)

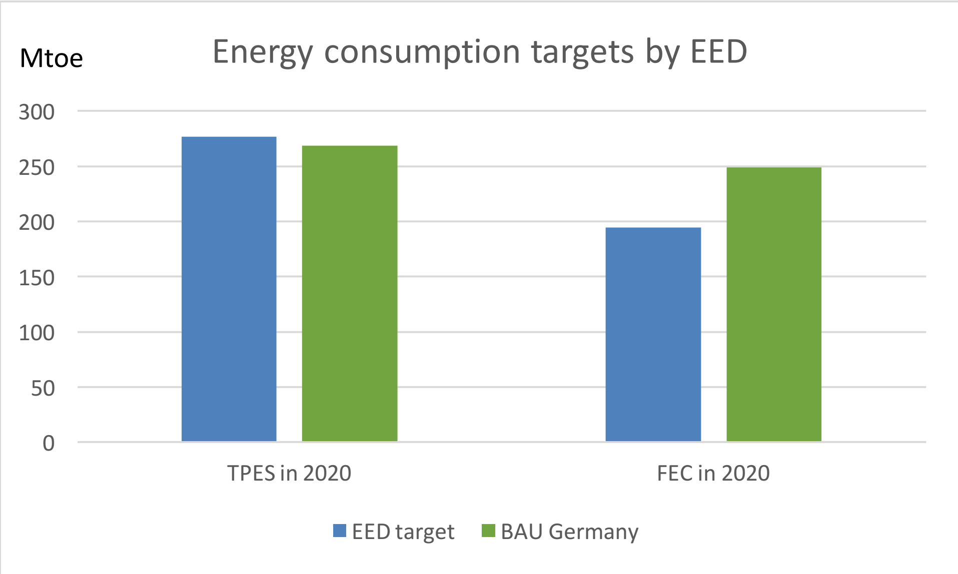


Figure 32. Energy consumption targets and Germany BAU scenario.

The NEEAP3 targets of Germany

In the NEEAP3 of Germany, the primary energy consumption PEC is 250.1 Mtoe and PEC including non-energy-related consumption is 273.8 Mtoe in 2020 (German Government 2014, 8). Figure 33 shows that PEC in 2020 in Germany BAU would be higher than the set target, and also a 20% reduction target compared to the year 2008 would not be reached. The PEC including non-energy-related consumption target (273.8 Mtoe) is not taken into account in the calculations.

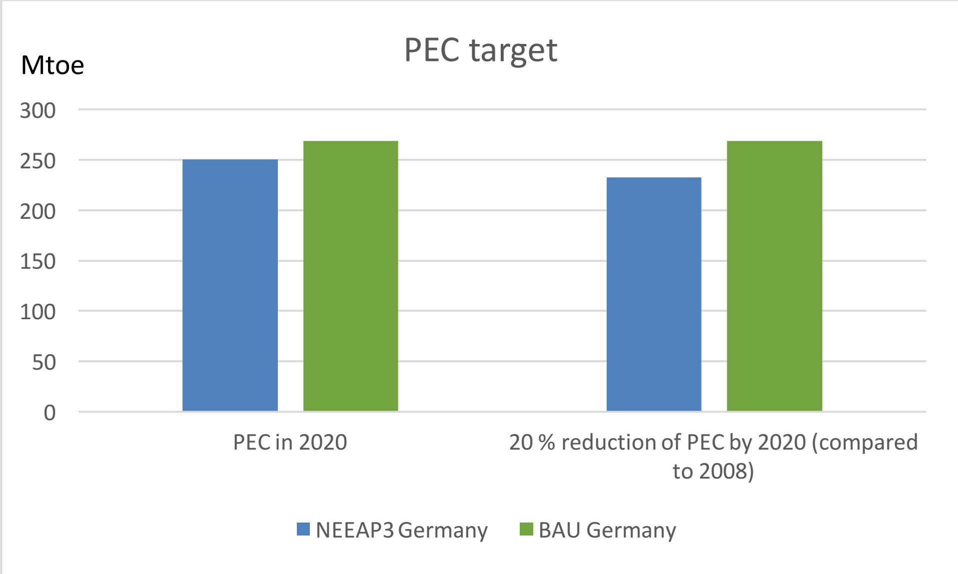


Figure 33. Primary energy consumption by 2020 in BAU Germany.

7.2.2 Energy efficiency targets vs. other scenarios

As the intensities of the Finland scenarios, also the intensities among the Germany scenarios vary. In 2020, industry, service and non-renewable scenarios would have the same, bigger intensity figures, and renewable and BAU scenarios slightly smaller intensities. In 2030, industry and non-renewable would have bigger and service, renewable and BAU smaller intensities. Despite the differences in intensities, all the five scenarios of Germany would easily reach the EU targets for 2020/2030. (Figure 34)

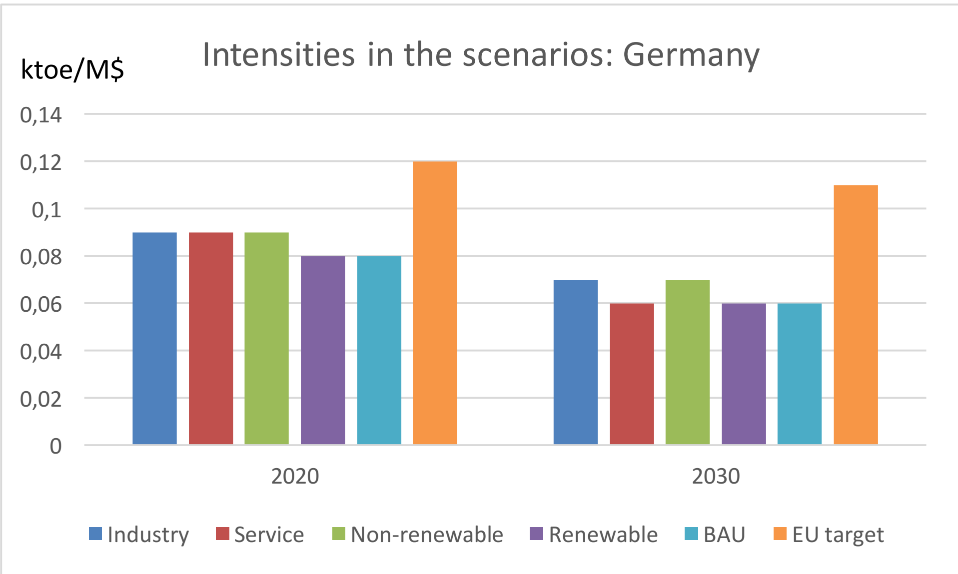


Figure 34. Development of energy intensities in all scenarios of Germany.

When comparing the scenarios with the EED targets, it can be seen that industry and non-renewable scenarios would have slightly higher Total Primary Energy Supply (TPES) figures than the rest, and that BAU scenario would have the lowest figure. In addition to BAU, only renewable scenario would reach the TPES target for 2020. In case of Final Energy Consumption (FEC), all the five scenarios would have higher FEC figures than the target, service slightly lower figure than the four others. TPES figures in 2030 are also presented in Figure 35 to get a better idea of the energy development in the scenarios.

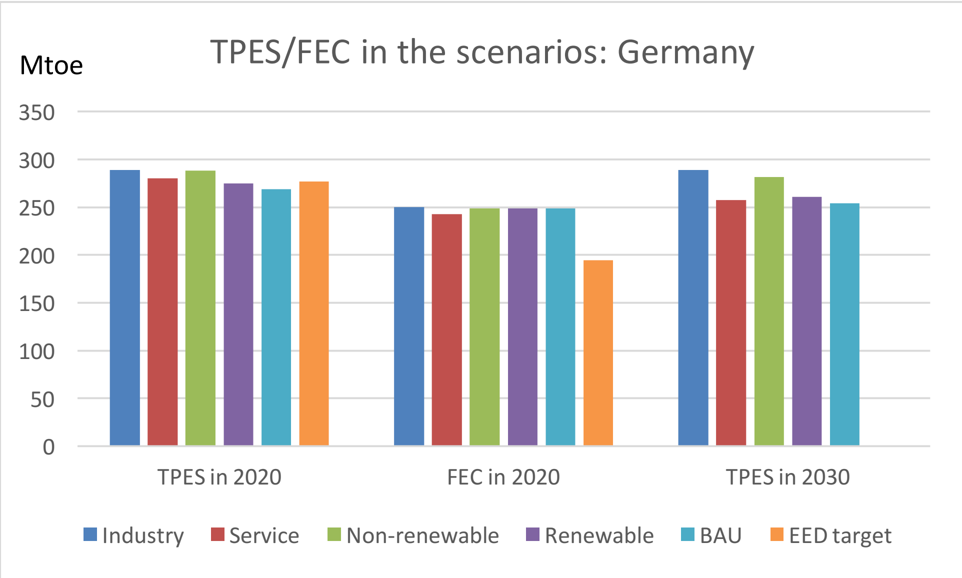


Figure 35. Energy consumption in 2020 in all scenarios of Germany.

7.2.3 EKC and de-linking

The EKC figure for Germany BAU shows very different kind of development than for Finland BAU: the EK-Curve can be seen, and already in 1990 the energy consumption has started to to slow down while GDP per capita has increased. Between 2010-2020, the energy consumption would decline more strongly than between 2020-2030. This kind of development could refer to re-linking instead of de-linking in the future. (Figure 36)

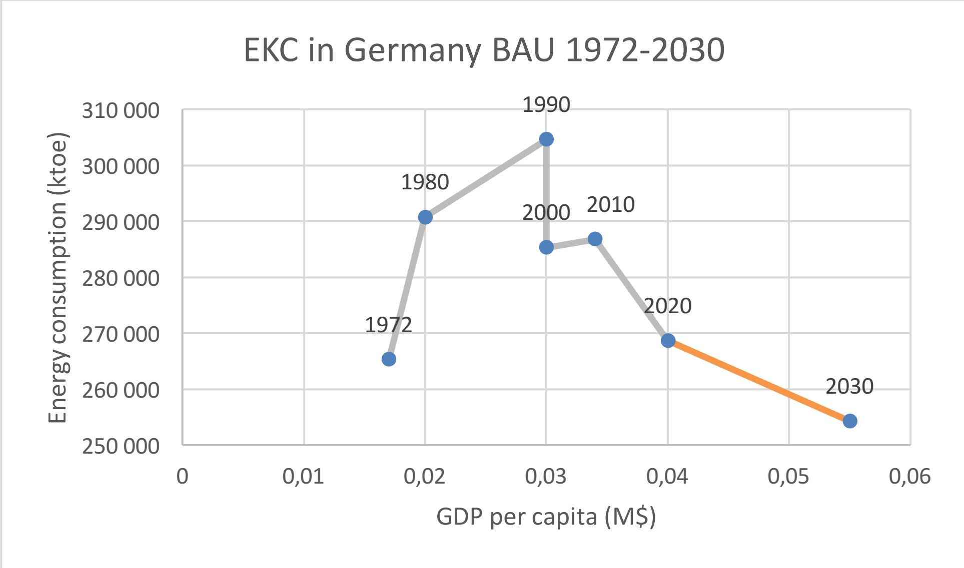


Figure 36. Relationship between GDP and energy consumption in Germany BAU.

De-linking energy consumption from GDP would happen in Germany BAU, and it would be strong de-linking compared to weak de-linking in Finland BAU. GDP would grow faster than in Finland – more than 100% growth in GDP from 1990 to 2030 –, and energy consumption would slowly decline after 2010. Intensity would decrease more after 2020 than before that. (Figure 37)

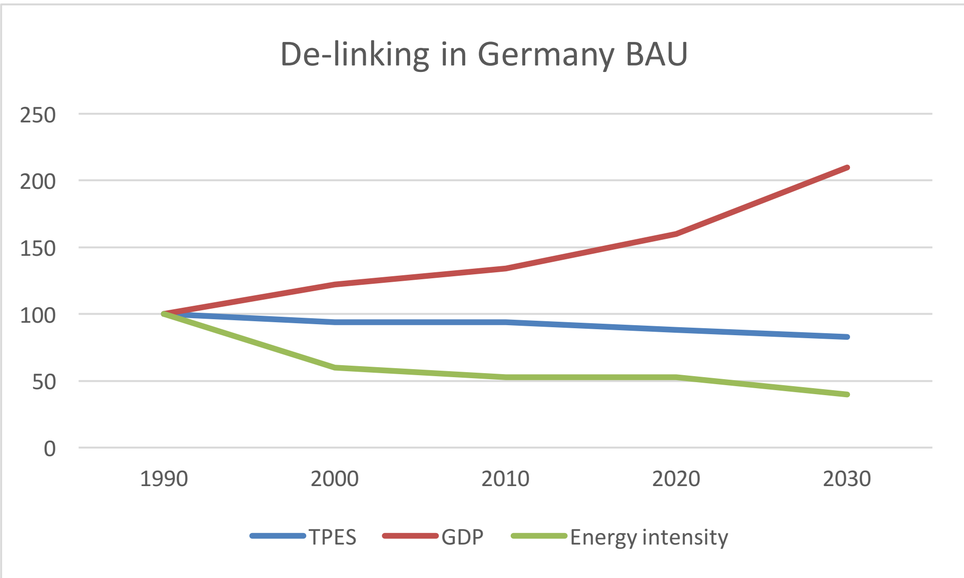


Figure 37. De-linking energy consumption from GDP in Germany BAU.

7.3 Intensity scenarios for Finland and Germany

In this chapter the point is to create scenarios that do reach the targets (backcasting) by changing only the annual energy intensities (electricity and energy/fuel use intensities) in different sectors between 2013-2030 in BAU, industry and renewable scenarios of Finland and Germany. The annual 1 % decrease in all sectoral intensities were estimated to these scenarios to reach the efficiency targets. By doing so, backward intensity scenarios were created for Finland and Germany. From the different energy efficiency targets, the EED targets were chosen to compare the intensity scenarios.

According to the Figure 38, Finland BAU scenario would already reach the EED efficiency targets of the EU. Since the target could be reached already in the BAU scenario, it could be concluded that either the Finland BAU already represents more of a preferable, backward BAU scenario than the only probable scenario or that the energy efficiency targets are too loose for Finland. The other scenarios – BAU -1%, industry -1%, and renewable -1% – all would have even better TPES/FEC figures than BAU scenario, and therefore they would perform even better in energy efficiency. In Germany, all the scenarios would have lower TPEC figures than the maximum level, but all of them would exceed the maximum FEC figure (Figure 39).

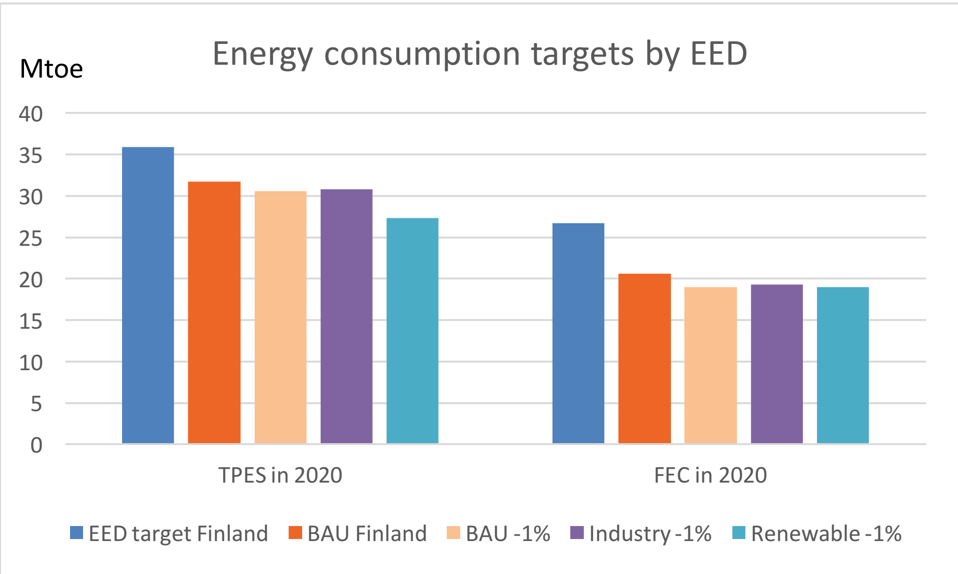


Figure 38. Energy consumption targets and intensity scenarios in Finland in 2020.

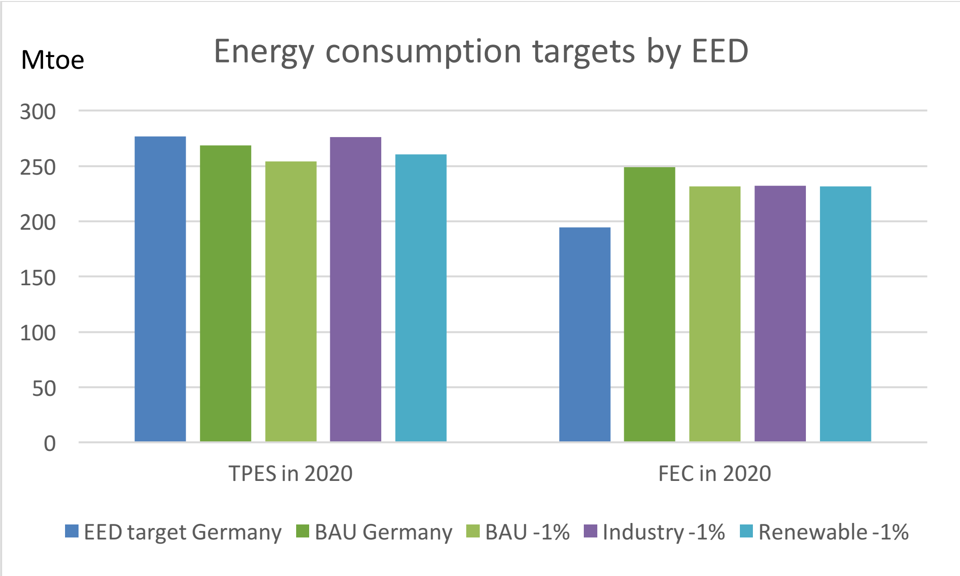


Figure 39. Energy consumption targets and intensity scenarios in Germany in 2020.

8 DISCUSSION

8.1 Summary of the key results

The aim of this thesis was to find out, how well Finland and Germany are reaching the energy efficiency targets of the EU. The research was based on global, regional, and domestic energy plans and scenarios, and was implemented by using LINDA modelling for producing various energy scenarios. First, business-as-usual BAU scenarios were created for both countries, and then industry and service as well as non-renewable and renewable scenarios were created to both Finland and Germany. In addition to those ten scenarios, three intensity scenarios were created for both countries. After creating the scenarios, comparisons to the EU targets were made. By visualizing the results with multiple figures combined with short textual analyses, it was easier to understand the research outcomes. In this chapter, I will answer the four research questions presented in the Introduction (Chapter 1.2). Each question will be considered separately in this chapter. In the end, I go through the ways to improve energy efficiency.

Question 1. *What are the possible energy efficiency futures for Finland and Germany that could fulfil the EU 2020 and 2030 targets?*

The term, *possible futures*, refers to the idea of possible *scenarios* of the future. In addition to possible, also probable and preferable scenarios or futures were created in this thesis. All the scenarios represent possible energy efficiency futures of Finland/Germany, and some of these were more probable and some more desirable. Similar to Amara, Börjeson et al. (Chapter 3.1) also divide scenarios into three categories: predictive, explorative and normative. In this thesis, BAUs represent predictive (forecast) scenarios that take into account historical trends, but also some expected structural and energy source changes in the economy. Industry vs. service and non-renewable vs. renewable scenarios again represent more explorative (strategic) scenarios. However, renewable and even service scenarios are also preferable (normative) scenarios due to climate change and therefore the demand to increase the amount of renewable energy sources both in Finland and Germany, and the demand to use less energy to produce value (energy efficiency). Also, the intensity scenarios in this thesis are normative, since they are targeting on the specific goals (backcast), in this case the EED targets of energy consumption in 2020.

In this thesis, all the scenarios reached the EU2020 and 2030 energy efficiency targets easily, and almost all the EED and NEEAP3 targets (Chapter 7). Overall, the renewable and service scenarios had lower intensities than industry and non-renewable scenarios. Since the results were very positive, it is important to think about the validity of the research and be enough critical with the results. How possible (and probable and preferable) these futures could be for Finland and Germany? More discussion about validity and limitation of this thesis in the next chapter (8.2).

When comparing the created BAU scenarios with the EU reference scenario (see Chapter 2.2), it can be noticed that GDP of Finland was around 5-10% bigger in Finland BAU than in the EU scenario. In energy consumption, TPES in 2020 was about 10% smaller in the BAU scenario and in 2030 3% bigger than in the EU scenario. These developments together led to better efficiency figures in Finland BAU than in the EU scenario. In Germany BAU, GDP was also around 10% bigger in 2020 and more than 30% bigger in 2030 than in the EU scenario. This is to due with the strong, 3% economical growth in Germany BAU between 2026-2030. In energy consumption, Germany BAU had smaller TPES figures than in the EU scenario: in 2020 about 15% and in 2030 about 10% smaller. To conclude, different GDP growth and energy consumption figures do produce very different energy intensity figures, which should all be critically evaluated. In addition to purely count intensities from GDP and energy consumption figures, determination of energy efficiency should be based on other factors, too, such as on what is the economical structure of the country and which are the main energy sources used. In that way, it is possible to get more rich picture of the energy efficiency situation of the country.

Since the BAU scenario for Finland and Germany were based on both historical trends and especially on future energy plans and assumptions of the development, anther option in making the BAU scenario could have been looking at the previous trends and figures in the LINDA model (1972-2012), and based on those, create a BAU scenario. But as future rarely looks the same as history, it seemed better to create BAUs based on future plans instead of previous development. Still, creating these BAUs based on barely historical trends, and comparing them with the BAUs done in this thesis, would be highly interesting. What would be the biggest changes? In general, creating many (energy) scenarios and comparison of those offers valuable knowledge for decision-makers of the unfold future.

Question 2. *How the structure of the economy and different primary energy sources affect the possibilities to reach energy efficiency targets in Finland and in Germany?*

A strong assumption is that economic structure of a country does have an effect on energy efficiency: economy with large industry sector uses more energy and has higher energy intensities than service-based economy (see e.g. Kaivo-Oja & Luukkanen 2004; Herring 1999; 2006). The results of this thesis do indicate this assumption to be correct: the intensities were higher in the industry scenarios than in the service scenarios in both countries in 2030, but in 2020, there were no differences in the intensities. In Finland, the intensity of the BAU scenario was lower than in industry, but higher than in service scenario. In Germany, the intensity of the BAU scenario ended up being the same as in service scenario. However, the differences in intensities were not that big, even though the sectoral GDP changes in industry and service scenarios were.

The assumption behind the role of energy efficiency and different energy sources is different: changing the main energy supply from non-renewables to renewables does not automatically mean improved energy efficiency. As Lund (Chapter 2.1) states, integrating energy efficiency more with renewable energy sources would offer a great alternative to consider, when deciding sustainable future energy paths for a country. Same idea is in the *Energy concept by 2050* for Germany (Chapter 2.4.2) in which 100% renewable energy vision combined with energy efficiency, is introduced. This system would require a decentralized energy system with a mix of renewable energy sources. In Finland, both *Energy and Climate Roadmap 2050* and *Energy and climate strategy 2016* (Chapter 2.4.1) have a vision of carbon-neutral energy system by 2050 meaning a strong 50-100% renewable energy consumption. A 100% increase of renewable energy globally is described in *Energy [R]evolution* by Greenpeace (Chapter 2.3). However, in the two global energy scenarios for 2050 by World Energy Council (Chapter 2.3), the share of renewables is increasing, but only 20% and 30% by 2050. In this thesis, the energy intensities of non-renewable scenarios ended up being higher than the renewable scenarios in both countries in 2020 and 2030. In Finland, the intensity of the BAU scenario was lower than in non-renewable, but higher than in renewable scenario. In Germany, the intensity of the BAU scenario ended up being the same as in renewable scenario. As said, the renewable scenario would also be more desirable in the context of environment and global warming. Also, multiple (renewable) energy sources do increase energy self-sufficiency and security of a country.

Question 3. *How well forward scenarios and the targets correspond each other (GAP analysis) and what is needed for the backward scenario?*

In backcasting, the starting point is some high-level target and some preferable future, like the EU 2020/2030 targets, whereas forecasting in exploring futures based on historical trends and possibly future plans. Especially Robinson (Chapter 3.2) has criticized forecasting energy futures, but instead using backcasting for a better technique for that. According to him, backcasting is about how desirable futures can be achieved (normativity), not how probable those futures are. As Vergragt and Quist (Chapter 3.2) state, backcasting is about visioning and analysing future alternatives and creating pathways and strategies to reach the target.

In this thesis, BAUs and industry vs. service and renewable vs. non-renewable scenarios were forward and intensity scenarios backward scenarios. However, forming the BAUs and other forward scenarios were more than just extrapolation of past trends, but also taken into consideration future energy plans and visions. Because the BAU scenarios of Finland and Germany already reached the efficiency targets of the EU (Chapter 7), these scenarios could be seen as alternatives to backward scenarios. The intensity (backward) scenarios in this thesis were made so that only the annual energy intensities (electricity and energy/fuel use intensities) in different sectors were all decreased by 1% in BAU, industry and renewable scenarios in both countries to see, how much the sectoral efficiency improvements affect to the total efficiency of the scenario (Chapter 7.3). Since the original scenarios (BAU and the other four) of Finland and Germany already reached the EU targets (Chapters 7.1.2 and 7.2.2), the new intensity scenarios performed even better in the efficiency. Instead of equally lowering all the sectoral intensities in the intensity scenarios, another option would have been to low only some of them, like the intensities only in industry or service sector, or change only electricity intensities, not energy/fuel use intensities, or other way around. How would those change the overall energy consumption and affect energy efficiency targets?

Question 4. *What should be changed in the economy (with policy support) that would enable de-linking and EKC to occur and what is the share of energy efficiency in this change?*

EKC appeared in Germany BAU, but not (yet) in Finland BAU. In Finland, weak de-linking happened, whereas in Germany, de-linking appeared to be strong. (Chapters 7.1.3 and 7.2.3). This means that in Finland, economic growth was increasing strongly and also energy consumption slightly, while energy intensity was decreasing during the timeframe. In Germany, only GDP was growing (strongly), and both energy consumption and intensity were declining. As Proskuryakova & Kovalev (Chapter 3.4) state, de-linking GDP growth from energy use is the direct result of decreasing energy intensity and improved energy efficiency. Panayotou (Chapter 3.3) argues that total GDP, the share of industry sector of GDP and the structure of industry have a close relationship. According to him, the structural changes in industry can alone explain the EKC to occur, as can be seen in the BAU scenarios, where most of the GDP growth comes from service sector instead of industry. Also, government policy has an important role in postponing or accelerating structural change and technological development, and thus saving the environment. As Grossman (Chapter 3.3) states, the demand for a cleaner environment and supportive policies are the main theoretical support for the EKC. As Kara states in the foreword of *Energy visions 2030 for Finland* (2001), energy consumption is not growing as fast as GDP in developing countries, which reflects the structural change of the economy. However, more energy-efficient processes and solutions are needed to keep the trend decreasing.

General energy comparisons of Finland and Germany

The comparison of the scenario results of Finland and Germany is rather demanding due to very different energy structures, but also other things, such as population, GDP and sectoral differences of the countries. However, some comparisons could still be made based on the results (Chapter 7). In both countries, energy efficiency figures in BAU scenarios ended up being better than the set targets. This might be related to that both GDP growth and energy consumption targets were too low or high for the future forecasts or other assumptions that affect the EU targets. Also, many targets and assumptions of future energy sources were taken into account, when creating BAU scenarios, and by doing that, creating hybrids of forward and backward scenarios. That said, it could be that they became more preferable than possible BAU scenarios.

In addition to the specific numbers and figures related to the scenarios of Finland and Germany, also more general and qualitative comparisons can be made between these countries. For example, in Finland nuclear power is still seen as an important source of energy in the future – despite the challenges with current built Olkiluoto 3 power plant – , whereas Germany is shutting down all the nuclear power plants by 2022. Due to its rich forests, Finland has more capacity to use wood-based biomass for energy production and to produce biofuels used in transportation. Actually, Finland is more eager to invest in biofuel cars than electric cars, even though globally, like in Germany, countries are putting more effort on electrifying the transport sector. In the case on waste incineration plants and electricity and heat production, the situation is similar in both Finland and Germany: in both countries' waste incineration plants are taking care of the waste that can not yet be recycled. Due to strict EU regulations, all EU countries need to enhance recycling of waste and end putting waste on landfills. Germany has traditionally been the top country in waste recycling, but also Finland is doing pretty well, too. In the future, when recycling processes develop and recycling will be close to 100%, there is not enough waste to burn anymore, and therefore it might be that electricity and heat production in incineration plants will be history, and other sources, like wind and solar are needed to reach the capacity demand.

In renewable energy production, Germany is way ahead of Finland: Germany has for long time invested in wind and solar capacities, and now through *Energy transition,* targeting for society based on renewable energy sources. Finland has also seen the value of renewables, and advanced energy production from renewables, but the development has been rather slow. It must be remembered that investing heavily in peat production is not the same thing as investing in renewables. Finland has made a brave decision to abandon coal as energy source during next decade. Due to shutting down nuclear power plants, it might be a challenge for Germany to abandon coal totally. Actually, to reach energy demand, Germany might have to rely even more on coal, if the increase of renewable energy is not enough to feed the energy system. The situation with oil & natural gas is pretty similar in both countries. Global and regional political situations and environmental reasons affect heavily on availability and use of oil and gas.

By sector, both countries are service economies, or rather digitalized economies. Most of the industry has moved to Asian countries with cheaper production costs, and economic growth is relying more on service sector. However, due to the forests Finland is still active in forest industries, but the production has changed from traditional heavy industry to more chemical industry. This change is better in the perspective of energy efficiency: less energy is needed to produce more value. Recent news about growing maritime and car industries in Finland might also anticipate growing industry sector. Traditionally German has been one of the top industrial countries globally, and still is. Especially car and electronic production has been strong. Does this trend continue, or shall Germany invest more on service sector in the future? In any case, the energy needed in these sectors will be used more efficiently and mainly renewable sources will be utilized.

Transportation or mobility in general is going through huge revolution globally. Electric and biofuel cars are becoming more popular than combustion engine cars, from personally owned transportation vehicles to new mobility-as-a-service systems, self-driving robotic cars, shared taxis and bicycles to mention some of the current trends in the field. It is hard to say, when and especially how these new modes of mobility will actualize permanently in Finland and in Germany. And how all of this will affect human behaviour and the choices we make. This is why it is quite challenging to say, what kind of transportation systems do Finland and Germany have in 2030. Hopefully, all the cars and preferably other vehicles by then would be electrified or run by biofuel. Also, contributions to shared mobility systems, walking and cycling would act positively to climate actions to reduce global warming.

How to improve energy efficiency?

In addition to structural changes of the economy, there are also other ways to improve energy efficiency. Some of these solutions are related to technical, some are more consumer-based related to choices and actions. For example, efficient electric devices and smart equipment are some of these technical solutions. Public authority regulations, environmental taxes and promoting dematerialization and immaterialization (chapter 3.4) in energy efficiency are again ways to guide people and their behaviour. The most energy-consuming sectors are transport, building, and energy production. Even 40-60% of energy gets lost in the energy production process, and that is why more effort should be put to improve the efficiency of the sector. (European Commission 2005; chapter 2.2). The question is then: Which energy sectors are the most energy intensive or efficient? How is this related to the renewable and non-renewable discussion? Combined Heat and Power (CHP) is another way to improve efficiency. In building sector, there are several ways to increase efficiency, such as alternative heating systems and renovation techniques, zero energy buildings, and energy efficient lighting. In transportation, the solutions are electric and biofuel cars, shared mobility modes, and taxes on normal cars. When comparing Finland to Holland, my own empirical perception is that in Finland private homes are overheated. In Holland, often only the rooms, where people actively spend time are heated, and often no more than 20 degrees Celsius. In Finland, usually all the rooms of a house are warm, and the average temperature is more than 20 degrees. What comes to wind power, is it because of the attitudes (not-in-my-backyard NIMBY) of Finns and/or lack of Governmental support that the wind capacity has grown slowly? The factors that most often prevent energy efficiency to occur, are large investments in the beginning stage (like new wind power plants), relatively cheap energy prices, large public subsidies of fossil fuels, and human behaviour and consumption patterns.

8.2 Methodological considerations

As all research papers, this study also has its limitations. There are several ways to create energy (efficiency) scenarios, but I chose LINDA model for my method, because it was already decided upon the EUFORIE project. I also had a personal interest to use quantitative method for my research, and therefore LINDA model suited well for this purpose. I was not familiar with the method before I started this thesis, so I learnt the method by doing during the research work. By choosing another model or method instead of LINDA, the research and the results would have looked different. Since it is possible to create multiple scenarios with LINDA model, it was rather challenging to decide, which ones to choose and are 'good enough' for my research. Since there are no (clear) criteria for possible scenarios, the decision process was tricky. Now I think that creating bigger differences to the scenarios, would have given more interesting and varied scenarios and thus energy intensity figures.

Another bigger challenge related to the scenario structure was to choose the 'right' data to use in the scenarios. Also, the data, like new plans and strategies evolve constantly, for example Energy and Climate Strategy 2016 for Finland (chapter 2.4.1) was just published, when I was finalizing my thesis, so I used the older version from 2013. Sometimes the correspondence of numeric data sources and the numbers in LINDA did not match. The interpretation of mainly textual plans and visions and presenting them in clear numbers in LINDA, caused some challenges. It was challenging to find accurate data about energy efficiency estimates and targets. Since energy efficiency is understood in different ways, even the EU has various interpretations of energy efficiency, whether it means savings, or decreasing energy intensity/increasing energy efficiency measured by multiple ways and indicators. In the beginning of my thesis work, I felt overwhelmed by all the energy efficiency plans and strategies. The challenge was to take into account the most relevant ones according to the research. But in the end, I think I came up with a clear structure in presenting the EU, global and domestic data materials. The LINDA used in this thesis was the second newest version of the model. Due to the older version of LINDA model, the years 2013-2015 are not data from the statistics, but decided upon the author. This older version of LINDA might have affected to the results by creating inaccuracy in the scenarios. Also, the possible errors in the model or in the existing input data can affect the reliability of the scenarios. In this thesis, only one indicator (energy intensity) was used in the de-linking process, but more is said to be better (see chapter 3.4). LINDA model could be further developed by taken into account also de-linking and EKC.

8.3 Conclusions

The global energy system is by far one of the most complex systems. Global energy trends and unexpected disruptions in energy demand and supply affect also regional and local energy policy and decision-making. In addition to immediate affects to energy systems, also indirect political, economic, social and environmental changes can have an effect on the energy balance. An example of a disruption that has global affects, is newly elected US President Trump and his actions. Already his election for the next President of the USA was a ’black swan’. He has denied the existence of global warming, even though climate change is real and ’common truth’ proved by many scientific researches. Neglecting this truth has already affected the policies US is pushing forward, such as supporting fossil fuels instead of renewable energy production. It is unclear, what are the global consequences of those actions, but proactive actions are needed from the rest of the world to prevent negative affects to the climate. An example of a current strong trend in Finland is a ’hype’ of circular economy and bio-industry, which have a positive affect in energy efficiency. Shared economy also reduces the amount of primary materials used and the needed energy consumption. Even though Finland has taken positive actions regarding sustainable development, the country also gives subsidies to large corporations that are heavy energy consumers. Then again, Finland has internationally insisted cutting down subsidies for fossil fuels. Even though it is impossible to predict the future (of energy), with the help of the theories and methods of futures studies and foresight, its is possible to research alternative (energy) futures and be better prepared for years to come (anticipation). Instead of reactive action, proactive action is needed when the target is set and the clear pathways to get there constructed (backcasting).

There are some problems in defining energy efficiency. Measuring energy efficiency is not as easy as estimating the amount of renewable energy. Even though the EU has set several targets for the efficiency, it is challenging to interpret, what is meant by each of the figures. Easier targets and measuring systems could still be developed to help the EU countries to reach these targets. Another thing related to the current EU targets is that are the set target ambitious enough? Should the targets be stricter and aim higher? But as the EE plan (chapter 2.2) states, *“Energy efficiency targets are affective in trigger action and establish political movement”*, even the targets would not be reached. Backcasting should be actively used, and in addition to ambitious target setting, especially clear, structured roadmaps and strong commitment of the key actors are needed to reach those targets. As stated in the de-linking chapter (3.4), there are eight possible combinations of GDP and energy consumption, if we assume GDP and energy consumption always to grow or decline. It would be interesting to research also de-linking of GDP and energy consumption when both have 0-growth. Energy intensity, EKC and de-linking are theories based on GPD growth, but what if (strong) growth would be disputed and instead, sustainability, humanity and equality would be valued higher? How would these theories work with the assumption of a set GDP target for a 'happy country'? In the conclusion part of his energy efficiency study, Herring (2006) considers questions about the 'good life'. According to him, the desired energy lifestyles are more ethical and cultural rather than technical or economic based. He asks whether people can consume more goods and services with less materials and energy, and if a lower energy lifestyle could be made desirable by cultural example.

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APPENDIX

FINLAND: energy intensity calculations and comparisons

Energy intensity can be counted as follows:

Energy intensity = Energy input / Value added = Total Primary Energy Supply TPES / Gross Domestic Product GDP

Energy intensities of BAU scenario and change percentages

According to the BAU scenario of Finland LINDA:

Year 1990 TPES = 24,937 ktoe
Year 2020 TPES = 31,687 ktoe
Year 2030 TPES = 34,051 ktoe

Year 1990 GDP = 129,890 M$
Year 2020 GDP = 210,445 M$
Year 2030 GDP = 253,861 M$

Energy intensities for the years 1990, 2020 and 2030:
Year 1990 energy intensity = 24,937 ktoe / 129,890 M$ = 0.19 ktoe/M$
Year 2020 energy intensity = 31,687 ktoe / 210,445 M$ = 0.15 ktoe/M$
Year 2030 energy intensity = 34,051 ktoe / 253,861 M$ = 0.13 ktoe/M$

The change (percentage) in energy intensity compared to 1990 level in 2020 and 2030 can be counted as follows:

100 % * (Intensity 2020 – Intensity 1990) / (Intensity 1990)

100 % * (0.15 ktoe/M$ – 0.19 ktoe/M$) / 0.19 ktoe/M$ = -21.1 %

100 % * (Intensity 2030 – Intensity 1990) / (Intensity 1990)

100 % * (0.13 ktoe/M$ – 0.19 ktoe/M$) / 0.19 ktoe/M$ = -31.6 %

Finland would meet its EU 2020 and 2030 targets, i.e. 20 % improvement in energy efficiency by 2020 and almost double the 27 % improvement in energy efficiency by 2030 according to BAU scenario.

The EU 2020 and 2030 targets

The EU 2020 and 2030 targets can be counted from the 1990 level:
Year 1990 energy intensity = 24,937 ktoe / 129,890 M$ = 0.19 ktoe/M$
EU 2020 target: 0.8 * 0.19 ktoe/M$ = 0.15 ktoe/M$
EU 2030 target: 0.73 * 0.19 ktoe/M$ = 0.14 ktoe/M$

When comparing the intensities of the EU targets and Finland BAU, we see that in 2020 the intensities are the same, but in 2030 the efficiency is better in the Finland BAU scenario.

The EED targets of Finland

According to Energy Efficiency Directive EED (European Parliament 2012), the set target for Finland for primary energy consumption (= TPES) is 35.9 Mtoe and for final energy consumption (FEC) 26.7 Mtoe in 2020 (European Commission 2016b; TEM 2014b).

The EED: Primary energy consumption (= TPES) target for 2020 = 35.9 Mtoe
The EED: Final energy consumption (FEC) target for 2020 = 26.7 Mtoe

According to the BAU scenario of Finland LINDA:

Year 2020 TPES = 31,687 ktoe = 31.7 Mtoe
Year 2020 FEC = 20,608 ktoe = 20.6 Mtoe

TPES LINDA = 31.7 Mtoe < 35.9 Mtoe = EED target (difference 4.2 Mtoe), so the set target for TPES by the EED can be reached in the BAU scenario.

FEC LINDA = 20.6 Mtoe < 26.7 Mtoe = EED target (difference 6.1 Mtoe), so the set target for FEC by the EED can be reached in the BAU scenario.

The NEEAP3 target of Finland

In the NEEAP3 of Finland, the figures present energy savings, like e.g. estimated *Total Energy Saving All* in 2020 51,844 GWh/a (TEM 2014b, 13).

Transforming GWh/a to Mtoe:
Since 1 kWh = 8.5984522785899E-5 toe, and 1 GWh = 85.984522785899 toe, then
51,844 GWh = (51,844 x 85.984522785899) toe = 4,457,781.5993 toe = 4.46 Mtoe

Energy saving target is 4.46 Mtoe by 2020 compared to 1990.

According to the BAU scenario, energy saving (TFEC) between 1990-2020 is:
20,608.4 ktoe – 22,240.0 ktoe = -1,631.6 ktoe = 1.63 Mtoe < 4.46 Mtoe (difference 2.83 Mtoe). The consumption decreases between 1990-2020, but the set target would not be reached in the BAU scenario.

Energy efficiency targets vs. other scenarios

Energy efficiencies of industry and service scenarios as well as non-renewable and renewable scenarios are compared to EU 2020 and 2030, EED and NEEAP3 targets of Finland.

In non-renewable and renewable scenarios, GDPs are the same as in BAU:
210,445 M$ (2020) and 253,861 M$ (2030). In industry and service scenarios GDPs are: 210,402 M$ (2020) and 253,598 M$ (2030) in industry and 210,428 M$ (2020) and 252,750 M$ (2030) in service.

Industry 2020: 31,895 ktoe / 210,402 M$ = 0.15 ktoe/M$
Industry 2030: 36,686 ktoe / 253,598 M$ = 0.14 ktoe/M$
Industry TPES/FEC in 2020: 31.9 Mtoe / 20.9 Mtoe
Industry energy savings 1990-2020: 20,917 ktoe – 22,240 ktoe = -1.32 Mtoe

Service 2020: 31,017 ktoe / 210,428 M$ = 0.15 ktoe/M$
Service 2030: 30,655 ktoe / 252,750 M$ = 0.12 ktoe/M$
Service TPES/FEC in 2020: 31.0 Mtoe / 20.3 Mtoe
Service energy savings 1990-2020: 20,308 ktoe – 22,240 ktoe = -1.93 Mtoe

Non-renewable 2020: 31,596 ktoe / 210,445 M$ = 0.15 ktoe/M$
Non-renewable 2030: 34,567 ktoe / 253,861 M$ = 0.14 ktoe/M$
Non-renewable TPES/FEC in 2020: 31.6 Mtoe / 20.6 Mtoe
Non-renewable energy savings 1990-2020: 20,586 ktoe – 22,240 ktoe = -1.65 Mtoe

Renewable 2020: 28,323 ktoe / 210,445 M$ = 0.13 ktoe/M$
Renewable 2030: 27,831 ktoe / 253,861 M$ = 0.11 ktoe/M$
Renewable TPES/FEC in 2020: 28.3 Mtoe / 20.6 Mtoe
Renewable energy savings 1990-2020: 20,608 ktoe – 22,240 ktoe = -1.63 Mtoe

GERMANY: energy intensity calculations and comparisons

Energy intensities of BAU scenario and change percentages

According to the BAU scenario of Germany LINDA:

Year 1990 TPES = 304,640 ktoe
Year 2020 TPES = 268,674 ktoe
Year 2030 TPES = 254,338 ktoe

Year 1990 GDP = 2,052,742 M$
Year 2020 GDP = 3,293,241 M$
Year 2030 GDP = 4,318,258 M$

Energy intensities for the years 1990, 2020 and 2030:
Year 1990 energy intensity = 304,640 ktoe / 2,052,742 M$ = 0.15 ktoe/M$
Year 2020 energy intensity = 268,674 ktoe / 3,293,241 M$ = 0.08 ktoe/M$
Year 2030 energy intensity = 254,338 ktoe / 4,318,258 M$ = 0.06 ktoe/M$

The change (percentage) in energy intensity compared to 1990 level in 2020 and 2030 can be counted as follows:

100 * (Intensity 2020 – Intensity 1990) / (Intensity 1990)

100 * (0.08 ktoe/M$ – 0.15 ktoe/M$) / 0.15 ktoe/M$ = -46.7 %

100 * (Intensity 2030 – Intensity 1990) / (Intensity 1990)

100 * (0.06 ktoe/M$ – 0.15 ktoe/M$) / 0.15 ktoe/M$ = -60.0 %

Germany would meet both EU targets according to BAU scenario.

The EU 2020 and 2030 targets

The EU 2020 and 2030 targets can be counted from the 1990 level:
Year 1990 energy intensity = 304,640 ktoe / 2,052,742 M$ = 0.15 ktoe/M$
EU 2020 target: 0.8 * 0.15 ktoe/M$ = 0.12 ktoe/M$
EU 2030 target: 0.73 * 0.15 ktoe/M$ = 0.11 ktoe/M$

When comparing the intensities of the EU targets and Germany BAU, it can be seen that actually in BAU the intensities are lower, and so is the level of efficiency better in the Germany BAU scenario.

The EED targets of Germany

According to Energy Efficiency Directive EED (European Parliament 2012), the set target for Germany for primary energy consumption (= TPES) is 276.6 Mtoe and for final energy consumption (FEC) 194.3 Mtoe in 2020 (European Commission 2016b; German Government 2014, 7).

The EED: Primary energy consumption (= TPES) target for 2020 = 276.6 Mtoe
The EED: Final energy consumption (FEC) target for 2020 = 194.3 Mtoe

According to the BAU scenario of Germany LINDA:

Year 2020 TPES = 268,674 ktoe = 268.7 Mtoe
Year 2020 FEC = 249,001 ktoe = 249.0 Mtoe

TPES LINDA = 268.7 Mtoe < 276.6 Mtoe = EED target (difference 7.9 Mtoe), so the set target for TPES by the EED can be reached in the BAU scenario.

FEC LINDA = 249.0 Mtoe > 194.3 Mtoe = EED target (difference 54,7 Mtoe), so the set target for FEC by the EED can not be reached in the BAU scenario.

Germany might have stricter targets than Finland, since their targets can not be reached in the BAU scenario unlike Finland's.

The NEEAP3 targets of Germany

In the NEEAP3 of Germany, the primary energy consumption PEC is 250.1 Mtoe and PEC including non-energy-related consumption is 273.8 Mtoe in 2020 (German Government 2014, 8).

According to the BAU scenario, PEC in 2020 is:
268,674 ktoe = 268.7 Mtoe, and the difference between the NEEAP3 target and LINDA Germany BAU is 250.1 Mtoe - 268.7 Mtoe = -18.6 Mtoe, hence the target would not be reached in the BAU scenario.

In the NEEAP3, the reduction target of primary energy consumption is 20 % by 2020 compared to 2008.

PEC LINDA in 2008 = 290,538 ktoe

The target for 2020 is 80 % from 2008 level:
0.8 * 290,538 ktoe = 232,430 ktoe

PEC LINDA in 2020 = 268,674 ktoe > 232,430 ktoe (difference 36,244 ktoe = 36.2 Mtoe) which means that the target can not be reached in the BAU.

Energy efficiency targets vs. other scenarios

In non-renewable and renewable scenarios, GDPs are the same as in BAU:
3,293,241 M$ (2020) and 4,318,258 M$ (2030). In industry and service scenarios GDPs are: 3,292,062 M$ (2020) and 4,310,602 M$ (2030) in industry and 3,294,630 M$ (2020) and 4,318,358 M$ (2030) in service.

Industry 2020: 289,323 ktoe / 3,292,062 M$ = 0.09 ktoe/M$
Industry 2030: 289,231 ktoe / 4,310,602 M$ = 0.07 ktoe/M$
Industry TPES/FEC in 2020: 289.3 Mtoe / 249.9 Mtoe

Service 2020: 280,846 ktoe / 3,294,630 M$ = 0.09 ktoe/M$
Service 2030: 257,719 ktoe / 4,318,358 M$ = 0.06 ktoe/M$
Service TPES/FEC in 2020: 280.8 Mtoe / 243.0 Mtoe

Non-renewable 2020: 288,452 ktoe / 3,293,241 M$ = 0.09 ktoe/M$
Non-renewable 2030: 281,405 ktoe / 4,318,258 M$ = 0.07 ktoe/M$
Non-renewable TPES/FEC in 2020: 288.5 Mtoe / 249.0 Mtoe

Renewable 2020: 275,017 ktoe / 3,293,241 M$ = 0.08 ktoe/M$
Renewable 2030: 260,964 ktoe / 4,318,258 M$ = 0.06 ktoe/M$
Renewable TPES/FEC in 2020: 275.0 Mtoe / 249.0 Mtoe