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Besvarelsesinformationer

Analysis of the possibility of reaching the Paris Agreement's temperature targets

Civil Engineering in Energy Technology

1st Semester

Course number: T600024101

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Abstract

This paper examines whether it is possible, by realistic measures, to keep the temperature increase within the 1,5 and 2-degree Celsius targets shaped in the Paris Agreement. Various actions in different sectors are investigated. To forecast future temperature a "frozen policy"-scenario, this papers reference scenario, is initially created that shows the future temperature change according to a business-as-usual-projection. Three scenarios are created to illustrate what opportunities the different sectors hold towards changing the future temperature for the better. The three scenarios represent respectively the institutional sector (mostly energy suppliers), the individual "sector" and a combined effort where both sectors cooperate. All scenarios will be split up into worst-, median-, and best-case projections where the BAU-projection represents the worst-case projection. A median and best-case projection allow looking both realistically and optimistically at future greenhouse gas emissions and temperature. The split-up scenarios for respectively the institutional and individual sector alone only show compliance with the Paris Agreement's 2,0-degrees target for the best-case projections but will not cause the future temperature to meet the 1,5-degrees target. In the 3rd scenario, where institutions and individuals work together, a fair probability of reaching the 2,0-degrees target is concluded. Overall, it can though be concluded that the scenarios presented in this paper will not meet the 1,5-degrees target – to reach this target action, optimised technologies, and international cooperation must take place briefly and on a large scale.

Preface

Through this paper, references for all appendices, but a few, is made. Firstly, Appendix A and Appendix B are not referred to, as they have nothing to do with the problem or results of this paper. Those appendices appear since this paper is the product of an engineering project at SDU, where a condition for the paper is an appendix regarding the group process, and an appendix describing the contribution of different courses attended in relation to the engineering education. Moreover, Appendix M is different from the other. In this appendix, an overview of the attached excel files necessary for reading this paper is made. When these excel files are referred to, it's done in a specific way. When for example referring to the "Frozen Policy, BAU.xlsx" the reference is on the form [Frozen Policy, BAU].

Abbreviations

Alphabetically ordered.

Abbreviation	Meaning
BAU	Business-As-Usual
BP	British Petroleum
CHP	Combined Heat Plant
COP21	The 21st Conference of the Parties
COP26	The 26th Conference of the Parties
CO_2e	CO_2 Equivalent
CORDIS	Community Research and Development Information Service
EIA	U.S. Energy Information Administration
EOP	Electricity-Only Plant
GHG	Greenhouse gas(es)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goal(s)
Solar PV	Solar Photovoltaics
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

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1. Introduction

The human impact on the environment has been a topic for a while now. However, it is only in recent years that the climate truly has been put on the agenda in most countries. More people than ever before take part in our common climate responsibility. The reality is that we are experiencing climate changes already. Widespread drought and major wildfires. Big floods and generally more extreme weather are already knocking on the door, threatening especially some of the poorest people in the world. Thereby, basic human rights such as access to water, food and the possibility of decent housing, health, and sanitation are challenged. If we are to solve the increasing challenges and avoid a large flow of climate refugees, as well as an unrecognizable world, we must change the high concentration of greenhouse gases in the atmosphere which is resulting in raising the temperature on earth, thereby creating a more extreme climate. The increased amount of greenhouse gases and especially CO_2 in the atmosphere is primarily anthropogenic. We can therefore solve the climate crisis by drastically reducing our GHG-emissions. This must be done quickly if we are to avoid a changing climate on earth. With the increased focus on climate in recent years, the Paris Agreement was made in 2015. The main focus is to avoid a temperature increase of more than 2.0-degrees Celsius and preferably 1.5-degrees Celsius compared to preindustrial levels.

The problem for this project itself is worded as follows:

"Which changes must happen to the existing trends for the development of the global energy system in order to meet the Paris Agreement of maximum 1.5-degrees Celsius temperature rise?

Are these changes realistic?"

2. Methodology

To make it manageable projecting the possibility of reaching the Paris Agreement targets, the following method has been used. Firstly, a scenario model calculating future temperature was created. This model was created using quantitative IEA [6] data for energy balances, which for all countries is shaped evenly, wherefore the data appropriately could be cumulated. To have a reference for the future, a “frozen policy”-scenario based on a “business as usual”-analysis was estimated. Afterwards, realistic, yet optimistic, future scenarios were shaped. In predicting different future values (e.g. the amount of renewable energy used for electricity generation) within the scenarios, two different methods were used. The first method of predicting was based on assumptions, from where future relevant values were calculated. Secondly, quantitative historic data and future predictions were used. The future predictions were either used directly in the scenarios or modified realistically to fit into the scenarios. The historic data was used primarily for regression purposes to forecast the future. When having forecasted different tendencies within the different scenarios, one returned to the “frozen policy”-scenario to implement the found values. In the scenarios, the necessity of reaching the Paris Agreement target was not implemented. Instead, the method for this research was to project future tendencies, in a realistic way, and then observe the influence of these on the future temperature. The benefit of using this method was that the scenarios were shaped realistically through realistic assumptions and historic data. When having these realistic scenarios, concluding whether they comply with the Paris Agreement targets or not was easy. By using this method, instead of a method with a necessity of reaching the Paris Agreement target, unrealistic assumptions and projections were not as likely to happen. One the other hand, this method only makes it possible projecting what is to be done to reach the 1,5-degrees target qualitatively.

In general, when analysing future scenarios, the world was divided into OECD-countries [7] and non-OECD-countries. This was done due to great differences within these two categories. Usually, OECD-countries are more developed, have gone through major economic growth, and have a higher energy per capita consumption than the non-OECD-countries [8]. Therefore, it is fair to assume that these two parts of the world do not have the same ability or willingness to act in relation to climate change and global warming. Naturally, in different parts of respectively OECD- and non-OECD-countries, different approaches to climate change would take place. Therefore, within this division of the world a general assumption lies, which is that roughly all OECD-countries act alike, and that roughly all non-OECD-countries act alike.

3. The Paris Agreement

The Paris Agreement is an international agreement within the UN's climate convention called UNFCCC. The agreement was formed under the COP21 in Paris in 2015. It is a legally binding contract negotiated by 196 countries regarding the problem of global warming [9].

3.1. Background

During the last 70 years, the population size and the energy per capita rate have risen, resulting in a rapid increase in energy production and consumption [1] (figure 1). In the process of producing energy, the most used source for retrieving energy has in the last hundred years been fossil fuels, as for example oil and coal [10]. Combustion and use of these fossil fuels lead to the emission of greenhouse gases, especially CO_2. An increased quantity of CO_2 in the atmosphere contributes to the greenhouse effect, which makes it harder for the heat to slip out of the atmosphere (elaborated explanation is made in section 4). Looking at figure 2 [1], the causality between atmospheric CO_2 concentration and temperature becomes quite clear. Explained in another way: an increase of atmospheric CO_2 concentration results in a rise of earth temperature also called global warming. The problem within this phenomenon is that global warming results in unmanageable environmental and climate consequences, such as natural disasters and melting of ice [11]. Those are the facts faced by the UN. This resulted in the Paris Agreement formed under the COP21-conference in 2015, where several targets for the future climate were set.

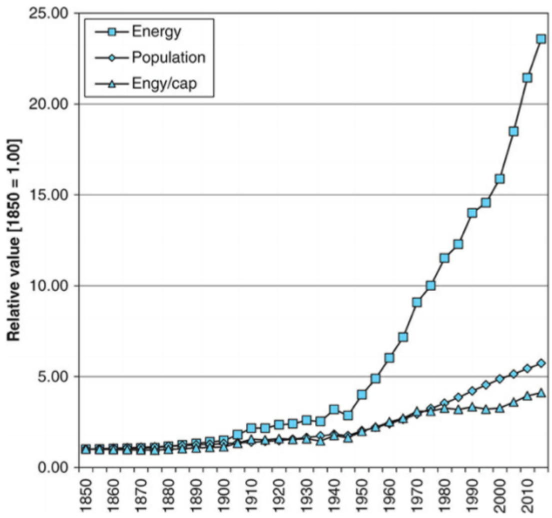

Figure 1: Historic energy production and population [1]

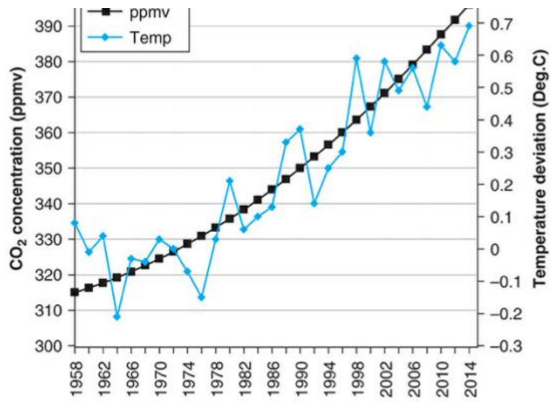

Figure 2: Causality between CO_2 concentration and temperature [1]

3.2. Targets

The initial target of the Paris Agreement was to keep the world's increase in temperature under 2 degrees Celsius and preferably under 1,5 degrees Celsius, compared to preindustrial levels, to limit global warming and its consequences [9]. Nevertheless, a temperature change at both 1,5 and 2 degrees Celsius will have consequences for our climate [11], wherefore this problem needs to be taken extremely seriously. This again emphasizes that the 1,5-degrees Celsius target is the clearly preferred target. To comply with this target, one of the main goals of the Paris Agreement is to make sure CO_2-emissions drop as soon as possible and the countries who entered the agreement must top their yearly CO_2-emission value as quickly as possible. There is no description in the Paris Agreement of the term 'preindustrial level'. However, IPCC sets the preindustrial period to being between 1850 and 1900 [12]. Temperature measures for this period are not easily accessible. Though, the best measure for calculating an average temperature in the preindustrial period is from Earth Policy Institute [13], whose temperature measures suggest an average of 13,8 degrees Celsius in the period between 1880 and 1990 (assumed applicable for the 1850-1900 period). The definition of the pre-industrial temperature of 13,8 degrees Celsius is the reason for later implementation of 1,5- and 2,0-degrees targets, as temperatures of respectively 15,3 and 15,8 degrees Celsius. Worth mentioning is that the EU and all its member states have agreed on fulfilling the Paris Agreement. To do that, they want to be the first climate-neutral society before the year 2050. One of the sub-targets for this strategy is to reduce the EU's greenhouse gas emissions by at least 55% before 2030. This is compared to 1990 levels [14].

4. Theoretic Understanding of the Climate Problem

To theoretically understand the reason for this problem, one needs to investigate different aspects such as the greenhouse effect, greenhouse gases, their absorption of radiation in the atmosphere, and the carbon cycle in general. Investigation of these aspects is the purpose of this section.

4.1. The Greenhouse Effect & Greenhouse Gases

The problem addressed in this paper origins from the phenomenon often referred to as the greenhouse effect, an effect whose impact results in global warming. In this phenomenon the atmosphere acts as a greenhouse in relation to the earth, allowing the entrance of light from the sun while capturing an amount of the heat released from the surface of the earth. The greenhouse effect is essential and necessary for life on earth, as calculations show that without an atmosphere and thereby without the greenhouse effect, the surface temperature on earth would be minus 18 degrees Celsius [1]. Nevertheless, the impact of the greenhouse effect can exceed appropriate limits, bringing difficulties and problems regarding climate and global warming along its way, highly relevant problems that we in this moment of time are facing on earth. The often referred to as sinner of the problem, is the emissions of anthropogenic greenhouse gases, especially CO_2. The increase in CO_2-emissions is inevitably linked to our energy use, accounted for in section 3, and therefore the production of energy. Fuel combustion has in recent years been the easiest way to accede to this energy demand, but by extracting and burning fossil fuels, CO_2 is emitted into the atmosphere. Another mentionable anthropogenically emitted greenhouse gas is methane (CH_4), primarily emitted when producing fossil fuels and from processes regarding food production [1]. Methane is also stored within the ice, wherefore a dangerous cycle can appear if the earth's temperature continues to rise and large amounts of ice melt. Methane has a 100-year global warming potential of 28, meaning that it as a greenhouse gas is 28 times as powerful as CO_2 in a time horizon of 100 years [15].

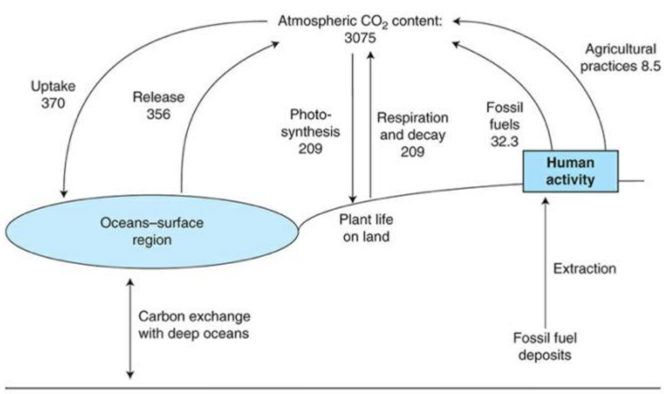

Figure 3: The 2012 Carbon Cycle. Unit of the values is 10^9 tonnes CO_2 [1]

4.2. The Carbon Cycle

The carbon cycle that moves CO_2 in and out of the atmosphere is seen in figure 3. Both a short- and a long-term cycle are at work. In the completely natural cycle, trees, plants, and animals living on the earth's surface exchange carbon dioxide with the atmosphere through photosynthesis and respiration. Some CO_2 is stored more permanently in trees, and this now stored CO_2 within the trees is released back into the atmosphere in decomposition processes [1]. Moreover, the oceans on earth also absorb and release CO_2. What also appears in figure 3 is a "human activity"-box, a result of our extraction and use of fossil fuels, which emit CO_2 into the atmosphere. The atmospheric content of CO_2, which was $3075 \cdot 10^9$ tonnes CO_2 in 2012, is not a constant value. It can vary in both directions. For the last many years, the concentration of CO_2 in the atmosphere has risen (figure 2, page 3). This is a result of an increase in the "human activity"-box in figure 3. So, to lower the CO_2-concentration of the atmosphere, we, as humans, must act and change behavior in regards of, especially, fossil fuel combustion.

4.3. Radiation & Absorption

When speaking of climate change and GHG-concentration in the atmosphere, Black Body Radiation is a useful phenomenon to introduce. It is the description of how an object exchanges heat with its surroundings. Both earth and sun are considered black bodies, and the energy flux of these bodies is defined by the function [1]:

$$F_{BB} = \sigma T^4$$

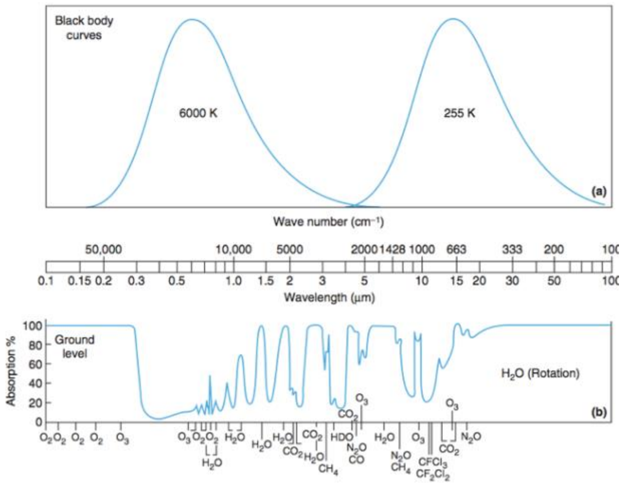

Figure 4: Black body curves for sun and earth and corresponding absorption of different wavelength [1]

In this formula, one notices the great effect of temperature on the flux, as the temperature, T, is raised to the fourth power. The black body curves of respectively earth and sun are, when speaking about climate change and global warming, particularly interesting. Those curves can be seen in figure 4. The top figure shows the black body curves of respectively sun and earth. The figure shown below states the spectrum of wavelengths in which different greenhouse gases absorb radiated photons [1]. Looking at the figure, H_2O is a great contributor to the greenhouse effect. Nevertheless, H_2O has reached its full potential as a greenhouse gas, absorbing as much as possible. Therefore, increasing the H_2O-concentration in the atmosphere will not be dangerous in relation to increasing the concentration of the anthropogenic greenhouse gases CO_2 and CH_4. If the concentration of these gases is increased, the greenhouse effect becomes stronger, resulting in global warming on planet earth.

4.4. The Energy Balance

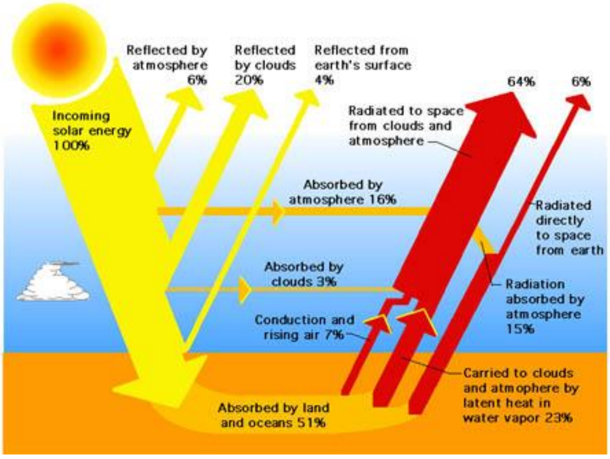

Figure 5: Earth-atmosphere energy balance [3]

It has now been explained how the greenhouse gases absorb radiation - now it's time to look at the earth-atmosphere energy balance (figure 5). From the sun, short-waved radiation reaches the atmosphere, wherefrom some waves are reflected, some are absorbed, and some continue towards earth [1]. The atmosphere also exchanges heat with the earth, as long-waved radiation is radiated from the earth and carried to clouds and the atmosphere. The atmosphere lets some of the radiation from earth pass into outer space, and some are absorbed by the atmosphere. In figure 2, it's seen that the concentration of CO_2 in the atmosphere is increasing, and in section 4.3 the absorption ability of CO_2 is accounted for. Therefore, the more greenhouse gases present in the atmosphere, the greater a part of the radiation from earth is absorbed. This results in increasing the temperature on earth - that is global warming.

4.5. The Very Simple Climate Model

It is possible to describe future temperature with the "Very Simple Climate Model". In this model, the future temperature T is calculated on basis of known temperature and CO_2-concentration of the atmosphere from a given year, T_n and C_n, and the new CO_2-concentration in the atmosphere C [16]:

$$T = T_n + S \cdot \log_2\left(\frac{C}{C_n}\right)$$

An important notice is a fact that C and C_n is in the unit of ppm. S is the "climate sensitivity", describing how many degrees Celsius the temperature will increase if the CO_2-concentration of the atmosphere is doubled. This model can be misleading as the value for climate sensitivity vary greatly in different calculations (this will be accounted for and discussed in section 8). The new CO_2-concentration is calculated in the following way:

$$C = \left(C_n + \frac{C_e \cdot y \cdot 0{,}45}{2{,}13}\right) \cdot (1 - 0{,}001)^y$$

C_e is the annual CO_2-emission, y is years in the future the CO_2-concentration is calculated, 0,45 is the share of CO_2 not absorbed by oceans and 2,13 is the conversion rate from Gt CO_2 to ppm [16]. In this formula, it's noteworthy that only 0,1 % of the CO_2 in the atmosphere finds its way out of the atmosphere per year. This shows the inertia of the system, meaning that even if we rapidly slow down our CO_2-emission on earth it will still take a long time for the CO_2-concentration in the atmosphere to really decrease.

4.6. Population Forecast

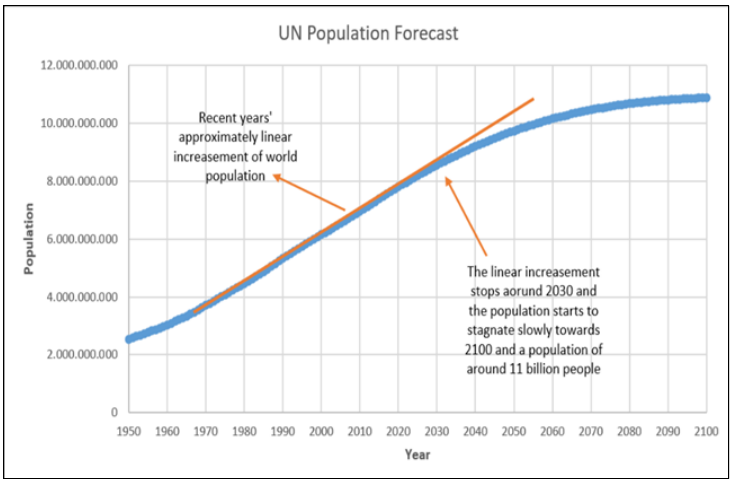

Figure 6: Forecast of world population [Frozen Policy, BAU]

When considering the forecast of energy consumption and other future factors, a key information is the population size of the world. The UN's medium forecast for the future population in the entire world [17] suggests, when graphing its values in [Frozen Policy, BAU] (see figure 6) that the linear growth in the population will stop in 2030 and stagnate from there, where it becomes almost constant in 2100. Since the world is divided into OECD- and non-OECD countries in this project, the population forecast for both OECD- and non-OECD-countries are necessary. The forecasted population within each part of the world will show itself useful in later calculations accounted for in this paper. A forecast for OECD-population in the future towards 2061 [18] is used in order to also calculate the projected population in non-OECD-countries. As seen in figure 7, the population of OECD-countries stagnates after 2060, giving a reason for calculating the non-OECD-population after 2061 on basis of the OECD-population in 2061. In figure 7, it is easy to notice that in the future, the non-OECD-countries will have the greatest contribution to overall population growth. The exact forecast for the population in OECD- and non-OECD-countries can be found in the "population forecast"-sheet within [Frozen Policy, BAU]. When the future population in this paper is mentioned, these are the numbers referred to and used in calculations.

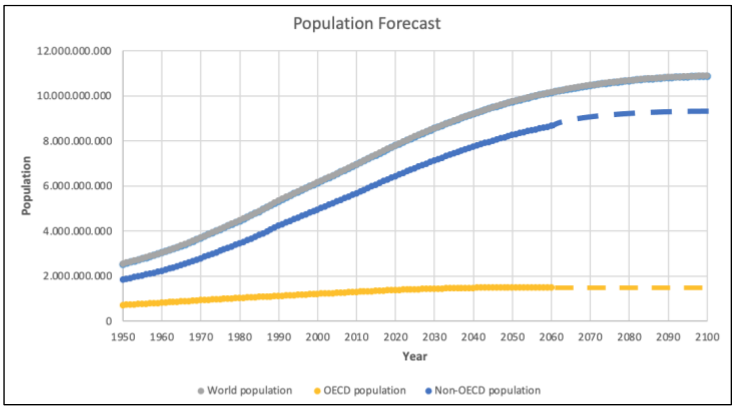

Figure 7: Forecast of OECD and non-OECD population [Frozen Policy, BAU]

5. Projection model

To calculate necessary values for creating projections showing the changes in temperature in future years, a projection model is used. This projection model is the basis for future temperature calculations and can be found in most of the attached excel files. A visualization of the projection model can be found in Appendix C using "key figures" for OECD in 1995 and a forecasted "energy balance" for OECD in 2030 as an example. The "key figures" for respectively OECD- and non-OECD-countries are calculated on basis of IEA's data for historic energy balances [6]. Firstly, respectively OECD and non-OECD is divided into consumption and production sectors - an example of this is shown in figures C1 and C2 for OECD-countries in 1995 in Appendix C. Here, the industrial sector makes up 28%, the transport sector 35%, the residential sector 22%, commercial and public services 13%, agriculture and forestry 2%, fishing 0%, and non-specified 1% of the energy consumption. Each of these sectors is then divided into different subsectors (an example for "industry" is seen in Appendix C). In the industrial sector in OECD in 1995, it is seen that 14% of the consumed energy is obtained from coal, 0% from crude oil, 19% from oil products, 29% from natural gas, 0% from renewables (geothermal, wind, solar, etc.), 5 % from biofuels and waste, 30 % from electricity and 2% from heat. Transport losses of electricity and heat and efficiency of final consumption of fuels, fuels in transport, electricity are other measures considered. Within the total final consumption, a sector for the industry's own use is also implemented, as the industry consumes some of its energy produced. The production sector of both electricity and heat is divided into different supply plants, respectively electricity-only plants (EOP), CHP plants, and heat plants. Both CHP plants and heat plants produce and distribute heat, and in 1995, according to Appendix C, CHP plants made up for 68% of the distributed heat. Furthermore, values for how big a share of renewables in relation to fuels that the plants use, is also defined. In addition to that, for every plant, the fuel distribution for each plant is also considered. When having forecasted these values for 2030 and 2050, they are used to produce a forecasted energy balance with an input and output side of every category (figures C3 and C4 in Appendix C). The starting point of the calculation of the future energy balance is found within the value of projected total energy consumption in a chosen year. With this value and the "key figures", the rest of the values in the energy balance in figures C3 and C4 in Appendix C are made. Using the input side values of energy sources in "entry electricity, district heating and oil products" and "exit energy" and the emissions factors of fossil fuels (figure C5 in Appendix C), the total CO_2-emission of each category is found. The sum of these constitutes the total CO_2-emission in the chosen year in the future. When being in possession of historic and future values for CO_2-

emissions per year, the "Very Simple Climate Model", accounted for in section 4.5, is used in calculating temperature in future years (an example-sheet is seen in figure C6 in Appendix C.)

6. "Frozen policy"-scenario - a business-as-usual projection

Assuming a "frozen policy"-scenario, meaning no big steps taken and no meaningful new laws or policies in the coming years regarding energy consumption and CO_2-emissions, the BAU-model (business-as-usual-model) is appropriate to use to project, what the future looks like. Finding the values of energy consumption, CO_2-emissions, energy mix, and temperature in years 2030 and 2050 under the assumption of a "frozen policy"-scenario makes a good reference point for the other scenarios presented in this paper. This BAU-analysis of a "frozen policy"-scenario is devised looking at the world as split in OECD-countries and non-OECD-countries. To make this projection the starting point is taken in the projection model accounted for in section 5. On the percentage values for 2015 and 2018 in every category, but the efficiency ones, for respectively OECD-countries and non-OECD-countries, linear projection is performed. Hereby, the percentages values for each category in years 2030 and 2050 are found. This is visualized in figure 8 using the "share of consumption" in non-OECD-countries as an example. Naturally some percentages value in 2030 and 2050 will, due to the way of calculation, exceed 100 % or pass the 0 % limit. These calculations are set to 100 % and 0 % and the rest of the rows in the category are modified so that the total sum of each category adds up to 100 %. Small modifications like these are necessary for this type of projection, but the effect of these in the calculated total CO_2-emissions are fortunately extremely small and therefore negligible. In projecting the future total energy consumption in 2030 and 2050, a forecast [19] made by EIA, based on future population and energy intensity, is taken into consideration. This forecast makes it possible to calculate the percentage increasement in energy consumption, in relation to our reference year 2018, in respectively OECD and non-OECD in 2030 and 2050. In this "frozen policy"-scenario, two reference projections are made; one without any progress within efficiency regarding fuels in transport and thermal plants; and one where the efficiency is assumed to rise. Therefore, in the first

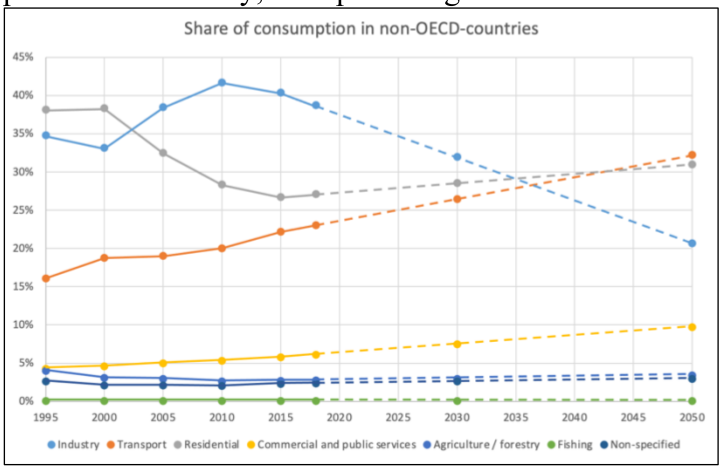

Figure 8: BAU-projection of "share of consumption" in non-OECD-countries

of mentioned projections, nothing is changed. In the other projection, the efficiencies of thermal plants are BAU-projected using the same method as in figure 8. Moreover, the efficiency of fuels in transport are projected to respectively 35 % and 45 % in 2030 and 2050, due to a realistically expected rise in, especially, efficiency of vehicle engines. Using these calculations and the approximated percentage values for every category in the projection model for both OECD-countries and non-OCED-countries gives the values of total GHG-emissions in 2030 and 2050 seen in table 1.

GHG-emissions in "frozen policy"-scenario *(million ton. CO_2e)*		**2018**	**2030**	**2050**	**2075**	**2100**
Without efficiency projections	**OECD-countries**	15.692	13.579	12.400	9.161	6.321
	Non-OECD countries	27.081	32.444	40.191	43.556	40.835
	Total	42.774	46.023	52.591	52.717	47.156
With efficiency projections	**OECD-countries**	15.692	12.716	10.268	5.924	1.808
	Non-OECD countries	27.081	30.878	34.957	30.516	16.564
	Total	42.774	43.594	45.225	36.440	18.371

Table 1: Light grey boxes: BAU-projected values. Dark grey boxes: projected from BAU-projections ([Frozen Policy, BAU] and [Frozen Policy, BAU, efficiency])

The projections for 2075 and 2100 for OECD-countries are projected linearly from emission data since the GHG-emissions in OECD-countries topped, in 2005, to 2050. For non-OECD-countries polynomial regression for emission data from 1995 towards 2050 is used to project the emissions in 2075 and 2100 (see an example in Appendix F). The reason for the difference within regression type is due to differences within the OECD-countries and non-OECD-countries. The OECD-countries already have topped their CO_2-emissions (see table 1), whereas the non-OECD are to do so in the future (see table 1). In the future, the technologies and efficiencies are expected to be better than today, wherefore the CO_2-emissions when having topped in non-OECD-countries are assumed to decrease by a faster rate than in the OECD-countries. Therefore, the non-OECD-countries' CO_2-emissions after having topped are projected differently than the emissions of OECD-countries. Looking at table 1, it's noticed how big a difference a future rise in efficiency can make. The historic GHG-emissions and calculations for future GHG-emissions in both parts of the world (OECD and non-OECD) help sketching the temperature graph on figure 9 using [Frozen Policy, BAU] and [Frozen Policy, BAU, efficiency]. The forecast for temperature in figure 9 shows that the "frozen policy"-scenario will not bring us even close to reaching the Paris Agreement target of a preferred temperature increasement of 1,5 degrees Celsius. The preferred temperature limit will be reached in either 2038 or 2040, whereafter the temperature continues to rise, breaking the maximum allowed temperature increasement of 2,0 degrees Celsius in either 2064 or 2072, depending on which projection is observed. Though, one notices again the difference a rise in efficiencies can constitute.

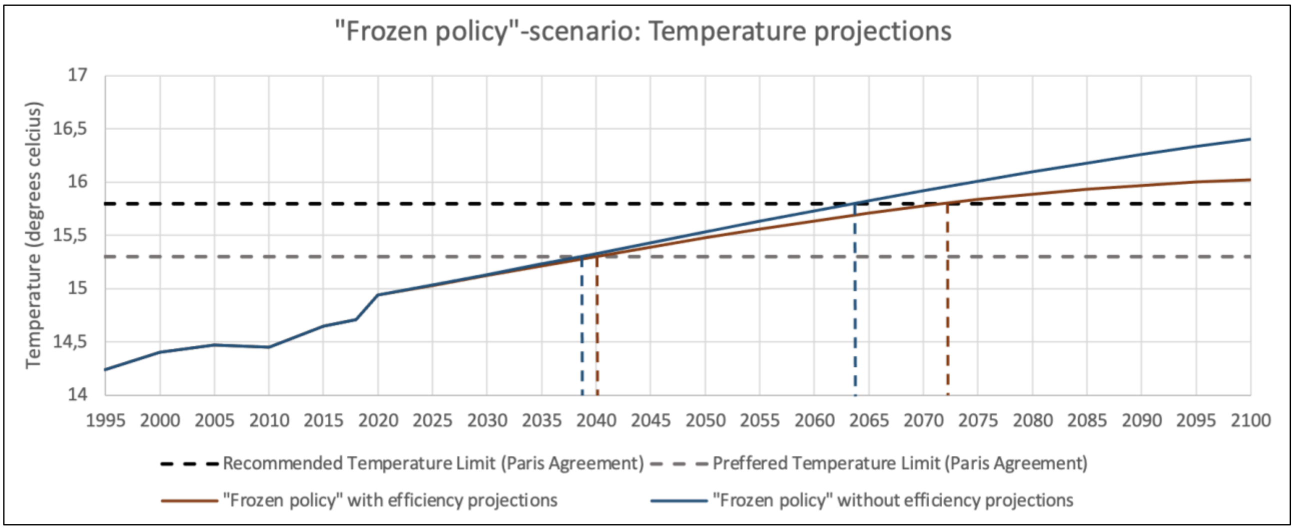

Figure 9: Temperature forecast in "Frozen Policy"-scenario

Verifying, or at least giving some sort of possibility of, these "frozen policy"-projections, is a statement in the European Commission's conclusion [20] on the COP26-meeting: "Before COP26, the planet was on course for a dangerous 2,7 degrees Celsius of global warming". Looking at the "frozen policy projection without efficiency projections", one notices that this projection takes the planet's temperature towards approximately 16,4-16,5 degrees Celsius, which is equivalent to a global warming of 2,6-2,7 degrees Celsius when using the previously stated 13,8 degrees Celsius as the preindustrial temperature. On basis of this "frozen policy"-scenario it can be concluded that serious action needs to be taken to meet the targets of the Paris Agreement. In the following sections and scenarios, these two different projections within the "frozen policy"-scenario are used as reference-projections regarding calculations in the scenarios of this paper.

7. Projected future scenarios

The scenarios for a realistic development regarding the global climate, climate warming, and the energy sector presented in this paper are based upon several so-called “game changers”. “Game changers” are events or major growing trends that potentially could cause a paradigm shift within our perception of global warming and how to cope with its’ related challenges. It’s hopefully possible that these “game changers” could result in environmental-friendly behaviour of individuals and institutions taking greater responsibility for sustainable development. Such “game changers” could be natural disasters (fires, droughts, floods), climate refugees, the COP26-conference, and perhaps the effect of the COVID-19-pandemic. These potential “game changers” cause the line-up of 3 future scenarios; a scenario based upon an effort within the energy supply sector; another scenario focusing on individual effort; and finally, a scenario where both institutional and individual effort is implemented. Common for all these scenarios is that the “frozen policy”-projections accounted for in section 6 is used as a reference for calculations in the scenarios. Within each scenario, a median and a best-case projection are made for chosen values in 2030 and 2050 to be fitted into the projection model accounted for in section 6. In every projection within all scenarios, the CO_2-emission per year is forecasted linearly towards 2100 for OECD-countries, and for non-OECD-countries polynomial regression is performed (the reason for this is accounted for in section 6).

7.1. Scenario no. 1: Institutional (supply-based) effort

In the first scenario, the focus lies within the industrial effort towards the green transition, meaning that there will be taken a closer look at the concrete numbers for what the opportunity for renewable energy is, and thereby create a forecast of what the future might look like in regards of renewable energy. The scenario intends to examine whether changes in the industrial sector have a great enough impact on the environment to reach the Paris Agreement’s temperature targets.

In the projections (median and best-case) the focus lies on the industrial sector’s conversion from fossil fuels to renewable energy and what the possibilities are. Numbers from IRENA [21] are used as historical numbers, whereas the projection of future numbers will vary according to the case. Within both projections, the main focus lies on energy generated by wind power and solar PV, as those are the renewables considered to have the most potential in the future [22]. The exact calculations and values for shown figures can be found in [Electricity generation scenario 1].

In the median case for OECD-countries, the future increase in electricity generation is forecasted using linear regression on the two latest values from respectively 2018 and 2019 for wind power and solar PV. Through the last ten years, the hydro and geothermal electricity generation and in OECD has been approximately constant [21], wherefore these constants rate is assumed applicable for the future. The forecast for wind and solar PV can be seen in figure 10. The values for electricity generated for each source in 2030 and 2050 are then calculated on basis of the linear regression.

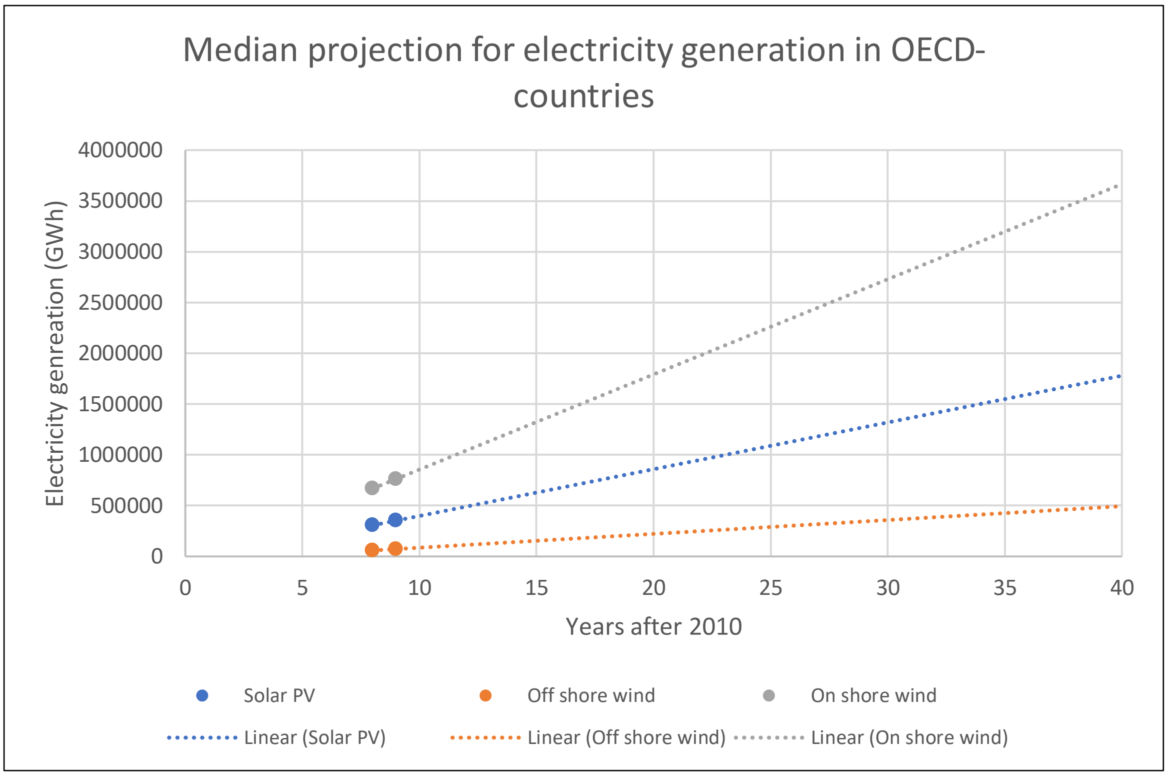

Figure 10: Forecast of electricity generation in median projection for OECD-countries

In the best-case projection for OECD-countries, a more optimistic approach is taken, performing polynomial regression on all the historical data to produce the optimistic projections for future electricity production by renewable sources (wind and solar PV) (see figure 11).

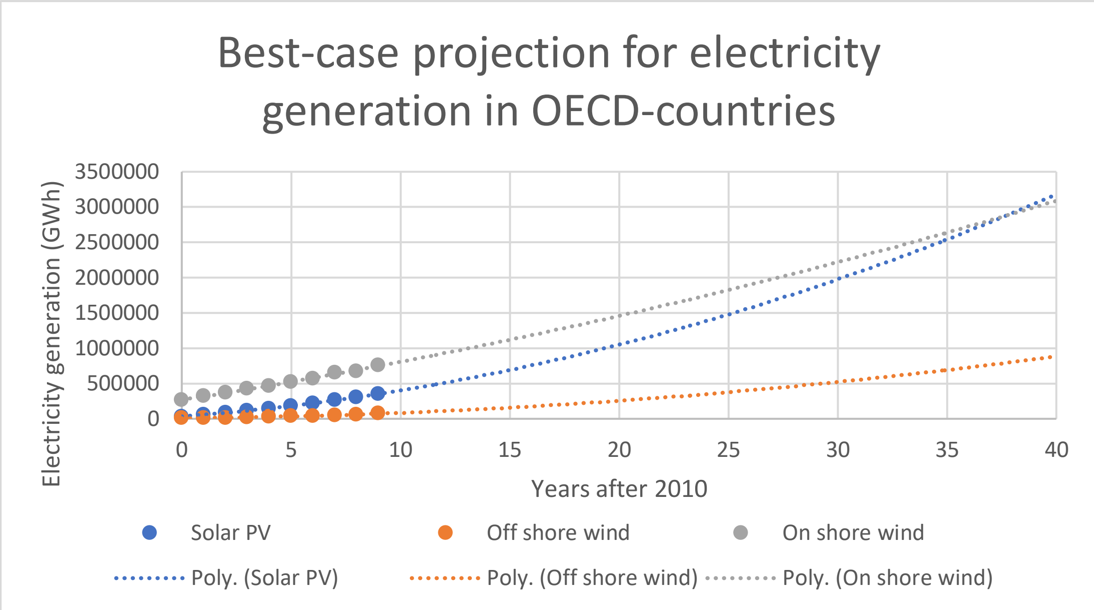

Figure 11: Forecast of electricity generation in best-case projection for OECD-countries

Again, on basis of the polynomial regressions, values for generation in the best-case projection within scenario no. 1 in 2030 and 2050 are calculated. For non-OECD-countries, hydropower electricity has still increased through the last ten years [21], and the potential for future deployment of hydropower generation in non-OECD-countries is assumed to still be there. Therefore, also hydroelectricity generation along with wind and solar PV is projected to rise in the future in non-OECD-countries. In the best-case scenario, future values for electricity generation by wind, hydro and solar PV are forecasted using, "positive" regression types. Wind and solar PV are, as for OECD-countries, forecasted polynomially, whereas the hydroelectricity generation is forecasted exponentially (see figure 12).

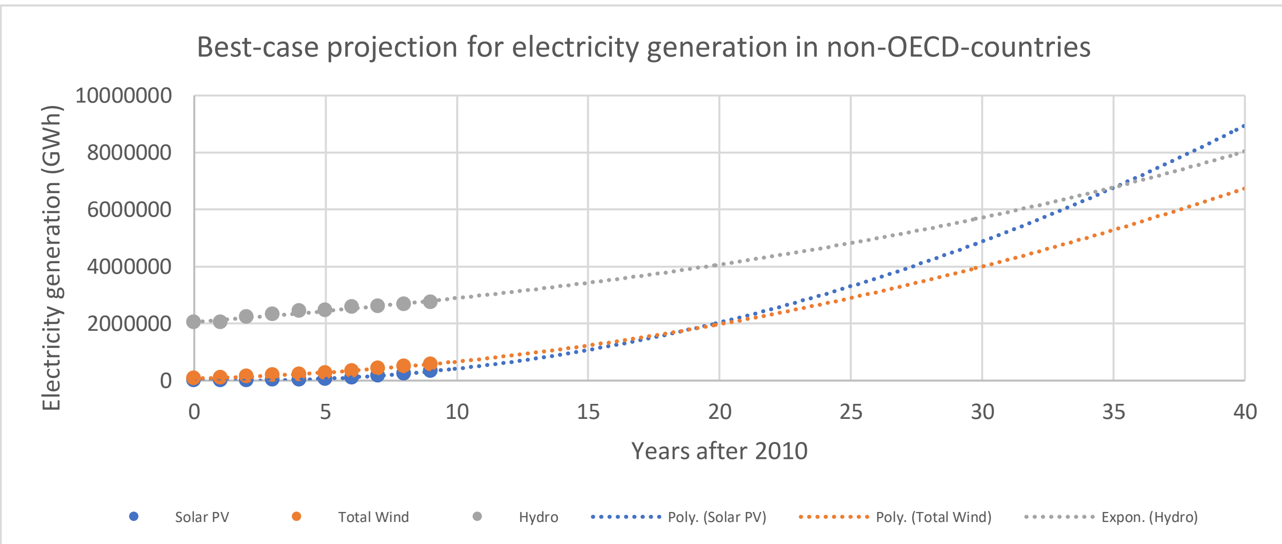

Figure 12: Forecast of electricity generation in best-case projection for non-OECD-countries

When attempting to forecast the median projection of electricity generation in non-OECD-countries, using the same method of linear regression as for OECD-countries, a problem arises. The expected future values of electricity generated by wind power and solar PV become way lower than the ones found in the BAU-projection for the renewables on EOP's in non-OECD-countries. Therefore, in the median projection for non-OECD-countries only linear regression on the hydro generation is performed. The share of other renewables-category (wind, solar, etc.) is then assumed to be equivalent to the BAU-value of the share of renewables on EOP's.

Now, having found the expected electricity generation for the chosen sources, the share of them on EOP's can be found using the expected electricity generation on EOP's in respectively 2030 and 2050 in OECD and non-OECD-countries, seen in the "energy-balance"-sheet in the projection model (Appendix C). Using found values for electricity generation and total electricity generation on EOP's values for share of a hydro and "other renewables" on EOP's in the future can be found (see table 2).

Projection	Share of hydro in EOP (OECD)	Share of other renewables in EOP (OECD)	Share of hydro in EOP (non-OECD)	Share of other renewables in EOP (non-OECD)
2030 median	15,81 %	29,27 %	18,46 %	BAU
2030 median with efficiency projections	15,87 %	29,38 %	18,55 %	BAU
2050 median	15,34 %	58,13 %	17,02 %	BAU
2050 median with efficiency projections	15,54 %	58,87 %	17,26 %	BAU
2030 best-case	15,81 %	28,15 %	21,27 %	20,99 %
2030 best-case with efficiency projections	15,87 %	28,26 %	21,38 %	21,11 %
2050 best-case	15,34 %	69,35 %	27,54 %	53,75 %
2050 best-case with efficiency projections	15,54 %	70,79 %	27,93 %	54,52 %

Table 2: Forecast of share of renewable energy sources in production on EOP's

Those different values for shares of renewables on EOP's are afterwards added to the projections in the excel files within the "Projections - scenario no. 1"-folder, and the effect of this can be seen in figure 13.

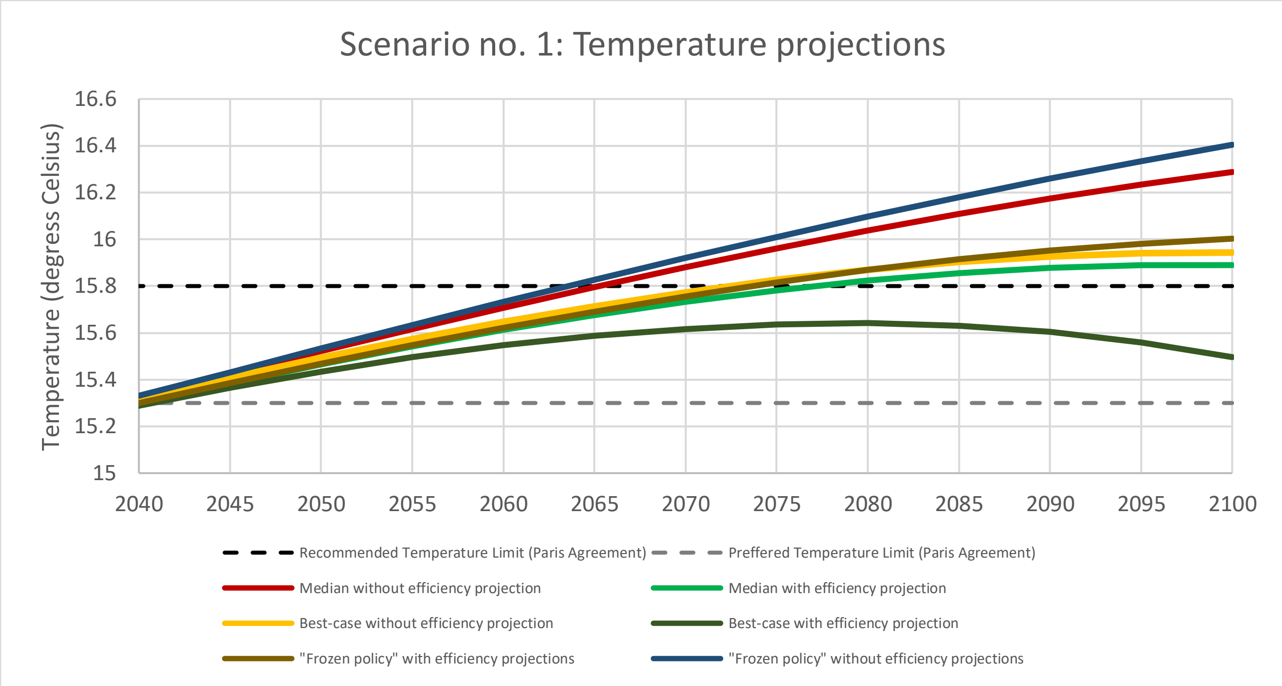

Figure 13: Temperature projections in scenario no. 1

Examining figure 13, one notices that only the best-case projection with efficiency projections makes the 2,0-degrees target of the Paris Agreement. Other projections just cross the 2,0-degrees line. Note that these projections for the future are only due to changes made in the general electricity generation in OECD- and non-OECD-countries. Later, in the third scenario of this paper, a scenario where more factors are changed in relation to the BAU-projections, is made.

To determine whether these projections are fair to assume realistic, the area needed to install solar PV cells and numbers of wind turbines must be found. A report [23] from a Danish solar PV installation suggests that it takes 1,21 acres to produce 1 GWh, which is equivalent to 0,0121 square kilometres per GWh. This value is multiplied by the amount of electricity needed according to the projections, and the total area of installed solar PV in OECD and non-OECD is found in Appendix D. Calculations find that, in the best-case projection with efficiency projections, the total area of solar cells needed is 139.000 km^2. That is approximately 3 times the size of Denmark. Naturally, this is quite a large area, and big investments in solar PV must be made in order to make this projection possible. Besides solar PV plants, the demand for wind turbines will also increase over the years according to the projections created. Again, calculations with the purpose of determining the needed number of windmills to accommodate this demand are made. In 2016, there were a total of 341.000 windmills in the world [24]. Therefore, with the produced electricity in 2016 [Electricity generation scenario 1], an assumed measure for electricity generation per windmills is found to be 2,8 GWh/year. With this value and the projected values for future electricity generation by wind power, the estimated number of windmills needed to be installed can be calculated (see results in Appendix E). The results show that 3,3 million windmills in the best-case scenario in 2050 need to be installed to meet the projected electricity generation from wind power. According to the Global Wind Energy Council [25], approximately 23.000 mills were installed in 2019. Linear forecasting using this value shows an installed 667.000 mills in 2050. This is only around 20 % of the forecasted mills installed in the best-case projection. But installations each year will hopefully begin increasing, and as the mills become more efficient, the installation of what would be equivalent to 3,3 million 2016-mills towards 2050 doesn't seem unrealistic, but still optimistic. Notable is also the fact that the potential for both off and onshore wind turbines differs within the geological positioning [26].

7.2. Scenario no. 2: Individual effort

In the second scenario, things are approached differently, meaning that the effort regarding climate change and global warming lies at the feet of only the individuals. The intention of this scenario is thereby to examine to what extent a general change in the individuals' lifestyle and behaviour would affect future years' GHG-emissions and temperature. Another way of saying this: what is the individual's role in the upcoming climate conversion and how big a part can we, as individuals, play? In this section, two big drivers within the individual sector, namely the impact of changing food habits, and changes in personal transport method are examined, respectively in OECD-countries and non-OECD-countries. Naturally, people in respectively OECD-countries and non-OECD-countries will have different opportunities to act, which is taken into consideration making the calculations in this section.

When considering the consumption of energy in the transport sector in the future, the aftermath of COVID-19 could play a role. Both research [27] and forecasts [28] suggest growth in people working from home as a result of the pandemic showing the functionality and efficiency of online meetings and working from home. In the median projection, the growth of working from home is assumed to have the potential to decrease the total energy consumption of passenger cars by 5 % and 10 % in respectively 2030 and 2050. In the best-case projection within scenario 2, the values are projected to be 10 % and 20 %. Those assumptions are applied both OECD- and non-OECD-countries and result in reductions in passenger car energy consumption seen in tables 3 and 4. An elaborated method of calculating the reduction in energy consumption for the passenger cars can be found in Appendix G. Moreover, in relation to what the individual can do regarding transport, the growth in electric vehicles among passenger cars is also to be considered. In their "International Energy Outlook 2021" [19], EIA projects that in 2050, 34,4 % and 28,4 % of passenger cars in respectively OECD and non-OECD will be electric [Share of EV passenger cars - EIA-projection]. These percentage values are used in the median projection in this paper. For the best-case projection, assumptions for 40 % in OECD-countries, and 35 % in non-OECD-countries are applied. Given these percentage values for the projected rate of electric vehicles in 2030 and 2050 in both median and best-case projection, calculation of the share of electricity in the transport sector, in general, can be calculated and seen in table 5 (examination of the calculation can be found in Appendix H). These percentage values and the values from tables 3 and 4 are applied to the belonging excel files in the "Projections - scenario no. 2"-folder in the transport category. As the electricity value is increased by a certain percentage, the "oil products" category is reduced by the same percentage value, as it's fair to assume that oil is what will be cut in the transport sector in the future.

Median	$E_{PC,BAU}$ (PJ)	$E_{PC,projected}$ (PJ)	$E_{PC,saved}$ (PJ)
OECD 2030	32.054	30451,3	1.603
OECD 2050	36.715	33043,5	3.672
Non-OECD 2030	35.366	33597,7	1.768
Non-OECD 2050	67.736	60962,4	6.774

Table 3: Reduction of transport energy use in median-projection

Best-case	$E_{PC,BAU}$ (PJ)	$E_{PC,projected}$ (PJ)	$E_{PC,saved}$ (PJ)
OECD 2030	32.054	28848,6	3.205
OECD 2050	36.715	29372	7.343
Non-OECD 2030	35.366	31829,4	3.537
Non-OECD 2050	67.736	54188,8	13.547

Table 4: Reduction of transport energy use in best-case-projection

Projection	**Share of electricity in the transport sector - OECD-countries**	**Share of electricity in the transport sector - non-OECD-countries**
Median (2030)	4,3 %	3,0 %
Median (2050)	19 %	16 %
Best-case (2030)	5,8 %	3,8 %
Best-case (2050)	23,2 %	19 %

Table 5: Projected share of electricity in transport sector

So far in scenario 2, only factors regarding energy usage and reduction of energy usage have been accounted for. Nevertheless, within a possible behavioural change in an individual's animal product consumption lies a great opportunity to cut GHG-emissions. The first step in the method used in this paper for approximating the cut in GHG-emissions in future scenarios (for an elaborated explanation, see Appendix I), is to state the emissions factor of the different animal products. In this paper, the biggest emitters within animal products, namely beef, pork, poultry, sheep, and cheese, are examined. Using how much CO_2e each product emits per kg product [2], with data for consumption of each product per year per capita in OECD [4] and non-OECD [29], the total GHG-emission (in CO_2e) from these animal products can be calculated. The result of these calculations shows that 13 % of the total GHG-emissions in 2018 in the world came from animal food production and consumption. Therefore, a great possibility for cutting global emissions lies within our food habits. The 2018 emission from animal product consumption is used as a reference in calculating how much CO_2e in respectively the median and best-case can be "saved" each year in the future. Assumptions regarding reduction in animal food consumption for OECD- and non-OECD-countries in the median and best-case projection can be seen in table I1 in Appendix I. These assumptions and the calculations in [GHG from food and released land area], accounted for in Appendix I, help sketching the graph of figure 14 showing how much CO_2e can be saved each year in relation to the reference year 2018. The difference between the two graphs is naturally due to the differences within assumptions belonging to respectively median and best-case projection. In the median projection, the animal product consumption decreases by fixed percentage values, whereas the consumption in the best-case jumps more drastically as people possibly will cut animal products more drastically. When having the amount of CO_2e "saved" in relation to the BAU-projection, those values for "saved" CO_2e are withdrawn from the total CO_2e-emissions (in the excel files of the "Projections- scenario no. 2"-folder), the category included in the calculations for future temperature using the "Very Simple Climate Model". When having implemented accounted measures for both

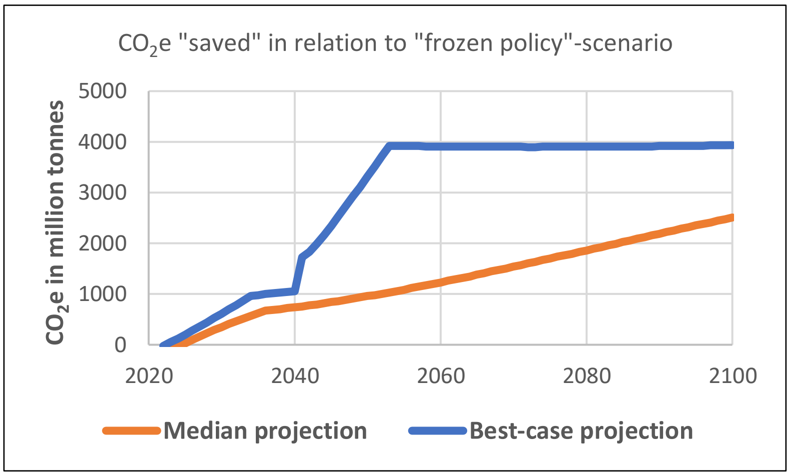

Figure 14: CO_2-emissions "saved" due to changes in food habits

median and best-case projection to the excel files of the "Projections- scenario no. 2"-folder, results for future temperature projections as seen in figure 15 emerges.

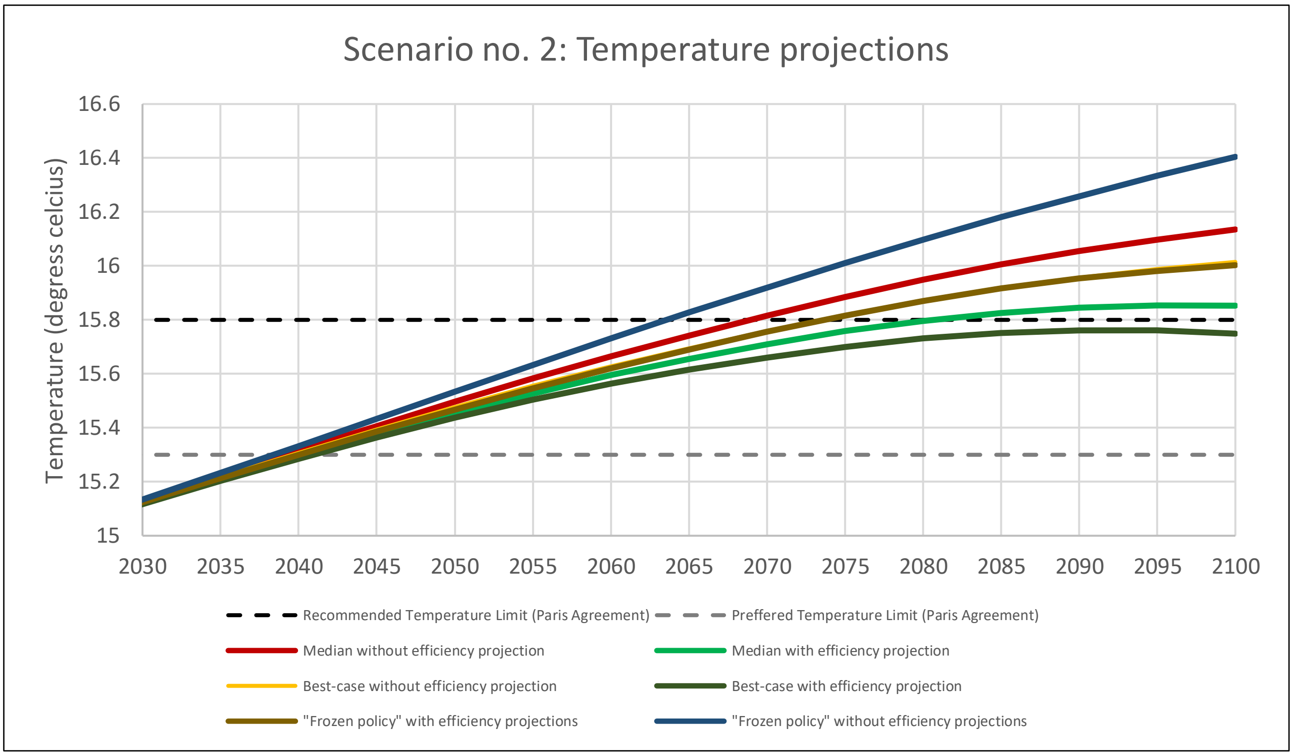

Figure 15: Temperature projections in scenario no. 2

Looking at figure 15, one notices that all projections cross and do not comply with the Paris Agreement target of only increasing the temperature by 1,5 degrees Celsius in relation to preindustrial levels. Nevertheless, the best-case projection with assumptions regarding efficiency makes the Paris Agreement target of a maximum increasement of 2,0 degrees Celsius. What's also noteworthy is the fact that the assumption regarding efficiency makes a great difference. Concluding partially on the second scenario, it can be said that the efforts made by individuals won't meet the 1,5 degrees-target but have the potential in a best-case-projection to meet the 2,0-degree-target.

7.3. Scenario no. 3: Mixed - Institutional and individual effort

In this third scenario, the efforts from scenario no. 1 and scenario no. 2 are brought together. Therefore, an assumption within this third scenario is that both institutions and the individuals of the society act towards cutting GHG-emissions. This means that all calculations and results in different projections within scenarios no. 1 and 2 are applied to the projection model. The calculations for %-rates of renewables in electricity generation in this scenario can be found in [Electricity generation scenario 3]. By mixing the scenarios, the projections for future temperature in scenario no. 3 in figure 16 are found.

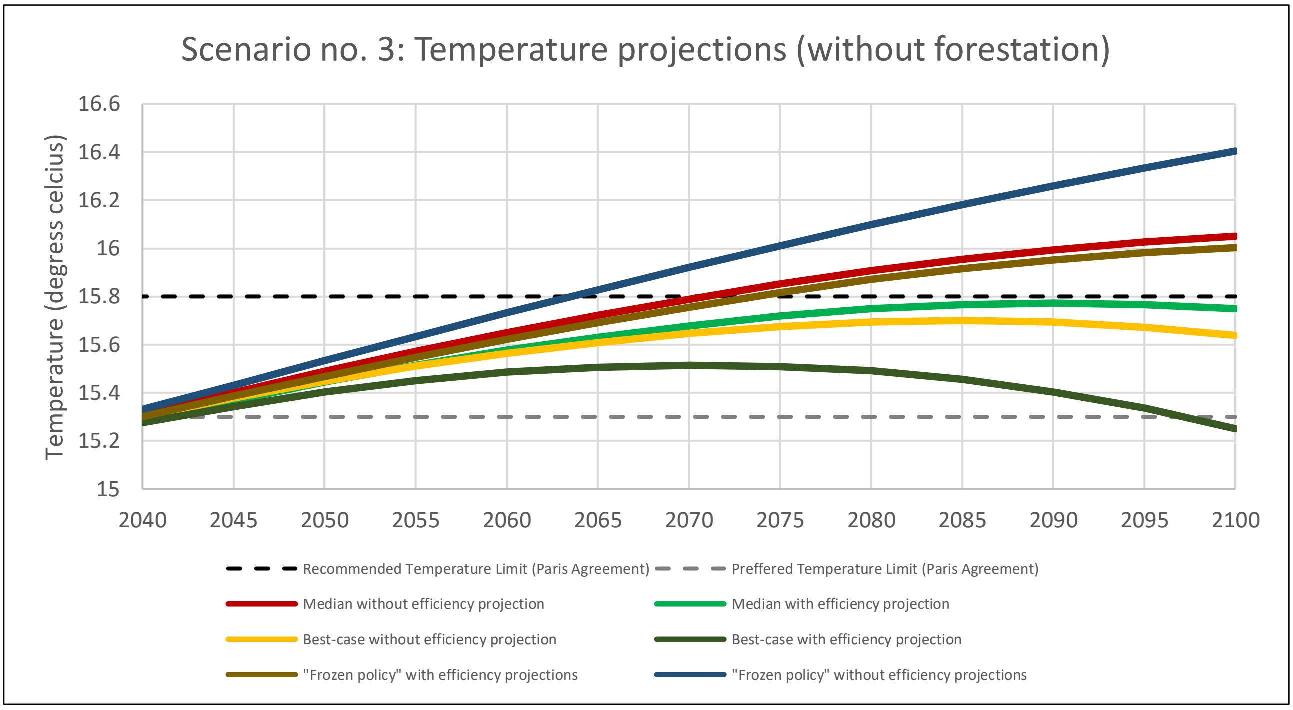

Figure 16: Temperature projections in scenario no. 3 (without taking forestation into consideration)

When examining these projections, it is noticed that the median projection (with efficiency projections) and both best-case projections comply with the Paris Agreement target of a maximum temperature increasement of 2,0 degrees Celsius in relation to pre-industrial levels. None of the projections makes the 1,5-degrees target, but there is still hope, as the best-case projection (with efficiency projections) shows an increase of temperature since pre-industrial levels of “only” 1,7 degrees Celsius.

So far, the third scenario has only brought together scenarios no. 1 and 2. Nevertheless, another thing can be added to this third scenario, as the individual’s behaviour in the second scenario regarding a decrease of animal product consumption releases a serious amount of land area that previously was used for livestock and dairy. On this, now abandoned land area, institutions, being the effort maker of the first scenario, have the possibility to act even more by beginning to forestate this land area. In an article [30], "World Resource Institutes" cites research saying that forests globally had a net absorption of on average 7,6 billion tonnes CO_2 per year between 2001 and 2019. With this value and with the total global forest area being 39 million km^2 [2], it's easy to calculate that each square kilometer of forest absorbs approximately 194,9 tonnes of CO_2 per year. The total area for livestock and dairy on a global scale is 40 million km^2 [2]. It's assumed that the relationship between reduction in animal food consumption and the released livestock and the dairy area is proportional, meaning that a 10 % reduction of consumption leads to 10 % of the total livestock and dairy area being abandoned, and thereby ready for forestation. In addition to that, it's assumed that 50 % of the released area will be forestated in these projections since the area of plant-based food production must be increased due to our new food habits, and since some of this land possibly will not enable forestation. Using the calculations for the decrease in animal food consumption accounted for in Appendix I, it is possible to calculate the amount of released land area each year towards 2100, and thereby the projected CO_2-absorption of planted forests in this area. Forecasts for CO_2-absorption of the forests can be seen in figure 17. Elaboration of these calculations can be found in Appendix J referring to [GHG from food and released land area].

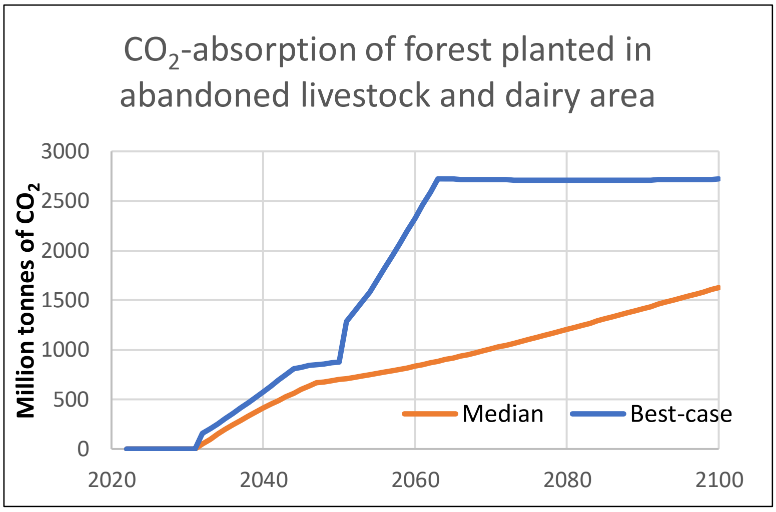

Figure 17: CO_2-absorption of forest planted in abandoned livestock and dairy area

The calculations show that in the median projection, an area of approximately 9 million km^2, almost equivalent to the area of the USA, will be forestated from 2021 to 2100, whereas the forestated area from 2021 to 2100 of approximately 14 million km^2 in the best-case projection will be almost equivalent to the area of North America without Canada. Those are extremely big areas, and the question of whether a forestation of this size is possible to reach before 2100 is hard to answer. Nevertheless, a study [31] from Science.org (where unfortunately only the abstract is available), shows an area of 9 million km^2 available for forestation. In an article from the Guardian [32] that describes the study, the study's co-author Thomas Crowther forecasts that it will take 50-100 years for the reforestation of mentioned area to reach its full potential. This does not fully verify, that projections for forestation in this scenario are possible, but it still gives hope for an optimistic approach to the calculations stated in Appendix J. When withdrawing these values for CO_2-absorption by the planted forests in the projection pictured in figure 16, new projections for scenario no. 3 arise (see figure 18).

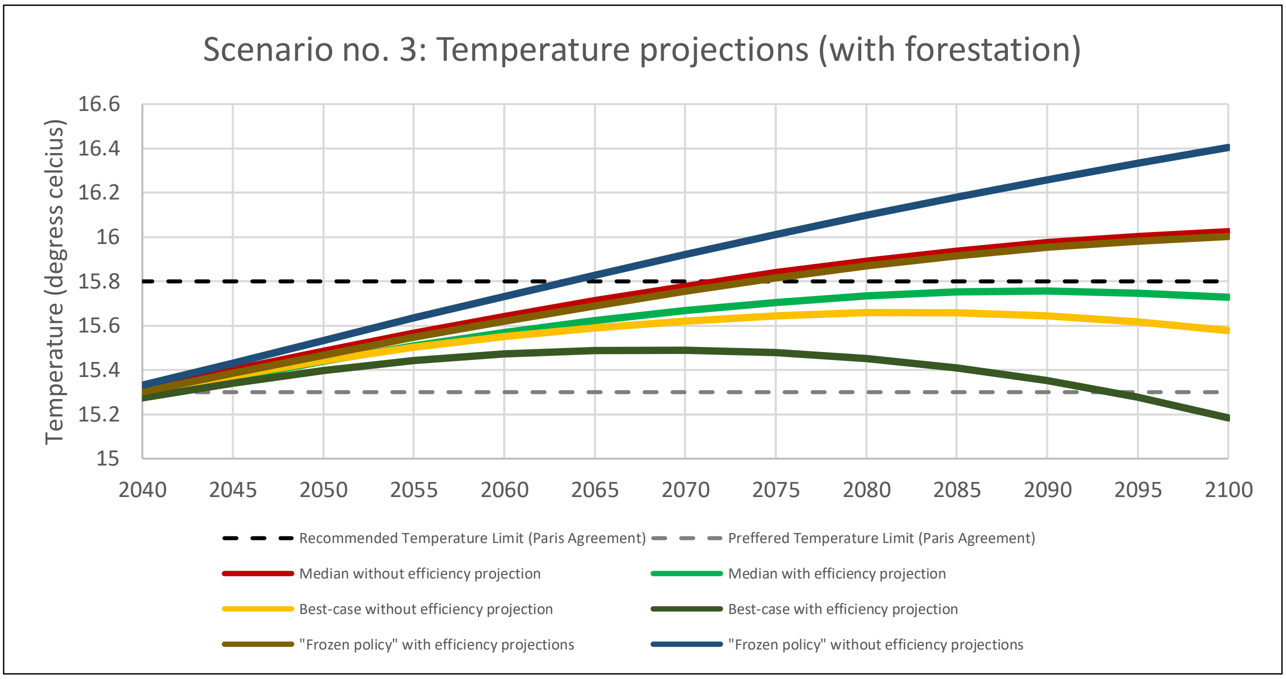

Figure 18: Temperature projections in scenario no. 3 (when taking forestation into consideration)

The projections of figure 18 show that adding forestation to the third scenario, will not either comply with the 1,5-degrees target of the Paris Agreement, but it will bring us a bit closer. Still, the temperature of each projection will all cross the 1,5-degrees target but will from there on head in different directions. The best-case projection (with efficiency projections) again reaches a maximum of 1,7-degrees temperature increase since preindustrial levels. Furthermore, the best-case projection (without efficiency projections) and the median projection including efficiency projections more clearly reach the 2,0-degrees target of the Paris Agreement than in the projection without forestation. The reason for the forestation not contributing more to a decrease of temperature in the future is the fact that it will take a long time for the forestation to reach its full potential.

7.4. Comparative analysis of the scenarios

The purpose of this section is to compare the projections within each scenario of type median, median with efficiency projections, best-case, and best-case with efficiency projections. The visualization of the compared temperature projections can be found in Appendix K.

When examining the figures K1 and K2 (Appendix K), for the median projection (with and without efficiency projections) it becomes quite clear which effect an assumed increased efficiency of thermal plants and fuels in transport constitute. In the median projection without efficiency projections, not even scenario no. 3's projection with forestation, beats the "frozen policy"-projection with efficiency projection. Looking at the median projections with efficiency projections, it's seen that both projections of scenario no. 3 comply with the 2,0-degrees target of the Paris Agreement, whereas scenarios no. 1 and 2 will exceed the 2,0-degrees limit (but only with around 0,1-degrees Celsius). Hence, the median scenario with efficiency projections will not comply with the 1,5-degrees target but could potentially comply with the 2,0 degrees target of the Paris Agreement.

Taking a closer look at figure K3 (Appendix K), showing the best-case temperature projections without efficiency projections, one notices again that the projection for temperature in scenario no. 1 only just beats the "frozen policy"-projection with efficiency projections. Scenario no. 2 does not, which again emphasizes the fact that an increased efficiency for thermal plants and fuels in transport is a major key to reaching the temperature target of the Paris Agreement. In this figure, both best-case projections easily beat the 2,0-degrees target but aren't close to complying with the 1,5-degrees target. Nevertheless, in the best-case projections (with efficiency projections, figure K4), hope arises, as all future scenarios' temperature projections, but the "frozen policy", comply with 2,0-degrees target. The projections of scenario no. 3, respectively with and without forestation, show a maximum temperature increase of 1,7-degrees Celsius. This is the closest to reaching the 1,5-degrees target, the scenarios presented in this paper will come. Another thing to be mentioned from the comparison of both scenario no. 3 temperature projections is the actual minimal effect of the forestation. Naturally, the forestation projection beats scenario no. 3 without forestation, but the difference is very small. Again, it must be stated that the maximum potential of forestation will take a long time to reach, and when reaching this, the temperature will already have broken through the 1,5-degrees increase barrier.

The breakthrough of the 1,5-degrees barrier is similar for all scenarios and projections in this paper, as all projections cross this line somewhere between 2035 and 2042 - none of them will comply with the preferred temperature limit of the Paris Agreement. Therefore, it can be said that it is a difficult challenge for the world to reach the 1,5-degrees target. This naturally has something to do with the inertia of the system, as CO_2 has a processing time in the atmosphere of around 50-200 years [33]. This means that a drastic decrease in CO_2-emissions now, will not have an influence in a short time scale. More time (perhaps a decade or two) needs to pass before the effect is shown. That is why action must be taken now, and the entire world, OECD-countries as non-OECD countries, institutions as individuals, must work corporately and fast to reach the 1,5-degree target. With that being said, the projections of this paper give hope for reaching the 2,0-degree target, which is the maximum acceptable temperature increase since preindustrial levels stated in the Paris Agreement.

8. Discussion

The pros and cons of the chosen method, assumptions, and projections accounted for in this paper, including the "frozen policy"-scenario, the "Very Simple Climate Model", notable factors not taken account for, and the probability of presented scenarios is naturally to be discussed. That is the purpose of this section.

8.1. Method

Firstly, the BAU-analysis of the "frozen policy"-projections is to be discussed. In the projections for future values for the entire energy sector seen in section 6, the future values in 2030 and 2050 are calculated on basis of the development within each sector between only 2015 and 2018. Naturally, this adds some uncertainties to the future projected values, as setbacks or unexpected factors can have affected the development within each category between 2015 and 2018, not making it representable for future development. Therefore, within the BAU-analysis notable assumptions lie. An example can be found in the sheet for non-OECD in [Frozen Policy, BAU]. In almost every end-use category (industry, transport, residential, etc.), it is seen that electrification is taking place, which seems reasonable for the future taking the expected electricity demand for developing countries into account [34]. On the other hand, the assumptions within the BAU-analysis, perhaps not as possible for the future, also occur. An example is the BAU-proposal of a total phase-out of coal in the industry sector in both OECD and non-OECD (see [Frozen Policy, BAU]). This total phase out of coal is naturally beneficial for the climate, but still quite a rough consumption, especially taking BP's forecast [5] for growth by source in the industrial sector into consideration (see Appendix L). In their BAU-projection, coal in the industry sector is "only" expected to decline by approximately 0,3 % each year. On the contrary, BP's BAU-projection backs up the BAU-projection of this paper in relation to the growth of natural gas in the industrial sector. To sum up, the "frozen policy"-scenario makes an acceptable reference for the future but has its weaknesses.

Another thing to be discussed in relation to the way of calculating future values of GHG-emissions and temperature in the future is the choice of the "Very Simple Climate Model". The model is (cf. its name) very simple and only calculates future temperature on basis of CO_2-emissions. In its formula for temperature $T = T_n + S \cdot \log_2(C/C_n)$, the climate sensitivity, S, plays a key role. Climate sensitivity is a measure of how much the atmospheric temperature will rise because of a doubling of the atmospheric carbon concentration. The value of S varies a lot in different studies and is therefore not completely certain. Nevertheless, a comparative analysis of 142 different studies measuring climate sensitivity, shows an average value of 3 degrees Celsius [35]. That is the value for climate sensitivity used in all temperature projections presented in this paper. IPPC expects climate sensitivity to be in a range from 1,5 degrees Celsius to 4,5 degrees Celsius [36]. The effect of varying the climate sensitivity can be seen in figure 19.

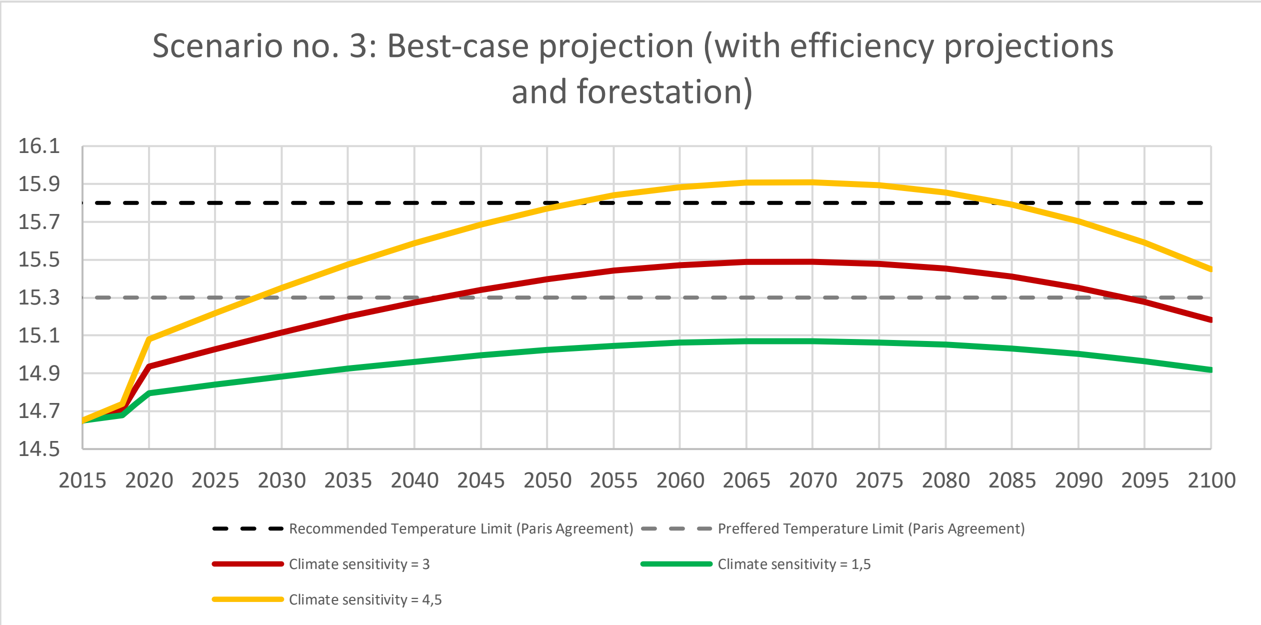

Figure 19: Variation in temperature projections by varying the climate sensitivity

Figure 19 emphasizes that different values ranging from 1,5 to 4,5 degrees of the climate sensitivity cause great differences within the conclusion of for example the best-case projection in scenario 3. This figure, therefore, presents a notable uncertainty within the use of the "Very Simple Climate Model". Nevertheless, climate sensitivity of 3 degrees Celsius is what the conclusions presented in this paper are based upon.

The general method of forecasting values in 2030 and 2050 for the energy sector without setting a requirement for reaching the 1,5-degrees target is also to be discussed. The disadvantage of forecasting the values of for example scenario no. 1's renewables in electricity generation in this way, is that it is not quantitively expressed what is to be done to reach the Paris Agreement target of a maximum temperature increase of 1,5 degrees Celsius since preindustrial levels. On the other hand, using the method described in this paper, realistic projections for the future are found. When having these realistic, and yet optimistic, scenarios for the future, it can then qualitatively be described which extra effort is needed for compliance of the 1,5-degree-target.

8.2. Probability of scenarios

Determining whether the scenarios presented in this paper are realistic, is yet to be discussed. The overall goal for the project was to examine what measures are needed to be taken if the Paris Agreement is to be met and if these measures even are realistic. To do that it is chosen to split the project into 3 scenarios: Institutional, individual, and mixed. This is done based on the different aspects that come into action within the scenarios. For example, the individual efforts regarding the green transition do not have any effect on the institutional implementation of renewable energy. It is chosen to look past the economic aspects in all the scenarios, merely because of the complexity behind it. The economy of course plays a role whether it is in the installation of new windmills or converting the primary energy source from on-grid electricity to solar panels in private households. Furthermore, the difference between private wealth differs a lot among OECD- and non-OECD-countries. In other words, it cannot be expected that citizens in non-OECD-countries are investing the same amount of money into the green transition as citizens in OECD-countries.

In the first scenario, new technologies and improvements of these are also not considered. There is a constant improvement and enhancement of existing technologies, and new technologies are constantly on the verge of a breakthrough, which makes it hard to consider these when making a realistic projection of the future. The European Commission's CORDIS has almost 800 projects dealing with the development and enhancement of sustainable energy [37]. To make an example one of the projects is SolarSharc [38], which is dealing with dirt on solar panels that cause losses of more than €40 billion per year and over 100 tonnes of CO_2 emission. Their product is still in the testing phase and might show itself to be a much better alternative than the current solution. It is impossible to realistically predict when products like this will be on the market and to what extent they will help the climate problem. Also, technology that is not making huge contributions in the overall green transition is disregarded, for example, the development and use of geothermal energy that is stagnating. Therefore, in scenario 1, the future electricity generated by geothermal energy is not expected to grow. Moreover, the fuel distribution category for different plants is not changed in relation to the BAU-projections. For instance, biofuels and waste are also factors that could play a role in the future when it comes to energy production. Factors like these are not considered, resulting in a slightly less optimistic scenario no. 1 temperature forecast. Furthermore, new and forecasted game-changing technologies such as carbon capture and storage (CCS) and molten salt reactors whose future is uncertain could have been implemented in scenario no. 1. Nevertheless, due to the uncertainty of mentioned technology, these are not incorporated in scenario no. 1.

The project investigates how changing our food habits can change GHG-emissions and release a large amount of land are that can be used for forestation. An assumption made in scenario no. 2 is that individuals will change their way of living by reducing their animal food consumption. The question is if it is even a possibility for the population to make this kind and change in their lives, yet? How much interest do we, as a population, have in being environmental-friendly, when we must change or even sacrifice our way of living to do so? This is a very complex question that requires in-depth social scientific analysis to be answered in a probabilistic way. These types of analysis are not within the scope of this examination, wherefore the assumptions made in scenario no. 2 is slightly rough. Nevertheless, the assumptions are still found useful and therefore used in the projection of the scenario. As new and upcoming technologies in scenario no. 1 could have been implemented, also assumptions regarding off-grid solar PV and heat pump use in individual households could have been applied scenario no 2.

8.3. COP26

This paper takes its starting point in the Paris Agreement of COP21 in 2015 and its target. But in the middle of this projects' timeline, a new climate conference, COP26 in Glasgow was held, which also is worth discussing. The main points from COP26 relevant to this project are:

- The Global Methane Pledge [39]: Over 100 countries have agreed to pursue cutting methane emissions by 30 % by 2030. This target seems smart, as methane has a processing time in the atmosphere of only ten years, and the fact that methane as a greenhouse gas in relation to CO_2 is extraordinarily strong [33]. Therefore, by reducing methane emissions quickly, the increase of earth surface temperature in the near future can hopefully be slowed down.
- Securing global net-zero by mid-century and keeping 1,5-degrees temperature change within reach [40]: This target is naturally great, as it gives countries within the agreement a reference to aim for, but still has a quite abstract formulation. It does not set a specific target for reaching a maximum temperature increase of 1,5 degrees since preindustrial levels.

- Mobilise finance [40]: Developed countries, representable for OECD-countries, must fulfil their promise of raising 100 billion dollars in climate finance for developing countries per year. Adhering to this target is essential for helping not-developed countries in economic growth, while simultaneously keeping the growth green by using renewables as an energy source.

Overall, the agreements and initiatives of the COP26 are positive and could potentially affect the climate in a positive way. Though, in some points, the targets (as point two in above-stated points) seem a bit superficial.

8.4. The UN's Sustainable Development Goals

Projections and assumptions within stated scenarios can either be catalysed by or help some of the UN's targets of sustainable development [41]. SDG no. 7 could potentially act as a catalyst for scenario no. 1 regarding electricity generation, as a subgoal of the target suggests increasing the amount of renewable energy use, globally [42]. The initiatives of scenario no. 1 could among others help achieve SDG no. 9 and 13, regarding respectively industry and innovation, and climate action. Speaking of the second scenario presented in this paper, this could help achieve SDG no. 12, which targets to contribute to a cognitive paradigm shift within the private sector's consumption patterns and overall use of energy. Another mentionable SDG is SDG no. 17 - "partnership for the goals" - this target emphasizes the importance of cooperation to achieve other SDG's. This goal is almost directly corresponsive to an overall target of the COP26, namely "work together to deliver" [40].

9. Conclusion

Initially, the problem of this project was defined. The overall problem targeted to examine to the possibility of reaching the temperature increase targets of the Paris Agreement. Afterwards, the method of forecasting realistic future values in the energy sector in different scenarios on basis of a projection model and then seeing their contribution temperature-wise was defined. Theoretical considerations allowed a certain comprehension of the problem stated. After having accounted for black body radiation, greenhouse gases, absorption of photons in the atmosphere, and more, it was made clear that our society's greenhouse gas emitting resource use is the sinner of the problem.

Different scenarios were lined up. A "frozen policy"-scenario, respectively with and without assumptions for future efficiencies of thermal plants and fuels in transport, was made. The temperature projections of the scenario showed that continuing current tendencies will lead to higher future temperatures than recommended. This "frozen policy"-scenario constituted a reference scenario for the following scenarios.

A scenario only investigating the effect of converting our resource use for electricity generation, by using more renewable energy sources (as hydro, wind, and solar energy), was initially made. The results showed that a green transition of only the electricity generation only in the best-case could comply with the 2,0-degrees target of the Paris Agreement. A transition of only the electricity generation won't reach the 1,5-degrees target!

Another scenario regarding efforts from the individuals was also established. The possibilities for individuals to reduce greenhouse gas emission, with a focus on changes in food habits and personal transport, were investigated. On basis of the results, it can be stated that individuals alone cannot cause the 1,5-degrees target to be reached. Nevertheless, results show that individual efforts alone can accomplish compliance with the 2,0-degrees target.

Lastly, the two scenarios, respectively focusing on institutional and individual effort, were combined. From the results of this scenario, it can be said that with an effort from both institutions and individuals, compliance with the 2,0-degrees target seems realistic. Though, the best-case projection with forestation within this scenario shows a maximum temperature increase since preindustrial levels of 1,7 degrees Celsius. This gives reason for stating that the scenarios presented in this paper do not have the opportunity to comply with the recommended 1,5-degrees target of the Paris Agreement!

Nevertheless, the scenario comes close to reaching the 1,5-degrees target, and when taking into consideration factors, not included in the scenarios, hope for reaching the 1,5-degrees target arises. Compliance with the target can though only be reached if action is taken rapidly and if international cooperation on a large scale, involving both OECD and non-OECD-countries, takes place.

Whether the changes presented in the scenarios are realistic was concluded hard to state, as economic and social scientific factors were necessary to give an accurate answer to this. Though, the changes presented in this paper is used, as they assumingly give an acceptable insight into the possibilities that lie within the institutional and the individual sector.

In conclusion, it can be said that complying with the 2,0-degrees target of the Paris Agreement seems possible, but that the recommended 1,5-degrees target will be harder to reach. For reaching this target rapid action, technological improvements, and international cooperation, regarding both OECD and non-OECD-countries, are essential.

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Appendices

A. The group process

For this semester's project, we had to make our groups in mutual agreement in the class. To help us with that, we were given tools, as the Belbin profiling test. The test can show how you as an individual will work in a group and what kind of roles you will play in a group composition. The Belbin profiling test describes 9 different roles that should be present in a group to work in the best possible way. Notice that you don't need 9 participants. One person can have more than one role in a group. In order to know your Belbin profile and your main roles in a project group, you had to fill out a test. It should tell how you prefer to work in a project group. However, this test will only look at how you see yourself. Therefore, your test response is coloured of how you may think you would like to act in a group situation, and not how you necessarily act when doing group work.

We did our best to distribute everyone in groups according to what the Belbin profile told us without really knowing each other and our way of doing group work. This may cause a wrong composition of Belbin roles in a group.

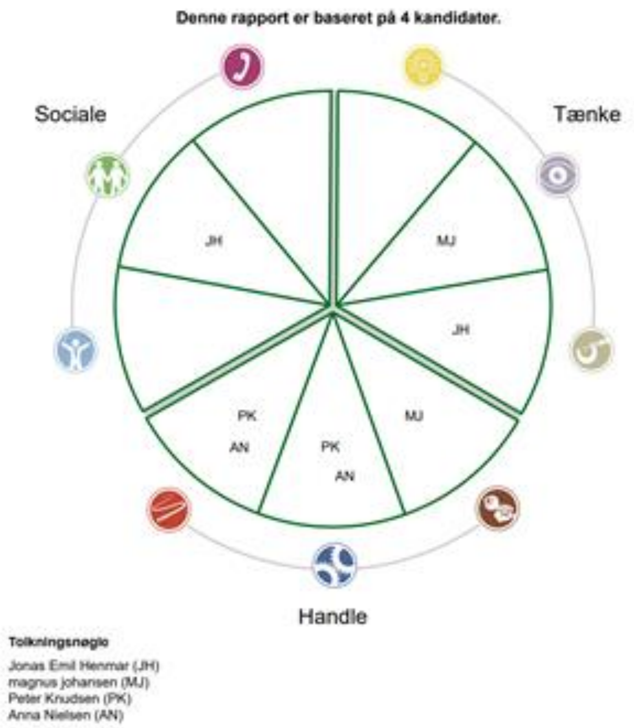


Figure A1: Belbin profile of our team

In our group, we began being 6 individuals. Unfortunately, 2 members of the group dropped out shortly after starting the group work. We, therefore, had problems covering all 9 roles in the group, to get the best group work done. Especially, the social side was missing out according to our group profile. This could give us a problem when taking consideration to each other, and we could have a hard time making the right team spirit. Only one person had a social role, the meditator. Sadly, this person had personal issues and had a hard time participating in the project. Nevertheless, we managed and made the teamwork work in the best possible way by being extra attentive to this challenge. The remaining group members are mostly people of action, and this came as an advantage.

Working with the project, we have used the 6-stage model to build up the process with the project and to create a clear line throughout the whole project. The following part will describe our work with the model.

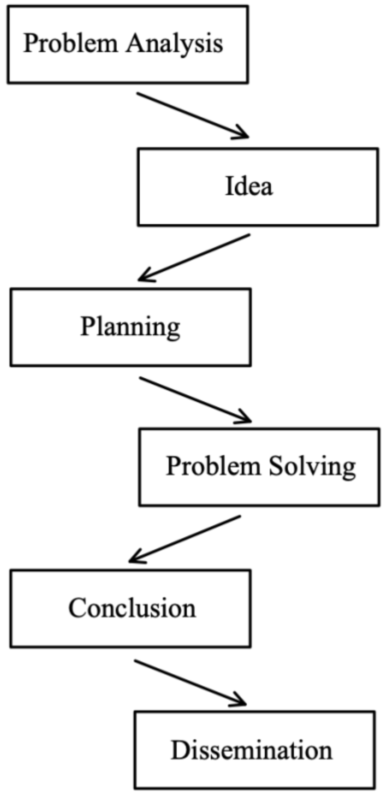


Figure A2: The 6 stages of the 6-stage model

Stage 1: Problem analysis

In this stage, the point was to set the main goals for our project. We were already given a description of the project, but we were to figure out what we wanted to achieve by fulfilling the project. To get the best conditions to have a well-functional group we had to find some common ground. Common values and goals. We started brainstorming what we wanted to achieve with this project and what every single member of the group had of expectations to one another and to the project itself. It was very clear from the beginning that we agreed on making a project that we would be proud of to put our name on. A project we could vouch for. We agreed on being disciplined and being ahead of the schedule within the project. At this stage we also made a group contract, describing our expectations to the project and the group members. It was made in agreement with all the group members. In the contract, we described when and where we would meet to make the project and how the meetings should run. We also made a verbal agreement with our counselor about group counseling and what to expect.

Stage 2: Idea stage

At this stage we had to figure out a direction and what kind of scenarios we wanted to work on. Furthermore, vi had to specify which methods we wanted to work with. We started brainstorming the project itself. We used tools as individual and common brainstorm to come up with different ideas regarding the scenarios we wanted to work with. Many great ideas came up, but at last, we narrowed it down to a few ideas that we felt positive about proceeding with.

Stage 3: Planning

In the third stage, we identified and described the workload that needed solving. We made a Gannt diagram to describe our time schedule. It was important for us to have specified every step of the process. In order to do that, we got some partial goals established and tried to measure how much time we would use for every subgoal. One of the more important things for us was to be well in advance with the project. Therefore, we have had group meetings every week to work on the project from the beginning of the project. Also, home assignments were given to everyone to finish off for the next group meeting. Our last subgoal was to be done with the dissemination of the report by the 1st of December to have time finishing the report and make the last changes. We also agreed that it was a good idea to make this subgoal, in case we were too optimistic with the time schedule or delays would occur, so we wouldn't sit with the project at the last moment. That could very easily happen because of our inexperience running this kind of group project. However, we have accomplished keeping the schedule more or less. Some of the subgoals took longer than we excepted. Another factor was that two members of the group choose to drop out. Furthermore, the matters occurred for some of the group members to delay their home assignments and participation in the project.

Stage 4: Problem solving

Throughout this stage, we solved all the subgoals described in our time schedule. From collecting data and processing it, to make calculations and forecasts based on the method chosen. We made sure to document all the data and sources we found in this stage. We also described why we choose to use one method instead of another. This would make the writing process easier later on, and make sure that a reader would not sit back with unsolved questions.

Stage 5 and 6: Conclusion and dissemination

One of the main ideas of this stage was to make sure we kept our target as described in the idea- and planning stage. We also made sure that our project meets the demands of the semester project. At this point of the process, we narrowed in the project even more. We made sure that we had kept the red line throughout the work and sorted out the things that weren't relevant or that we didn't have time to dive further into. We had a hard time not diving into small details because of our excitement with the project itself. So, to hold the time schedule, we had to those out the things we wanted to focus on in the writing process.

B. 1st semester's courses and their contribution to this project

This paper constitutes the product of an engineering project made by four 1st semester students at SDU's "civil engineering in energy technology"-programme. In the first semester, four different courses have been attended: Mathematics and Physics, Energy Systems, Science Theory, and Data Engineering and Programming. Each of these courses contributed in their own way.

Overall, the course "Energy Systems" is the biggest contributor to this project. In this course, the fundamental knowledge regarding energy systems, climate change, and climate models was attained, making the creation of scenarios, and the development and understanding of the projection model possible. This course showed the historic development of energy consumption, fossil fuel use, and GHG-emissions in the energy and climate sector, and the difficulties within the transition of the entire sector towards being more environmental-friendly. Another thing that the course has contributed to is the fact that understanding the historic development and tendencies within the societies of the world is essential to try forecasting the future. Furthermore, the course explained in general how different factors in energy systems works, cooperate, and affect each other. All these factors were essential for the making of this project.

"Mathematics and Physics" proved itself particularly important in understanding and using a different variety of models and relationships accounted for in this paper. Generally, physics was used mostly in understanding and explaining the black body radiation, the carbon cycle, and the energy balance of the earth and the atmosphere. The projection model could not have been established without using basic mathematics, and physic measures as for example emission factors of different fuels. Furthermore, mathematics contributed to the understanding of the "Very Simple Climate Model", especially the formula for future temperature $T = T_n + S \cdot \log_2(C/C_n)$. In this formula, the effect of variations within the not precise climate sensitivity, S, could be explained mathematically. Looking at the formula, one notices that a small value of S proposes minor changes in future temperatures and that a relatively high value of S proposes the oppositive, greater changes in future temperature.

The sub-course within "Energy Systems", "Science Theory" has also contributed in different ways to this project. First the course, in general, talked about correct scientific behaviour, including important learning of literature research and reference management. Especially, the fundamentals of finding proper and credible research were useful in this project. Furthermore, the explanation of the importance of clarifying the methods used in a project showed itself to be useful and helpful in the making of the methodology section (section 2) of this paper.

Lastly, the course “Data Engineering and Programming” should be mentioned, though its contribution to this project has been small compared to the other courses. The programming part of the course was not used in the process of this project, but the learning about data management and data handling showed itself useful in the process of finding historic energy data and managing them.

C. Visualization of projection model in Excel

The “key figures” sheet:

	1995
Total final consumption	-125627
Share of consumption	
- Industry	28%
- Transport	35%
- Residential	22%
- Commercial and public services	13%
- Agriculture / forestry	2%
- Fishing	0%
- Non-specified	1%
Share of energyforms ***Industry***	
- Coal	14%
- Crude Oil	0%
- Oil products	19%
- Natual Gas	29%
- Geothermal, Solar, Wind, etc.	0%
- Biofuels and Waste	5%
- Electricity	30%
- Heat	2%
Transport losses	
- Electricity	8%
- Heat	10%
Industry one use	
Industry one use (% of total consumption)	10%
Distribution between energiforms	
- Electricity	21%
- Heat	1%
- Coal	6%
- Natual gas	28%
- Crude oil	0%
- Oil products	44%
- Biofuels and waste	0%
Distribution of production between technologies ***Heat***	
- CHP plants	68%
- Heat plants	32%
Electricity consumption on Heat plants	
- % of heat production on Heat plants	3%
Ratio between electricity and heat production on CHP plants ***(Electricity)***	
- Cm-value	1,74
Distribution of production between technologies ***Oil products***	
- Oil refineries	100%
Share of non-fuel RE for ***Electricity-only plants***	
- Hydro	17%
- Geothermal, Solar, Wind, etc.	4%
- Fuel based plants	79%
Share of non-fuel RE for ***CHP plants***	
- Geothermal, Solar, Wind, etc.	1%
- Fuel based plants	99%
Share of non-fuel RE for ***Heat plants***	
- Geothermal, Solar, Wind, etc.	2%
- Fuel based plants	98%
Efficiencies thermal plants	
- Electricity-only plants	35%
- CHP plants	47%
- Heat Plants	85%
- Oil refineries	100%

Figure C1: 1995 Key figures in OECD - part 1 [Frozen Policy, BAU]

Fuel distribution for Electricity-only plants	
- Coal	46%
- Crude Oil	1%
- Oil products	7%
- Natual Gas	10%
- Nuclear	34%
- Biofuels and Waste	1%
Fuel distribution for CHP plants	
- Coal	40%
- Crude Oil	0%
- Oil products	5%
- Natual Gas	35%
- Nuclear	3%
- Biofuels and Waste	17%
Fuel distribution for Heat plants	
- Coal	37%
- Crude Oil	0%
- Oil products	19%
- Natual Gas	34%
- Nuclear	0%
- Biofuels and Waste	11%
Fuel distribution for Oil refineries	
- Crude Oil	100%
- Biofuels and Waste	0%
	0%
Fluegas cleaning	
Coal fired power plants	
Oilfired power plants	
Natual gas fired power plants	
Biomass-fired power plants	
Efficiency of final consumption	
Fuels	
Fuels in Transport	
Electricity	
Other	

Figure C2: 1995 Key figures in OECD - part 2 [Frozen Policy, BAU]

The forecasting "energy balance" sheet:

Coal	Crude oil	Oil Products	Natual Gas	Nuclear	Hydro	Geothermal, solar, wind, et	Biofuels and waste	Electricity	Heat	Energy Services	Total consumption	OECD 2030
CC	CCO	COP	CNG	CNU	CHY	CGSW	CWB	CE	CH	CES	fbrbr	Structures
c	c	c	c	c	c	c	c	c	c	c		
											0	Entry fuels
-16248	-53463		-67970	-19257			-14373				-171311	Transport of fuels
											0	Entry On-Grid RE
-13693	-53462	-2970	-32087	-19257	-5122	-9820	-5016	-3296	-402	0	-145126	Entry electricity, district heating and oil products
-11606	0	-566	-20443	-19257	-5122	-9543	-2356				-68894	Electricity-only plants
-1410	0	-161	-5098	0		-138	-2272				-9079	CHP plants
-105	0	-12	-308	0		-139	-348	-13			-923	Heat Plants
	-53454						0				-5[illegible]454	Oil refineries
-571	-8	-2232	-6238				-41	-3283	-402		-127[illegible]	Energy Industry one use
		-49555						-35762	-3096		-88412	Transport electricity, district heating and oil products
											0	En[illegible] Off-Grid RE
-2556	-1	-49555	-35883	0	0	-658	-9356	-34349	-2820	0	-143311	Exit en[illegible]y
-2202	-1	-3321	-13675			-21	-4154	-10250	-1141		-34765	Industry
-1		-41696	-1821			0	-2703	-423	0		-46643	Transport
-353	0	-4538	-20388	0	0	-636	-2499	-23676	-1679	0	-53770	Other
-318		-1632	-12366			-516	-1965	-10578	-961		-28337	Residential
0		-706	-7800			-75	-307	-10355	-705		-1[illegible]49	Commercial and public services
-35		-2111	-221			-42	-225	-694	-10		-3338	Agriculture / forestry
0		-88	0			-3	-1	-16	-3		-111	Fishing
0		0	0			0	0	-2034	0		-2034	Non-specified
											-143311	Energy Services

Figure C3: Energy forecasting balance OECD - input side [Frozen Policy, BAU, efficiency]

OECD 2030			Faktor	Total production	Efficiency	Production	Coal	Crude oil	Oil Products	Natual Gas	Nuclear	Hydro	Geothermal, solar, wind, e	Biofuels and waste	Electricity	Heat	Energy Services	Loss	CO2-emissions
Structures	ID	ID Parent	factor	pbrpr	pvrkg	P	PC	PCO	POP	PNG	PNU	PHY	PGSW	PWB	PE	PH	PES	PTAB	PCO2
							P	P	P	P	P	P	P	P	P	P	P		
						0												0	0
Entry fuels	ETP			171311			16248	53463		67970	19257			14373					
Transport of fuels	TRAP			171311			16248	53463		67970	19257			14373				0	
Entry On-Grid RE	ELP1			14941								5122	9820						
Entry electricity, district heating and oil products	ES			95082			0		52525						39058	3498		50044	3356
Electricity-only plants	ESEP	ES		35070	0,38										35070			33823	2311
CHP plants	ESCHP	ES		6598	0,72										3988	2610		2481	437
Heat Plants	ESHP	ES		888	0,97											888		36	28
Oil refineries	ESOR	ES		52525	0,98				52525									929	0
Energy Industry one use	ESNSP	ES		0	0,00													12775	579
Transport electricity, district heating and oil products	TRAS			86724					49555						34349	2820		1688	
Entry Off-Grid RE	ELP2			658									658						
Exit energy	EX			91984													91984	43194	6054
Industry	EXI	EX		29582	0,85												29582	5183	1241
Transport	EXT	EX		16579	0,36												16579	30064	3273
Other	EXO	EX		45823	0,80		0	0	0	0	0	0	0	0	0	0	45823	7946	1541
Residential	EXOR	EXO		24552	0,87												24552	3785	859
Commercial and public services	EXOC	EXO		17669	0,89												17669	2281	498
Agriculture / forestry	EXOA	EXO		1618	0,48												1618	1720	176
Fishing	EXOF	EXO		52	0,47												52	59	7
Non-specified	EXON	EXO		1932	0,95												1932	102	0
Energy Services	EN			91984	0,64												91984	51327	

Figure C4: Energy forecasting balance OECD - output side [Frozen Policy, BAU, efficiency]

	mio. ton/PJ
Coal	0,095
Crude Oil	0
Oil products	0,076
Natual Gas	0,057
Nuclear	0
Hydro	0
Geothermal, Solar, Wind, etc.	0
Biofuels and Waste	0
Electricity	0
Heat	0
Energy Services	0
Biofuels and Waste with cleaning	0,1

Figure C5: Emissions factor for different fuels [Frozen Policy, BAU, efficiency]

The “future temperature” calculation-sheet:

Temperature Change					
Year	2018	2030	2050	2075	2100
		OECD Countries			
CO_2 emissions (mio. Ton)	11.612	9.410	7.599	4.383	1.338
Share of CO_2 emissions from Transport & Energy	74%	74%	74%	74%	74%
Total CO_2e emissions (mio. ton)	15.692	12.716	10.268	5.924	1.808
		Non-OECD Countries			
CO_2 emissions (mio. Ton)	20.040	22.850	24.383	22.582	12.257
Share of CO_2 emissions from Transport & Energy	74%	74%	74%	74%	74%
Total CO_2e emissions (mio. ton)	27.081	30.878	32.950	30.516	16.564

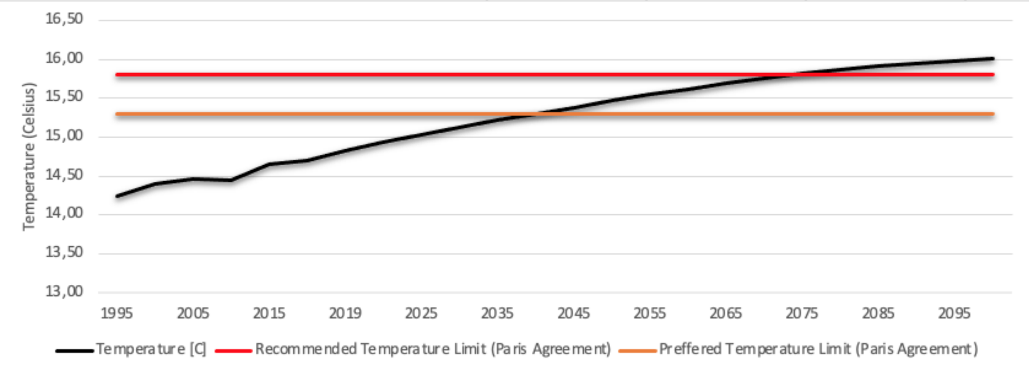


Figure C6: Temperature forecasting in [Frozen Policy, BAU, efficiency]

D. Projected area of installed solar PV in scenario no. 1

	OECD		Non-OECD	
	Medium case	**Best case**	**Medium case**	**Best case**
Solar PV area reference (2018) (km^2)	3701	3701	2974	2974
Solar PV area 2030 (km^2)	10370	12664	26963	24628
Solar PV area 2050 (km^2)	21484	38410	88536	108078
Installed since 2018 in 2030 (km^2)	6669	8963	23989	21654
Installed since 2018 in 2050 (km^2)	17783	34708	85563	105105

To translate the numbers in the table into comprehensive data, the median case in OECD plants around 2 times the size of Funen by 2030 and 60% the size of the Danish part of Jutland by 2050 of solar PV. In the best-case scenario, it corresponds to installing the size of Zealand and Lolland-Falster by 2030 and the size of Denmark without Zealand by 2050. In non-OECD countries, the numbers in the median case scenario correspond to installing 80% of the size of Jutland by 2030 and 2 times the size of Denmark in 2050. In the best case, it is needed to install 73% the size of Jutland in 2030 and 3 times the size of Denmark without Zealand by 2050. Even though these sizes might sound big it is important to note that in praxis the total area is spread among all the countries in the world and different countries hold different potentials of implementing solar PV plants. For example, Yemen is among the countries with the highest average solar energy potential in terms of global horizontal irradiance [43], a proxy of the strength and concentration of solar energy hitting a PV panel , which means that they do not necessarily need to implement the same number of panels to produce the same amount of energy as Greenland might. Furthermore, future development in solar PV technology might occur which will increase the efficiency.

E. Projected numbers of installed windmills in scenario no. 1

	OECD		Non-OECD	
	Medium case	**Best case**	**Medium case**	**Best case**
Number of windmills reference (2018)	2607912	260792	180085	180085
Number of windmills 2030	722673	614255	776410	709168
Number of windmills 2050	1492475	1404675	1982807	2420457
Installed since 2018 in 2030	461881	353464	596326	529083
Installed since 2018 in 2050	1231683	1143883	1802722	2240372

F. "Frozen policy"-scenario: GHG-emissions towards 2100

The projection without efficiency projections within the "frozen policy"-scenario ([Frozen Policy, BAU]) is used as an example. To project the CO_2-emissions in OECD-countries, data from since the CO_2-emissions in OECD-countries topped (2005) towards projected emission values for 2030 and 2050, are examined (table F1).

Year	2005	2010	2015	2018	2030	2050
Years after 1995	10	15	20	23	35	55
CO_2-emissions in (million tonnes CO_2)	12.873	12.375	11.656	11.612	10.048	9.176

Table F1: CO_2-emissions in OECD-countries in "frozen policy"-scenario (projection without efficiency assumptions)

Examining these values gives reason to forecast future GHG-emissions in 2075 and 2100 linearly on basis of the values in table F1 (see figure F1).

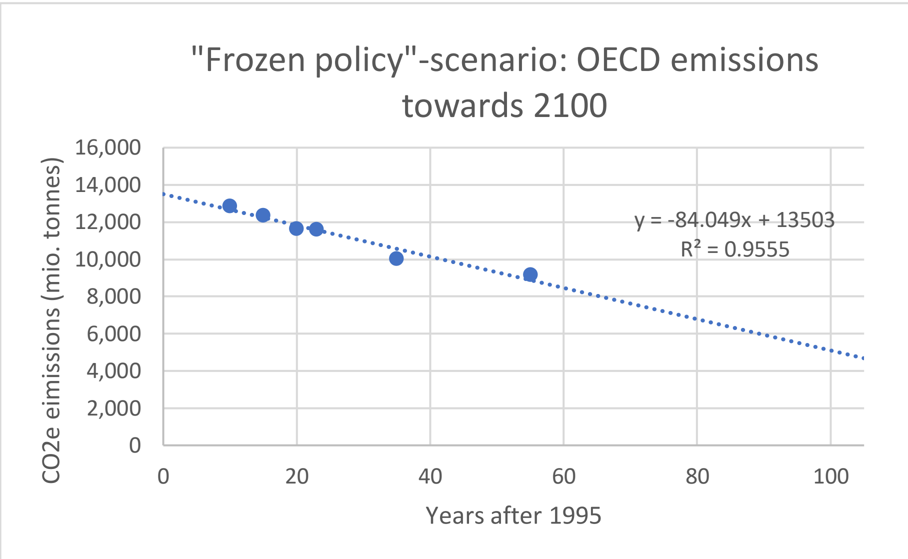


Figure F1: Projected CO_2-emissions in OECD-countries in "frozen policy"-scenario (projection without efficiency assumptions)

Using the function of the linear regression gives following values of CO_2-emissions in 2075 and 2100:

$$CO_2(2075) = 6779\ mio.tonnes \qquad CO_2(2100) = 4678\ mio.tonnes$$

In the "frozen policy"-scenario it's assumed that the "share of CO_2 emissions from Transport & Energy" remains at a constant rate of 74 %. Therefore, the total GHG-emissions in CO_2e in OECD-countries in 2075 will be 9161 million tonnes and in 2100 the value will be 6321 million tonnes (see

[Frozen Policy, BAU]). To project the same values for non-OECD-countries, data from 1995 towards the projected values in 2030 and 2050 regarding CO_2-emissions, are examined (table F2).

Year	1995	200	2005	2010	2015	2018	2030	2050
Years after 1995	0	5	10	15	20	23	35	55
CO_2-emissions in (million tonnes CO_2)	9.021	9.749	13.120	16.749	19.014	20.040	24.008	29.742

Table F2: CO_2-emissions in non-OECD-countries in "frozen policy"-scenario

Examining these values gives reason to forecast future GHG-emissions in 2075 and 2100 on basis of a polynomial regression performed on the values in table F2 (see figure F2).

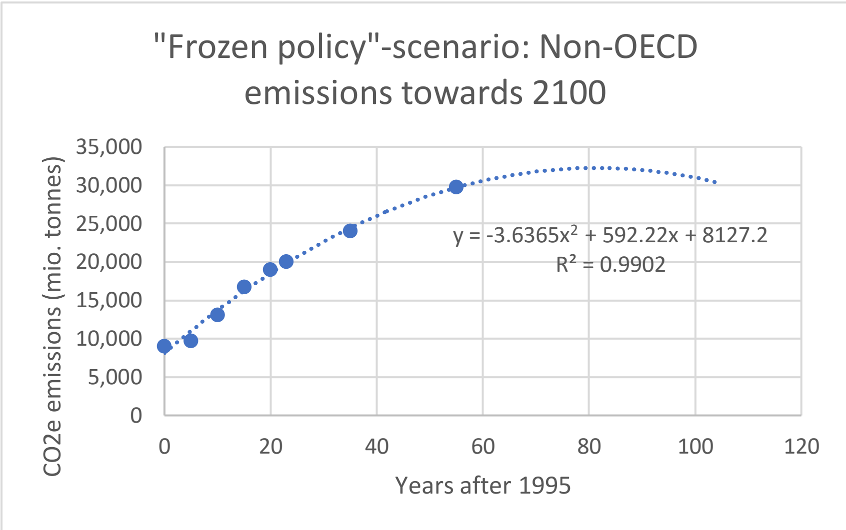


Figure F2: Projected CO_2-emissions in non-OECD-countries in "frozen policy"-scenario (projection without efficiency assumptions)

Using the function of the polyonymic regression gives following values of CO_2-emissions in 2075 and 2100 in non-OECD-countries:

$$CO_2(2075) = 32231\, mio.tonnes$$

$$CO_2(2100) = 30218\, mio.tonnes$$

In the "frozen policy"-scenario it's assumed that the "share of CO_2 emissions from Transport & Energy" remains at a constant rate of 74 %. Therefore, the total GHG-emissions in CO_2e in non-OECD-countries in 2075 will be 43.556 million tonnes and in 2100 the values will be 40.835 million tonnes.

G. Forecasting the individuals' effect on the transport sector energy consumption (scenario no. 2)

Taking a starting point in the BAU-projection (for example [Frozen Policy, BAU]) for OECD-countries in 2030 and 2050, the total final energy consumption $E_{transport,OECD,BAU}$ in the transport sector is forecasted to be:

$$E_{transport,OECD,BAU}(2030) = 143311\ PJ \cdot 37{,}91\ \% = 54329\ PJ$$

$$E_{transport,OECD,BAU}(2050) = 160{,}387\ PJ \cdot 38{,}80\ \% = 62230\ PJ$$

In 2018 in IEA-countries, assumed to be representable for OECD-countries, 59 % of the final energy consumption in the transport sector is credited to passenger cars [44]. Assuming that this percentage value is applicable for OECD-countries in 2030 and 2050 in the BAU-projection, the "frozen policy"-scenario projects the total final energy consumption for passenger cars $E_{PC,OECD,BAU}$ in respectively 2030 and 2050 to be:

$$E_{PC,OECD,BAU}(2030) = 54329{,}2\ PJ \cdot 59\ \% = 32054\ PJ$$

$$E_{PC,OECD,BAU}(2050) = 62239 \cdot 59\ \% = 36715\ PJ$$

These numbers are calculated without taking any form of "game changers" into consideration. OECD-people, in general, could realistically, due to a change of mindset, begin increasing their use of public transport in favour of their car. Furthermore, the pandemic of COVID-19 has helped people to understand the functionality and efficiency of online meetings and working from home [27][28], wherefore people in general, could be working more often at home, lowering their transport energy use. In the median projection, these actions are assumed to have the potential to decrease the total energy consumption of passenger cars by 5 % and 10 % in respectively 2030 and 2050. In the best-case-projection within scenario 2, the values are projected to be 10 % and 20 %.

The share of energy consumption of passenger vehicles in relation to total transport energy consumption in the non-OECD, is not given as easy as for OECD-countries. It can though be said that non-OECD-countries are expected to have economic growth like the OECD-countries have already gone through. Therefore, it is realistic to assume that in 2050 in the BAU-projection, approximately 59 % of transport energy use in non-OECD will come from passenger vehicles. As a result of that, the percentage value for 2030 in the BAU-projection could be 50 %. Using the same method as for OECD-countries, $E_{PC,Non-OECD,BAU}(2030) = 35366\ PJ$ and $E_{PC,Non-OECD,BAU}(2050) = 66738\ PJ$ is calculated. The same assumption for respectively median- and best-case-projection for OECD-countries regarding the decrease of passenger cars energy consumption is used, and the following tables can be made:

Median	$E_{PC,BAU}\ (PJ)$	$E_{PC,projected}\ (PJ)$	$E_{PC,saved}\ (PJ)$
OECD 2030	32.054	30451,3	1.603
OECD 2050	36.715	33043,5	3.672
Non-OECD 2030	35.366	33597,7	1.768
Non-OECD 2050	67.736	60962,4	6.774

Table G1: Reduction of transport energy use in median-projection

Best-case	$E_{PC,BAU}\ (PJ)$	$E_{PC,projected}\ (PJ)$	$E_{PC,saved}\ (PJ)$
OECD 2030	32.054	28848,6	3.205
OECD 2050	36.715	29372	7.343
Non-OECD 2030	35.366	31829,4	3.537
Non-OECD 2050	67.736	54188,8	13.547

Table G2: Reduction of transport energy use in best-case-projection

This future reduction is then applied the transport sector in corresponding excel files within the "Projections - scenario no. 2"-folder.

H. Forecasting the share of electricity in the transport sector (scenario no. 2)

To calculate percentage values of electricity in the transport sector for respectively OECD-countries and non-OECD-countries, its necessary to take the calculations in Appendix G into consideration. On basis of the reduction of the transport sector, and the reduction of the passenger vehicle-sector within, and the BAU-assumed amount of energy use in the transport sector from passenger cars, the fixed amount of energy use in the transport sector from passenger cars in the median and best-case-scenario can be calculated (see table H1)

Year	Amount of energy use in transport sector from passenger cars - OECD (median)	Amount of energy use in transport sector from passenger cars - OECD (best-case)	Amount of energy use in transport sector from passenger cars - non-OECD (median)	Amount of energy use in transport sector from passenger cars - non-OECD (best-case)
2030	58 %	56 %	49 %	47 %
2050	56 %	47 %	56 %	54 %

Table H1: Projection of the share of energy use in the transport sector coming from passenger cars.

In EAI's "International Energy Outlook 2021" [19], their data for expected growth in the share of electric vehicles in OECD- and non-OECD-countries are used via [Share of EV passenger cars - EIA-projection] to find the data in table H2. This data is used for calculation in the median projection presented in this paper.

Year	Share of passenger vehicles being electric in OECD-countries	Share of passenger vehicles being electric in non-OECD-countries
2030	7,49 %	6,06 %
2050	34,38 %	28,36 %

Table H2: Projection of electric vehicle share of passenger vehicles in 2030 and 2050 - median-projection

In the best-case projection within scenario 2, more optimistic assumptions (table H3) are made:

Year	Share of passenger vehicles being electric in OECD-countries	Share of passenger vehicles being electric in non-OECD-countries
2030	10 %	8 %
2050	40 %	35 %

Table H3: Projection of electric vehicle share of passenger vehicles in 2030 and 2050 - best-case-projection

Tables H2 and H3 can be used with the projections from table H1 to calculate the projected share of electricity in the transport sector for respectively OECD- and non-OECD-countries, projections that can be seen in table H4.

Projection	Share of electricity in the transport sector - OECD-countries	Share of electricity in the transport sector - non-OECD-countries
Median (2030)	4,3 %	3,0 %
Median (2050)	19 %	16 %
Best-case (2030)	5,8 %	3,8 %
Best-case (2050)	23,2 %	19 %

Table H4: Projected share of electricity in transport sector

I. Forecasting the effect of changing our food habits (scenario no. 2)

When attempting to project the effect of changing our food habits in relation to climate change, one method is examining the emission factor of the animal products that we consume the most. Emission factors from ourworldindata.org [2] for the biggest emitters in seen in table I1. To calculate the amount of CO_2e emitted per year coming from chosen animal products, the consumption of each animal product per capita per year needs to be found. This data is easily accessible regarding OECD-countries. For the reference year of 2018, the second column in table I2 show how much meat (in kg) the average OECD-person consumed in 2018 [4]. The beef category is evenly divided into respectively “beef herd” and “beef dairy”[2].

Name of animal product	Emission per kg. product (kg CO_2e)
Beef (beef herd)	60
Beef (dairy herd)	21
Pork	7
Poultry	6
Sheep	24
Cheese	21

Table I1: Emission factor of the animal products emitting most GHG [2]

The reason for the * in the cheese category is that an exact value for OECD-countries doesn’t exist along with the other shown values. Though, clal.it (“an Italian dairy economic consulting firm) have data [45] for cheese consumption for chosen countries that give reason to assume an average cheese consumption in OECD-countries and non-OECD-countries in 2018 to respectively 15 and 3 kg per capita.

Name of animal product	Average consumption per OECD capita in 2018 (kg)	Average consumption per non-OECD capita in 2018 (kg)
Beef (beef herd)	7,25	4,3
Beef (dairy herd)	7,25	4,3
Pork	23	9,1
Poultry	30,7	18,3
Sheep	1,3	3,0
Cheese	15 *	3 *

Table I2: Average meat consumption for OECD- and non-OECD countries in 2018 ([4][GHG from food and released land area])

The average consumption per non-OECD capita in 2018 is not as easy to access, as for the average OECD capita. Therefore, meat consumption data for 136 different non-OECD countries [29] is examined. The dataset is from consumption in 2017 but is assumed applicable for 2018 meat consumption in non-OECD-countries. The calculated values for average meat consumption per capita in non-OECD-countries can be seen in the third column of table I2 (the specific calculations can be found in the sheet “non-OECD” within [GHG from food and released land area]).

Given the average consumption per capita, the emission factor of each animal category, and the future population (see "population forecast within [Frozen Policy, BAU]), the GHG-emissions in CO_2e per year can be calculated. For our reference year 2018, it's in [GHG from food and released land area] calculated that the meat consumption in OECD-countries emits 1648 million tonnes CO_2e and the meat consumption in non-OECD-countries emits 4089 million tonnes CO_2e. One noticed that emissions from meat constitutes $\frac{\#GHG_{emissions(animal\,products\,2018)}}{\#GHG_{emissions\,(total\,2018)}} = \frac{1648\,CO_2e+4089\,CO_2e}{44588\,CO_2e} = 13\ \%$ of the total GHG-emissions in 2018. Therefore, when comparing with emissions factors of non-meat-food [2], a great opportunity for cutting emissions lies within cutting our meat consumption. These values from 2018 are used as reference when later calculating the amount of emitted CO_2e that we in future years, under assumptions in table I3, can "save". This table tells under which assumptions the "saved amount of CO_2e" is calculated in OECD- and non-OECD-countries in respectively the median projection and the best-case-projection.

Projection	Assumptions towards 2100 for OECD-countries	Assumptions towards 2100 for non-OECD-countries
Median	The average OECD capita will from 2022 reduce its meat consumption by 5 %, until the meat consumption is halved. Afterwards, the reduction rate will be 1 % towards 2100.	The average non-OECD capita will from 2022 reduces its meat consumption by 1 %, towards 2100.
Best-case	Every third year from 2022 the meat consumption will be reduced by what will be equivalent to a meet-free-day (14 %). When reaching only two "meat days", the reduction rate will be 1 % towards 2100.	Due to the later growth of non-OECD-countries the reduction as assumed for OECD-countries in the best-case-projection will begin taking place in 2040. When reaching only two "meat days", the meat consumption is held constant to meet same standards as OECD-countries towards 2100.

Table I3: Assumptions regarding reduction in meat consumption for OECD- and non-OECD-countries in median- and best-case-projection

On basis of these assumptions and the forecasted population of respectively OECD- and non-OECD countries, the projected emission from meat consumption every year towards 2100 is calculated (see [GHG from food and released land area]). All these values are compared to the reference values of 2018 (which is assumed representable for the future in the BAU-projection) to determine the amount of "saved CO_2e" that can be withdrawn from the total emissions in the excel files in the "Projections - scenario no. 2"-folder. The total "saving" each year will be withdrawn from the total CO_2e-emissions, not in the OECD and non-OECD category, as it's not known where in the world these savings will occur, as the reduction in meat consumption "saves" emission regarding transport, land use for the animals and their feed, packaging and so on [2]. To visualize where the “saved” amount of CO_2 is withdrawn in the excel sheets, see figure I1.

Intervals between year	**2018**	2019	2020	2025	**2030**	2035	2040
CO2e emissions (mio. Ton) (before meat-reduction)	**42.774**	43.100	43.426	44.241	**44731**	45168	45606
CO2e emissions (mio. Ton) (after meat-reduction)	42.774	43.100	43.426	44.040	44.120	44.191	44.546

	2045	**2050**	2055	2060	2065	2070	**2075**	2080	2085	2090	2095	**2100**
	46043	**46481**	45219	43957	42695	41433	**40171**	37204	34237	31270	28304	**25337**
	43.701	43.170	41.300	40.048	38.792	37.533	36.271	33.301	30.329	27.356	24.380	21.402

Figure I1: CO_2e-emissions in best-case projection (without efficiency projections) scenario no 2. (with and without meat reduction)

In figure I1, it’s seen that a new (orange) row has been calculated. The values for “saved” CO_2e from [GHG from food and released land area] are withdrawn from the blue row, and the orange row is calculated. The rest of the excel sheet, where the future temperature is calculated via the Very Simple Climate Model is modified so that it calculates on basis of the numbers in the orange row.

J. The effect of forestating abandoned area (scenario no. 3)

The purpose of this appendix is to calculate what amount of CO_2 that possibly can be extracted from the atmosphere when planting forests and what amount of forest that possibly can be planted towards 2100. In Appendix G, the reduction in meat consumption is examined. Using these numbers and the assumption that the relationship between meat reduction and abandoned area of livestock and the dairy area are proportional, it is possible to calculate what amount of area that's no longer needed for food production. This area can then be used for forestation purposes. When calculating this area, the world division in OECD and non-OECD is not used. Instead, the total meat consumption in the world in 2021 is used as a reference in calculating what percentage change the reduction in meat consumption will cause, in relation to the reference. The total meat consumption, from chosen animal products, in 2021 was $3{,}88 \cdot 10^{11}\ kg$ (see [GHG from food and released land area]), and this is assumed to be representable as a reference for the years towards 2100. Afterwards, each year's total meat consumption (from 2022-2100) and its reduction rate (in % in relation to the 2021 reference) are calculated, respectively for median projection and the best-case-projection (see [GHG from food and released land area]). The released area from livestock and dairy in each year is then calculated on basis of the meat reduction rate in that year and the total land area on earth used for livestock, meat, and dairy, which is 40 million km^2 [2]. The released land area per year is calculated too. An example for the year 2050 in the median projection is:

$$\#reduction\ rate_{2050} = 1 - \frac{\#consumption_{2050}}{\#consumption_{reference=2021}} = 1 - \frac{3{,}08 \cdot 10^{11}\ kg}{3{,}88 \cdot 10^{11}\ kg} = 20{,}6\ \%$$

$$\#total\ released\ area_{2050} = \#reduction\ rate_{2050} \cdot \#reference\ area_{2021} = 20{,}6\ \% \cdot 40 \cdot 10^6\ km^2 = 8{,}23 \cdot 10^6\ km^2$$

$$\#released\ area_{2050} = \#total\ released\ area_{2050} - \#released\ area_{2049} = 8{,}23 \cdot 10^6\ km^2 - 8{,}07 \cdot 10^6\ km^2 = 0{,}16 \cdot 10^6\ km^2$$

The land area that possibly can be forestated within the released area is assumed to be 50 %. This is due to general difficulties regarding the planting of forests and the fact that the area for other food products realistically will rise. Therefore, the land forestated from the released area in 2050 is:

$$\#forestated\ land_{2050} = 50\ \% \cdot \#released\ area_{2050} = 50\ \% \cdot 0{,}16 \cdot 10^6\ km^2 = 0{,}08 \cdot 10^6\ km^2$$

To be able to project what amount of CO_2 is captured by the planted forests, a research [30] saying that global forests through the years of 2001-2019 provided a carbon sink of 7.6 billion tonnes CO_2 per year, is taken into account. Knowing that forests in total constitute a land area of approximately 39 million km^2 [2], a "carbon sink factor" can be calculated:

$$CSF = \#carbon\ sink\ factor = \frac{7{,}6 \cdot 10^9 \frac{tonnes}{year}}{39 \cdot 10^6\ km^2} = 194{,}9 \frac{\frac{tonnes}{year}}{km^2}$$

Furthermore, a general assumption that the forest planted in year x, firstly begins capturing CO_2 in year $x + 10$ since trees must be given time to grow, is also applied the calculations in the excel sheet. Therefore, when calculating the CO_2 captured by forestated forests in 2050 in the median projection, the released land area of 2040 is used:

$$\#CO_2\ capture_{2050} = \#forestated\ land_{2040} \cdot CSF + \#CO_2\ capture_{2049}$$
$$= 0{,}059 \cdot 10^6\ km^2 \cdot 194{,}9 \frac{\frac{tonnes}{year}}{km^2} + 687{,}6 \cdot 10^6 \frac{tonnes}{year} = 698{,}7 \cdot 10^6 \frac{tonnes}{year}$$

This means that in 2050 in the median projection, the forest forestated in abandoned livestock and dairy are is forecasted to capture 698,7 million tonnes of CO_2. Calculation for each year in respectively median and best-case projection is found in [GHG from food and released land area]). On basis of these calculations, figure J1 and figure J2 are made. The same method for withdrawing the CO_2-absorption of forest as in Appendix I, figure I1 is used.

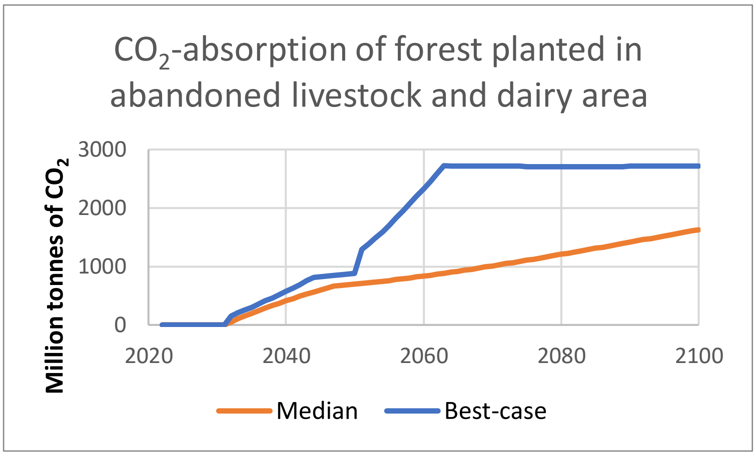


Figure J1: CO_2-absorption of forest planted in abandoned livestock and dairy area

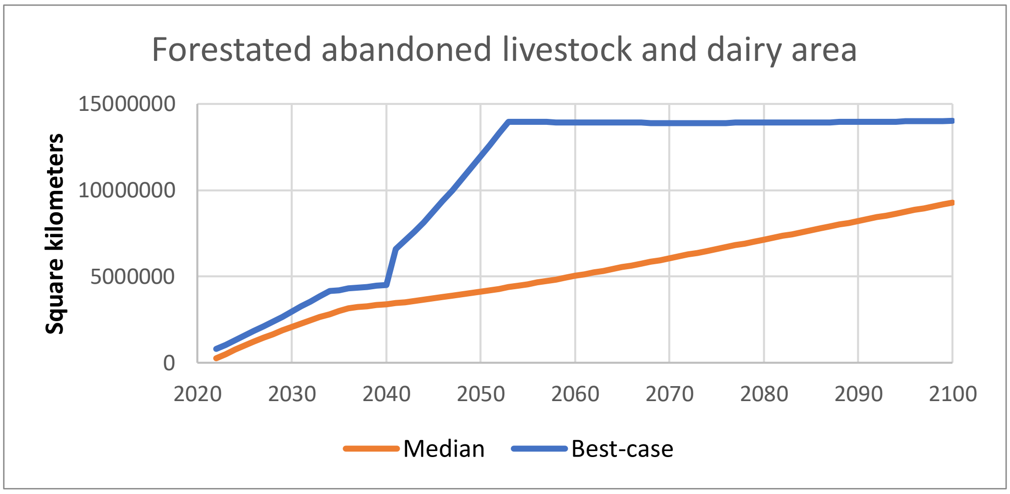


Figure J2: Forestated abandoned livestock and dairy area in square kilometers

K. Comparison of temperature projections within each projection type

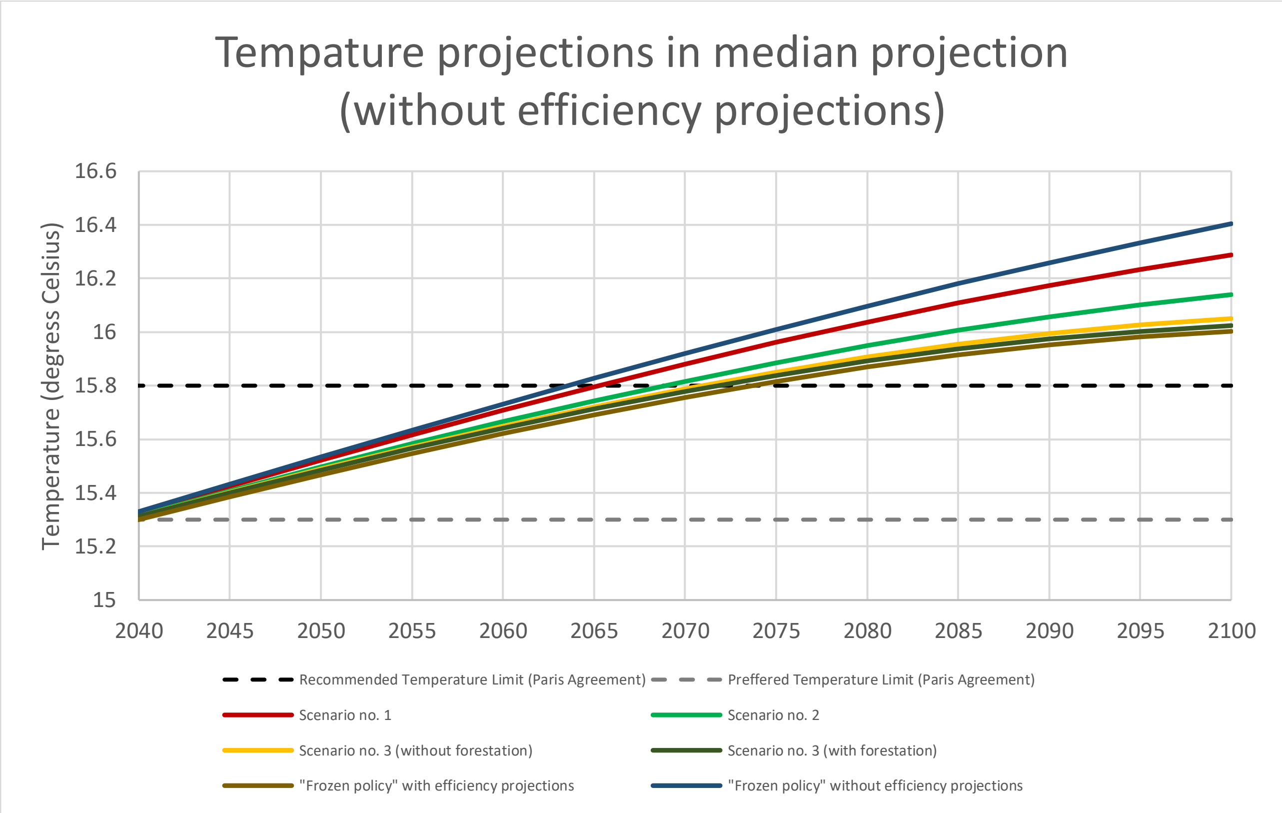


Figure K1: Comparisons of temperature projections in all median projections (without efficiency projections)

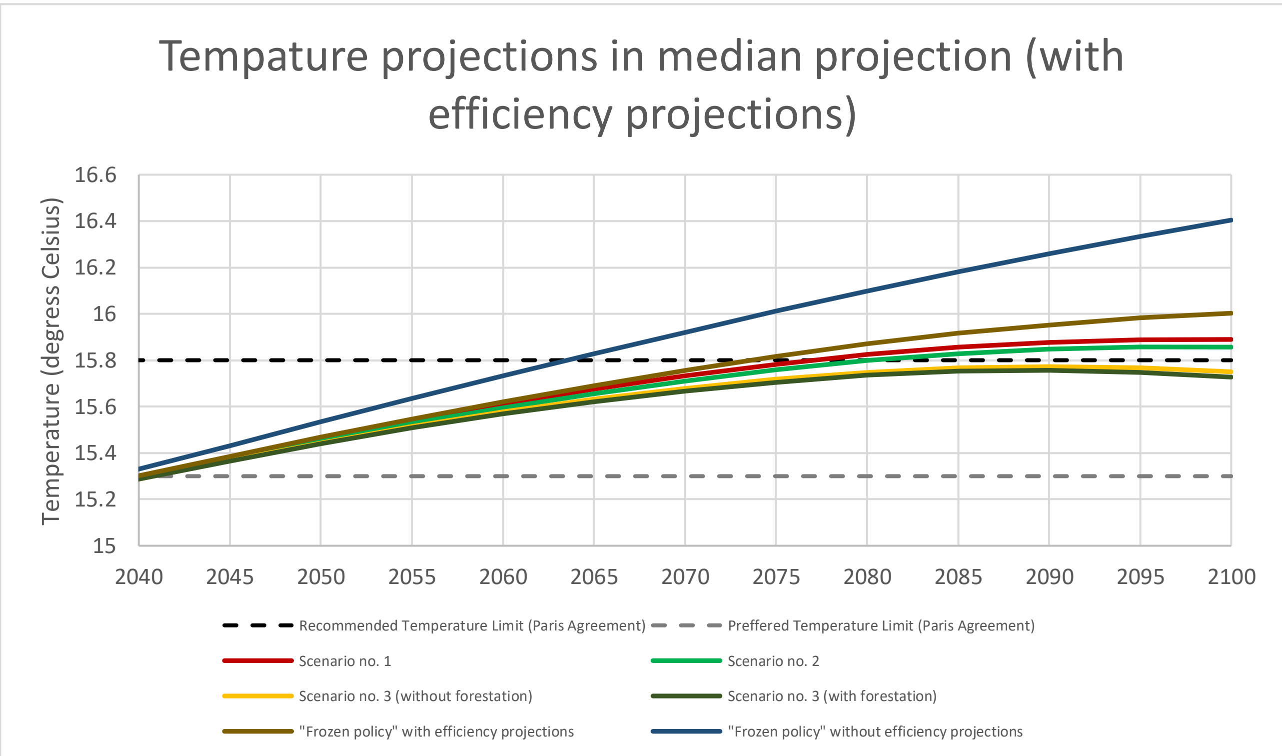


Figure K2: Comparisons of temperature projections in all median projections (with efficiency projections)

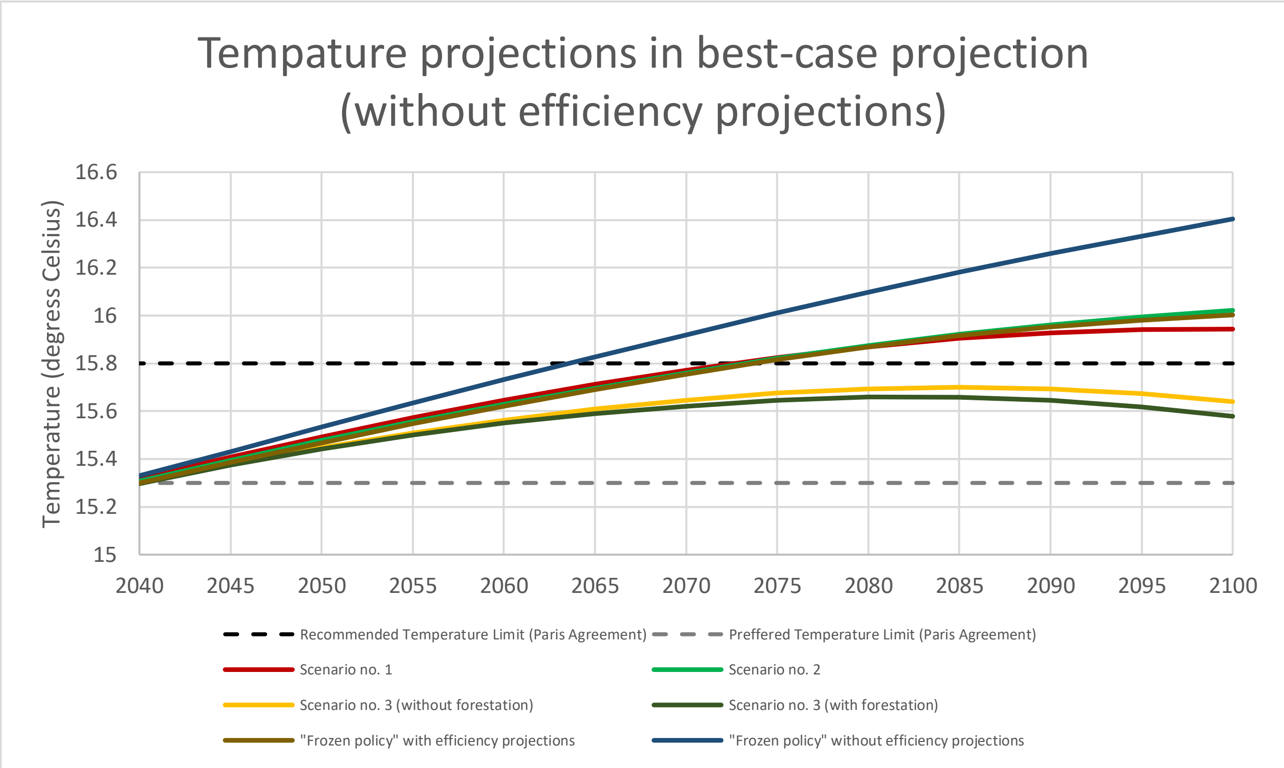


Figure K3: Comparisons of temperature projections in all median projections (without efficiency projections)

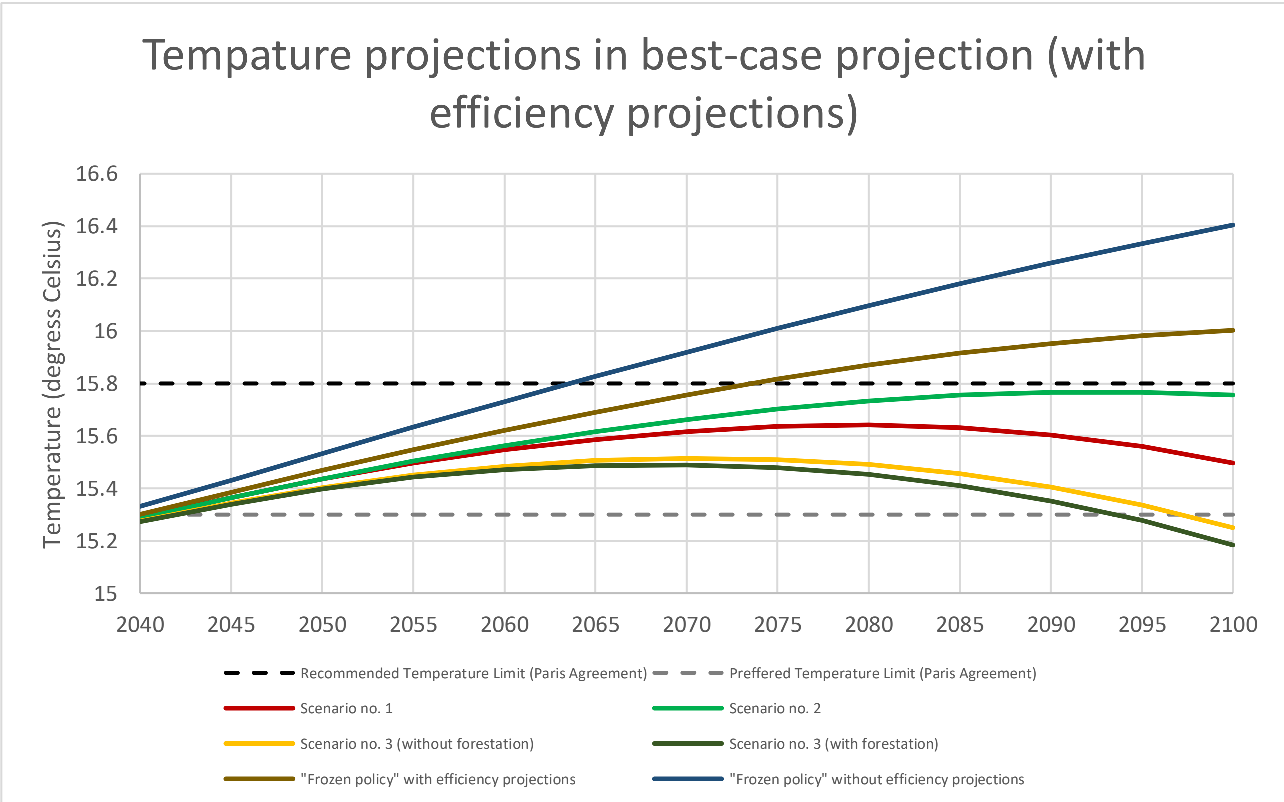
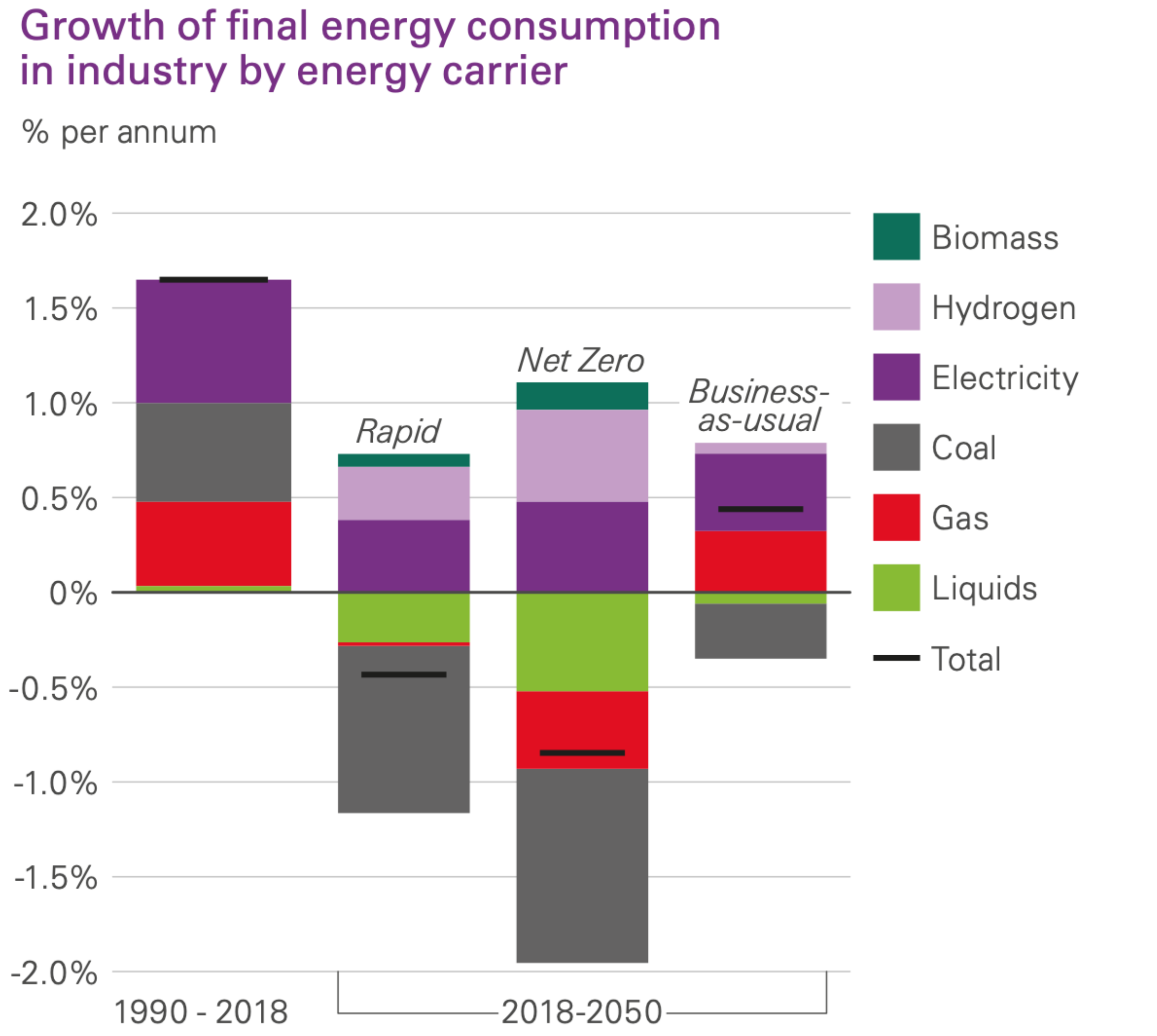


Figure K4: Comparisons of temperature projections in all best-case projections (with efficiency projections)

L. BP-forecast for growth in final energy consumption by sector in industry



From BP's "Energy Outlook 2020 Edition"[5]

M. Overview of attached excel-files

In the zip-file named “Appendix, excel files” attached to this paper, 22 excel-sheets appear. “Appendix, excel files” consists of five folders and four separate excel-files:

Electricity generation scenario 1.xlsx

Electricity generation scenario 3.xlsx

Frozen policy scenario

- Frozen Policy, BAU, efficiency.xlsx
- Frozen Policy, BAU.xlsx

GHG from food and released land area.xlsx

Projections - scenario no. 1

- S1, best, efficiency.xlsx
- S1, best.xlsx
- S1, median, efficiency.xlsx
- S1, median.xlsx

Projections - scenario no. 2

- S2, best, efficiency.xlsx
- S2, best.xlsx
- S2, median, efficiency.xlsx
- S2, median.xlsx

Projections - scenario no. 3

- S3, best, efficiency.xlsx
- S3, best.xlsx
- S3, median, efficiency.xlsx
- S3, median.xlsx

Projections - scenario no. 3 without forestation

- S3, best, efficiency-kopi.xlsx
- S3, best-kopi.xlsx
- S3, median, efficiency-kopi.xlsx
- S3, median-kopi.xlsx

Share of EV passenger cars - EAI-projection.xlsx