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Effects of New Fossil Fuel Developments on the Possibilities of Meeting 2°C Scenarios

- Final Report -

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Summary

Recent years have seen an increasing activity in developing new fossil fuel production capacity. This includes unconventional fossil fuels, such as tar sands and shale gas, fossil fuels from remote locations, and fossil fuels with a very large increase in production in the near future. In this report, the impact of such developments on our ability to mitigate climate change is investigated.

Our inventory shows that the new fossil fuel developments currently underway consist of 29,400 billion cubic meters of natural gas, 260,000 million barrels of oil and 49,600 million tonnes of coal. The development of these new fossil fuels would result in emissions of 300 billion tonnes of CO_2-equivalent (CO_2e) from 2012 until 2050.

Until 2050, a "carbon budget" of 1550 billion tonnes CO_2e is still available if we want to of keep global warming below 2 °C with a 50% probability. For a 75% probability to stay below 2 °C this budget is only 1050 billion tonnes CO_2e. So, the new fossil fuel developments identified in this report consume 20 – 33% of the remaining carbon budget until 2050.

In a scenario where the new fossil fuels are developed, we need to embark on a rapid emission reductions pathway at the latest in 2019 in order to meet the 50% probability carbon budget. Avoiding the development of new fossil fuels will give us until 2025 to start further rapid emission reductions.

These calculations are based on the assumption that the maximum emission reduction rate is 4% per year and that the maximum change in emission trend is 0.5 percentage point per year. The starting year for rapid emission reductions depends on the choice of these parameters. A sensitivity analysis shows that, in all cases, refraining from new fossil fuel development allows for a delay of 5 to 8 years before we should embark on a rapid emission reduction pathway.

The high investments required for developing new fossil fuels lead to a lock in effect; once developed, these fossil fuels need to be exploited for several decades in order to recuperate investment costs. Since emission reductions need to start soon, i.e. within the next decade, recuperating these costs will be difficult. This will either lead to destruction of capital or not staying within the carbon budget.

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5 References

1 Introduction

Currently, the fossil fuel industry has a strong interest in developing new fossil fuel production facilities. More and more, these are in remote areas and have relatively high greenhouse gas emissions. The question is to what greenhouse gas emissions these new developments will lead and what the implications of these developments will be for climate change. These questions are addressed in this report.

A key issue addressed in this report is the effect of the development of these new fossil fuels on carbon budgets for limiting global warming to 2°C by 2050. It is also shown how the development of these fossil fuels affects the year in which emission reductions need to start taking place in order to stay within these carbon budgets. This includes looking into maximum reduction rates and delayed action reduction pathways.

Chapter 2 provides an inventory of the most important new fossil fuels developments and the greenhouse gas emissions related to their exploitation. These emissions are shown in a pathway from 2012 to 2050.

Chapter 3 explains the concept of carbon budgets and delayed action emission reduction pathways. It also shows for both a scenario with and a scenario without the development of the previously identified new fossil fuels in which year reductions need to start in order to limit global warming to 2 °C. The chapter also contains tables which show the effects of different reduction rates and emission trend changes on the starting years.

2 Greenhouse gas emissions from new fossil fuel production

This chapter elaborates on the amount of greenhouse gas emissions (CO_2) per year over the period 2012 until 2050 from new fossil fuels. A first estimate was made of the greenhouse gas emissions related to the production, the transport and the combustion of fossil fuels extracted at these new developments.

2.1 Methodology

2.1.1 Overview of steps

Greenhouse gas emissions from new fossil fuel sources are estimated in four steps.

1. At the first step, an overview was made of the most important new developments of primary fossil fuel production. This inventory has been based on corporate sources, such as Petrobras and Wood Mackenzie, and on publications from institutes such as the International Energy Agency (IEA), the United States Geological Survey (USGS) and Geoscience Australia.

   Resources have been selected for three different reasons:
   - They consist of unconventional fossil fuels, such as tar sands and shale gas;
   - They are extracted at new or remote locations, such as the arctic and the pre-salt formation in Brazil;
   - Their production is expected to increase strongly in the nearby future, such as oil and natural gas in the Caspian and coal production in China.

2. In a second step, for each of the developments, an estimate was made of the expected fuel production until 2050.

3. The associated CO_2 emissions were calculated per year and over the total 2012-2050 period. A first estimate was made of the emissions from combustion of fossil fuels produced from new sources.

   Emissions factors for CO_2 have been taken from the Intergovernmental Panel on Climate Change (IPCC)[1]. Conversion factors for energy, such as the energy contents of a cubic meter of natural gas have been taken from a number of trustworthy sources, including the National Institute of Standards and Technology (NIST), the IEA and the American Physical Society (APS).

4. Emissions of greenhouse gases do not only occur through combustion of fossil fuels, but also early on in the process chain (upstream). CO_2 emissions occur due to energy consumption for production, mining, transportation, gas compression, refining, etc. In addition, emissions of

[1] 2006 IPCC Guidelines for National Greenhouse Gas Inventories
http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

methane occur in relation to coal mining, natural gas venting and leakages in gas transportation and distribution. These indirect emissions vary widely from source to source, depending a.o. on production methods and transportation distances.

For tar sands and shale gas, which can have significant upstream emissions, emission factors from literature were used to quantify and account for these emissions. For the other new fossil fuels, a mark-up on our emission estimates has been included (see section 2.3).

2.1.2 Disclaimer

The figures presented throughout this report originate from institutions such as the International Energy Agency and from corporate sources, such as Petrobras. Figures on petroleum resources and production rates in the future are estimates based on geological data and petroleum expertise. No matter how thoroughly they have been composed, it remains impossible to verify these numbers. This should, however, not be a problem, since the figures are not meant to describe the only possible or most likely scenario, but merely the future in which current fossil fuel industry plans are realised. It should furthermore be noted that the objectivity of some of these sources cannot be guaranteed. These figures should therefore be considered an indication and should not be taken for face value.

2.2 Identified new developments of fossil fuel production

Table 1 below presents a production based on annual extraction rates of fossil fuels for each identified location.

Considering oil, estimated production until 2050 based on extraction rates is about 260,000 million barrels of oil equivalent by 2050 (see Table 2), which has an energy contents of approximately 1,214,000 EJ. Oil from Iraq represents the largest potential capacity with around 53,000 million barrels of oil by 2050, followed by tar sands in Canada.

Gas production from major new fields could total 29,400 billion cubic meters by 2050 (see Table 2), with an energy contents of close to 1,000,000 EJ. The largest share is expected to come from the Arctic (9,200 billion m^3 [2]), followed by shale gas from the United States (8,400 billion m^3) and African gas (7,100 billion m^3).

Estimated coal production (based on extraction rate) from major new locations could total 49,600 million tonnes by 2050 (see Table 2), with an energy contents of around 1,135,000 EJ. By far the largest new locations are available in China (23,000 millions tonnes), followed by Australia (13,000 million tonnes) and coal in the United States 7,000 million tonnes).

[2] This is equivalent to 54,000 million barrels of oil equivalent

Table 1: Estimated resources and total production based on annual extraction rates from 2012 to 2050 for fossil fuel resources by location

Fossil fuel resource	Type	Unit	Production based on extraction rate	References
Tar sands in Canada	Tar sands/oil sands	million barrels	52,000	IEA, Oil and Gas Security - Emergency Response of IEA Countries Canada 2010. Canada National Energy Board - Canada's Energy Future: Energy Supply and Demand Projections to 2035 - Crude Oil and Bitumen Highlights, 2011.
Deepwater oil drilling (pre-salt) Brazil	Oil	million barrels	41,000	US EIA IEO 2011 . Rio Treasure Secretary Study, Pré – Sal: de quanto estamos falando?, May 2010. Petrobras, Plano de Negocios e Gestao 2012-2016, June 2012.
Gulf of Mexico deepwater oil drilling	Oil	million barrels	27,000	U.S. Department of the Interior (MMS), "Assessment of Undiscovered Technically Recoverable Oil and Gas Resources of the Nation's Outer Continental Shelf, 2006". U.S. Department of the Interior (MMS), OCS Report, Gulf of Mexico Oil and Gas Production Forecast: 2007 - 2016, 2007.
Coal expansion in China's Western provinces	Coal	million tonnes	23,000	5 different sources, see below
Coal in the United States	Coal	million tonnes	7,000	DOE/EIA Annual EnergyOutlook 2011 with Projections to 2035, 2011. Greenpeace: Sightline.
Coal in Indonesia	Coal	million tonnes	6,300	Wood Mackenzie, 2011.
Orinoco tar sands (Venezuela)	Tar sands/oil sands	million barrels	25,000	An Estimate of Recoverable Heavy Oil Resources of the Orinoco Oil Belt, Venezuela. USGS. 11 January 2010. IEA World Energy Outlook 2011.
Unconventional gas in the United States	Mostly shale gas	billion cubic meters	8,400	World Energy Outlook 2011 Special Report - Are we entering a golden age of gas?.
Caspian oil production (Kazakhstan)	Oil	million barrels	29,000	IEA World Energy Outlook 2010.
Caspian gas production (Turkmenistan, Azerbaijan and Kazakhstan)	Gas	billion cubic meters	4,800	IEA World Energy Outlook 2010.
African gas production	Gas	billion cubic meters	7,100	IEA World Energy Outlook 2011.
Iraqi Oil	Oil	million barrels	53,000	IEA World Energy Outlook 2011.
Coal in Australia (aggregated)	Thermal and Metallurgical coal	million tonnes	13,000	Bureau of Resource and Energy Economics (2012). Australian bulk commodity exports and infrastructure – outlook to 2025. Canberra. ISBN: 978-1-922106-19-3 (pdf).
Artic drilling for oil and gas	Oil and gas	million barrels of oil equivalent	86,000	2008 United States Geological Survey.

Table 2 Production of natural gas, oil and coal until 2050 based on annual extraction rates at new major locations

Fossil fuel resource	Production until 2050 based on extraction rates	Unit
Natural Gas	29,400	billion cubic meters
Oil	260,000	million barrels
Coal	49,600	million tonnes

In the sections hereafter, we discuss the assumptions and the results for each location in more detail.

2.2.1 Tar sands in Canada

Due to the fact that tar sands are considered unconventional fossil fuels, all production of tar sands in Canada is assumed to be additional to developments in a baseline scenario.

Production of tar sands until 2050 is estimated by assuming that production increases linearly from 1.5 million barrels per day in 2010 to 4.5 million per day in 2035 (estimates from IEA, 2011). From 2030 until 2050, production is assumed to remain at this level. All production from 2012 to 2050 is assumed to be additional.

This results in an estimated production of 52,000 million barrels of tar sands/oil sands by 2050.

2.2.2 Arctic drilling for oil

All production of oil in the Arctic is assumed to be additional.

Production of oil from the Arctic until 2050 is calculated by assuming a linear growth of production from zero in 2012 to 3 million barrels per day in 2030 (estimates from USGS, 2008). From 2030 to 2050, production is assumed to remain constant at 3 million barrels per day.

This results in a total production of 32,000 million barrels of oil by 2050.

2.2.3 Arctic drilling for gas

All production of natural gas in the Arctic is assumed to be additional.

The production of natural gas in the Arctic from 2012 to 2050 is calculated by assuming a linear growth in production from zero in 2012 to 5 million barrels of oil equivalent per day in 2030 (estimates from USGS, 2008). From 2030 to 2050, production is assumed to stay constant at 5 million barrels of oil equivalent per day.

This results in a total production of 54,000 million barrels of oil equivalents of natural gas by 2050. This is the equivalent of 9,200 billion m^3 of natural gas.

2.2.4 Deepwater oil drilling (pre-salt) Brazil

All production of oil from the pre-salt reservoir in Brazil is assumed to be additional.

Petrobras assumes production to reach 0.775 million barrels of oil by 2016 and 1.974 million barrels of oil per day by 2020 and 3.975 million barrels of oil per day by 2035 (estimates from Petrobras, 2011 and EIA, 2011). It is assumed that oil production starts in 2015. From 2035 until 2050, production is assumed to be constant at 3.975 million barrels of oil per day.

This results in a total production of 41,000 million barrels of oil by 2050.

2.2.5 Gulf of Mexico deepwater oil drilling

All production of oil from the Gulf of Mexico is assumed to be additional.

Production in the Gulf of Mexico is assumed to start in 2016 when 2.1 million barrels of oil can be produced per day (estimates from United States Department of the Interior, 2006 and 2007). Until 2050 production is assumed to stay at this level.

This results in a total production of 27,000 million barrels of oil by 2050.

2.2.6 Coal expansion in China's Western provinces

The expansion of coal in China is considered to be additional.

Additional coal production in China is estimated to start in 2012 and grow linearly to 616 million tons per year in 2015. From 2015 to 2050, the production is expected to stay constant at this level (estimates from several Chinese sources such as the Xinjiang coal development plan 2011-2015 and the IEA, 2009, detailed information can be found in the references section).

This results in a total production until 2050 of 23,000 million tonnes. For the calculations on the energy contents and the greenhouse gas emissions of the coal, this coal is assumed to be raw coal.

2.2.7 Coal in Australia

Australia is currently a large coal producing country and is expected to increase coal production significantly over the next decades. The increase in production from 2012 to 2050 is assumed to be additional.

The projected additional production of coal is taken from the Bureau of Resource and Energy Economics (2012). Figures are provided on the additional production per year, rising gradually from 0 Mt in 2009 to 408 Mt per year in 2025. From 2025 to 2050, production is assumed to stay constant at the 2025 level. Only production from 2012 up to 2050 is considered in this study.

This results in a total production until 2050 of 13,000 million tonnes. For the calculations on the energy contents and the greenhouse gas emissions of coal from Australia, the specific emission factor and net calorific value for Australian coal has been used, distinguishing between thermal black coal and coking coal.

2.2.8 Coal in the United States

Competition of cleaner energy sources has reduced domestic demand for coal in the United States. As a reaction to this development, coal companies are planning to greatly increase export of coal to Asia. Many new coal export terminals are planned in Oregon and Washington. The production of this coal intended for export, is assumed to be additional.

For the United States, coal production is expected to meet the additional demand for the new export terminals planned in Oregon and Washington. The combined increased export capacity of these export terminals is assumed to be 191 Mt per year, starting with 0 in 2012 and growing linearly to 191 by 2016 (estimates from Sightline Institute, 2012 and IEA WEO, 2011). From 2016 to 2050, export, and hence production, is assumed to remain constant.

This results in a total production until 2050 of 7,000 million tonnes. For the calculations on the energy contents and the greenhouse gas emissions of coal in the United States, this coal is assumed to be Powder River Basin coal.

2.2.9 Coal in Indonesia

Only the increase in coal production in Indonesia from 2012 to 2050 is considered additional.

To arrive at this figure, additional coal production was set to 0 in 2011 and assumed to grow linearly to 180 million tonnes per year in 2020 (estimates from Wood Mackenzie, 2011). From 2020 to 2050 it is assumed to stay constant at this level.

This results in a total production until 2050 of 6,300 million tonnes. For the calculations on the energy contents and the greenhouse gas emissions of the coal, this coal is assumed to be sub bituminous thermal coal.

2.2.10 Orinoco tar sands (Venezuela)

All production of tar sands/oil sands from the Orinoco oil belt in Venezuela is assumed to be additional.

The total production is calculated by interpolating the production of 0.5 million barrels per day in 2010 to the 2.3 million barrels per day in 2035 (estimates from USGS, 2010 and IEA, 2011). From 2035 to 2050, production is assumed to remain constant at this level. Total production is calculated from 2012 to 2050 (i.e. 2010 and 2011 are not taken into account).

This results in a total production of 25,000 million barrels of tar sands/oil sands by 2050.

2.2.11 Unconventional gas in the United States

Shale gas from the United States was included in this analysis because its production is expected to grow sharply over the following decades (World Energy Outlook (WEO) Special report on gas, 2011).

All unconventional gas in the United States is assumed to be shale gas (i.e. no tight gas or coalbed methane). Only shale gas which is produced in addition to the annual 360 billion cubic meters in 2008 is considered additional.

Additional shale gas production from the US is estimated using the IEA Golden Age of Gas Scenario (GAS Scenario), which results in a high estimate. Production is assumed to increase linearly from 0 billion cubic meters in 2012 to 310 billion cubic meters in 2035 (estimates from IEA, 2011). From 2035 to 2050, production is assumed to stay constant at this level.

This results in a total production of 8,400 billion cubic meters of natural gas by 2050.

2.2.12 Caspian oil production (Kazakhstan)

Caspian oil production is included in this analysis because it is expected to grow strongly over the coming decades (WEO, 2010). Only the increase in oil production from 2012 to 2050 is considered additional.

The total additional Caspian oil production was calculated by assuming additional oil production to be 0 in 2009 and to grow linearly to 2.5 million barrels a day in 2025. From 2025 to 2030, production is expected to stay constant at this level. From 2030 to 2035, it is expected to drop to 2.3 million barrels per day (estimates from IEA, 2010). From 2035 to 2050, it is assumed to stay constant at this level. The total production was calculated for the period 2012 to 2050 (i.e. 2009, 2010 and 2011 are not taken into account).

This results in a total production of 29,000 million barrels of oil by 2050.

2.2.13 Caspian gas production (Turkmenistan, Azerbaijan and Kazakhstan)

Caspian natural gas production is included in this analysis because it is expected to grow strongly over the coming decades (WEO 2010). Only the increase in natural gas production from 2012 to 2050 is considered additional.

The total additional natural gas production in the Caspian has been calculated by setting it to 0 in 2009 and assuming linear growth to 101 billion cubic meters per year by 2020. From 2020 to 2035, this is assumed to grow linearly to 151 billion cubic meters per year (estimates from IEA, 2010). From 2035 to 2050, production is assumed to stay constant at this level.

This results in a total production of 4,800 billion cubic meters of natural gas by 2050.

2.2.14 African gas production

African gas production has been included in this analysis because it is expected to grow substantially up to 2050. The IEA (WEO, 2011) estimates that production will double by 2035 compared to 2009. Only the increase in natural gas production from 2012 to 2050 is considered additional.

The total additional natural gas production in Africa is assumed to be 0 in 2009 and grows linearly to 64 billion cubic meters per year by 2015. From 2015 to 2035, production is assumed to grow linearly to 246 billion cubic meters per year (estimates from IEA, 2011). From 2035 to 2050, production is assumed to stay constant at this level.

This results in a total production of 7,100 billion cubic meters of natural gas by 2050.

2.2.15 Iraqi oil

Iraqi oil has been added based on the very large growth in oil production as projected by the IEA (WEO, 2011).

Additional production is expected to increase to 1.87 million barrels per day by 2016 and from there on increase linearly to 4.9 million barrels per day by 2035.

This results in a total production of 53,000 million barrels from 2012 to 2050.

2.3 Associated greenhouse gas emissions

Judging from annual extraction rates, coal expansion in China and Australia represent the largest emissions of CO_2 by 2050 (52, respectively 38 $GtCO_2$), followed by arctic drilling for oil and gas (29 $GtCO_2$) and oil from Iraq (24 $GtCO_2$).

Compared with CO_2, methane (CH_4) emissions associated with the burning of fossil fuels are very small. In spite of a Global Warming Potential (GWP) that is roughly 25 times as much as that of CO_2 (IPCC, 2007), calculations show that the contribution of CH_4 to the greenhouse gas emissions of fossil fuel combustion is so small that it is not taken into account in this study.[3]

In addition to emissions related to the combustion of fossil fuels, emissions also occur during production and transport of the fossil fuels. Values for these indirect emissions found in the literature typically are in the range of 10 – 25% of the combustion emissions (Dones et al., 2007; Koornneef et al., 2008. In this report, the greenhouse gas emissions associated with the production and transport of conventional oil and coal is taken into account by assuming a mark-up of 15% on the emissions for the combustion on the fossil fuels. For tar sands, shale gas and natural gas more specific figures from literature have been used, since indirect emissions for these fuel types are generally higher. For tar

[3] The CO_2 equivalents of CH_4 emissions are generally over 10,000 times smaller than CO_2 emissions in the emission calculations

sands, indirect emissions of 122 kg CO_2e per barrel were included (NETL, 2008). For natural gas and shale gas, indirect emissions consist mainly of methane leakage during the production, transport and storage phase of these fuels. For natural gas a leakage percentage of 2.5% was taken into account and for shale gas a leakage percentage of 3.9% was taken into account (Howarth et al. 2012). These methane leakages where then expressed in CO_2e by taking the GWP of methane into account.

In the future these percentages could increase, due to the increased reliance on resources that are more distant and more difficult to produce. On the other hand, cleaner production technologies and more efficient equipment may reduce emissions.

Environmental consequences of producing tar sands and shale gas, such as deforestation and water pollution, have not been considered in this study.

2.4 Development pathway new fossil fuels

The aggregated emissions related to the development of these fossil fuels result in the following emission pathway, as shown in the figure below:

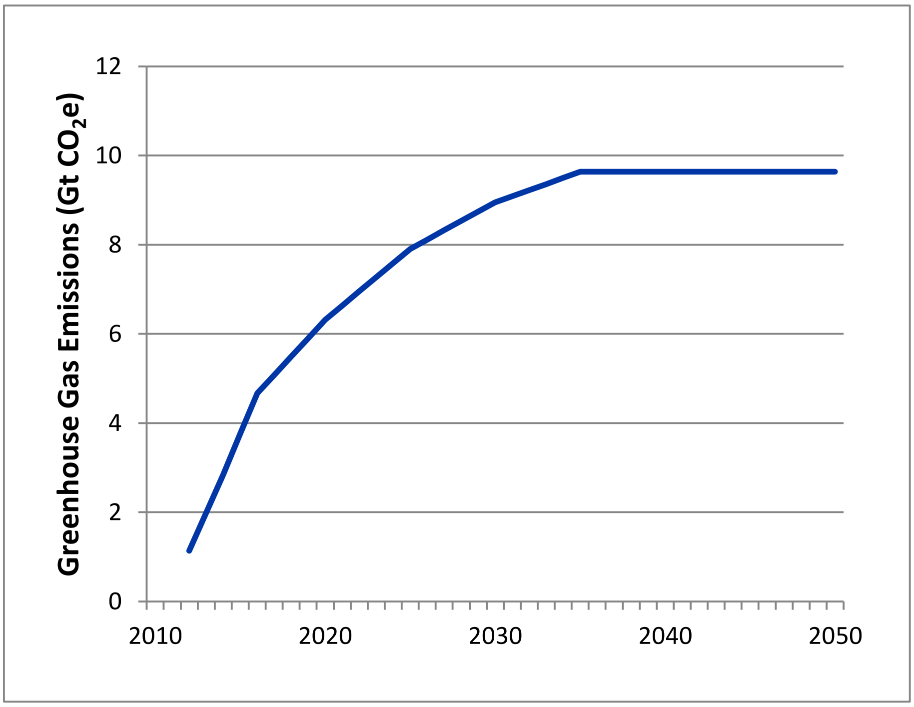

Figure 1: Greenhouse Gas Emission pathway for the emissions associated with the development of new fossil fuel sources.

2.5 Subset of new fossil fuels with the highest projected annual CO_2 emissions in 2020

In order to show which of the previously described fossil fuels have the largest impact on the chances of limiting global warming to a maximum of 2°C, the new fossil fuels have been ranked below based on the highest emissions by 2020 (Table 3). The ranking is based on CO_2 emitted instead of quantity of fuel produced in order to make a comparison possible. The indirect emissions related to the production of these fossil fuel resources has already been taken into account in the table.

Table 3: Ranking of the fossil fuel resources which emit the highest amount of CO_2 in 2020.

Fossil fuel resource	Type	CO_2 based on extraction rates in 2020 (Mtonnes)
Coal expansion in China's Western provinces	Coal	1,400
Coal in Australia (aggregated)	Thermal and Metallurgical coal	760
Artic drilling for oil and gas	Oil and gas	520
Coal in Indonesia	Coal	460
Tar sands in Canada	Tar sands/oil sands	420
Coal in the United States	Coal	420
Iraqi Oil	Oil	420
Gulf of Mexico deepwater oil drilling	Oil	350
Deepwater oil drilling (pre-salt) Brazil	Oil	330
Caspian oil production (Kazakhstan)	Oil	290
Unconventional gas in the United States	Mostly shale gas	280
African gas production	Gas	260
Caspian gas production (Turkmenistan, Azerbaijan and Kazakhstan)	Gas	240
Orinoco tar sands (Venezuela)	Tar sands/oil sands	190

3 Effects of New Fossil Fuel Developments on the Carbon Budget and Emission Reduction Scenarios

3.1 Introduction

This chapter shows the effects of the development of new fossil fuels on the possibilities of limiting climate change to 2°C.

We will take the following approach. First of all, we will identify the carbon budgets that are still available if we want to stay within a 2°C temperature increase with a certain probability. We will calculate how much of that budget is "eaten up" by the new fossil fuel developments.

Next, we will identify two scenarios: one with new fossil fuel developments, and one without new fossil fuel developments. For each scenario we will determine what the latest date is for implementing maximum CO_2 emission reductions in order to meet this budget. This latest date is determined based on a maximum emission reduction rate and a maximum emission trend change obtained from literature.

3.2 Effects of New Fossil Fuel Development on Carbon Budgets for 2050

The original concept of carbon budgets originates from publications by Meinshausen et al. (2009). A carbon budget represents the maximum amount of CO_2 that can be emitted globally in order to meet a certain degree of warming with a certain probability. In a paper on emission pathways to 2°C scenarios, Höhne et al. (2009) refer to two carbon budgets for the period 2000 to 2050. The first budget of 2000 $GtCO_2e$ results in a 50% probability to meet a 2°C global warming scenario. The second budget of 1500 $GtCO_2e$ results in a 75% probability to meet a 2°C global warming scenario. The historic emissions from 2000 to 2010 are also included in Höhne et al. (2009) and amount to around 450 $GtCO_2e$. This means that about 1550 $GtCO_2e$ remains from the budget for the 50% probability scenario and 1050 remains of the budget for the 75% probability scenario.

In order to stay within the carbon budgets, annual CO_2 emissions need to be reduced at some point. There are a wide number of emission pathways and emission scenarios available in literature.

The following image shows four illustrative emission reduction pathways taken from Höhne et al. (2009), which follow a path corresponding to one of the two previously mentioned carbon budgets. Following the green or the yellow pathway will result in meeting the carbon budget that corresponds with the 75% probability to meet 2°C global warming. The orange and the blue line correspond to the 50% probability to meet the meet 2°C global warming.

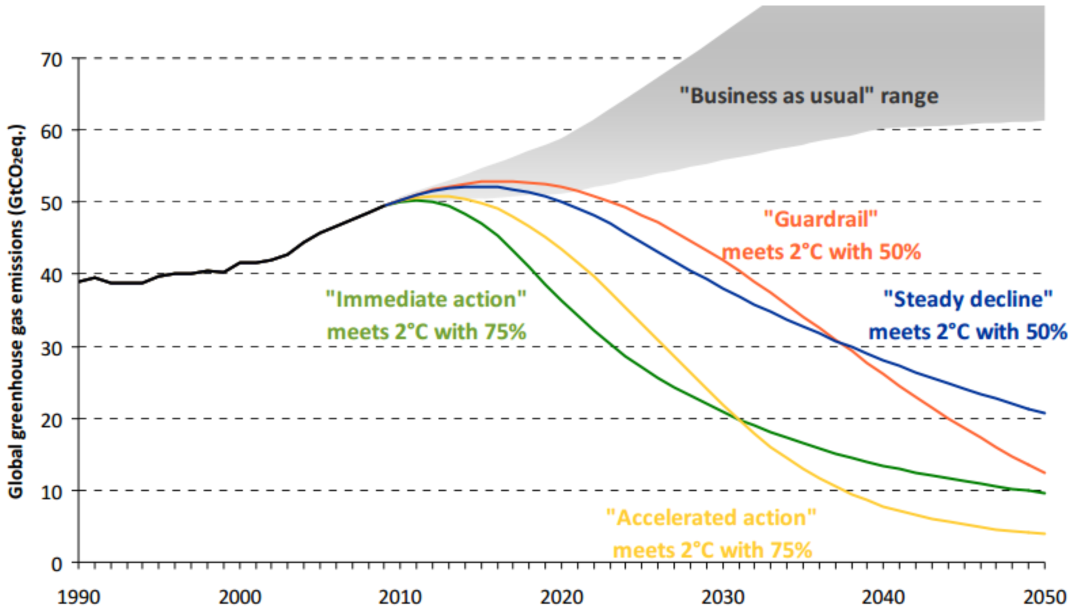

Figure 2: This figure, taken from Höhne et al. (2009), shows for each of the carbon budgets, two exemplary pathways to stay within the budget.

In the previous chapter, we found that developing the new fossil fuels from the inventory results in the emission of a little over 300 $GtCO_2e$ during the period from 2010 to 2050. This represents around 20% of the 1550 Gt budget for the 50% probability scenario. It represents about 30% of the 1050 Gt budget for the 75% probability scenario. This is shown below, in Figure 3.

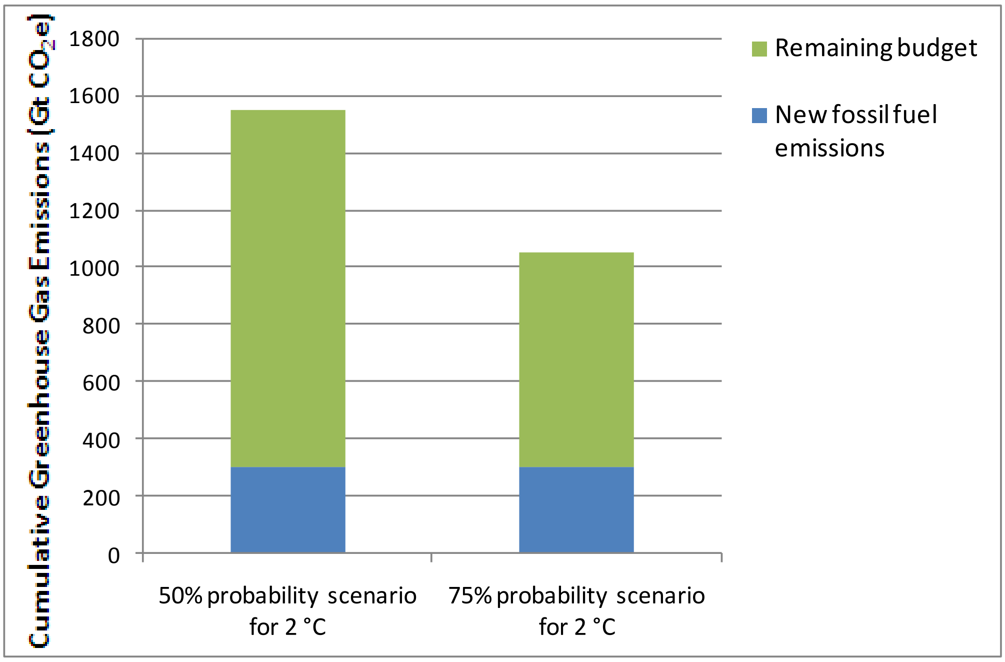

Figure 3: This figure shows the effect of the emissions of new fossil fuel developments from 2010 to 2050 on the carbon budgets for a 50% probability of a 2°C warming and on the scenario for a 75% probability of a 2°C warming scenario.

3.3 Scenarios with and without new fossil fuel developments

In order to determine the effect of developing or not developing the previously defined new fossil fuels, two different emission pathways have been developed, one including and one excluding the development of new fossil fuels.

The first is the reference scenario, which is an adjusted version of the PRIMAP4 baseline[4]. The projections are primarily based on the World Energy Outlook of the International Energy Agency (IEA) until 2035 and on the POLES model[5] until 2050. The scenario was updated for this study using energy-related CO_2 emission growth rates from the Current Policy Scenario (CPS) of IEA's World Energy Outlook (WEO) 2011 (IEA 2011).

The projected developments of the new fossil fuels are largely in line with the Current Policies Scenario (CPS) from the WEO until 2035. The WEO (2012) projects the following increase of fossil fuel production from new sources in the CPS, see Table 4. This table shows that the additional production of new sources in 2035 in the CPS is partially met by the production of new fossil fuel sources from our inventory. For the initial period, the new fossil fuel developments identified in this

[4] Potsdam Institute for Climate Impact research PRIMAP4 Baseline Reference

[5] POLES (Prospective Outlook on Long-term Energy Systems), ENERDATA

report will largely cover the additional fossil fuel needs in the reference scenario. However, going towards 2035, the reference scenario will require even more new fossil fuel developments to meet demand.

Table 4: Additional production of coal, oil and natural gas in 2025 and 2035 from the WEO 2011 Current Policies Scenario and the new fossil fuels inventory, shown in million tonnes of oil equivalent (Mtoe), million barrels and billion cubic meters. For coal and natural gas this figure is the difference between production in 2011 and 2025/2035. For oil, this is the difference between the production of sources from 2011 in 2025/2035 and the production in 2025/2035. Since current oil sources are decreasing over the next couple of decades, this figure is larger than simply the difference between production in 2011 and production in 2025/2035. For coal and gas these figures are not available.

		Coal	Oil	Natural Gas
2020	**Additional production from new sources in the WEO**	600 Mtoe	5,000 million barrels	550 billion m^3
	New fossil fuels production	800 Mtoe	5,000 million barrels	500 billion m^3
2025	**Additional production from new sources in the WEO**	1,000 Mtoe	8,800 million barrels	900 billion m^3
	New fossil fuels production	1,000 Mtoe	6,400 million barrels	700 billion m^3
2035	**Additional production from new sources in the WEO**	1,400 Mtoe	15,800 million barrels	1,700 billion m^3
	New fossil fuels production	1,400 Mtoe	8,400 million barrels	1,000 billion m^3

Since the scenarios from the WEO only run until 2035, it is difficult to ascertain that our projected new fossil fuel developments from 2035 to 2050 are fully in line with the reference scenario.

The scenario without the development of new fossil fuels is called 'reference scenario minus fossil fuels' and is the reference scenario subtracted by the fossil fuels developments pathway shown in chapter 2.4. The figure below (Figure 4) shows the emissions belonging to the reference scenario and to the reference scenario minus new fossil fuels.

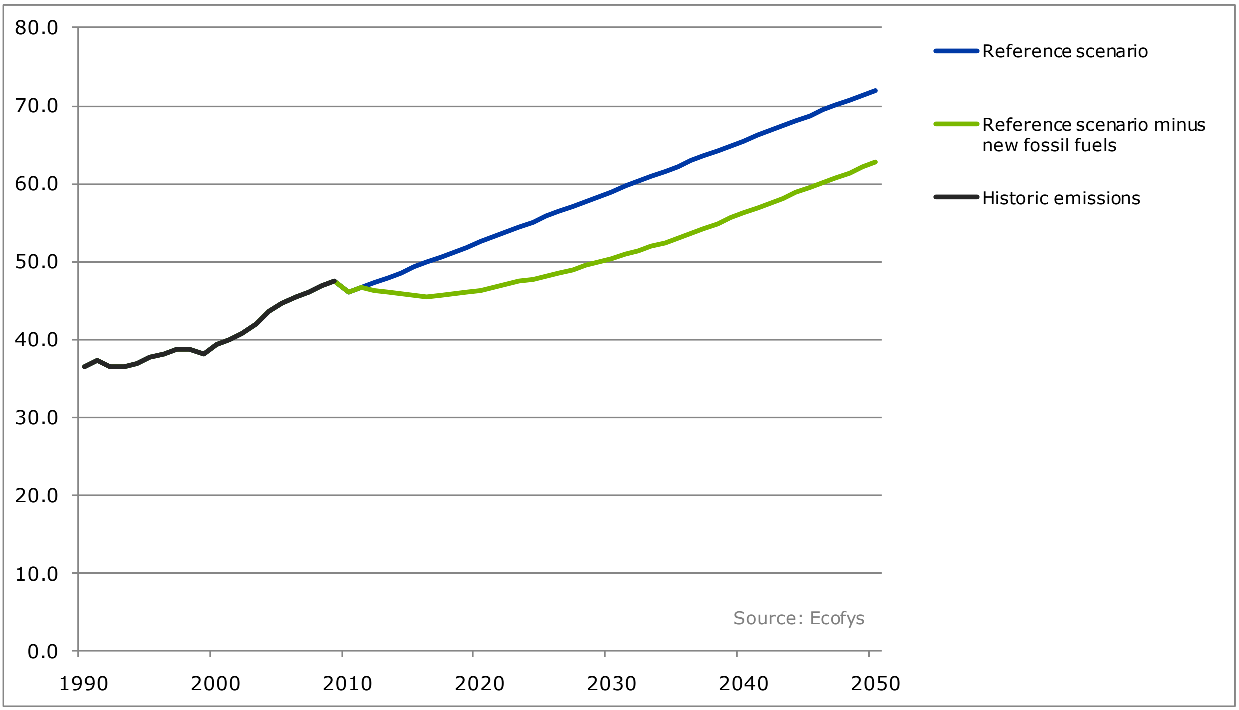

Figure 4 Annual global CO_2 emissions from 1990 to 2050. The black line represents historic emissions, the blue line representes the reference scenario and the green line represents the reference scenario minus the development of the new fossil fuels

3.4 Maximum rates of greenhouse gas emission reduction

We will now for both scenarios identify what the last year is to change direction and embark on a 2 ºC pathway. In doing that, we need to make two assumptions, following a methodology that was used by (Höhne, 2005):

- How rapid can we change track from a pathway with increasing emissions to a pathway with decreasing emissions? This stands for the maximum change in the year-on-year rate of change of greenhouse gas emissions, expressed in percentage points.
- What is the maximum reduction rate of greenhouse gas emissions? We will express this as a maximum percentage change per year.

Not much information is available on delayed action pathways and the maximum reduction rates achievable afterwards. Most studies take a more comprehensive approach and construct pathways that assume a smooth introduction of greenhouse gas emission reduction options.

Although there is an increasing interest in delayed action pathways, the amount of studies dealing with this topic is as of yet quite limited. This table shows the reduction rates from two different available studies, the studies from Van Vliet et al. (2012) and the OECD (2011).

For comparison, we have also included emission reduction rates for two scenarios that focus on a rapid transition to sustainable energy system. However, both scenarios only treat energy-related CO_2 emissions, so no comprehensive treatment of all greenhouse gas emissions. It may well be that certain non-CO_2 greenhouse gas emissions (e.g. in agriculture) are more difficult to reduce than energy-related CO_2 emissions.

Based on the emission reduction rates from Table 5, the default value for the maximum emission rate has been set to 4%. The default value for the maximum trend change has been set to 0.5% based on Höhne (2005).[6]

Table 5: Maximum emission reduction percentages per year for three different scenarios spanning several periods from 2020 to 2050.

	2020-2030	2030-2040	2040-2050	2020-2050	2030-2050
Van Vliet et al. (2012)	1.6%	3.2%	5.9%	2.5%	3.0%
OECD (2011)	1.2%	3.1%	4.4%	2.9%	3.7%
Greenpeace-Energy [R]evolution 2012	3.1%	6.2%	11.5%	7.0%	8.9%
WWF/Ecofys The Energy Report	2.9%	6.4%	10.4%	6.6%	8.4%

3.5 The last year for embarking on a 2 ºC pathway

In order to stay within the carbon budgets that were presented in the previous chapter, annual emissions will need to be reduced in the near future. If this would not happen and emissions would continue in a business as usual scenario, total emissions would exceed 2370 $GtCO_2e$ and global warming will most likely not stay within a 2 °C range.

Meeting the carbon budget depends on the following variables:

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[6] A maximum trend change of 0.5% means that if reductions are to start, the annual emission 'growth rate' can only change by 0.5 percentage point at a time. So if emissions from 2020 to 2021 increased by 4% and reductions start from 2021, the emissions growth for 2022 is 3.5%, for 2023, 3.0%, for 2024, 2.5%, etc. The 'growth rate' will continue to decrease until it reaches the maximum emission reduction rate (for example 4%, this means a 'growth rate' of -4%).

- The reference pathway, e.g. whether or not the new fossil fuels will be developed or not
- The maximum emission reduction rate
- The maximum trend change of the emission pathway (a change in emissions is a gradual process and cannot occur ad-hoc)
- The starting year of the reductions

We have calculated in which year emission reductions need to start in order to meet the two carbon budgets using the scenario with and without the development of new fossil fuels.

The following figure (Figure 5) shows the reference scenario and the reference scenario minus the development of the new fossil fuels. It also shows in which years emission reductions need to commence in order to meet the 1550 $GtCO_2e$ for both the reference and the reference scenario minus fossil fuels and for the 1050 $GtCO_2e$ budget for the reference scenario minus fossil fuels, taking the 4% maximum emission reduction and the 0.5% maximum trend change into account

We conclude that if the reference scenario is followed, the last year to move to a 2 °C pathway (50% probability) is 2019. In the scenario were these new fossil fuels are not being developed, this shifts to 2025. The 1050 $GtCO_2e$ budget cannot be met with the 4% and 0.5% constraint in the reference scenario including the new fossil fuels. In the reference scenario minus fossil fuels, the 1050 $GtCO_2e$ budget can be met when reductions start in 2012.

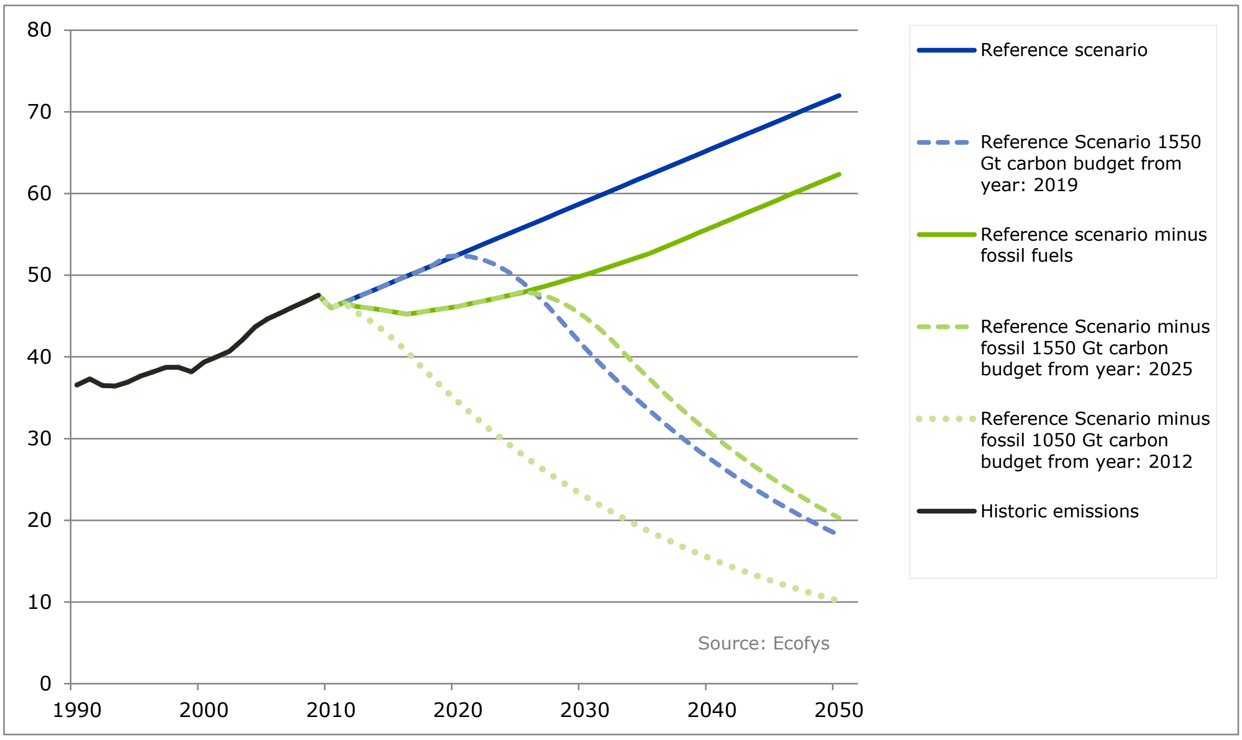

Figure 5: This figure shows the reference scenario and the reference scenario minus the fossil fuels and the three different emission pathways required to meet the two previously defined carbon budget.

Note that the pathway for meeting the 1050 Gt carbon budget based on the reference scenario is not shown because under these specific conditions it is not possible to meet the budget.

In order to perform a sensitivity analysis for the maximum reduction rate and the maximum trend change, the effects of several different values were tested and shown below. Five different values for the maximum reduction rate (2% to 6%) and three different values for the maximum emission pathway trend change (0.2% to 1.0%) were considered.

Table 6: Latest reduction years for staying within the carbon budget for a 50% or a 75% probability to stay within 2°C (1550 and 1050 $GtCO_2e$ from 2010-2050) for the Reference Scenario and the Reference Scenario Minus Fossil Fuels. N/A means that the budget cannot be met under the selected constraints.

Max budget for 50% probability to stay within 2°C (1550 $GtCO_2e$ from 2010-2050)						
Reference Scenario		Maximum Reduction rate				
		2%	3%	4%	5%	6%
Maximum trend change	0.2%	N/A	N/A	2012	2012	2012
	0.5%	2014	2017	2019	2020	2021
	1.0%	2016	2019	2022	2023	2024
Reference Scenario Minus New Fossil Fuel		Maximum Reduction rate				
		2%	3%	4%	5%	6%
Maximum trend change	0.2%	2017	2019	2020	2020	2020
	0.5%	2020	2023	2025	2025	2026
	1.0%	2022	2025	2027	2028	2029
Max budget for 75% probability to stay within 2°C (1050 $GtCO_2e$ from 2010-2050)						
Reference Scenario		Maximum Reduction rate				
		2%	3%	4%	5%	6%
Maximum trend change	0.2%	N/A	N/A	N/A	N/A	N/A
	0.5%	N/A	N/A	N/A	N/A	N/A
	1.0%	N/A	N/A	N/A	2013	2015
Reference Scenario Minus New Fossil Fuel		Maximum Reduction rate				
		2%	3%	4%	5%	6%
Maximum trend change	0.2%	N/A	N/A	N/A	N/A	N/A
	0.5%	N/A	N/A	2012	2015	2016
	1.0%	N/A	N/A	2014	2016	2017

As can be seen from the tables above, both the assumptions for the maximum trend change as well as for the maximum reduction rate affects at what time reduction has to start in order to meet the carbon budget. Refraining from developing the new fossil fuels results in 5 to 8 additional years before maximum reduction has to set in. It should be noted that postponing the reduction of emissions implies higher reduction costs in most scenarios.

The results can also be interpreted in another way. If, for instance, in 2020 the pathway would be changed, in the case of the reference scenario including the development of the new fossil fuels, an extreme 5% emission reduction rate would need to be achieved, whereas in the reference scenario minus the new fossil fuels scenario a 2% emission reduction rate would be sufficient.

4 Conclusions

The development of these new fossil fuels would result in emissions of 300 billion tonnes of CO_2-equivalent (CO_2e) from 2012 until 2050. In a scenario where the new fossil fuels from the inventory are developed, reductions need to start the latest at 2019 in order to meet the 50% probability carbon budget. If these new fossil fuels are not developed, reductions should start in 2025 to meet the 50% probability carbon budget.

These reduction years can be seen as a 'point of no return'. If emission reductions don't start by these years, it becomes unlikely that global warming will stay below 2 °C. The analysis above implies that not developing the new fossil fuels gives 5 to 8 years of additional 'breathing space' to meet the 50% carbon budget. Formulated differently, developing these fossil fuels brings the point of no return 6 years closer.

Recuperating the costs involved in developing fossil fuels requires the exploitation of these resources for a long period, often spanning several decades. This means that once developed, these fossil fuels are likely to be exploited. This leads to a lock in effect; developing fossil fuels in the coming years results in a steady stream of additional emissions over the following decades.

As shown previously, increasing the probability to keep global warming at a 2 °C maximum requires extensive emission reductions starting in the near future, i.e. from a couple of years to a little over a decade from now. The development of new fossil fuels causes the previously described lock in effect, which means emissions will increase over the next decades instead of decrease, in turn making it very unlikely to stay within a 2 °C carbon budget. In combination with the early dates for starting reductions, this means that the development of new fossil fuels makes it a lot more difficult to limit global warming to 2 °C.

In short, developing new fossil fuels makes it necessary to start reductions at an earlier date than not developing new fossil fuels. Developing new fossil fuels makes it difficult to start these reductions since stopping production of the fuels would lead to investment costs not being recovered. The combination of these two effects makes developing new fossil fuels not only a negative influence on the climate but also a bad investment; their development of new fossil fuels makes it necessary to start maximum emission reductions earlier, while at the same time making it impossible to recuperate investment when this is done and production is stopped.

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