Closing the emissions gap: sectoral emission reduction potentials in 2030 for the G20 and world regions

An overview of potential greenhouse gas emission reductions for selected measures in the six largest economic sectors in the G20 countries and world regions

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"In a world of change, the learners shall inherit the earth, while the learned shall find themselves perfectly suited for a world that no longer exists."

Eric Hoffer

Executive summary

Since the Paris climate conference in 2015, where 196 countries made a pledge to reduce greenhouse gas emissions, several steps have been made to ensure that the global temperature rise will stay well below 2℃ compared to pre-industrial levels, with the additional effort of keeping temperature rise below 1.5℃. Most nations have submitted their *Intended nationally determined contribution (INDC)*, a document that describes its decarbonization and their role in the achievement of the previously mentioned goal. Subsequently, of all countries that made pledges during the conference 181 parties have ratified the accord so far, turning their INDC into *Nationally Determined Contributions (NDCs)*. It is projected, however, that all NDCs combined do not cover enough emission reductions to be in line with a scenario in which temperature rise is limited to 2℃. Moreover, current policy projections by the UN and the IEA estimate that goals mentioned in the respective NDCs are not going to be achieved by 2030 (CAT, 2018b). Simultaneously, the accord has received a large blow by the United States announcing to leave the climate agreement, under the Trump administration. A gap between the emissions of current policy scenarios, NDC compliant scenarios, and the 2℃ has become clear; *the emissions gap*.

With the emissions gap known, emphasis should be put on finding a way to close this gap. To find out what needs to be done a sectoral approach is taken. In recent years several studies have been carried out to determine the sectoral emission reduction potential. The most studies have been carried out by UNEP (2017), McKinsey (2010) and IPCC (2007). These studies focus on the mitigation potential for the year 2030 on a global scale, with the IPCC (2007) also specifying several regions. This is the central problem in this thesis. One the one hand global and regional scale mitigation potentials are available for a range of scenarios, but on the other hand there is an absence of information regarding national and regional mitigation potential data for specific mitigation measures. Since the G20, an international forum of governments, is an entity which is large in surface area, population, economy and trade, and pollution its regions are chosen as the main scope for this research. This research is carried to fill the knowledge gap with regards to national and regional sectoral mitigation potentials, and to subsequently create an overview of these mitigation potentials. Additionally, this research is done to investigate if the G20 and its member states can achieve their NDCs by 2030 and partially or completely close the emissions gap to keep temperature rise below 2℃ and 1.5℃.

The mitigation potential for the G20 and the world regions in 2030 is determined for certain climate mitigation measures. The selection of the treated measures was based on the *Emissions Gap Report 2017*, which covers 6 sectors and 37 measures. The sectors are *agriculture, buildings, energy, forestry, industry* and *transport.* The selection of the measures that are treated in this thesis is based on an extensive literature study assessing for which measures recent, high quality literature containing regional or national data was available. A selection of 9 measures is made for which regional and/or national data is available. Additionally, according to the *Emissions Gap Report 2017,* these measures combined represent over half of the envisioned mitigation potential in 2030. For each of the sectors a baseline is chosen which represents a trajectory, either assuming only current policies or including implemented announced policies and technologies. These baselines do not, however, take new technologies and expected policies into account. Subsequently, for each sector a scenario is taken from leading literature or is constructed using recent data. Only measures that are possible below $100 per tonne of CO_2e are considered. Data which is not available on country or regional level is either extrapolated or interpolated using the country's GDP as a variable, or by assuming that the region or country has similar growth, energy use or emissions trends to another region or country. This is also the biggest limitation of this research, since assumptions are made on national levels, neglecting country specific factors. Additionally, focus is solely put on technical mitigation potentials beneath a financial threshold. No attention is given to regional or national factors such as the political situation and direction, and/or public opinion.

The results found in this thesis are displayed in ES1 and ES2, which depict the global and regional mitigation potential, as well as the mitigation results found for the G20. Furthermore, in Table ES1 the global mitigation potentials are displayed per measure in Table ES1.

Table ES1. Global mitigation potential in 2030

Measure	Mitigation potential (GtCO₂e/year)
Solar PV	2.85 – 5.7
Wind energy	2.5 – 5
Reducing deforestation	1.6 – 4.1
Efficient appliances and lighting	3.3
Reforestation	3.1
Direct energy efficiency in industry	2.6
Efficient light duty vehicles	1.6
Peatland management	1.0
Cropland management	0.7
Total	19.1 – 27.0

In total, the global mitigation potential in 2030 on a global scale was found to range from 19 $GtCO_2e$ to 27 $GtCO_2e$. This means that with only the 9 measures treated in this thesis, it is possible to completely close the emissions gap between a current policy scenario and a scenario in line with limiting temperature rise to 2℃, ranging from 18 $GtCO_2e$ to 22 $GtCO_2e$. This statement also holds true for closing the emissions gap between current policies scenario and a 1.5℃ pathway since the emissions gap for this scenario is estimated to range from 24 $GtCO_2e$ to 27 $GtCO_2e$ in 2030. However, this cannot be said with the same certainty since this is more ambitious and will therefore be harder to achieve.

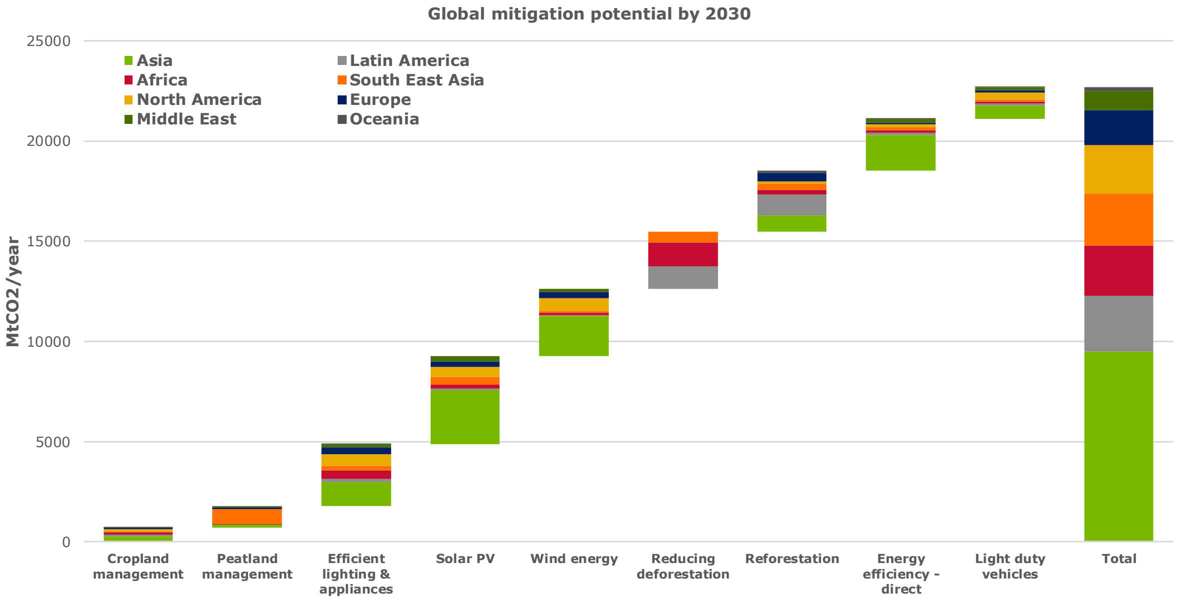

Figure ES1. Global mitigation potential in 2030 per in this thesis treated measure. In this figure, for the measures solar PV and wind energy, the region Asia also contains the region Oceania.

The G20 has a total envisioned mitigation potential in 2030 for the treated measures ranging from 14.4 $GtCO_2e$ to 20 $GtCO_2e$. It is concluded that the G20 can mitigate large amounts of greenhouse gasses and has a key role in the closing of the emissions gap. As can be seen in ES2, China by far has the largest mitigation potential in 2030, followed by the US and India. The national emissions reduction potentials calculated in this thesis are deducted from a current policy scenario to determine whether each G20 member can achieve their respective conditional or unconditional NDCs in time. The results concluded that all NDCs are achieved within the given time by a large margin.

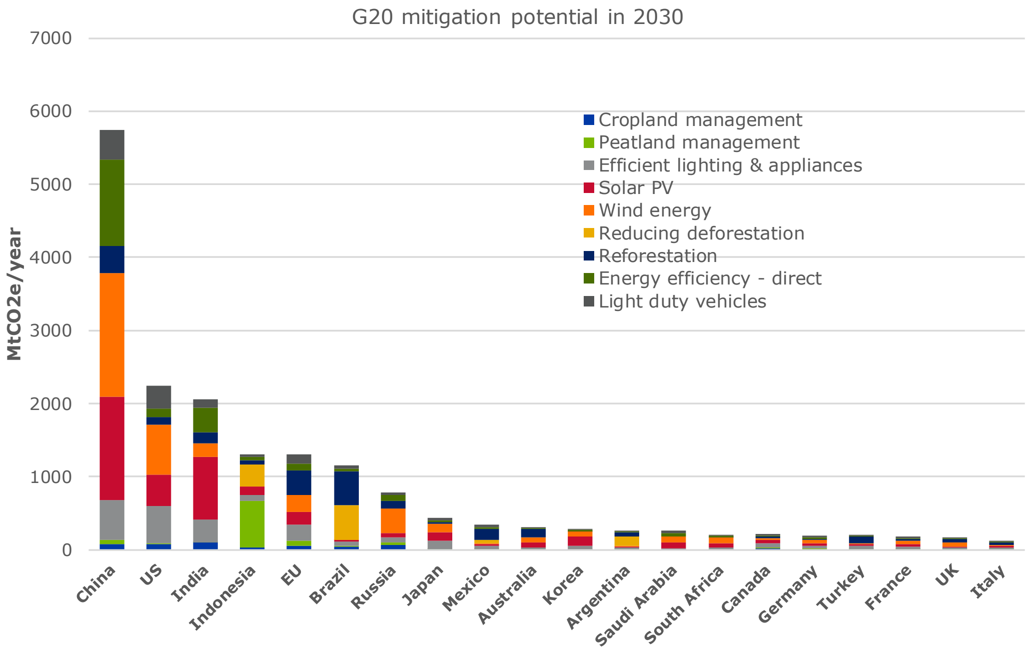

Figure ES2. G20 mitigation potential in 2030

In conclusion, this research shows that significant emission reductions can be achieved globally, regionally, and in the G20 by focusing on 9 established mitigation measures below 100$ per tonne CO_2e. Subsequently the emissions gap can be closed to be in line with a below 2℃-pathway. Although this research provides a good indication of the emission reduction potential, the analysis is not done on a level of detail that provides insights in the implementation of these measures. However, since the estimated potential is already promising it is recommended to perform country wide feasibility studies for these measures in the investigated countries. Furthermore, we provide detailed suggestions for data improvement in the discussion chapter.

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Preface

It has been more than 8 months ago since I started working on my thesis which is now called: ''Closing the emissions gap: sectoral emission reduction potentials in 2030 for the G20 and world regions''. The writing of this thesis is the final hurdle to fulfill the graduation requirements of the sustainable energy technologies master program at the Delft University of Technology.

The entire period spent on my thesis has taken place within Ecofys, a Navigant company, as an internship, where I have had the pleasure and opportunity to work in the Utrecht and London offices. I came across this opportunity after a conversation with my supervisor Kornelis Blok. Together, we formulated a broad scope for this research after which the focus later became clear. The research was sometimes challenging, but I was able to answer the main questions formulated in this thesis. This in part was due to Kornelis Blok and Irina van der Hoorn always being available for advice when needed.

I would like to express my deepest gratitude to Irina van der Hoorn for her outstanding and heartfelt guidance during my time spent at Ecofys, a Navigant company. She has given me advice and help with regards to my thesis but also by lending moral support and by being patient with my questions. When I found myself unable to make progress, a meeting with Irina would give me clear direction and positive spirit. Additionally, I would very much like to thank Kornelis Blok for giving sound and clear advice with regards to the broad lines of the thesis and keeping me on the path we set out at the start of this internship. I would also like to thank Kornelis Blok for giving me the opportunity to be within the company for the entire length of my thesis and offering me the opportunity to spend a brief amount of time abroad. I would also like to thank Yvonne Deng for her guidance and mentorship during my stay in London. She has enabled me to work more efficient during the remainder of my thesis after I left the office in London.

All other colleagues at Ecofys, in Utrecht as well as in London, have my thanks for making me feel useful and at home. I sincerely had the feeling I could ask questions to anyone regarding anything, which has created a very nice environment for me to write my thesis in. Many a time has a colleague approached me to ask if I could help in a project, and so learn more about different companies and sectors. I know I have learned a great deal about day-to-day live within this company and feel that this will help me further.

I hope this thesis lives up to the expectations anyone might have, but above all that it is a good read offering new insights.

Jelmer van den Heijkant

Utrecht, October 31st, 2018

Contents

List of figures

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List of Tables

1. Introduction

In December 2015, at the Paris climate summit a collective pledge was made by 196 countries to keep average global temperature well below 2℃ with respect to pre-industrial levels, through mitigation and reduction of greenhouse gas (GHG) emissions. Furthermore, the goal is to limit temperature rise below 1.5℃ (UNFCCC, 2015a). On 4 November 2016, the agreement became effective and up until now 181 of the 196 initial countries have ratified the Paris climate accord (UNFCCC, 2018). Relative progress towards these goals has been made although there are still much efforts to be made to achieve this ambitious climate target. Another effect of the Paris agreement is that the GHG emission should rapidly reach peak levels and should decline in the years shortly thereafter (EC, 2018). To this end, each of the participating countries determined their own contribution to the common goal. This term was coined *National Determined Contribution* (NDC) (UNFCC, 2015b).

So far, a lot of concessions, agreements and pledges regarding climate mitigation have been made, but a lack of knowledge on how to do this and where the reduction potentials lie, inhibits these promises. Moreover, there is only small understanding as to how the GHG emission moderation should be brought about. The field of research into this subject shows a knowledge gap on how to offset the emission gap, and gradually decrease the total output of GHG's. In a 2017 research commissioned by the *United Nations Environment Programme* (UNEP), the global reduction emission potential under *100$ per tonne of CO_2 equivalent* (tCO_2e) for the year 2030 is synthesized. In this report, the *Emissions Gap Report 2017,* estimates are made on a sectoral basis, consisting of the largest global sectors; agriculture, buildings, energy, forestry, industry, and transport. The report goes on to divide these sectors into climate mitigation measures. Concludingly, the report goes on to show that it is (in theory, easily) possible to close the emission gap by the year 2030 (UNEP, 2017). As mentioned, the report focusses on the global mitigation potential without making distinctions between regions or countries.

This thesis is grounded on the notion that there is a lack in knowledge regarding sectoral GHG emission reduction potential for climate mitigation measures on a nation or regional scale in 2030 (Ecofys, 2017), which hinders the development of appropriate focus on measures that are economically and technologically feasible. As mentioned in the section above the bottom-up potentials, or sectoral emission reduction potentials, give a good, general insight as to in which sector or measure the largest climate mitigation potential resides. However, it remains unclear in which sectors or measures the largest $GtCO_2e$ reduction can be achieved on a national or regional level. This thesis will try to shed light upon exactly that; national and regional sectoral emission reduction potential in the year 2030 for the countries of the Group of 20 (G20). This choice is based on the G20 encompassing the 20 countries with the largest trade and economies, population, and pollution. Subsequently, this thesis aims at answering the following research question(s):

What are the sectoral emission reduction potentials for the considered measures that can be utilized, at or below 100$/$tCO_2e$ for the G20 and world regions in 2030? Further, can NDCs be achieved so that the emission gap can be closed to achieve the Paris agreement's goal to stay well below 2℃ above pre-industrial levels, and additionally try to limit temperature rise to 1.5℃?

Furthermore, attention will be given to the fairness of these mitigation potentials in an economic sense in case the mitigation potentials are in countries which are less developed, making it more difficult to realize these mitigation potentials. Addressing the reduction potentials in this way will hopefully give a clearer view as to how the future regarding GHG emission reductions will take form, and which measures or sectors should be focused on in the pursuit of creating a sustainable, emission free future.

The significance of this report is multifold, and it so does try to increase scientific and academic knowledge in the field of climate mitigation. It is relevant in the following ways. Firstly, this report tries to add to the narrowing of the knowledge gap regarding sectoral reduction emission potentials that was already partially filled by the *Emissions Gap Report 2017* report regarding global emission reduction potentials (Ecofys, 2017). This report will try to carry on along the same line, so that better estimates and projections can be made. However, in contrast to the *Emissions Gap Report 2017* report, this thesis will focus on the G20 member states and the region that they are in. This regional and national knowledge regarding sectoral emission reduction potential is currently lacking, although it is crucial to policy makers. Making this type of information available will lead to better policy creation and insight regarding future scenarios (UNEP, 2017).

Secondly, the Paris climate accord of 2015 went into effect and policymakers are putting efforts into reaching that goal. However, the question arises how has the progression been so far? This thesis can possibly provide greater insights into how current estimates and publications judge the viability of ambitious climate goals defined in the Paris Agreement. Next to the global feasibility of the necessary emission reductions, as dealt with in the *Emissions Gap Report 2017*, it is also interesting to see how countries of the G20 perform on their self-formulated NDCs and to see if these NDCs can easily be reached for \$100/tCO_2e.

Thirdly, there is a clear lack of sufficient publications regarding worldwide, regional, or national mitigation potentials. This report can aid in the moderation thereof. Lastly, up until this point there have been several publications about emissions reduction potentials of one or more emission reduction technologies and measures. However, in most cases this has only been done to the extent of the ‘’main stream’’ technologies and measures such as wind energy and solar energy. This report can help to gain insights when less conventional, less developed technologies or measures such as afforestation, and peatland management are involved.

The report will be structured into a theoretical framework, explaining the concept at the basis of this thesis, and a scope chapter demarcating the areas and measures on which will be focused. This will be followed by six chapters treating each of the previously stated sectors and their selected measures. The methodology used differs per sector according to available data found in literature and will be described per sector in the corresponding chapter, though, in all sectors available data in literature will be used to project future emissions. Unless stated otherwise, baselines portraying pathways that include current policies and trends until 2030 are compared with ambitious scenarios utilizing technologies under \$100/tCO_2e. This will be done on regional and national level. When all sectors have been treated, the results are aggregated and discussed. A discussion chapter will then debate the largest limitations and uncertainties of this thesis and its methodologies. Finally, a conclusions chapter will answer the main research question.

2. Theoretical framework

In this section, the goal is to sketch the theoretical framework in which this thesis is positioned. In this framework, the presumed theories and concepts are described.

2.1 Environmental peril

The underlying theme in this thesis is that the global environment is in immediate danger. This danger, among others, consists of rising temperature due to the greenhouse effect, rising sea levels, acidification of earth's oceans, loss of biodiversity, depletion of natural elements and resources, and human health issues. At the basis of these problems are the rise in emissions of GHGs since the industrialization in the 19th century. Another matter is the increasing global population and the rise of developing economies such as China, India, and large parts of Africa. The rise of these economies, and their desire to prosper causes emissions to sky rocket, further worsening the environmental issues caused by emission of GHGs such as carbon dioxide (CO_2) and methane (CH_4).

Although CO_2 and CH_4 are considered two of the largest contributors to the greenhouse effect, they are not the only GHGs often considered in reports and publications. Next to CO_2 and CH_4 a considerable source of the greenhouse effect are the fluorinated gasses, such as Hydrofluorocarbons, Perfluorocarbons, Nitrous Oxides and Sulfur Hexafluoride (EPA, 2017b; IPCC, 2013). This report considers all the mentioned GHGs to create a more complete image of emission reduction potentials. Considering that the different GHGs do not have the same impact on the environment, common practice is to make it comparable by expressing it in a default value. This value is called the CO_2-equivalent (CO_2e) and makes it possible to express all emissions in CO_2 values. For example, CH_4 effects the environment between 28 and 36 times as much as CO_2. This ratio of effect is given by the *global warming potential (GWP)*, which often assumes the effect of the emitted GHG on the environment in 100 years (EPA, 2017a). In this thesis the GWP as used in the original sources is taken.

2.2 Paris climate accord

The imminent danger of rising average global temperatures was already recognized early on (Arrhenius, 1896; Plass, 1956), but relatively little attention has been given to the mitigation of this phenomenon. Now that the problem is becoming more apparent, countries all over the world are trying to cut back their GHG emissions to avert the further subsequent temperature rises. Although countries are currently trying to decrease their emission output, one could say it is too little too late and more efforts must be made to prevent the negative consequences of a warmer atmosphere. To that end an international agreement has been made. The agreement was drawn up during the 21st Conference of the Parties (COP21) to the 1992 United Nations Framework Convention of Climate Change (UNFCCC). This agreement was dubbed the Paris Climate Accord, the Paris Agreement, or the Paris Climate Agreement.

The goals of the Paris climate accord are formulated as follows (UNFCCC, 2015a)

- *Holding the increase in the global average temperature well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1,5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;*
- *Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;*

- *Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development*.

Additionally, the member countries opt to reach a global GHG emissions peak as soon as possible (UNFCC, 2015a).

The Paris Climate Accord was accepted and should go into effect when 55 countries that together represent 55% of the emission reduction signed and ratified the agreement. On 4 November 2016, the agreement became effective.

To reach the ambitious goal to stay ''well below 2°C temperature rise (..)'' and the even more ambitious ''1.5°C'' target each partaking country has made a pledge. As mentioned earlier the pledge of every country is called an *intended NDC* (INDC). Once the climate accord is ratified such a pledge is called an NDC. Out of the 197 countries present at the COP21, up until now 181 have ratified the Paris climate accord. The pledges vary per country and two different NDCs exist; the unconditional NDC and the conditional NDC.

When a country makes a pledge regarding emission reductions and they intend to do it regardless of what other countries do, or regardless of other factors such as help from other countries or external funding it is called an unconditional NDC. When a country makes a pledge that they will only strive to achieve with aid from other countries, in the form of financial or other help, it is called a conditional NDC. About 45% of all pledges that were submitted by countries on 25 December 2015 contained unconditional as well as conditional NDCs. Furthermore, around one-third of the proposals was fully conditional (Rogelj *et al*., 2016).

Although the NDCs are goals set out by the countries themselves, they are not in any way compulsory. In other words, if a proposed contribution is not met by the country that set it, there will be no legal, financial or other repercussions. This makes the system fragile. In May 2017, President Donald Trump of the United States (US) has declared that the US will withdraw from the Paris Climate Accord. This will make efforts to reaching the previously mentioned set-out goals of the accord even harder since the US is responsible for around 15% of the global emissions (EC, 2017a; World resources institute, 2014). According to Zhang *et al.* (2017), this diminishes the likeliness that the goals set out by the Paris climate accord will be reached and might even make these goals unachievable. In this manner, the agreement could start to fray, and might potentially lose its strength (Druzin, 2016). Individual countries can also be behind schedule when it comes to their climate targets and NDCs. So far only Morocco, and the Gambia are in line with their objective of staying well below 2℃ and even staying below 1.5℃ above pre-industrial levels. Most of the countries that are member states of the G20 are considered *Insufficient* and *Highly Insufficient* by the Climate Action Tracker (CAT) (2018).

2.3 The emission gap

Considering the large amount of countries that have ratified the Paris climate accord, and have submitted NDCs, conditional or unconditional, it is apparent that governments want to treat the environmental problems induced by global GHG emissions. However, it remains unclear as to how the future will look like in terms of emitted GHGs, and to what level the subsequent NDCs will be achieved. To illustrate the possible future GHG emissions worldwide various scenarios can be drafted. Rogelj *et al.*

(2016) portraits 6 different scenarios regarding global emission varying in climate policy and levels of achieved NDCs. The 6 scenarios that are described by Rogelj *et al.* (2016) are (UNEP, 2016; 2017):

- No-policy baseline scenarios
- Current policy scenarios
- INDC scenarios
    - Unconditional NDC scenario
    - Conditional NDC scenario
- Global warming mitigation scenarios
    - 2℃-scenario
    - 1.5℃-scenario

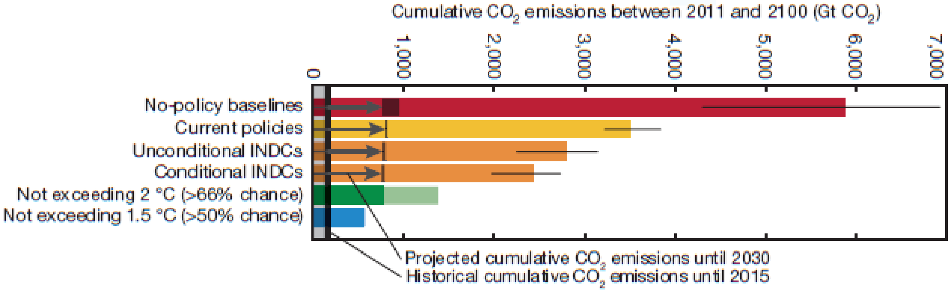

Figure 1. Cumulative global CO_2 emissions for six emission pathways. Source: Rogelj et al. (2016).

The *No-policy baseline scenarios* describe future emission projections that assume no new climate policies being put in place since the year 2005. These scenarios are founded on the findings of the IPCC AR5, and exclude climate policies (IPCC, 2014). They can, however, include energy efficiency and energy security policies. The *Current Policy Scenarios* are based on the most recent global emission estimates and include national policies (IEA, 2014; den Elzen et al., 2015; CAT, 2015). Both the unconditional and conditional NDC scenarios estimate the amount of emitted GHGs if NDCs are achieved. These estimates are based on a variety of global NDC analyses of nationally endorsed estimates that were submitted to the UNFCCC. Lastly, the first of the two *Global Warming Scenarios* are based on scenarios from the Intergovernmental panel on climate change (IPCC) fifth assessment report (IPCC, 2014) that have a greater than 66% probability of keeping global temperature rise well below 2℃ respective to pre-industrial levels, and the second one on is based on scenarios that have a greater than 50% probability of keepings global temperature rise below 1.5℃ respective to pre-industrial levels. Further, they assume that pledges under the UNFCCC Cancun Agreement are totally realized before 2020. The emission reductions are spread out over regions in the most cost-optimal way, also called least-cost. All scenarios express their annual emission estimates in billions of tCO_2e ($GtCO_2e$/year). Rogelj *et al. (2016)* goes on to create an image of the potential cumulative future global emissions for each of the different scenarios. This can be seen in Figure 1. The UNEP Emission Gap Report 2016 and the UNEP Emission Gap Report 2017, draw upon the scenarios sketched by i.e. Rogelj *et al.* and characterize the 6 pathways as can be seen in Figure 2.

Figure 2 shows a set of emission gaps. According to the UNEP 2017 report when taking the *Unconditional NDC* scenario and the *Conditional NDC* scenario as baselines, the emission gap with the pathway in which the temperature rise will stay well below 2℃, are estimated at 13.5 $GtCO_2e$ and 11 $GtCO_2e$, respectively. In the same way, when taking the same baselines but the 1.5℃ pathway as intended outcome, the respective reductions are 19 $GtCO_2e$ for the *Unconditional NDC* scenario and 16

GtCO$_2$e for the *Conditional NDC* scenario. Moreover, the UNEP 2017 report evaluated the emission gap when taking the CPS as a baseline and the greater than 66% probability of staying below 2℃ as well as the 50% probability of staying below 1.5℃ as possible outcomes. The projected emission gaps equal 17 GtCO$_2$e and 22.5 GtCO$_2$e, respectively. The CPS is used as a baseline instead of the *Unconditional NDC* scenario. This decision is based on several factors; the successful implementation of all the individual NDCs is uncertain. They are ambitious goals that are determined nationally, without a framework to reprimand if goals within the NDC are not completed. This makes it something to strive for at best, instead of something that must be done. Moreover, such as is the case with the US, countries can withdraw from the Paris accord and thus abandon their commitment to implement their self-set NDC (UNEP, 2017).

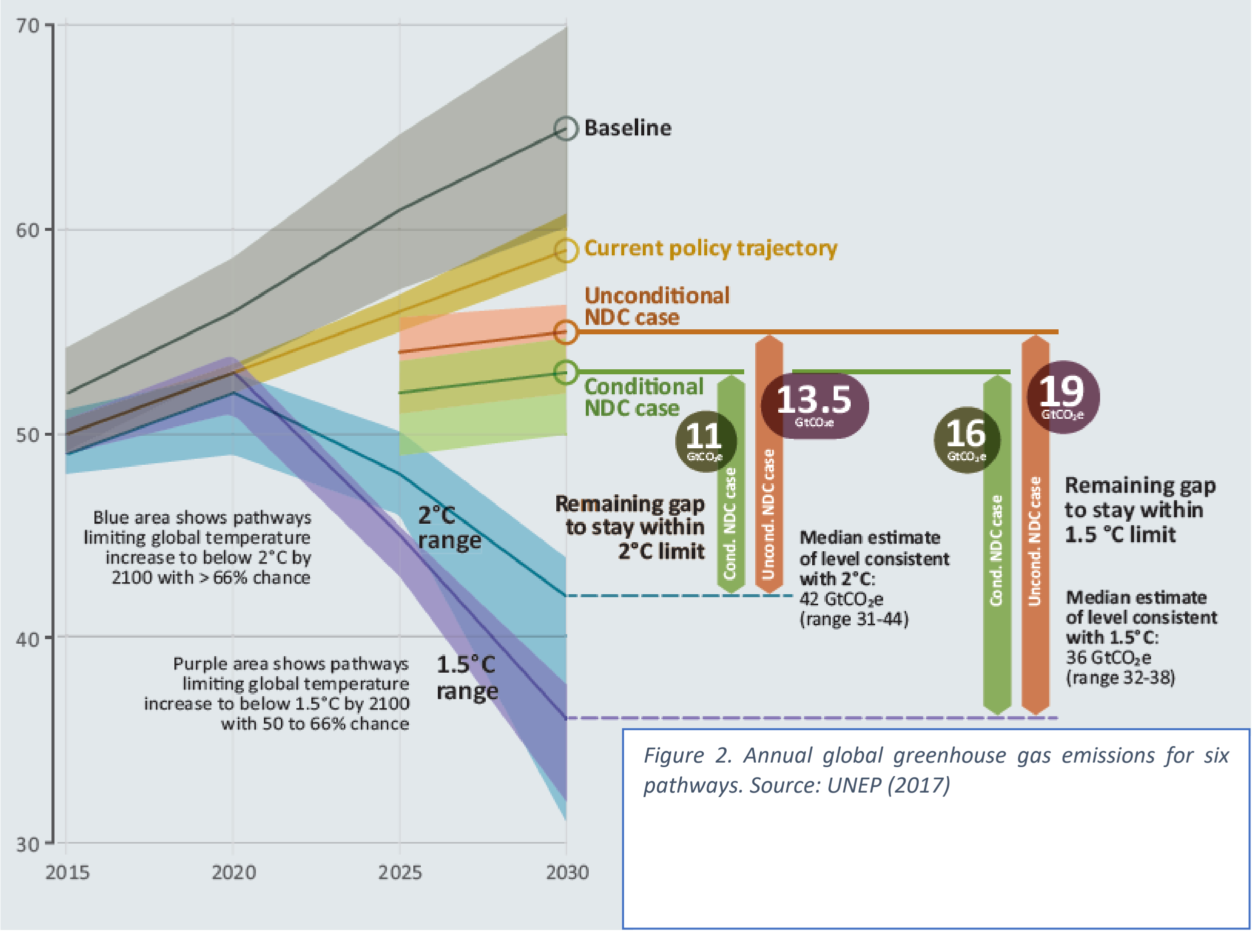

Figure 2. Annual global greenhouse gas emissions for six pathways. Source: UNEP (2017)

2.4 Bottom-up and top-down approach

The sectoral emission reduction potentials mentioned in the *Emissions Gap Report 2017* are also called bottom-up potentials. The bottom-up approach treats the components of a system separately and researches what is possible given the scope and the wanted outcome of the study. In the case of this thesis a sectoral and measure-wise literature study is conducted. This leads to emission reductions per sector leading to a global total for the selected measures. The bottom-up approach leads to a sub-divided, stepwise overview of emission reduction potentials, which can be visualized into marginal abatement cost curves (MACCs). McKinsey & Company (2009) was one of the first to utilize this method on a global scale with regards to GHG emission reduction methods. The World Bank and their Energy Sector Management Assistance Program (ESMAP) identified emission reduction possibilities using the MACC-method for the countries of China, India, Indonesia, Mexico, and the Republic of South Africa (ESMAP, 2012). Furthermore, MACC studies have been done for the countries Germany (Barthel *et al*., 2006), Ireland (SEAI, 2009), and the Netherlands (Blok *et al*., 1993). Moreover, a MACC was created for the extensive region of Europe (Blok *et al.*, 2001). There are only few publications producing a global MACC, however all publications suggest further efforts to be made towards the end of reducing GHG emissions (Ibrahim, 2016). There are two global MACC for the year of 2050 (IEA, 2008; Akashi & Hanaoka, 2012), one for 2030 (McKinsey, 2009), and one in response exhibits the effect of the financial crisis on carbon economics (McKinsey, 2010). Additionally, in the IPCC (2007) not a MACC was made, but a distinction was made between the mitigation potential below several economic thresholds.

In contrast with the bottom-up approach is the top-down approach. This often involves integrated assessment models (IAMs). IAMs are used simulations to model potential futures using scenarios with a wide range of variables. With regards to climate mitigation, IAMs use different scenarios with different climate change policies, so that governments and policymakers can see the (probable) consequence of a change in policy. IAMs concerning climate change contain economic and natural processes that add to the emission of GHGs such as CO_2. Although all IAMs project the effect of these GHGs on the earth as a system, they differ greatly from one another. This is due complexity, number of variables and the size of the model (Weyant, 2017). The main difference between the bottom-up and the top-down approach when comparing them to one another, is that the bottom-up approach is fundamentally focused on solution finding, while top-down approaches were made to describe changes at market level due to, for example, a change in price of variable X or Y at given levels of GDP. The bottom-up approach asks the question how little energy can be cost-effectively used to provide a given level energy services, while the top-down approach asks what the relation is between price and demand. It can be concluded that top-down models have trouble finding alternatives, while bottom-up models cannot describe market interactions very well (Wilson and Swisher, 1993). In this thesis, the approach used is the bottom-up approach since the technical and financial mitigation potential of using alternative policies or sources of energy are deduced. Furthermore, market indicators are not considered in this thesis. Lastly, the focus is on several measures in different sectors which differ in market size and market dynamics. For these reasons, the choice has been made not to use the top-down approach.

Once the emission reduction potentials are found for the different sectors using the bottom-up, they can be compared with the emission gap discussed earlier. This will give insights into the reachability of the targets set in the Paris Climate Accord.

3. Scoping

As outlined previously in the introduction, the *Emissions Gap Report 2017* discloses mitigation potentials on a global scale, which offers policy makers insights in to where the potentials mostly lie. However, what is does lack is regional specificity so that policy makers and companies can make a more tailored approach towards reaching the Paris climate agreement.

3.1 The group of 20 and the regions of the world

Considering the lack of knowledge regarding sectoral emission reduction potentials on a national level, it is useful to try and fill in this gap to aid policy makers, investors and others in determining where the potentials for GHG emission reductions are situated. In this report the countries of the G20, including the European Union (EU) are evaluated. This is relevant due to the sheer combined size of these countries as a group when looking at GDP, population, land area, and overall world trade. The countries that belong to the G20 are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, The Russian Federation, Saudi Arabia, Republic of South Africa (RSA), South Korea, Turkey, The United Kingdom (UK), the United States of America (US) and the EU (G20, 2018). In Figure 3, the members and guest countries of the G20 are indicated. This figure, shows the members, members of the EU, and permanent guest countries Spain and Chile, which will not be considered.

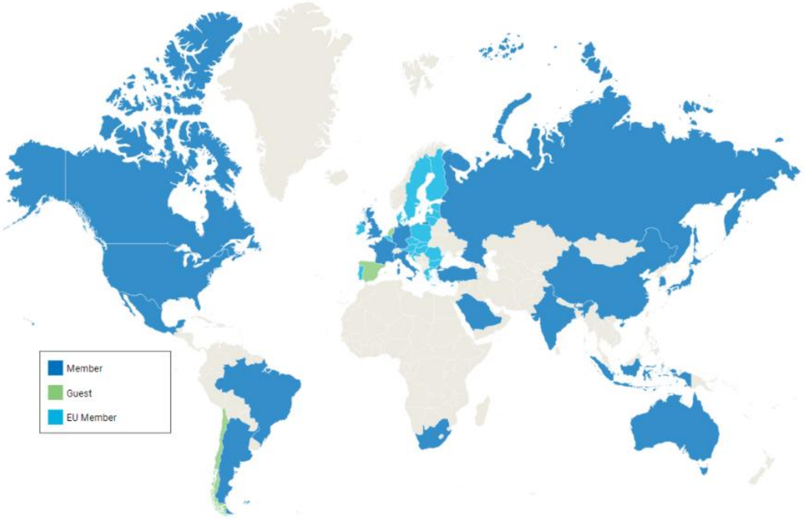

Figure 3. Members countries and guest countries of the G20. Source: G20.

Next to the geographical focus on the member countries of the G20, the focus will be directed at the world regions in which these G20 member countries are situated. To illustrate this with an example, Argentina, Brazil and Mexico are member countries of the G20 situated in Latin America. The other countries situated in Latin America will not be treated individually but will be included under the grouping Latin America. With regards to Northern America, this does not apply since Canada and the US are both member states of the G20. Furthermore, it also doesn't apply to the EU since it is itself a member state (G20, 2018).

The grouping of countries into a certain area gives rise to debate, as countries can be coupled according to several different variables such as geographic orientation, religion, culture, and GDP. Throughout literature, in the field of climate mitigation and in general, the division of the world has not been subject to a unilateral decision, which results into a variety of different thoughts as to which country belongs where. Countries or regions which mostly offer problems with regards to their ‘’whereabouts’’ are amongst others:

- The division of South and Central America.
- The bundling of South and Central America into a Latin America, that either does or does not include Mexico.
- The allocation of North African countries to the continent Africa or to the Middle-East due to lingual, cultural and religious patterns. The combined area is often dubbed Middle-East and Northern African (MENA).
- The European Union and Europe are two different things and encompass different countries.
- Turkey is often a country of debate since it can both belong to Europe but also to Asia. Sometimes the country is even split into two separate parts and is seen as a bridge between both continents.
- Russia is such a large country that it is a geographical part of Europe in the west but is mostly situated in Asia. However, most of the industry and the largest cities of Russia are situated in the West, adding to the difficulty of grouping it to one of the two continents.
- The division between Asia, Europe and the Middle-East is not always clear. As mentioned above, Turkey is often problematic. However, also several other countries such as Afghanistan, Georgia, Azerbaijan, and Armenia are often the matter of dispute.
- The Middle East is conventionally comprised out of countries surrounding the Arabian Peninsula. As previously mentioned, countries such as Afghanistan and Turkmenistan are sometimes included into the region Middle-East but are mostly considered Asian.
- The Middle East can be treated as a part of Asia.
- Due to its sheer size and population number, China is sometimes considered by itself.
- Greenland is often not considered since it is mostly uninhabited and well within the polar zone.

With the above in mind it is better to determine the boundaries of the world in advance, to prevent confusion and to manage expectations. The goal in this thesis is to give an image on sectoral emission reduction potentials in 2030 for G20 member countries and the regions they are in. For that reason, it is necessary that there is a G20 member state present in each of the treated regions. Furthermore, the regions used in this thesis should represent the entire world when they are combined, leaving no countries out of consideration, unless otherwise stated as is the case with Greenland. Lastly, the following division into regions is maintained when the regional data on a national level is available or when the data can be deduced using certain variables. If this is not possible it will be mentioned, and another division of the world will be given.

Looking at Africa, the RSA is the only G20 member state within the continent. Regarding the Americas, the decision has been made to combine South America with Central America, Mexico and the Caribbean so that a Latin America is formed. This decision has been made based on the region having similar linguistic, cultural, religious and economical traits. Moreover, Central America and the Caribbean have no representative G20 member states and must be allocated to South America. This automatically means that North America is comprised out of Canada and the United States. The European Union is comprised out of 28 countries and is further described as the EU. Europe however, is comprised out of more countries and the border with Asia is drawn at the Caucasus. Europe is comprised out of the countries West of Russia, North of the Caucasus, and west of Turkey. The Middle East and South East Asia will be treated by themselves and will thus not be included in the grouping *Asia*. Asia in turn will consist out of Russia, Continental Asia, including i.e. China, India, Pakistan, Kazakhstan, Turkmenistan, but also pacific countries such as Korea and Japan (Douglas, 2008). Additionally, Turkey will be added to Asia. Oceania will be comprised out of the Islands in the pacific as well as Papua New-Guinea, New Zealand and Australia. In Table A1 (Appendix A) the total overview of regions with the subsequently included countries can be seen.

3.2 Selected climate mitigation measures

Climate mitigation can be done in a large variety of ways which differ greatly from one another. That is the reason why publications in the environmental mitigation research field differ greatly from each other when it comes to the measures that are assessed. For example, the previously mentioned source *Emissions Gap Report* (UNEP, 2017) and Griscom *et al.* (2017), both assess mitigation potentials. However, the former assesses measures in the world largest six sectors, while the latter only considers ‘’natural’’ mitigation measures which are strongly related to agriculture and/or forestry. Moreover, even the measures that are mentioned in the agriculture or forestry sectors in UNEP (2017) differ from the measures evaluated in Griscom *et al.* (2017). To this end, the decision was made to use the most recent, and complete publication as a leading document with regards to the measures and sources involved in sectoral climate mitigation potentials. The *UNEP Emissions Gap Report 2017* consists of the most recent data that was compiled and contributed by leading authors in all the sectors, as well as leading institutions and organizations in the field of climate mitigation. For this reason, the measures as stated in the *Emissions Gap Report 2017* will be used in this thesis.

In the *Emissions Gap Report 2017* the global sectors are divided into climate mitigation measures, in total all sectors combined cover 39 climate mitigation measures. The *Emissions Gap Report 2017* found, using the bottom-up method, that the goals set by the Paris climate accord can be met with the appropriate measures. Moreover, they found that only six of the in total 39 measures combined can attribute more than half of the mitigation potential needed to bridge the emission gap. These measures are solar energy, wind energy, efficient appliances, efficient passenger vehicles, afforestation, and stopping deforestation.

As mentioned in the Introduction chapter, the measures that are stated in the *Emissions Gap Report 2017* are not relevant for all the countries in the world. For example, in China the potential for GHG emission reduction for rice land management is potentially relatively large, whereas the same potential in the Netherlands is virtually zero. Moreover, all six sectors of the *Emissions Gap Report 2017* combine to a total of 39 measures. With that in mind, the decision has been made to downsize the total number of measures considered in this thesis considerably so that emphasis can be placed on the most significant measures in the *Emissions Gap Report 2017* and so that consideration is given to the timeframe of this research. This led to development of several options regarding the selected climate mitigation measures treated in this thesis. The options are listed below:

1. Treat all the measures mentioned in the *Emissions Gap Report 2017* of which regional data was found
2. Treat the six measures that are largest according the *Emissions Gap Report 2017*

3. Treat the biggest measure of every sector mentioned in the *Emissions Gap Report 2017*
4. Treat the biggest measure of every sector mentioned in the *Emissions Gap Report 2017*, plus the six largest according to the *Emissions Gap Report 2017*

To decide which measures to evaluate, all the different sources that were used in the *Emissions Gap Report 2017* were analysed extensively to establish if these sources only considered global data or if they contain data that is usable on a regional scale, i.e. for a single or a set of specific countries. After having analyzed over 40 scientific sources, coming from leading authors, organizations, and institutions it was possible to clearly see for which measures regional data was available that was ready to be used. This insight was used in the first step of the downsizing of the total number of measures and shrunk the total number of measures from 39 to 19 measures. The availability of regional data was combined with the possible options mentioned above. This led to the conclusion that, if completed, option 4 would give a good image of where the mitigation potentials would lie in the G20 and would also be possible with regards to the availability of regional data, and within the research' timeframe.

Table 1. The set of sectors and their subsequent mitigation measures treated in this thesis.

Sector	Measure(s)
Agriculture	cropland management, peatland management
Buildings	efficient appliances and lighting
Energy	solar PV, wind energy
Forestry	reforestation, reducing deforestation
Industry	energy efficiency - direct
Transport	efficient light duty vehicles

For agriculture, the measures *cropland management* and *peatland management* are assessed. For the sector buildings, the measure *efficient appliances* is evaluated. In the process of evaluating the efficient appliances measure, the data for the sub-measure *Lighting* was also found. This measure is thus also evaluated in this thesis. Further, with regards to the sector energy, the measures *solar PV* and *wind energy* are discussed. After energy, the sector forestry and its measures *reforestation* and *reducing deforestation* are dealt with. Additionally, the measures *energy efficiency – direct* and *efficient light duty vehicles* are analyzed, for the sectors industry and transport, respectively. This leads to a set of 9 mitigation measures spread across six sectors, shown in Table 1.

3.3 Cut-off price for mitigation potentials

After the selected climate mitigation measures are chosen some more assumptions need to be made regarding the overall mitigation potential. For each of the measures a methodology will be used which can differ from the other measures. However, for all the measures analyzed in this thesis the same financial assumption is made to create a level playing field and realistically see what is possible when the same financial threshold is used. In recent publications regarding emission reduction potentials attention has, logically, only been given to technologies or measures that are also economically viable. This is done from the notion that if it is overly costly the measure will most likely not be implemented successfully. With that in mind, the cut-off price for these technologies and measures is often established at \$100/tCO_2e. This threshold was chosen since it is used in several comparable publications by UNEP (2015; 2016; 2017) and Griscom *et al*. (2017).

4. Agriculture

In this chapter, the sector agriculture will be discussed. The measures within the sector agriculture of which regional data was available and thus are evaluated for their mitigation potential are *cropland management* and *peatland management*. First, the focus is on the sector itself, after which cropland management will be discussed. The activities within cropland management are explained and the emission factors used in the analysis are given. Then, the term cropland is defined after which the growth rates and the technical mitigation potentials are calculated. Lastly, the economic mitigation potential for 2030 is calculated and shown. The term peatland is explained, as well as the methodology used in calculating its mitigation potential. Finally, the mitigation potential of peatland management in 2030 is given.

4.1 Extent of the sector

The agricultural sector is mainly responsible for the emission of greenhouse gasses other than CO_2, such as N_2O and CH_4. USEPA (2012) estimates that agricultural soils in 2030 are responsible for the largest amount of emitted N_2O, which is equal to around 2.48 $GtCO_2e$. Additionally, rice cultivation is estimated to lead to 0.51 $GtCO_2e$ in 2030. Furthermore, enteric fermentation in livestock contributes largely to the total emission in the agricultural sector. Livestock in 2030 emits CH_4 amounting to around 2.35 $GtCO_2e$. Additionally manure management leads to the emission of CH_4 as well as N_2O, which results in the emission of approximately 0.38 $GtCO_2e$. The burning of savannah and other agricultural waste or residues leads to mostly CH_4 emissions which add up to around 1.18 $GtCO_2e$ in 2030 (UNEP, 2017).

Peatland related emissions, due to degrading peatland or peatland fires, are often overlooked but arguably represent a large portion of agriculture's total emissions. The degradation of peatland and the subsequent emissions amount to around 1.6 $GtCO_2e$ per year on global scale (Tanneberger & Appulo, 2016). Moreover, peatland fires are estimated to emit around 0.3 $GtCO_2e$ per year. This is, however, variable on an annual basis. Adding these emissions will results in the estimated extent of the agriculture sector's emission in 2030. The total amount of emissions in 2030 is around 8.9 $GtCO_2e$, when peatland and the therewith belonging emission are included. Leaving these emissions out of perspective will result into a total of 6.9 $GtCO_2e$.

The amounts of emissions that potentially could be mitigated in the agriculture sector differ greatly from source to source. The potentials for the agricultural sector range from 0.26 $GtCO_2e$ to 4.6 $GtCO_2e$ in 2030. In this thesis, as mentioned previously, the measures that are treated are cropland management and peatland management. With regards to cropland management Smith (2008), estimates a mitigation potential in 2030 of 0.74 $GtCO_2e$. For both cropland management and peatland management an abatement cost lower than \$100/tCO_2e is assumed (McKinsey, 2011).

4.2 Cropland management

Before the mitigation potential for the measure cropland management is estimated it is important to define the meaning of cropland management, what measures or activities are considered, and what types of land cover are counted towards this category.

4.2.1 Methodology and assumptions

Cropland management is the umbrella name for a set of activities that are described by the IPCC (2007) and the *Emissions Gap Report 2017*. The main source concerning cropland management is Smith (2007). Smith sub-divides the measure cropland management into the following activities:

- Agronomy: practices that increase yields and increase the possible carbon inputs, thus leading to higher soil carbon storage, such as CO_2. Examples of such activities are extending crop rotations, using improved crop varieties, using cropping systems with reduced reliance on fertilizers, pesticides or other inputs.
- Nutrient management: practices that increase nitrogen use efficiency, taken from fertilizers, manures and biosolids. These include i.e. adjusting application rates to precise need estimates for a specific crop. Using slow- or controlled-release fertilizers or nitrification inhibitors, which reduce the formation of greenhouse gas N_2O.
- Tillage/residue management: Include practices that reduce the amount of soil disturbance, since that leads to soil carbon release. Due to advancements in weed control, it is now possible to produce crops with a minimum amount of tillage or even no tillage. Furthermore, retaining crop residues or avoiding the burning of residues reduces emissions. In some areas, no-tillage can lead to overall reductions of emissions, but in some areas, this can be the opposite. This type of cropland management is very dependent on the soil.
- Water management: the use of irrigation in the production of crops can increase the storage of carbon in the soil via increase yields and residue returns. Of course, water-management can only be applied to regions or areas where sufficient water is available. Water-management can also include the drainage of cropland lands in humid regions.
- Rice management: cultivated rice lands emit significant amounts of the greenhouse gas methane (CH_4). Practices within this measure include i.e. draining the rice land once every while during the growing season. Furthermore, in the off-season, keeping the ground as dry as possible and avoiding water logging can lead to emission reductions.
- Agroforestry: land-use management systems that plant trees, shrubs, and other bushes around cropland or a pasture make use of agroforestry. This type of land use management has some significant benefits compared to land-use systems in which this is not done. The benefits include increased biodiversity, reducing soil and land depletion, and increased drought-resistance. Moreover, it aids in climate mitigation due to the soil being able to sequestrate more carbon (Jose, 2009).
- Set-aside, land-use change: This concerns allowing or actively stimulating the conversion of cropland back to its natural vegetative state or another type of land that has a more environmentally friendly nature, due to the increased carbon sequestration potential. For example, letting an area of cropland be converted to a marsh or swamp like area will lead to higher carbon uptakes (Smith, 2007).

Smith (2007) goes on to say that these options were applied to total cropland areas, minus those under rice cultivation, irrigation, set-aside, or on organic soils or degraded lands. This is done because these lands are already undergoing mitigation and the activities are not able to co-exist. Thus, the mean of emission factors of the activities *agronomy, nutrient management, and tillage/residue management* is applied to 95% of the cropland. The activity *Improved biosolids* is applied to the other 5% of land.

According to Smith (2007) the area of cropland is build up as follows. Smith takes the thermal zones dataset from FAO GAEZ (2012) database as a basis, and sub-divides the planet into *warm* and *cool* for (sub-)tropical zones and temperate zones, respectively. The areas classified as *boreal* and *Arctic* by the *Food and Agriculture Organization Global Agro-Ecological Zones (FAO GAEZ)* are not included within the analysis since the amount of cropland is limited within these climate zones (Smith, 2007). Smith goes on to further divide the planet into *dry* and *moist*. The dry areas are subjected to severe moisture constraints or moisture constraints. The subsequent divisions of the world into climate zones yields 4 different outcomes; *Cool-dry, cool-moist, warm-dry, warm-moist*. Additionally, he provides emission factors for three greenhouse gasses (CO_2, CH_4, N_2O) for a range of climate mitigation activities, including the activities linked to cropland management mitigation. These emission factors are based upon a variety of different publications. For cropland management, these emission factors are mainly based on the work of Ogle *et al.* (2005) and IPCC (1997, 2003). The resulting emission factors are given for *Mean*, *High*, and *Low* pathways. In this paper, these emission factors are maintained for the measure cropland management as they illustrate the difference between climate zones, are relatively recent, and are used in the *Emissions Gap Report 2017*. To calculate the total and regional technical cropland management mitigation potential the emission factors, need to be multiplied with the corresponding amounts of (crop)land. The emissions factors are given in Table C1, in the appendix.

In the FAOSTAT (FAO, 2017) database land use data is given. The cropland relevant subdivision of land use is:

- Arable land
- Permanent crops
- Permanent meadows and pastures
- Agricultural area actually irrigated
- Total area equipped for irrigation
- Agricultural area

The two categories *Agricultural area actually irrigated* and *Total area equipped for irrigation* are eliminated due to them being water management, which is not take into this analysis. Furthermore, the *Permanent meadows and pastures* is removed because it is defined in the following way:

> *''Permanent meadows and pastures is the land used permanently (for a period of five years or more) for herbaceous forage crops, either cultivated or naturally growing. A period of*

FOOD AND AGRICULTURE ORGANIZATION (FAO)

The Food and Agriculture Organization of the United Nations, also known as FAO, created an interactive database called FAOSTAT that gives information on a set of different topics, such as Agricultural Production, Trade, Agri-environmental Indicators, Emissions from agriculture, and Forestry. With FAOSTAT it is possible to gain insight into, for example, historical data with regards land use, land cover, and livestock patterns for countries, regions or special groups such as the European Union or the OECD. The FAO also created another interactive database called Global Agro-Ecological Zones, also known as GAEZ. Here they focus on 5 themes: Land resources, suitability and potential yield, agro-climatic resources, actual yield and production, and yield and production gasps. GAEZ shows their data on global maps. In this way, for example, they show annual average temperatures and climate zones.

> *five years or more is used to differentiate between permanent and temporary meadows.'' –*
> *FAO, 2017*

In this manner ''agricultural area'' is also ruled out because it entails the previous category, ''permanent meadows and pastures''. This leaves two categories to be relevant in this research. This are the categories ''arable land'' and ''permanent crops''. Arable land is land that is under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow. The abandoned land resulting from shifting cultivation is not included. Additionally, the permanent crops category is the land cultivated with long-term crops which do not have to be replanted for a period of several years. It also includes land under trees and shrubs producing flowers, and nurseries. Using the FAOSTAT database it is possible to combine the categories arable land and permanent crops and to derive the amount of land that they cover as a percentage of the total land area, on a national level. In this research, the combination of arable land and permanent crops, as proposed by FAOSTAT, is the area relevant for the measure cropland management.

In the 2015 United Nations demographic yearbook (UN, 2016) the total land area of each country is given. Combined with the data taken from the FAOSTAT database for the year 2015 it is possible to calculate the total amount of hectares that are eligible for cropland management.

The climate zone in which the cropland is situated, determines the emission factor as was explained above and can be seen in Table C1. The climate zone that each country is in, is determined using the previously mentioned FAO AEZ thermal zones dataset.

Before an estimate of the cropland management mitigation potential can be given the total amount must be adjusted to reflect the amount of cropland in 2030. Smith (2007), and thus *Emissions Gap Report 2017* use the growth rates given by Strengers *et al.* (2004), which based them on the IPCC scenarios (2001). Due to them being relatively outdated the decision was made to use the growth rates as described by Lambin & Meyfroidt (2010). In this publication, the amount of cropland in 2000 and the projected amount of cropland in 2030 are given for two situations; low, and high. An addition has been made to take the average between the low and high situations to compromise the two values. A second addition has been made to include the estimate for the year 2015. For this the growth between 2000 and 2030 is assumed to be linear for both the *low* and *high* pathway. Because 2015 is precisely between 2000 and 2030, the value for 2030 can be multiplied with half of the estimated growth rate. The results are then compared with the outcome of the calculation for eligible cropland in 2015 using the UN census and the FAOSTAT database. The values calculated for the year 2015, are acceptably in line with the estimations made by Lambin & Meyfroidt (2010), though, their growth rates differ. Therefore, the mean is taken of the two growth rates, from 2015 to 2030. This yields an average projected growth rate of cropland area from 2015 to 2030. It is assumed that the growth in cropland is evenly distributed over the globe for simplicity. The growth rate is shown in Appendix C2.

4.2.2 Cropland management mitigation potential

To get the global or regional mitigation potential all the above needs to be combined. First the national calculated cropland for the year 2015 is multiplied with growth rate calculated for the years between 2015 and 2030. The resulting area is then multiplied with the emission factor given by Smith (2007) according to the climate zone the country is in. This will give technically possible mitigation potentials on a national level. For regional or global mitigation potentials, the corresponding national mitigation potentials need to be added. For example, for the mitigation potential of North America, the national mitigation potentials of the US and Canada need to be added.

The largest technical regional cropland mitigation potential for the year 2030 is in Asia. The three countries with the largest mitigation potential in Asia are India, China and Russia with 171 $MtCO_2$, 141 $MtCO_2$, and 110 $MtCO_2$, respectively. Asia is followed by Africa, in which Nigeria has the largest mitigation potential. For North America, the mitigation potentials of the US and Canada are 141 $MtCO_2$ and 45 $MtCO_2$, respectively. In Latin America, all three of the G20 member states are in the top three of countries with the highest mitigation potential. In Europe, the country with the highest mitigation potential is the Ukraine, followed by France, Spain, and Germany. With 44 $MtCO_2$ mitigation potential in 2030 Indonesia has the largest cropland mitigation potential in South-East Asia. Australia and Oceania, and the Middle East offer the smallest mitigation potential when it comes to cropland management.

The total technical mitigation potential of the G20 member states combined, without the individual EU member states mentioned previously, is around 908 $MtCO_2e$. This is equal to around 68% of the global technical mitigation potential. Additionally, the top 5 of countries with the largest technical mitigation potential in 2030 are India, the US, China, Russia, and the EU.

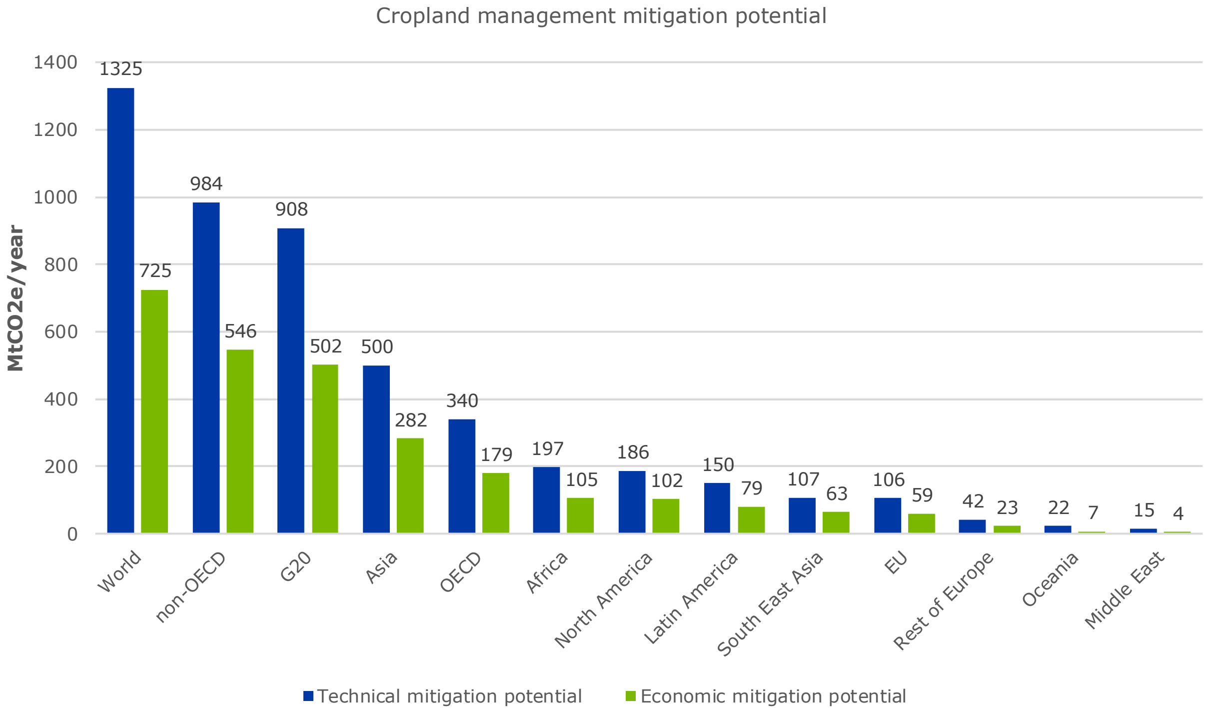

Figure 4. Cropland management mitigation potential in 2030 for the world's regions.

To get the economic mitigation potential on a regional or global level, the technical mitigation potential needs to be adjusted to below the previously determined maximum threshold of $100/$tCO_2e$. The further methodology for determining the economically feasible mitigation potential is taken from the publication of Smith (2007). Using US-EPA (2006) MACCs for various regions and activities the mitigation potential is reduced from around 1325 $MtCO_2e$ to 725 $MtCO_2e$ for activities below $100/$tCO_2e$. The global mitigation potential in this research will be of the same magnitude when only measures below

$100/tCO₂e are considered. However, there will be regional differences according to factors such as temperature, rainfall, and mitigation potentials per hectare. Effectively, differences will exist between climate zones.

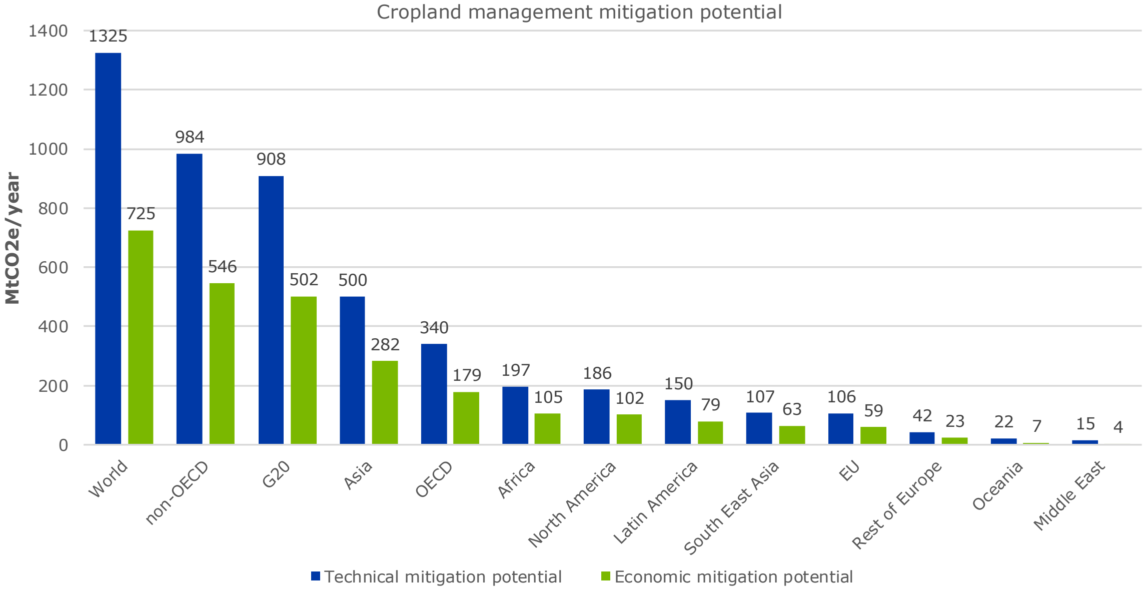

Figure 5. Cropland management mitigation potential in 2030 for the G20.

When looking at the technically feasible mitigation potential of cropland management 34.2%, 9%, and 56.8% is represented by climate zones *cool-moist, warm-dry,* and *warm-moist*, respectively. These values are then multiplied with the corresponding emission factor given in Table C1, to create a weighted emission factor reflecting the relative occurrence. The next step is to add these weighted emission factors, to get the average emission factor used in the analysis. After that, the share of the individual weighted emission factor per climate zone in the average emission factor is calculated, which is then multiplied with the fraction of economic mitigation potential as calculated by Smith (2007). The resulting value is then divided by the climate zones technically feasible mitigation potential as calculated in this analysis. This gives a percentage which represents the amount of the technically feasible mitigation potential that will remain in a climate zone after the threshold of $100/tCO₂e is applied.

As can be seen in Table C3, the threshold of 100$/tCO₂ has a stronger effect on the mitigation potential in climate zone warm-dry. This is most likely due to the dry aspect of the climate zone and effectively has effect on the Middle East, the Northern African area, and Australia. Additionally, due to the climate, the technological mitigation potential in these areas is relatively low when compared to the technical mitigation potentials of climate zone cool-moist and warm-moist.

The results generated in this section are based on numerous assumptions regarding i.e. cropland growth rates, climate zones and emissions factors creating uncertainty in the results. Moreover, the use of the MACC by US-EPA (2006) adds to this uncertainty due to the source's age. Although, these assumptions make the results somewhat uncertain, they do reflect realistic values of the potential of cropland management mitigation potential in 2030. This can be seen when the global mitigation potential of 0.73 GtCO₂e, seen in Figure 4 is compared to the results found in the *Emissions Gap Report 2017.* In that report the global mitigation potential for cropland management in 2030 was estimated to be 0.74 $GtCO_2e$

The found technically and economically feasible mitigation potentials for the measure cropland management are given for the G20 and the worlds' regions in Figure 4 and 5, respectively. Moreover, Table B1 and Table B2 contain the detailed results for the found mitigation potentials of cropland management. The total global cropland mitigation potential that is financially achievable below $100/$tCO_2e$ in 2030 is around 725 $MtCO_2e$. This potential is mostly situated in non-OECD countries and G20 member states. Again, Asia has the highest mitigation potential which is largely due to India, China and Russia. Asia is followed by Africa and close behind that by North America, with around 105 $MtCO_2e$ and 102 $MtCO_2e$, respectively. Overall, the same trend can be seen when comparing it to the technically feasible cropland mitigation potential for 2030. Additionally, this mitigation potential is in line with the mitigation potential of 740 $MtCO_2e$ for cropland management as was described by Smith *et al.* (2008).

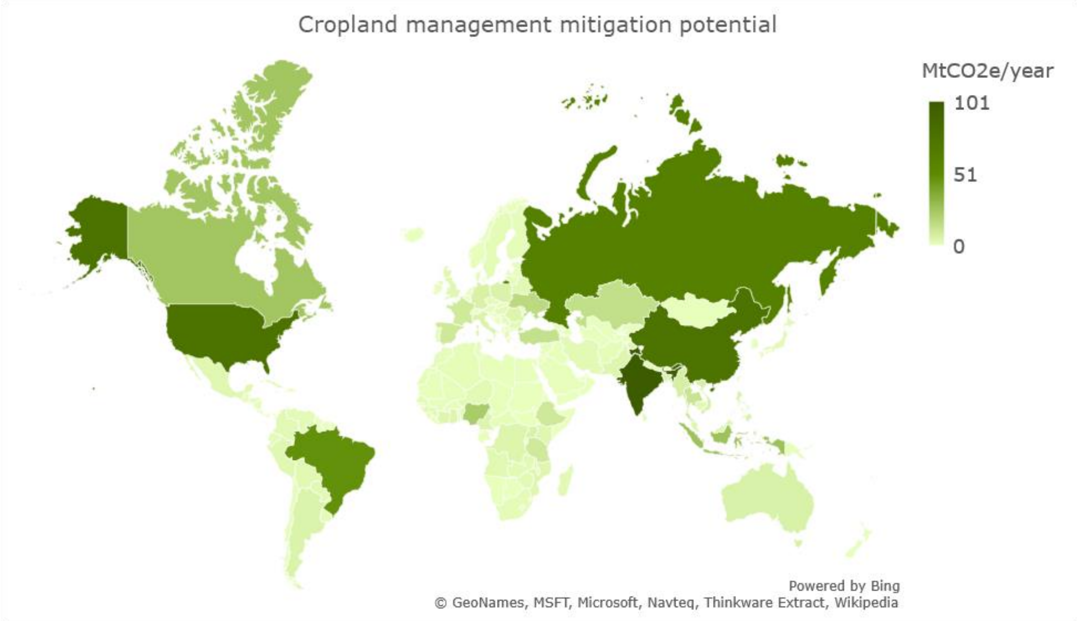

Figure 6. Map of cropland management mitigation potential in 2030.

The same goes for the individual G20 member states, shown in Figure 5, when comparing the economically feasible mitigation potential for 2030 to the technical mitigation potential. India is the country with the largest mitigation potential of around 101 $MtCO_2$. The US and China are close to one another at around 77 $MtCO_2e$ and 75 $MtCO_2e$, respectively. Russia has the fourth largest potential at 60 MtCO2e and is followed by the EU which has a mitigation potential of 59 $MtCO_2e$.

In Figure 6, the found economically feasible cropland management mitigation potentials are showcased in a map of the world. The darker green a country is, the higher its cropland management mitigation potential. Again, it is clearly visible the largest potentials lie in India, the US, China, Russia and Brazil. It is also visible that the total mitigation potentials are lowest in Saharan Africa and The Middle East, as well as in the northern European countries such as Sweden, Finland, and Norway.

4.3 Peatland Management

Another significant source of greenhouse gasses within the agriculture sector is the annual released flux of greenhouse gasses by peatland. Peatland is organic soil that, when drained or dried, starts releasing greenhouse gasses, i.e. CH_4.This happens due to microbial oxidation, and will continue until the organic soil is rewetted or until there is nothing left to oxidize, and the peat is thus lost (Bonn *et al.,* 2014). Additionally, peatland fires create a substantial greenhouse gas emitting flux. Peatland fires can be prevented easily by effective rewetting of the peatland, and by assigning economic value to the soil (Joosten *et al.*, 2012). Peatland fires, however, will not be included into this thesis.

4.3.1 Methodology and assumptions

A method is constructed to calculate the mitigation potential of peatland management. The results of this method are then compared to a literature source which gives the mitigation potential of peatland management in 2030. This source is Griscom *et al.* (2017). The calculation method combines the data regarding the amount of peatland on a national level, given by Joosten *et al.* (2010) and combines that with the emission factors for organic soil restoration given by Smith (2007). These emission factors are dependent on the climate zone that the country in question is in.

After the results of the calculations done was compared with the data given in Griscom *et al.* (2017), a significant discrepancy was seen. This led to the question how such a difference in both methods could exist. The foremost problems could be a large difference in emission factors used, and differences in climate zone grouping. Since Pete Smith, the lead author of the work used in the calculations method, was also involved in the Griscom *et al.* (2017) publication, personal contact was made regarding the discrepancy between both methods. Mr. Smith, who is one of the leading experts regarding agriculture climate mitigation, concluded it was best to use the most recent and elaborate paper: Griscom *et al*. (2017), since it was contributed by all the world leading experts, and had access to more recent and accurate emission factors (P. Smith, personal communication, 20th of April 2018).

The literature source used, which gives the mitigation potentials of peatland management for 2030 on a national level, is the work of Griscom *et al.* (2017). In this work, the mitigation potential of several natural climate solutions (NCS) is given. Two of these NCS regard climate mitigation for peatland management; *Avoided peatland impacts* and *Peatland restoration.* The potentials for both these measures are given on a national scale for all countries, including several maps on which the mitigation potential is mapped according to color schemes.

For the sub-measure *avoided peatland impacts*, a distinction is made between the emissions that are the result of the conversion of peatland in different climate zones; boreal, temperate, and tropical. For each of the three climate zones the annual conversion rates and annual emission rates are calculated. Subsequently, it is possible to determine the total emission coming from peatland conversion over a period, which is assumed to be 20 years. This is done by using the International Mire Conservation Group Global Database (IMCG, 2018; Greifswald Mire Centre, 2018). The peatland area per climate zone is gathered after which the change of intact peatland, and thus the rate of decrease, between 1990 and 2008 is calculated. The calculation is further based on the assumption that all peatland until a depth of one meter would be converted, and thus all carbon soil and biomass carbon stored within this peatland would be emitted. The country specific per area emission rate is calculated using the work of Joosten (2010) which offers data for degraded peatland areas and their emissions in 2008. This is then converted into an annual per area emission rate per climate zone, using the weighted averages of these country specific annual per area emission rates. In this way it is possible to calculate the annual emissions on a global scale. Griscom *et al.* (2017) present their results in a table including almost all countries.

For the sub-measure *peatland restoration*, again, the publication by Joosten (2010) is used to estimate the extent of degraded peatlands to which peatland restoration could be applied. The data in Joosten (2010) is given on a national level. Moreover, a choice has been made to omit a benefit of peatland restoration due to disagreement within literature. Additionally, peatland growth rates were added to soil sequestration area. This area of extent is then multiplied with the emission factors as given for the sub-measure avoided peatland impacts. This is then divided by the 20-year timespan to get the 2030 mitigation potential on a national and global scale.

4.3.2 Peatland management mitigation potential

Now that the decision is made to use the data as given by Griscom *et al.* (2017) and the methodology is discussed, the data given by Griscom *et al.* (2017) is rearranged so that they fit the regions as they are in discussed in chapter 3, given in Table A1. Griscom *et al.* (2017) give the mitigation for two types of peatland management sub-measures. Peatland restoration is the rewetting of degrading peatland so that it stops oxidizing and stops emitting greenhouse gasses such as CH_4 and CO_2. Avoiding peatland impacts is preventing the degradation of peatland in the first place, by preemptively rewetting the peat area. Additionally, in the approach of Griscom *et al.* (2017), the technical mitigation potential is given on a national basis. However, the mitigation potential that is possible to achieve at or below \$100/tCO_2e, is only given on a global scale. Globally 90% of the technical mitigation potential of avoiding peatland impacts is achievable below 100\$/tCO_2e. Likewise, 48% of the technical mitigation potential for restoring peatland remains when below 100\$/tCO_2 (Griscom *et al.*, 2017).

When processing the data given by Griscom *et al.* (2017) the mitigation potentials of several countries seemed to be significantly too high or too low. Direct contact with the authors has led to the discovery that these data points were indeed incorrect and were too high or too low. The mitigation data had been assigned to the wrong country is several cases. After a brief period, the correct data was given (B. Griscom, personal communication, 17th of May 2018).

In Figure 7 and 8, the found results are displayed. The global total economic mitigation potential for peatland management in 2030 is largely situated within three regions; South-East Asia, Asia, and the EU. The technical mitigation potential is around 1562 MtCO_2, while the economic mitigation potential is around 1066 MtCO_2. This potential is largely situated in non-OECD countries, as well as G20 member states.

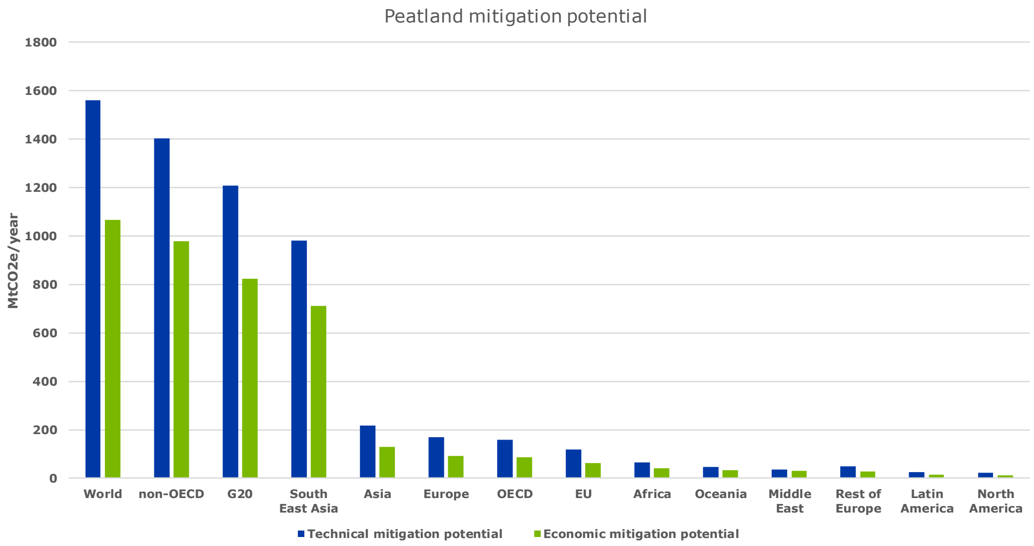

Figure 7. Peatland management mitigation potential in 2030 for the world's regions.

As the results show, most of the global peatland mitigation potential in 2030 is situated within South-East Asia. This is because Indonesia has the world's largest amount of peatland, degrading peatland and peatland mitigation potential. Additionally, Papua New Guinea and Malaysia have relatively large peatland reserves and large amounts of degrading peatland, adding to the total mitigation potential of South-East Asia. The second largest mitigation potential is located in Asia. The top three emitters within Asia are China, Russia and Mongolia. They have an individual mitigation potential in the year 2030 of 56 $MtCO_2$, 45 $MtCO_2$, and 26 $MtCO_2$, respectively. *Europe* has the third largest peatland mitigation potential, with a total of 91 $MtCO_2$ mitigation potential in 2030. This mitigation potential is mostly due to Finland, Germany, and Belarus.

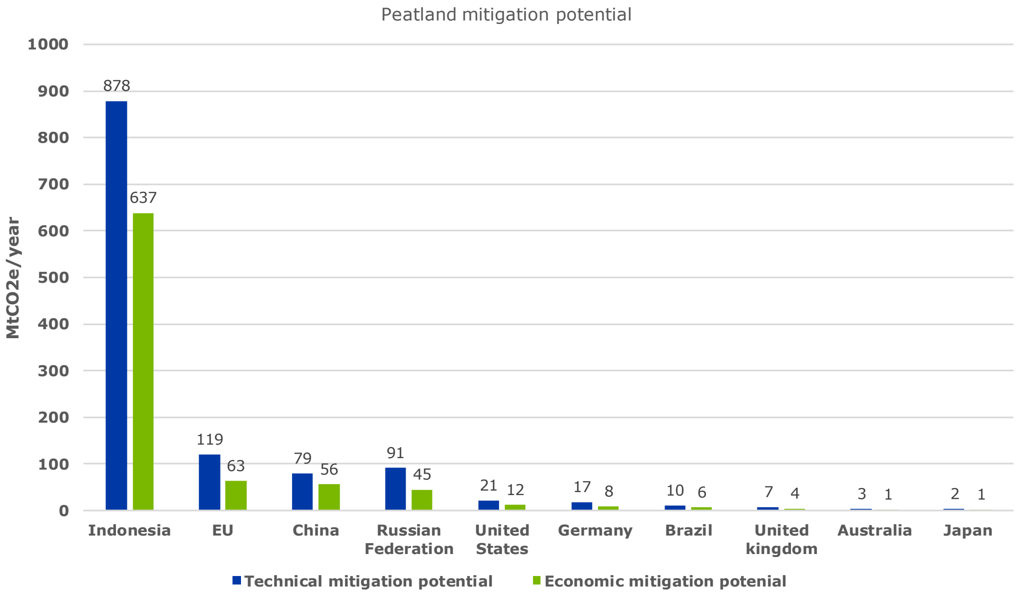

Figure 8. Peatland management mitigation potential in 2030 for the G20.

Regarding the G20 member states, the technical mitigation potential in 2030 is around 880 $MtCO_2e$. When the financial threshold is applied this amount shrink to around 640 $MtCO_2e$. Indonesia is by far the member state which has the largest peatland mitigation potential for the year 2030. It is followed by the EU, with all its member states, at 63 $MtCO_2e$. The overwhelming majority of the G20's mitigation potential regarding peatland comes from Indonesia. The three other largest potentials are situated in the EU, Russia and China. Other G20 countries such as Saudi Arabia, Argentina, the Republic of south Africa, Italy, Turkey, Korea, and Mexico show almost no mitigation potential in the year 2030. This is most likely due to the warm and dry climates in these countries, or the lack of peatland being there in the first place. The technical and economic mitigation potential for the world's regions and the G20 are displayed in Table B3 and B4, respectively.

Furthermore, the G20 represent around 77% of the global peatland mitigation potential for the year 2030. As mentioned before, Indonesia, EU and the Russian Federation are the largest contributors to the G20's total. On a global scale, the top 5 of countries with the largest mitigation potential are Indonesia, Russia, EU, China, and Malaysia.

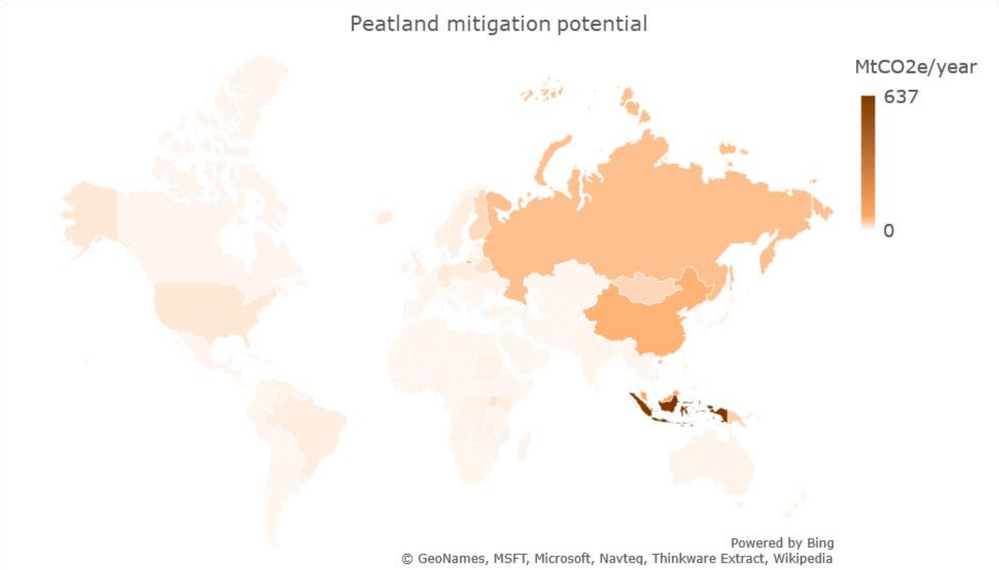

Figure 9. Map of peatland management mitigation potential in 2030.

The implementation of policies and legislation to do something about the emissions coming from peatland in South-East Asia could lead to a global reduction of 67.3% of global peatland emissions. Moreover, bringing back the emission from peatlands to zero in Indonesia alone would lead to a decrease of around 60% of total global peatland emissions. As mentioned before, in this situation only peatland restoration and reducing peatland impacts have been considered. Peatland fires have not been considered in this section. Although they might offer significant mitigation potentials, this measure is too uncertain to be assessed in this thesis since they fluctuate on an annual basis (World bank, 2016). In Figure 9, the results for the economic mitigation potential of peatland management are displayed. The results are shown on a world map, which shows where the potentials are situated. As can be seen in the figure, Indonesia is the darkest country on the map, which implies the highest mitigation potential through peatland management. Besides Indonesia, Russia, China, Malaysia, and Papua New Guinea show higher mitigation potentials.

5. Buildings

In this chapter, the sector *Buildings* will be discussed. The measures of which regional data is available on a large scale and which offer significant mitigation potential in the *Emissions Gap Report 2017,* are *Efficient Appliances* and *Lighting.* Firstly, the size and potential of having efficient appliances and lighting in the building sector will be discussed, followed by the definitions of the terms *appliances and lighting.* This is followed by a brief paragraph on the energy labeling policy tool. Then, the baseline is determined alongside the mitigation scenario for appliances and lighting. Lastly, the mitigation potential will be given.

5.1 Extent of the sector

The buildings sector is one of the sectors in which changes must be made to be in line with the previously mentioned goal to stay below 1.5℃ temperature increase with regards to pre-industrial levels. To that end, energy efficiency improvements in appliances and lighting is one of the promising short-term solutions for the decarbonization of the building sector (CAT, 2017). Moreover, compared to the 2℃-pathway, a 1.5℃ pathway requires an even faster and deeper decarbonization in the building sector, and this could thus be of importance in reaching the goals set in the Paris agreement and closing 'the gap' (Rogelj *et al.*, 2015; 2016). Currently, around 55% of all emissions in the building sector are related to appliances and lighting, which are mostly indirect emissions. Indirect emission are the emissions that are related to the use of electricity, which is generated elsewhere (CAT, 2018a; Molenbroek *et al*., 2015).

Technological advancements support the improvement of energy efficiency in appliances and lighting, and thus stimulate the decarbonization of the buildings sector. As described in a study by UNEP (2017b), using existing efficiency standards on a global scale is paramount in the fast decarbonization of the building sector, and thus bridging the emission gap by 2030 (CAT, 2018a). Additionally, the electrical energy usage in the buildings sector for appliances and for lighting is expected to rise by 51% and 18% by 2030, respectively. Moreover, currently 92% of the energy used for appliances and lighting is electric. The remaining 8% is from other sources and should also be electrified since this electricity could be generated using a sustainable energy source without fossil fuels being used. Lastly, in future years the electrical energy demand by existing end-uses is expected to rise, while simultaneously more electrical energy will be demanded by sectors or purposes that conventionally use other energy sources, such as the transportation sector or heating end-uses. The improvement of energy efficiency in the buildings sector will aid in offsetting this expected increase in electricity demand and so further the decarbonization of the energy system (CAT, 2018a).

5.2 Methodology and assumptions

Before the methodology and the subsequent mitigation potentials will be discussed and analyzed it is important to demarcate the sector *Buildings* as mentioned in this thesis and clarify the terms *appliances* and *lighting*.

With the sector *buildings*, the residential and services/commercial energy use in buildings is meant. The building itself, the building materials aspect, and the life cycle analyses are not considered. Furthermore, the term *lighting* is used for exterior and interior lighting in residential and commercial dwellings which mainly use electricity as a power source. *Appliances* is a term describing large household appliances also referred to as ''white goods'', and other smaller consumer appliances. Lastly, space cooling appliances such as air conditioning are included in the efficient appliances and lighting analysis and are treated appliances (CAT, 2018a; IEA, 2017a).

In this analysis, the mitigation potential of efficient appliances and lighting is assessed under the assumption that all governments successfully implement the highest existing energy performance and energy labeling standards. The combination of the two, adjusted over time, is the policy chosen to increase the uptake and development of efficient appliances and lighting (CAT, 2018a).

Minimum Energy Performance Standards, otherwise known as MEPS, is a tool that can be used on national or regional level and is used to define requirements regarding de energy performance of a certain device so that the life-cycle costs of the device are minimized. Effectively, what MEPS does is curb the allowed used amount of energy when the device in question is in operation. By defining the allowed amount of energy used, and thus the efficiency of the device, MEPS can be utilized to determine if a product is permitted to being brought on the market (Molenbroek *et al*., 2015). Energy labeling, on the other hand, deals with how well a device performs within the allowed range set by MEPS. It gives information or a rating on how well a product performs with regards to energy use. The use of energy labels is to inform potential buyers, such as consumers and companies, on the energy use of the product in such a way that a general comparison can be made between different devices and products (Molenbroek *et al*., 2015). Additionally, the implementation of efficient appliances and lighting by using MEPS is assumed to be below \$100/tCO$_2$e. This is based on the marginal abatement cost curve given by McKinsey (2011), which assumes the abatement cost of appliance efficiency gains and shifts in lighting to be negative in 2030.

For this overall policy to be effective, it is preferred that as many as possible national governments and regions, such as the EU, adopt energy efficiency measures. So far, over 60 countries have shown their intent and are willing to implement these measures (UN, 2016). To maximize the effects of MEPS and labeling standards, which should be aimed at achieving net negative costs for consumers, CAT (2017) states that governments should support capacity building and the institutional set-up required for implementation and enforcement of MEPS and energy labeling procedures. Furthermore, governments should keep track of the benefits that come from the implementation of MEPS and energy labeling to continuously incentivize technological development which could give manufacturers a competitive advantage. In this way innovation is stimulated. Additionally, national governments should work together towards a more harmonized MEPS and energy labeling environment, in which appliances and lighting can be rated with the same certificates, standards and can get the same accreditations. In this way, the costs of doing double work with regards to testing is eliminated (UNEP, 2017b). Lastly, governments should safeguard and monitor that public procurement rules include MEPS and energy labeling standards to facilitate that the public sector will serve as an example for how efficient products can ultimately have a financial benefit when compared to un- or less efficient products.

In this section the methodology used, and assumptions made to ultimately calculate the mitigation potential for efficient appliances and lighting are discussed in detail. First, the baseline for energy use in the buildings sector is discussed, after which the envisioned future scenario is revealed and explained.

It is apparent that stimulating efficient appliances and lighting using MEPS and energy labels is one of the key methods to decarbonize the building sector effectively and in the short-term. With that in mind it is interesting to see what exactly the mitigation potential of efficient appliances and lighting could be by 2030 for the G20 member states and their respective regions. To do that, a baseline must be chosen so that the difference with a tailored scenario, discussed later, can be measured.

The baseline used in this thesis will be based on the *Reference Technology Scenario*-data provided by the *Energy Technology Perspectives 2017* report (IEA, 2017a). In this report, the year 2014 is used as a base year and projections are made until the year 2060. For this thesis, the scope is until 2030, so only the data up until that year will be used. The *Energy Technology Perspectives 2017* report gives a variety of different splits in *total final energy consumption (TFEC)* data. For example, the TFEC data is split into residential energy use and Commercial energy use. The commercial energy use entails energy use in commercial and public services. Splits are also made with regards to the energy sources, i.e. oil, coal, natural gas and various renewable sources. Relevant for this thesis, a split is made between TFEC end-uses, including *Appliances and miscellaneous equipment*, *Lighting,* and *Space cooling*.

Energy Technology Perspectives 2017 gives detailed quantitative data for residential and commercial end-uses on a global scale, as well as for the OECD, the non-OECD, the ASEAN, Brazil, China, the EU, India, Mexico, Russia, South Africa and the US. When compared to the scope of this thesis, it can be concluded that this data is useful but does not cover all the G20 member countries. This poses a problem for the analysis since this will create an incomplete overview of the mitigation potential for efficient appliances and lighting for the scope of this thesis. For this reason, the data given in the *Energy Technology Perspectives 2017* is combined with data from another source, namely the *IEA Balances*-database (IEA, 2018a). This database, from the same organization as that published the *Energy Technology Perspectives 2017*, contains TFEC data for almost all countries and regions until 2015. When combining the data of the *IEA Balances*-database with the (projected) data of the *Energy Technology Perspectives 2017*, a baseline can be formed for all countries and regions within the scope of this thesis.

Table 2. Share of different end-uses in the total global residential or commercial TFEC for 2014 and 2030.

Type	End-use	2014	2030
Residential	Lighting	4%	3%
Residential	Appliances	11%	15%
Residential	Space cooling	3%	5%
Commercial	Lighting	12%	13%
Commercial	Appliances	28%	30%
Commercial	Space cooling	10%	11%

This is done as follows; first the growth rates of residential TFEC and commercial TFEC from 2014 to 2030 under the *Reference Technology Scenario* are calculated for the previously mentioned countries and regions of which data is available in the *Energy Technology Perspectives 2017*. These growth rates are assumed to be linear. After that, the relative shares of end-use TFEC within the total TFEC of the two different types (residential and commercial) are calculated. For example, in 2014 the share of residential lighting within the total residential TFEC was 4%, while in 2030 the same share is projected to be around 3%. In Table 3, an illustrative overview is given of the shares of different end-uses in the total energy consumption on a global scale for the years 2014 and 2030. In this manner, the percentage of the total residential and commercial TFEC per end-use for 2014 and 2030 is calculated for all the country and regions mentioned in the *Energy Technology Perspectives 2017*. The countries mentioned in the *Energy Technology Perspectives 2017* do not cover all the countries within the scope of this thesis. To that end, the growth rates that were calculated, as well as the percentages of the total residential and commercial TFEC per end-use, were assumed for the other G20 member states not mentioned in the *Energy Technology Perspectives 2017*. The growth rates and shares within the TFEC per end-use were assumed to be equal to those of comparable countries or regions, according to geographical situation, comparable economic situations, language and culture. This led to the following assumptions regarding these values:

- Canada is assumed to have equal values to the US
- Argentina is assumed to have equal values to Brazil
- France, Germany, Italy, and the UK are assumed to have equal values to the EU
- Indonesia, Saudi Arabia, Africa, Latin America and the Caribbean (excl. Chile), the Middle East (excl. Israel), Asia (excl. China, India, Japan, South Korea, and Turkey), and Oceania (excl. Australia and New Zealand) are assumed to have equal values to the non-OECD
- Japan, South Korea, Turkey, Chile, Israel, Australia, and New Zealand are assumed to have equal values to the OECD.

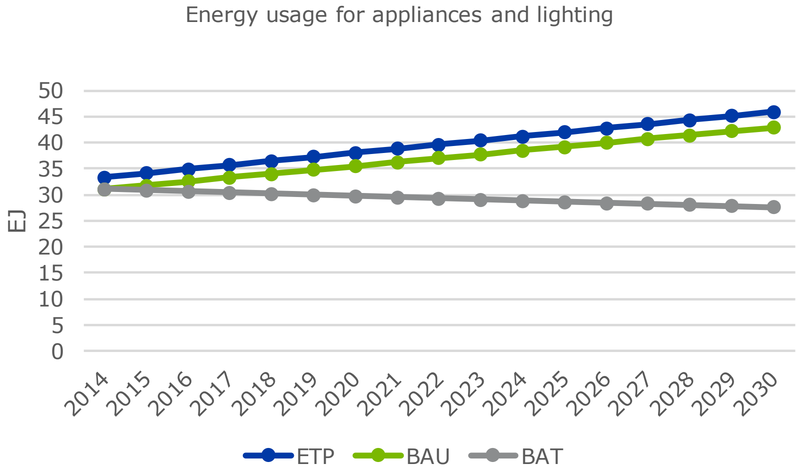

Figure 10. Global projected energy usage of appliances and lighting for baseline, BAU & BAT scenarios.

Thirdly, the growth rates per country or region calculated in the first step mentioned above, are applied to the respective country or region TFEC values found for the base year 2014 in the *IEA Balances*-database. This creates a projected baseline until 2030. Moreover, the shares within the TFEC per end-use were applied to the newly found baseline so that the TFEC per residential or commercial end-use can be calculated for 2030 using the *IEA Balances*-database.

In this way, a baseline is created for the total of all separate regions and countries, as well as the different end-uses by type. Because the *IEA Balances*-database is utilized instead of the *Energy Technology Perspectives 2017* data, and the two databases differ in values for the base year 2014, the values for 2030 differ as well. The two baselines are not parallel to one another and the created baseline using IEA Balances data is around 2.5 EJ lower in 2014 and around 3 EJ lower in 2030. Respectively, these are differences of around 6.5%. This slight divergence of the baselines towards the year 2030 is caused by the growth rate between 2014 and 2030 applied to a different base value, creating different end-values. In this thesis, the baseline constructed out of *Energy Technology Perspectives 2017* growth rates and *IEA balances* base values will be used and will be referred to as the *Business-as-Usual (BAU)* scenario. This can be seen in Figure 10.

Now that the TFEC baseline from 2014 to 2030 as well as the TFEC per end-use in the residential and commercial sectors are known, it is possible to calculate the mitigation potential in 2030. This scenario will be called *Best Available Technology (BAT)* scenario. For the calculation of the BAT scenario a reduction potential is needed, which will be applied to the BAU scenario. These reduction potentials will be taken from Molenbroek *et al.* (2015). In this publication, the reduction potentials for a 2030 scenario in which MEPS and energy labeling are applied, is given per end-use in the residential and commercial sectors. These reduction potentials are given for the World, China, the EU, India, South Africa, the US, and the Rest of the World (RoW). The reduction potentials used range from 50% to 60% for residential lighting and appliances, and from 15% to 20% for commercial lighting and appliances. In a similar fashion as before, these reduction potentials are applied to the countries and regions that are not mentioned by Molenbroek *et al*. (2015). Here it is assumed that:

- All the countries mentioned by Molenbroek *et al.* (2015) use their respective reduction potentials per end-use for the residential and commercial sectors
- Canada uses the reduction potentials per end-use for the residential and commercial sectors given for the US
- France, Germany, Italy, and the UK use the potentials per end-use for the residential and commercial sectors given for the EU
- OECD and non-OECD use the potentials per end-use for the residential and commercial sectors given for the World
- All other regions and countries use the potentials per end-use for the residential and commercial sectors given for RoW

Using the reduction potentials mentioned above it is possible to plot a global BAT scenario, which is shown alongside the BAU in Figure 10. The used reduction potentials from Molenbroek *et al.* (2015) are given in Table C4, in the appendix

5.3 Efficient appliances and lighting mitigation potential

Using the reduction potentials for appliances and lighting in the residential and commercial sector given by Molenbroek *et al.* (2015), the BAT scenario is constructed and plotted against the previously constructed BAU scenario. When the two scenarios are compared with each other, the saved energy usage in 2030 for both appliances and lighting can be calculated. This can be done on a global scale, as well as for the individual G20 countries, Africa, Asia, the EU, Europe, Latin America, the Middle East, North America, Oceania, South-East Asia, OECD and non-OECD. This saved energy usage per country or region is translated into emission mitigation potential using an emission factor. This emission factor describes how many PJ of used energy is equivalent to single megaton of CO_2 emitted into the atmosphere. The emission factors used are based on *Energy Technology Perspectives 2017* values for the year 2030 (IEA, 2017a). Additionally, the emission factors are marginal. This means that they are higher than average emission factors, based on the notion that emissions from power plants using fossil-fuels as fuel are generally avoided first instead of emissions from non-fossil-fuel based power plants. Especially, when the motive is climate mitigation (Blok & Nieuwlaar, 2016). Moreover, fossil-fuel based power plants commonly have higher variable operation costs per unit of electrical energy output than nuclear energy and most renewables. When demand for energy decreases the more expensive, fossil-fuel based power plant will be shut down first. This idea holds true even in long-term scenarios with a projected renewable share of up to 80% in the electricity generation sector. The marginal emission factor is thus defined using the weighted average emission intensity of fossil-fuel based power plants (Krzikalla *et al*., 2013).

Energy Technology Perspectives 2017 gives the emission factors in the buildings sector for the world, EU, US and South Africa. To calculate the mitigation potential, this emission factor is multiplied with the saved amount of energy between the BAT and the *Energy Technology Perspectives 2017*. For the individual G20 countries and the other regions that are in the scope of this research, but for which an emission factor is not included in the *Energy Technology Perspectives 2017*, assumptions have been made with regards to the emission factors used. It should be noted that these results contain uncertainty due to the many assumptions that have been made to reach a mitigation potential. The assumptions are that are made are as follows:

- Canada uses the marginal emission factor that is given for the US. This assumption is made on the basis that Canada, in this report, has the same reduction potential in 2030 for the various end-uses in the residential and commercial sectors.
- France, Germany, Italy, and the UK use the marginal emission factor that is given for the EU since they are member states thereof.
- All other G20 member states, Africa, Asia, Europe, Latin America, the Middle East, South-East Asia, and Oceania use the marginal emission factor given for the region World.

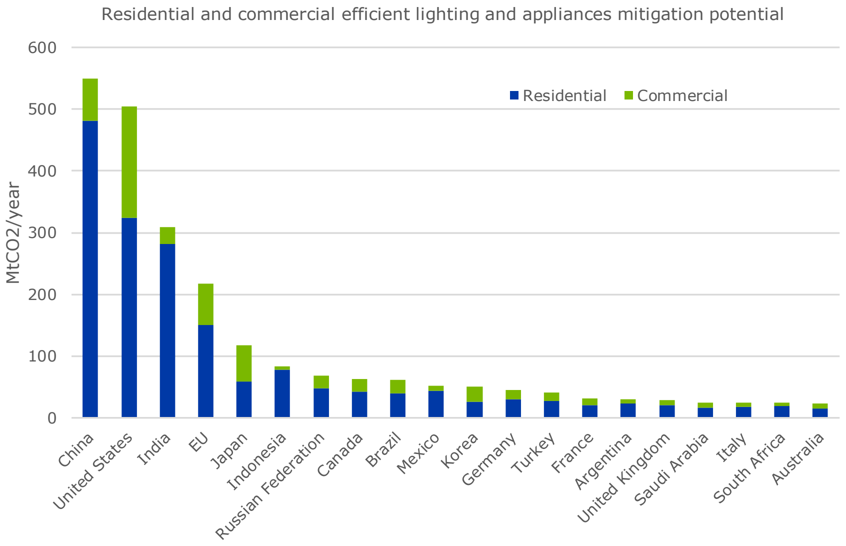

Figure 11. Efficient lighting and appliances mitigation potential for the G20 in 2030

The avoided energy usage in 2030, calculated between the BAU- and the BAT-scenario, multiplied with the correct marginal emission factor, as stated above, leads to the total averted emission potential in 2030 for efficient appliances and lighting in the residential and commercial sectors. The results are given for the G20 member states, and for the regions of the world in figure 11 and 12, respectively. The total global mitigation potential in the building sector due to efficient appliances and lighting is 3.1 $GtCO_2$ in 2030. This result is comparable with the result found in the *Emissions Gap Report 2017* (UNEP, 2017b), where the same potential had a value of 3.3 $GtCO_2$. Additionally, CAT (2018) in their memo on efficient appliances and lighting in 2030 come to a global potential of 3.2 $GtCO_2$. The discrepancy, however small, can in both cases be explained using the IEA Balances-database values for the base year 2014 instead of the values from the *Energy Technology Perspectives 2017* -database.

The G20 represents around 71% of the global mitigation potential, while the non-OECD and the OECD represent around 57% and 43%, respectively. The region where the highest mitigation potential is located is Asia, followed by North America, And Africa. In Asia, the countries that are the main drivers of this mitigation potential are, expectedly due to their population size, China and India. North America has the second largest mitigation potential, mostly driven by the US, with a potential of 505 $MtCO_2$. This high number could indicate that the energy usage of appliances and lighting per capita is higher than in other places of the world, such as China and the EU. This is also apparent from the fact that the EU, with its 511 million inhabitants (EC, 2017b), has almost 185 million inhabitants more than the US (USCB, 2017) but has a mitigation potential of less than half than that of the US, while almost the same emission factor is used for the year 2030. It also indicates that the appliances and lightbulbs used in North America are relatively far from efficient, and that the opposite is true for Europe. Although, the EU has more efficient appliances and lighting, the mitigation potential in 2030 is still significant and, thus, offers room for improvement. Africa has the third highest mitigation potential, this could potentially be attributed to the expected increase in residential and commercial appliances and space cooling due to increases in wealth and further development of economies (IEA, 2017a).

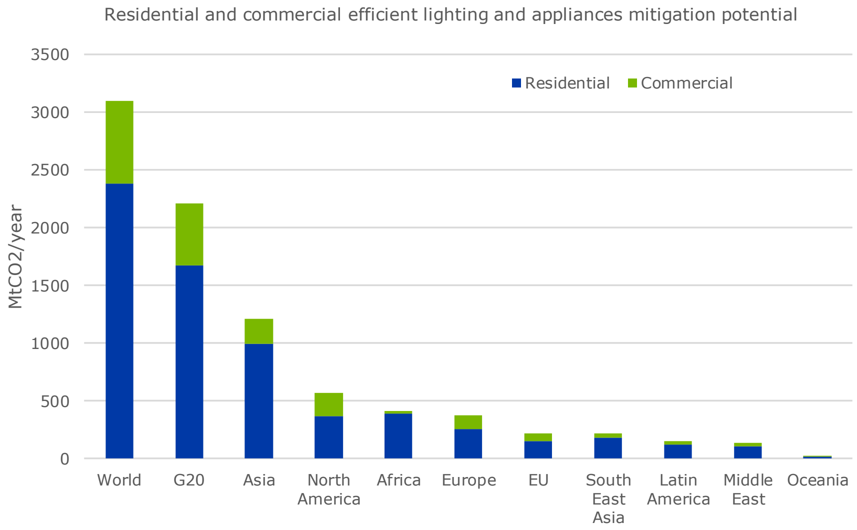

Figure 12. Efficient lighting and appliances mitigation potential for the world's regions in 2030

In Figure 12, it is visible that Oceania, the Middle East, and Latin America have the lowest mitigation potential when it comes to efficient appliances and lighting. In all three regions, the highest increase can be seen in residential and commercial appliances and in residential space cooling. Oceania has a low mitigation potential, partially due to its relatively small population of around 40 million (UN DESA, 2017). Additionally, the highest populated countries in Oceania are Australia and New Zealand. These are countries with relative high wealth levels and developed economies, which indicates that the energy use per capita from appliances and lighting is moderately high, especially in Australia, where the climate drives the energy use for space cooling. With this assumption in mind, it can be concluded that the appliances and lighting in Australia and to some extent in New Zealand are comparatively highly efficient, when comparing it to appliance and lighting energy use in the US. This, however, is not within the scope of this thesis, and it is thus not certain if this statement holds true when other factors are involved and more or other variables are considered.

With a potential of around 2.2 $GtCO_2$ the G20 represent around 71% of the global efficient appliances and lighting mitigation potential in 2030. In the residential sector only, this is around 70%, while in the commercial sector, this is around 75%. In Table B5 and B6 in the appendix, the residential, commercial and total mitigation for the world's regions and the G20 are shown, respectively. As can be seen, China, USA, and India are the countries with the largest potentials. Together they represent around 62% of the total G20 efficient appliances and lighting mitigation potential with a combined total of 1364 $MtCO_2$. Additionally, Australia, South Africa, and Italy have the lowest mitigation potential. Furthermore, the mitigation potential for the residential sector is always higher than the commercial mitigation potential. In Japan and South Korea, however, the commercial potential almost matches the residential potential. The two countries are like each other in the sense that both are highly technological economies with numerous tech companies that are well known and dominant on a global scale. This could partly clarify the origin of theses relatively high commercial mitigation potentials. In Figure 13, the found results for the combined residential and commercial mitigation potential in the G20 are displayed on a world map. The US, China, and India are the darkest countries, and thus have the highest efficient lighting and appliances mitigation potential in 2030.

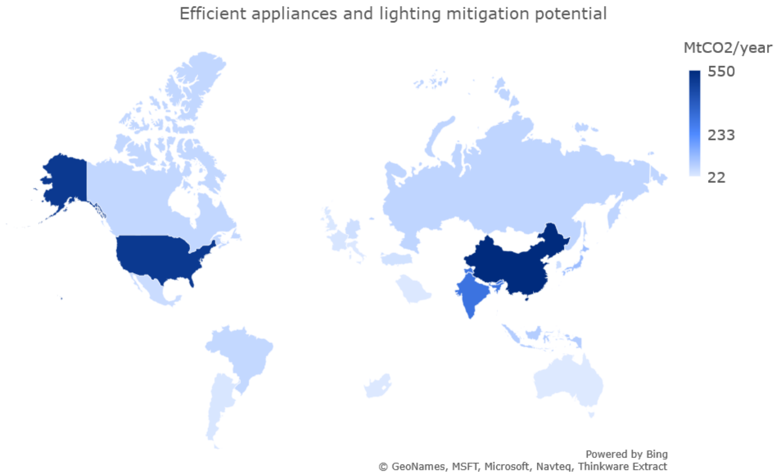

Figure 13. Map of efficient lighting and appliances mitigation potential in 2030.

CLIMATE ACTION TRACKER (CAT)

The Climate Action Tracker is consortium of Ecofys, NewClimate Institute, and Climate Analytics. Additionally, the Potsdam Institute for Climate Impact Research is a collaborating partner. The Climate Action Tracker has been established in 2009, and is an independent scientific analysis, which tracks the national progress of complying with the Paris climate accord's goal of keeping global warming below 2 ℃ and 1.5 ℃. Currently the Climate Action Trackers, covers 32 countries who together cover around 80% of the global emissions. It further quantitatively and qualitatively evaluates the commitments made by governments, and subsequently keeps track of the climate action progress. By doing so, it can determine the likely temperature increase by 2100. Additionally, the Climate Action Tracker develops pathways which are in line with the achievements of certain climate goals. Additionally, the effects of current policies on emissions, as well as the impact of NDCs are treated. Lastly, CAT determines the emissions gap for 2030 between 1.5 and 2 pathways and i.e NDCs, pledges, and current policies

6. Energy

In this chapter the sector *Energy* and its measures *Solar energy* and *Wind energy* are analyzed. The sources in the *Emissions Gap Report 2017* (UNEP, 2017) provided multiple sources of regional data. This is likely due to the large potential and current widespread implementation of the measures solar PV and wind energy. First, the relevance of this sector and especially these measures is discussed, after which the methodology for determining the mitigation potential in 2030 will be given along with the assumptions that have been made. Lastly, the mitigation potential will be calculated and displayed for the G20 and the worlds' regions.

6.1 Extent of the sector

It is estimated in the *Emissions Gap Report 2017* (UNEP, 2017) that the emissions of the energy sector, under a current policy scenario, amounts to around 21.6 $GtCO_2$. This makes the energy sector the sector with the largest projected emissions in 2030. Additionally, of the total of the energy sector around 16.3 $GtCO_2$ is estimated to be from power generation (IEA, 2016; USEPA, 2012).

The expectations and estimations regarding the size and emissions of energy sector differ greatly from one another. Reason for these differences are uncertainties about the future regarding the possible alternative technologies, such as renewables. In short, the uncertainty concerns the implementation of these technologies, the typology of the implemented technologies, and the development of the technologies with regards to the price and efficiencies. For example, with solar energy, it is likely but unclear if the prices will decrease and by how much they will decrease and within which timeframe. This, in turn, concerns the efficiency of the technique. Another example could be for wind energy, where there is uncertainty if the focus will be on off-shore or on-shore wind energy. Due to these uncertainties the future installed capacity and mitigation potential of solar and wind energy varies greatly between publications.

6.2 Methodology and assumptions

Wind energy is energy generated using a wind turbine. These turbines are different in size and have different rated powers and capacities. Electricity is created by the mechanical rotation set in motion by wind flowing ''through'' the turbine. This mechanical rotation is turned into electrical energy by using generators, located in the turbine. Often, several wind turbines are installed at a single site, forming a so-called wind park. Additionally, wind turbines can be placed onshore and off-shore. Onshore wind turbines offer a cheap source of electric energy but have an intermittent nature. Off-shore wind turbines offer a steadier and higher supply of electrical energy, but the maintenance and investment costs are significantly higher. The use of wind energy as opposed to conventional fossil-fuel based energy sources has several environmental benefits. For example, air pollution and the emission of greenhouse gasses is decreased and employment in increased (Afanador *et al.*, 2015; SITRA, 2015). Furthermore, it boosts energy security. According to REN21 (2018), the total global installed wind energy capacity was around 540 GW at the end of 2017. GWEC (2016) estimates this can grow further to 2110 GW in 2030, while Teske *et al.* (2015) estimated the amount of installed wind energy capacity in that year to be 3064 GW. When comparing this to the *Current Policy scenario* (IEA, 2016) used in the *Emissions Gap Report 2017*, that same number is estimated to be 940 GW. This difference is equal to an emission reduction of 2.6 to 4.1 $GtCO_2$, depending on which estimate is used (UNEP, 2017). Other sources, such as Breyer *et al.* (2017) and Jacobsen *et al.* (2017), speak of installed capacities of up to 5000 GW and 10000 GW in 2030, respectively. With all these projections in mind it is easy to see that there is quite some debate as to what the future potential really is and how that will develop over the years

There are several ways in which solar energy can be transformed into electrical energy of heat which can be used for human use. Mirrors, for example, can be used to direct the sunlight of a large area onto a single point or smaller area. This then heats a fluid or substance, after which this fluid or substance is transported, and the subsequent heat is used to generate electricity via a steam turbine. The overarching name for such types of installations is *Concentrated Solar Power*, and they come in various configurations. It is also possible to combine such a system with thermal storage tanks. The most developed way, however, is via photovoltaics (PV), which uses the sun light directly and converts it into DC electricity, using semi-conductor technologies. Advantages of this type of solar energy generation are that it is possible to implement this on very small scale as well as large scale; it can be placed on roofs, facades, in fields, and virtually on any other surface that catches rays of sunlight. Additionally, although PV technologies need the sunlight to operate and create electricity, PV cells don't need bright sunlight. They will produce electricity on cloudy and rainy days too (Teske *et al.*, 2015). Moreover, this technology is currently fully functioning in urban environments as well as isolated areas and is maturing at a fast rate, leading to lower costs and higher electricity yields per solar panel or PV cell. For these reasons, the focus in this thesis with regards to solar energy will be on PV technologies only, since they promise the highest future potential (2015; UNEP, 2017; SITRA, 2015; Afanador *et al.*, 2015).

At the end of 2017, the total installed global capacity for solar power was around 400 GW (REN21, 2018). According to the reference scenario by the IEA (2016), the amount of global installed capacity in 2030 could increase to around 708 GW. In the scenarios as proposed by Teske *et al.* (2015) the solar power capacity could have reached 3725 GW in 2030. When comparing this to the mentioned reference scenario, that equals an emission mitigation of around 3 $GtCO_2$ per year in 2030 (UNEP, 2017). Another source claims that the solar potential in 2030 is between 7100 GW and 9100 GW, leading to a mitigation potential of 5.5 $GtCO_2$ to 7.2 $GtCO_2$ (Breyer *et al*, 2017). Finally, another study estimates the potential of solar power to be between 3885 GW and 8722 GW in 2030. This would be equal to an emission reduction of around 2.5 $GtCO_2$ to 6.2 $GtCO_2$ (UNEP, 2017).

As was the case with the estimation regarding wind power potential in 2030, the projected solar power in 2030 varies strongly between different publications and used methodologies. However, they all converge on the conception that solar power has large potential and opportunity to reduce emissions in the energy sector by 2030 and will be a large contributor to a more sustainable energy mix. The methodology that is used in this thesis to ultimately determine the mitigation potential of solar power in the energy sector by 2030 will be discussed. Also, the assumptions made, and the sources used will be discussed.

For determining the mitigation potential of wind and solar energy the baseline as portrayed by the World Energy Outlook (WEO) 2017 (IEA, 2017b) is taken as a basis. This decision has been made because it offers the most recent and thus most precise predictions for the near future and takes more relevant recent and future developments into account. The baseline projection given in the WEO2017, is called the *current policy scenario*. This scenario is updated on a yearly basis to reflect actual developments and to adjust to new trends and/or policies.

Since the estimation regarding the mitigation potential of wind and solar energy are so diverging and different, the choice has been made to use two sources which are optimistic and somewhat ambitious. The sources used are Ram *et al.* (2017) and Teske *et al*. (2015). Both the publications and their future scenarios will be discussed in greater detail.

The REmap 2030 report by IRENA (2016) has been considered as a basis for a future scenario as well, however, this publication looks at how to achieve the goal to stay below 2℃, at minimum cost. The REmap 2030 scenario targets to reach around 32% of all electricity globally to be generated using renewable energy sources. IRENA (2016), thus, does not look at the maximum achievable mitigation potential and is thus excluded from the scope of this thesis.

The publication by Ram *et al.* (2017) is based on the idea that a global energy transition to 100% renewable electricity is technically possible and will be reached in the year 2050, however this can also be achieved earlier than 2050 under politically favorable conditions. This scenario is called the *global energy transition*-scenario

Additionally, the recommended policies that need to be focused on to achieve this ambitious scenario are given. Firstly, public support is paramount in this scenario. Secondly, a strong legislative framework should be put in place which promotes a rapid growth of renewables whilst simultaneously phasing out fossil fuel subsidies and nuclear energy generation.

Further, national governments need to implement laws that will bring forth a sufficient flow of private investments into renewable energy generation and storage technologies. To achieve this the following measures and tools are key:

- Instruments that enable direct private investments in renewable energy and other zero-emission technologies. In the publication the German renewable energy sources act (EEG) is taken as an example.
- Phasing-out of all state subsidies reserved for fossil-fuel and nuclear energy generation.

IEA BALANCES

The International Energy Agency (IEA), is an organization that was brought into existence by the OECD member countries after the energy crises in the 1970’s, so that countries manage their energy more effectively. Every year the IEA publishes the *world energy balances*.

These publications contain the complete energy balances regarding energy consumption, energy production, electricity usage and electricity generation, and other variables for over 150 countries. The units used are kilotonnes of oil equivalent (ktoe) and terajoules.

The data can be retrieved from a database in which the variables can be chosen as well as the countries, area’s, continents, and other special regions can also be selected.

- Investments in renewable energy should be stimulated with tax exemptions.
- The emission trading system should be replaced by a carbon and radioactivity tax.
- Education and research into renewable energy and other zero-emission technologies should be promoted.

With these policies in place it is furthermore possible to reduce the average cost of a MWh from $72 in 2015 to $52 in 2050. Bloomberg New Energy finance (2018) and IRENA (2017) report prices for on-shore wind energy in the range of $40 per MWh. For solar the reports mention auction prices ranging from $41 to $60 per MWh. This decrease in price is largely due to solar PV becoming very cheap and being the source that supplies most of the generated electricity, around 69% in 2050.

Teske *et al.* (2015) use three scenarios in their analyses. The first scenario is the *Reference Scenario*, which is based on the current policies scenario as described by the IEA (2014) in the WEO 2014. This scenario describes in which present trends and policies are extended into the future. It further only takes existing international energy and environmental policies into account. Furthermore, this scenario does not include additional policies which are aimed at reducing greenhouse gas emissions. It does include population growth and market trends in the renewable energy market.

The second scenario described in the publication by Teske *et al.* (2015) is the *Energy Revolution Scenario*. This scenario is based on the accomplishment of a set of environmental policy targets, which leads to an optimistic but feasible pathway aimed at and energy system that is extensively decarbonized by 2050. It is closely related to the reference scenario with regards to basic framework assumptions. Additionally, the energy revolution scenario assumes that the global CO_2 emission from energy use be decreased to a level of 4 $GtCO_2$. This is assumed so that the temperature increases since pre-industrial levels stays below 2℃, as described in the Paris climate accord. Secondly, it is assumed that nuclear energy is phased out on a global scale. The population and GDP growth are the same as used in the reference scenario.

The third and final scenario is the *Advanced Energy Revolution* (AER) scenario. This scenario is created to reflect a fully decarbonized energy system in 2050 by adding additional efforts to the energy revolution scenario, as discussed above. Firstly, this scenario assumes a much more rapid introduction and implementation of new technologies, leading to a faster decarbonization of the power, heat and transport sectors. Furthermore, this scenario requires more and stronger efforts to transform the energy systems, while the electricity generation needs to increase drastically due to changes in the heating and transport sectors. This scenario assumes electricity from renewable energy sources to be the main primary energy. In this thesis we look at the highest achievable mitigation potential for each of the treated measures by the year 2030. So, in this thesis we will be looking at the advanced energy revolution scenario.

In the WEO2017 (IEA, 2017b), a regional divide is given. This regional divide includes the areas *North America, Central and South America, Africa, Middle East, Europe, Eurasia,* and *Asia Pacific.* The countries that are grouped into a region can be seen in Table A2. The regions and the subsequent countries as described in the scope of this thesis and the regions as discussed in the WEO2017 do not match. The decision has been made to maintain the WEO2017 division of regions for the sector Energy and the measures wind and solar energy.

Furthermore, the WEO2017 in detail discusses energy demand and generation projections for Brazil, China, the EU, India, Japan, Russia, South Africa, and the US. The other G20 countries are not mentioned, however. To create a baseline electricity demand for these countries until 2030 the historical wind and solar PV electricity generation of 2015 for these countries, taken from the IEA Balances (IEA, 2018b), was multiplied with the electricity generation growth rate for wind energy and solar PV of the regions they are in. For example, the 2015 electricity generation data for solar PV and wind energy of Argentina was multiplied with the Central and South American growth rate of solar PV and wind energy generation from 2015 to 2030. In this manner, for all the countries for which the WEO2017 didn't give electricity generation data, this was created from 2015 to 2030. This was done with regards to total, fossil and RES electricity generation including solar PV and wind energy. Additionally, it was now possible to calculate the marginal emission factors for each country and region by dividing the total projected emissions by the total amount of fossil fuel generated electricity.

Ram *et al.* (2017) give the 2030 installed capacity and expected total energy generation per energy source for the areas *North America, South America, Europe, MENA, Sub-Saharan Africa, Eurasia, SAARC, Northeast Asia, and Southeast Asia.* The subsequent list of countries per region is given in Table A5. The regions are different than the areal demarcations used in the baseline WEO2017. However, in the publication projected electricity demand per energy source is given on a national level. With this data it is possible to adapt the electricity demand for the regions given by adding or subtracting the electricity demand for a single country or multiple countries to fit the regional divide given in WEO2017 (IEA, 2017b). This way it is possible to determine the total, fossil and RES electricity generation per country or region in the year 2030 under the energy transition scenario. Moreover, the share of solar PV and wind energy within the renewable electricity generation can be determined. Using this data and the CPS baseline of the WEO2017, it is possible to calculate the difference in terawatt-hours generated using RES, and thus solar PV and wind. This is done for all countries of the G20 and the regions as stated in the WEO2017. The difference in generated power between the CPS and advanced energy revolution scenario for solar PV and wind energy are then multiplied with their respective marginal emission factors, calculated earlier. This gives the mitigation potential in 2030.

The same methodology is maintained when using the publication by Teske *et al.* (2015). There are some other steps, however, that need to be made before this methodology can be applied. The publication provides a regional division; however, the regions do not match the regions as described in WEO2017. Instead, the regional division as given in WEO2014 (IEA, 2014) is used, shown in Table A3. They are however, somewhat comparable to the regions that are used in WEO2017. This can be seen in Table A4, in the Appendix. Additionally, no electricity generation data for G20 member countries, other than China and India, is given. For this reason, the following has been done. For all G20 countries, except China and India, the total, fossil and RES electricity generation data for the base year 2015, taken from the IEA balances and CPS, is multiplied with the electricity generation growth rate data from 2015 to 2030 of corresponding world regions given in Teske *et al.* (2015). This results in the envisioned electricity generation in 2030. Again, as done previously, the difference in RES generation with the CPS is taken and multiplied with the marginal emissions factors. This gives the mitigation potentials for solar PV and wind energy in 2030 under the AER scenario.

Both Solar PV and wind energy are assumed to have a marginal abatement cost which is below \$100/tCO_2e (McKinsey, 2011) and thus the total calculated potential is the potential emission reduction.

6.3 Solar PV and wind energy mitigation potential

Now that the methodology for the wind and solar PV mitigation potential is described, it is possible to generate the results. After reviewing the generated results by applying the scenarios of the two publications to the CPS data of the WEO2017, it became evident that the publication by Ram *et al.* (2017) is more ambitious and thus yields a higher mitigation potential in 2030 for solar PV wind energy. As said before, in this thesis the highest possible mitigation potential beneath the financial threshold is taken. Furthermore, the results gained using Teske *et al.* (2015) show a similar trend with regards to combined solar PV and wind energy but with significantly lower values compared to Ram *et al.* (2017), to a point that it is no longer realistic. Additionally, Teske *et al*. *(2015)* focus more on wind energy than on Solar PV, which is the opposite of the results yielded when using Ram *et al.* (2017). The decision has been made to use the results of Ram *et al.* (2017) as the leading results, and a 50% range will be taken in the results to reflect the insecurity of the future potential of solar PV and wind energy. The results are displayed in Table B9 and B10 in the appendix.

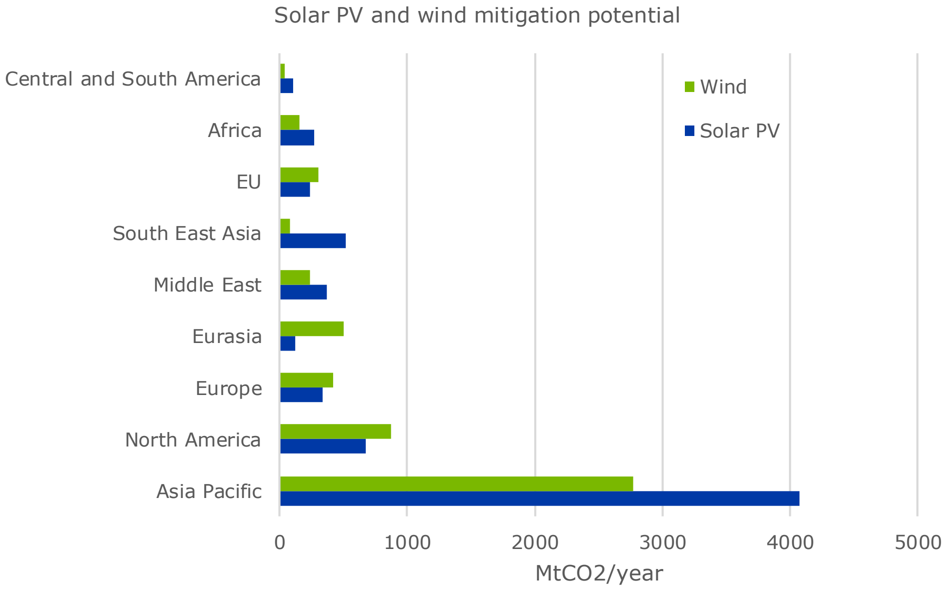

Figure 14. Solar PV and wind energy mitigation potential in 2030 for the world's regions.

In Figure 14, the mitigation potential in 2030 for solar PV and wind energy is given on a regional level. Asia Pacific is by far the area that has the largest potential for both energy sources, with mitigation potentials of around 4.1 $GtCO_2$ and 2.7 $GtCO_2$ for solar PV and wind energy, respectively. This result was to be expected since Asia Pacific is the largest area with regards to population as it amongst others includes China, India, Japan, South Korea, and Australia. Furthermore, it is largely situated in a warm climate zone, with a lot of solar irradiance. Asia Pacific is followed by North America, which has a wind energy mitigation potential of around 875 $MtCO_2$ and a solar PV mitigation potential of around 670 $MtCO_2$. In Europe, the solar PV mitigation potential in 2030 is around 340 $MtCO_2$ and the wind energy mitigation is 420 $MtCO_2$. Eurasia, shows that it predominantly has wind energy mitigation potential compared to solar PV. Eurasia's wind energy potential will account for a reduction of around 500 $MtCO_2$, while its solar PV mitigation potential will amount to around 124 $MtCO_2$. The solar mitigation potential in the Middle East, South-East Asia, and Africa is higher than that of wind energy, and amount to 370

$MtCO_2$, 522 $MtCO_2$ and 275 $MtCO_2$, respectively. The wind energy mitigation potential of the Middle East is 235 $MtCO_2$, while that of Africa is 159 $MtCO_2$. The wind energy mitigation potential is relatively low at around 80 $MtCO_2$. The EU shows a mitigation potential of 369 $MtCO_2$ for solar PV and 235 $MtCO_2$ for wind energy. Lastly, Central and South America has the lowest mitigation potential of around 37 $MtCO_2$ and 108 $MtCO_2$ for wind energy and solar PV, respectively. The results can be found in Table B11 and B12.

In Figure 15, the G20 combined wind energy and solar PV mitigation in 2030 is shown per country. China by far has the largest wind energy mitigation potential of around 1.1 to 2.2 $GtCO_2$, followed by the US and Russia with 456 to 912 $MtCO_2$ and 220 to 440 $MtCO_2$, respectively. The emission reduction in China is a 40% reduction of China's total power sector emissions in 2030. For the US and Russia this is 48% and 56%, respectively. The EU has a wind energy mitigation potential of 305 $MtCO_2$, equaling 33.3% reduction, and is followed by India which has a potential of around 248 $MtCO_2$, which is equal to a 12.8% emission reduction. Argentina has the highest percentagewise reduction at around 62.1%. However, this amount to a reduction due to wind energy of around 11 to 22 $MtCO_2$. Globally the emission reduction due to wind energy is 2.5 to 5 $GtCO_2$. This is equal to 16% to 31% reduction in total global emissions in the power sector in 2030.

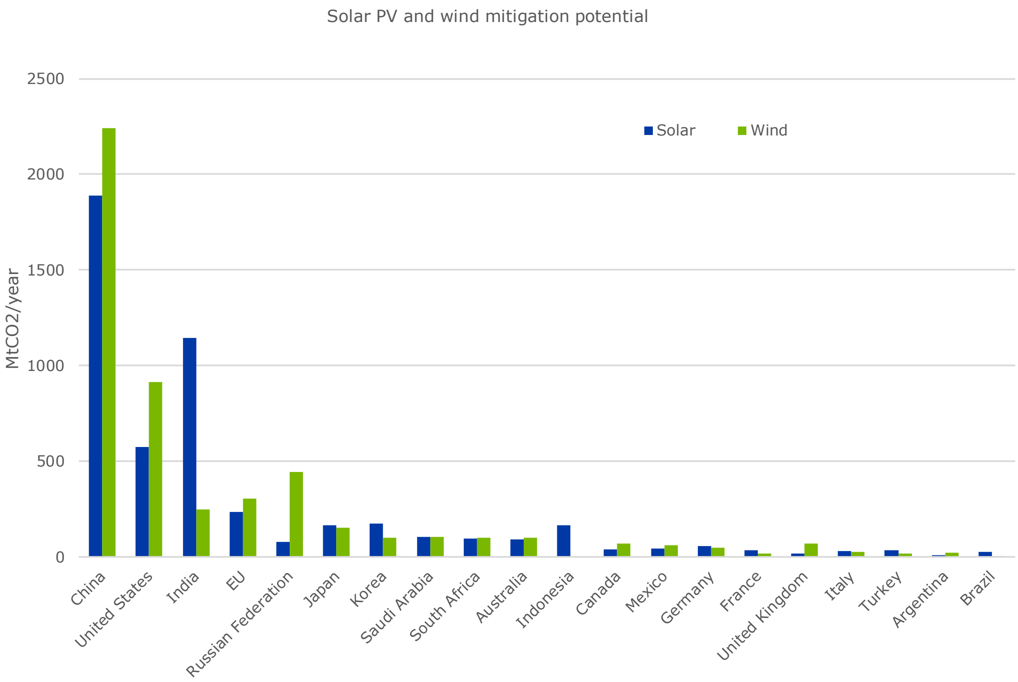

Figure 15. Solar PV and wind energy mitigation potential in 2030 for the G20.

When looking at the potential to reduce emissions in the energy sector due to the implementation of solar PV, China again has the highest potential within the G20, at around 1.89 $GtCO_2$. This is equal to a reduction of about 34% of China's total emissions related to the generation of electricity. China is followed by India which has a solar PV mitigation potential of 1.1 $GtCO_2$, which is an emission reduction of around 58% in the power sector. The US shows a solar PV mitigation potential of 574 $MtCO_2$ which is a reduction of 30%, while the EU has a potential of 236 $MtCO_2$ which is a 25% emission reduction in the energy sector. This is followed by Korea, Japan, and Indonesia which have mitigation potentials that lie very close to each other. Korea has a solar PV mitigation potential of 173 $MtCO_2$, while Japan and Indonesia have potentials of 164 $MtCO_2$ and 162 $MtCO_2$, respectively. Argentina, the UK and Brazil have the lowest absolute mitigation potential when it comes to solar PV in 2030. Argentina has potential of 7 $MtCO_2$, while the UK and Brazil represent around 18 $MtCO_2$ and 23 $MtCO_2$, respectively. The countries that have the largest mitigation potential due to the implementation of solar PV, percentage wise, in 2030 are Indonesia, India, and Mexico. Indonesia has a reduction potential or around 62%. India, as mentioned before, has a reduction potential of around 58%, and Mexico has a reduction potential of 50%. Globally, the mitigation potential of solar PV is around 2.9 to 5.8 $GtCO_2$, which means an emission reduction of around 18.5% to 37% in the worldwide power sector.

As can be seen in Figure 15, China, the US, India, and the EU have the largest absolute mitigation potential when looking at the combined solar PV and wind energy potential. When the two are combined this leads to a total emission reduction of about 74.9% in China, 71.6% in India, 78.6% in the US, and 59% in the EU. In Russia this will lead to a reduction potential of 66.9%. This is largely due to wind energy, as the implementation of Solar PV as proposed by Ram *et al.* (2017), will only lead to a reduction of around 10% in 2030 in Russia. In Figure 16, the results for the combined solar PV and wind energy mitigation potential per G20 country are represented on a map. Although the EU represents a high combined mitigation potential it is excluded from this overview, as that would obscure the results for France, Germany, Italy, and the UK. As the map shows, the largest national mitigation potentials lie in China, India, and the US.

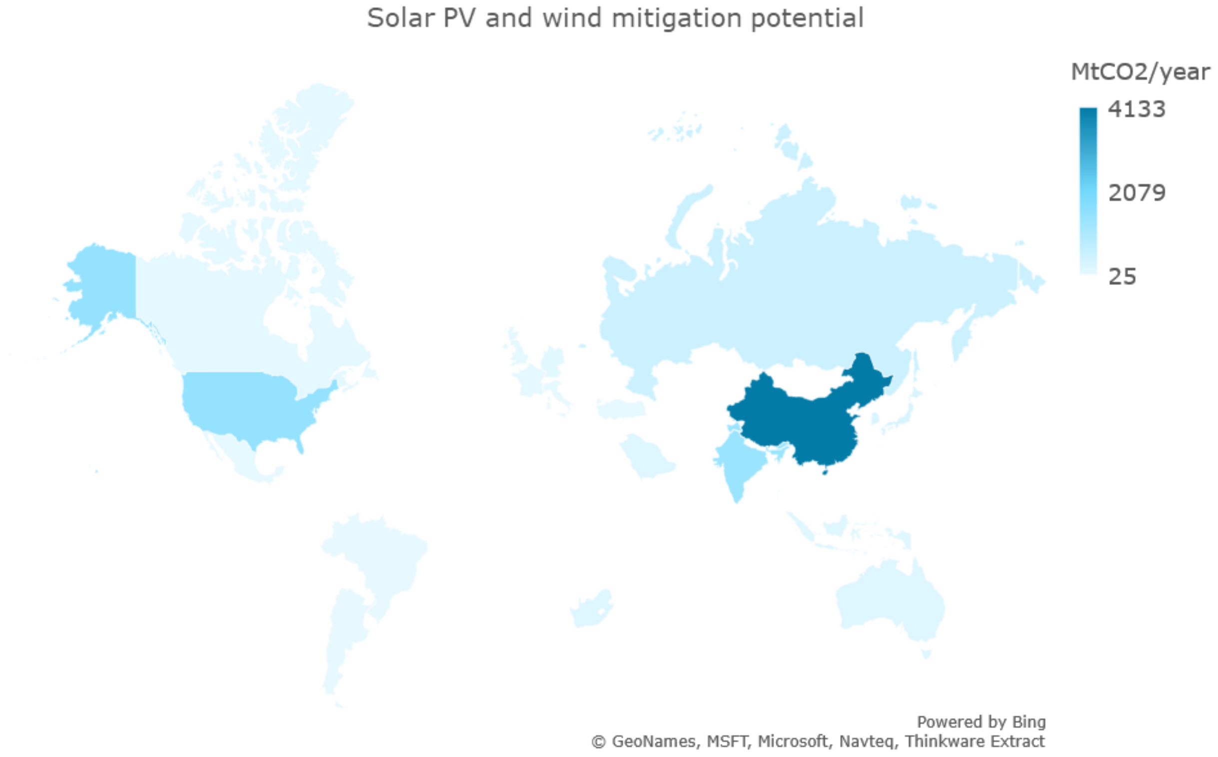

Figure 16. Map of Solar PV and wind energy mitigation potential in 2030.

7. Forestry

In this chapter the global sector *Forestry* will be treated. More specifically, Re*forestation* and *Deforestation* are the measures that will be discussed within this sector. These two measures are the only two measures that were discussed in the *Emissions Gap Report 2017* (UNEP, 2017). For both the measures, the definition used in this thesis will be given. Subsequently, the various estimation and projections regarding the mitigation potential in 2030 by various sources will be elaborated on. Then, the methodology used in the calculation of the measure's mitigation potential, as well as the applied assumptions and the used literature will be discussed. Lastly, the mitigation potential results will be given and analyzed.

7.1 Extent of the sector

The forestry sector, as described in the *Emissions Gap Report 2017*, is comprised out of two measures; *Reducing deforestation* and *Reforestation.* The measure reducing deforestation is in this thesis defined as the overarching name for activities that reduce deforestation, and in that way, prevent the emission of greenhouse gasses into the atmosphere that would have otherwise been adsorbed by the forest. The emission reduction potential of reducing deforestation is formulated in a somewhat odd way, since the emission would normally be absorbed. When areas are deforested this emission will not be absorbed anymore. Deforestation does not create higher emissions, it in fact absorbs less. This statement doesn't hold true when the emissions from machinery and fuels used in the process of deforesting, such as logging. *Reforestation* is the predominant term for activities that involve the planting of new trees and plants in areas which are not forests anymore, but where forest is the native cover type. In other words, reforestation is the replanting of trees in areas that were recently forest but aren't anymore due to deforestation. Reforestation will increase the amount of emissions that can be offset, and thus carbon sequestration (Griscom *et al*., 2017).

The *Emissions Gap Report 2017* states that the emissions related to deforestation were around 3.15 $GtCO_2e$ in 2015, and this is estimated to increase to 3.49 $GtCO_2e$ in 2030. Reasons therefore, are that other land-use change emissions that end up back in the atmosphere due to microbial decomposition will amount to around 0.93 $GtCO_2e$ in 2030, while afforestation and other forestry management activities will absorb around 0.88 $GtCO_2e$ in the same year (PBL, 2017).

The mitigation potential linked to the forestry sector is subject to debate, and subsequently studies have reported values for forestry mitigation potentials that range from 0.2 $GtCO_2e$ per year to 13.8 $GtCO_2e$ per year. According to Smith (2014) this is mainly due to the differences in the models used for the various analyses. Especially the mitigation potential of the measure reducing deforestation comes with great uncertainty since the effect of decreased deforestation on degradation and subsequent emission is unknown. Additionally, the baseline used in the analyses for deforestation is of great importance but also very unsure and subject to debate (GCEM, 2015).

The *Emissions Gap Report 2017*, assumes that the global mitigation potential for reducing deforestation will approximately reach 3 $GtCO_2e$ in 2030. This estimate is based on the work of Clarke *et al.* (2014), and the key assumption made here is that the baseline remains stable from current levels. With regards to reforestation, a central estimate of 2.3 $GtCO_2e$ has been made in the *Emissions Gap Report 2017*, with an uncertainty range from 1.6 $GtCO_2e$ to 3.4 $GtCO_2e$. This range is based on global commitments concerning reforestation in the *Bonn challenge* (Bonn Challenge, 2018) and the *New York Declaration on*

Forests (UN, 2014). These commitments would lead to the reforestation of 350 million hectare of degraded and deforested land. In conclusion, the emission reduction potential of the forestry sector is estimated by the *Emissions Gap Report 2017* to be around 5.3 $GtCO_2e$ in 2030 with an uncertainty range from 4.6 $GtCO_2e$ to 6.4 $GtCO_2e$.

7.2 Reducing deforestation

In this section the measure *reducing deforestation* will be discussed in greater detail. First, the definition, methodology and the subsequent assumptions that are made in the calculation of the mitigation potential will be explained. Then, the technical as well as financial mitigation potential will be given, and the results will be discussed.

7.2.1 Methodology and assumptions

The FAO states that deforestation implies the long-term or permanent loss of forest cover and implies transformation into another land use. This type of forest can only be induced by human interaction and behavior. Deforestation also includes areas of forest which have been turned into agricultural land, pastures, water reservoirs and urban areas. However, when areas where trees have been cut down for logging and where the forest is expected to grow back again are, it is not seen as deforestation. Deforestation is often measured over a large part of forest, since small patches in forests often shift in land use in a cycling fashion. According, to the FAO conversion of forest to other land use or the long-term reduction of the tree canopy cover below the minimum 10 percent threshold, is deforested land and thus this is also seen as deforestation. The FAO also sees areas where disturbance, over utilization or changing environmental conditions have such impacts that a tree cover above 10% cannot be sustained as deforestation (FAO, 2010). In 2004, the Brazilian government initiated the Action Plan for Prevention and Control of Deforestation in the Amazon which set out to decrease deforestation of their tropical forests by reducing illegal logging. The three main spearheads are:

- Territorial and land-use planning
- Environmental control and monitoring
- Fostering sustainable production activities

Brazil enforced these spearheads by adapting laws dedicated to effectively punish illegal logging, and by clarifying land ownership rules. Furthermore, changes have been made in the soy and beef industry to make the source of goods more transparent. Lastly, the protected areas have been expanded (MRV, 2014). This change in policy led to a deforestation rate of 84% between 2004 and 2012. It Is estimated that between 2005 and 2012 this has reduced emission by around 3.57 $GtCO_2$ (Afanador *et al.*, 2015). Other than emission reduction potentials, reducing deforestation has positive effects on the water cycle, improving the regulation of waterflows. Also, it has positive effects on the soil itself. Tree roots tend to consolidate the soil and stops the erosion of land due to flows of water or air. Lastly, deforestation helps preserve the large variety of animal and plant species that are found in the subsequent areas (MRV, 2014). Besides biological effects, policies regarding the reduction of deforestation also have impact on the indigenous people by strengthening their land tenure rights, and so helps protect them from illegal logging activities (UCS, 2011). Moreover, in Brazil deforestation policies have led to more wealth generation for the indigenous people since the government has started to buy their farmland products (MRV, 2014).

As discussed in chapter 3, the scope of this thesis is to shed light on the mitigation potential of several measures for the G20 member states and the world regions. However, with the measure reducing deforestation this is difficult since the potential therefor lies in countries where deforestation occurs. The countries where deforestation occurs are mostly situated in the tropical and sub-tropical belt and possess (sub-)tropical forests, and for a large part of the G20 member states this is not the case. For example, the countries situated in Europe and the EU itself don't have tropical or sub-tropical forests and thus cannot be part of the analysis. Likewise, Russia doesn't have (sub)-tropical forests and thus cannot be part of the analysis. This will automatically have effect on the regions that are assessed for this measure. The countries of the G20 and the subsequent regions they are in, as well as other countries included in this analysis will be discussed below.

The approach that will be taken for the assessment of the mitigation potential of reducing deforestation in 2030 will be like the approach used in the work done by Afanador *et al.* (2015). In this report several proven low-carbon solutions are scaled up from a best practice case country to the countries where there is potential for mitigation. In the case of reducing deforestation, Brazil is taken as the best practice country. Only the countries that had a deforestation rate of 0.2% or higher over the period 2010 to 2015, and had stayed constant or increased within this period, were considered. The deforestation rates over both periods were taken from the *Global Forest Resources Assessment (FRA) 2015* published by the FAO (2015). Only countries within the subtropical and tropical belt are considered. Applying the two requirements mentioned above leads to a set of low to middle income countries. Middle income countries are assumed to reach an 80% reduction of the deforestation rate in 2025, which will then remain constant until 2030. The low-income countries on the other hand are assumed to reach the same reduction in 2030. The reduction in deforestation rate between 2015 and 2025 for the middle-income countries, and the reduction in deforestation rate between 2015 and 2030 for the low-income countries are both assumed to be linear.

Creating a baseline for deforestation rates is difficult, since it is dependent on many aspects including politics, economics and other social factors. Moreover, there is clear knowledge gap regarding baselines for deforestation rates. Since a clear other baseline was lacking, the baseline as proposed by Afanador *et al.* (2015) is used in this thesis. This baseline assumes the deforestation rates to remain constant between 2015 and 2030, and further assumes it to be identical to the average historical deforestation rate as calculated for the period 2010 to 2015. In this way, a baseline and a future scenario, using the best-practice case, for each separate country included in the analyses is calculated. For Brazil, the best practice country, also takes this as a reference baseline. Then, the total amount of forest that has been converted or lost between 2029 and 2030 is calculated for both the baseline and the future scenario for each country individually. The amount of forest 'saved' is calculated by deducting the amount of forest area that was lost in the reducing deforestation scenario between 2029 and 2030 from the amount that was lost between 2029 and 2030 in the baseline scenario. To calculate the potential GHG mitigation the amount of land, calculated in hectares, is multiplied with the emission factor for deforestation as given in the IPCC's fourth assessment report (2007). The emission factor is assumed to be anywhere between 350 tCO_2e per hectare to 900 tCO_2e per hectare. The precise emission factor for a specific country or area is dependent on many aspects such as soil type, vegetation types, subsequent land use, and many other aspects. With that in mind the decision has been made to use the entire width of the range since these factors could not be assessed in their entirety. The multiplication of the protected forest land with the emission factors for deforestation will yield a range of mitigation potential in 2030.

7.2.2 Reducing deforestation mitigation potential

Here the results found with the methodology as described above are given and analyzed. The countries that were included in the analysis and their mitigation potentials are shown in Figure 17. Since the results do not include all regions and all G20 countries within the scope of this thesis the results are given for the countries for which they are available.

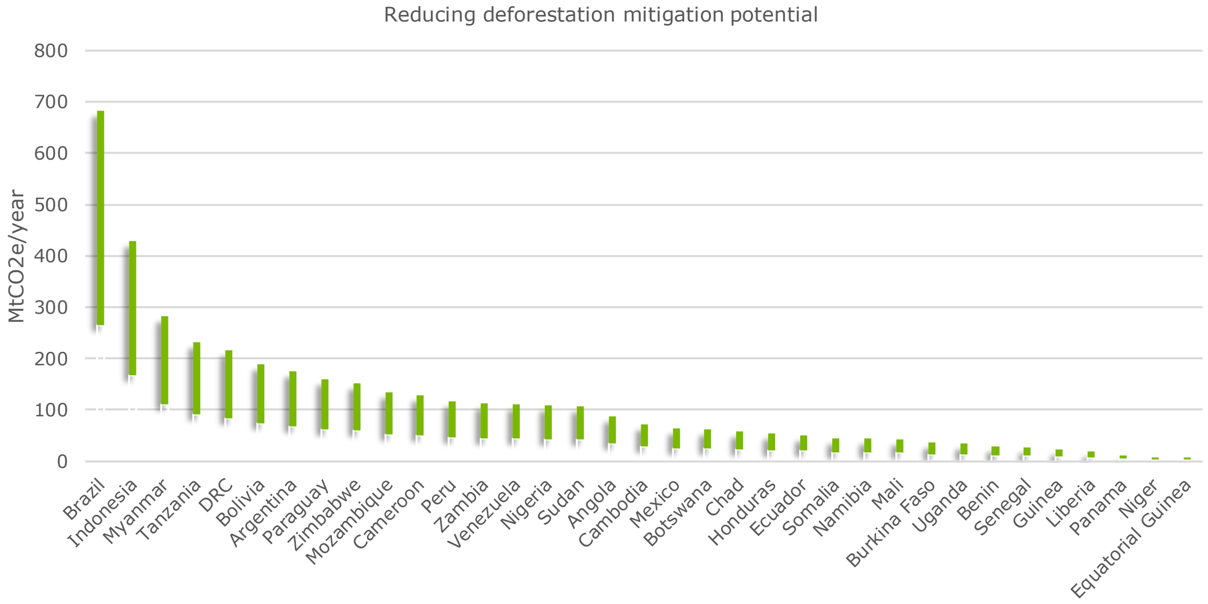

Figure 17. Reducing deforestation mitigation potential by 2030 in the tropical and sub-tropical belt.

The mitigation potentials calculated using the low emission factor (350 tCO_2/ha) are displayed in Figure 17 as the lower bound, while the potentials using the high emission factor (900 tCO_2/ha) are displayed as the higher bound. Although Brazil has one of the lowest deforestation rate at around 0.2%, it has by far the largest mitigation potential. This is due to the sheer size of the tropical rainforest in the country. The mitigation potential located in Brazil is between 265 $MtCO_2e$ and 680 $MtCO_2e$. Next to Brazil, the G20 countries Indonesia and Argentina show mitigation potential when it comes to reducing deforestation. Indonesia has a mitigation potential between 166 $MtCO_2e$ and 428 $MtCO_2e$, while Argentina has a potential between 67 $MtCO_2e$ and 174 $MtCO_2e$ in 2030. The detailed results are given in Table B11, in the appendix.

As seen, the highest mitigation potentials lie in Brazil, Indonesia, and Myanmar. Myanmar Shows potential to mitigate around 109-290 $MtCO_2e$ in 2030. Further relatively high mitigation potentials lie in Central Africa in Tanzania, and the Democratic Republic of the Congo. The countries have an emission reduction potential of 90-230 $MtCO_2e$ and 84-220 $MtCO_2e$, respectively. The highest mitigation potentials that are situated in South America, next to the potentials of Brazil and Argentina, are situated in Bolivia and Paraguay. The mitigation potential for Bolivia is 73-185 $MtCO_2e$, while the mitigation potential of Paraguay is 62-170 $MtCO_2e$.

The mitigation potential for reducing deforestation is divided between Latin America, Africa, and South-East Asia. Africa represents around 44% of the global total with a mitigation potential between 660 $MtCO_2e$ and 1740 $MtCO_2e$. Latin America has a mitigation potential ranging from 530 $MtCO_2e$ to 1370

$MtCO_2e$. Lastly, South-East Asia offers a mitigation potential between 307 $MtCO_2e$ and 800 $MtCO_2e$. This can be seen in Figure 18. The total global mitigation potential, when the assumptions mentioned in this thesis are applied, is around 1.6 $GtCO_2e$ on the low end and 4 $GtCO_2e$ on the high end.

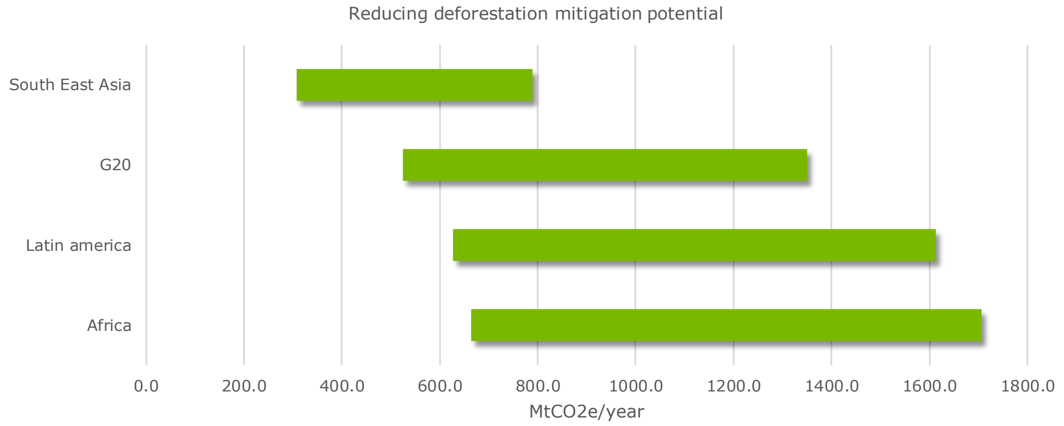

Figure 18. Reducing deforestation mitigation potential by 2030 for the world's regions.

The mitigation measures reducing deforestation is estimated to cost around 13$/$tCO_2e$ (McKinsey, 2009). This is far below the $100/$tCO_2e$ threshold mentioned in the beginning of this thesis, and all the calculated potential is financial mitigation potential. The mitigation potential in this thesis is in line with projections by other publications, such as *Emissions Gap Report 2017* (UNEP, 2017) where the mitigation potential is said to be around 3 $GtCO_2e$. Furthermore, McKinsey (2009) came forward with an estimate of around 3.6 $GtCO_2e$.

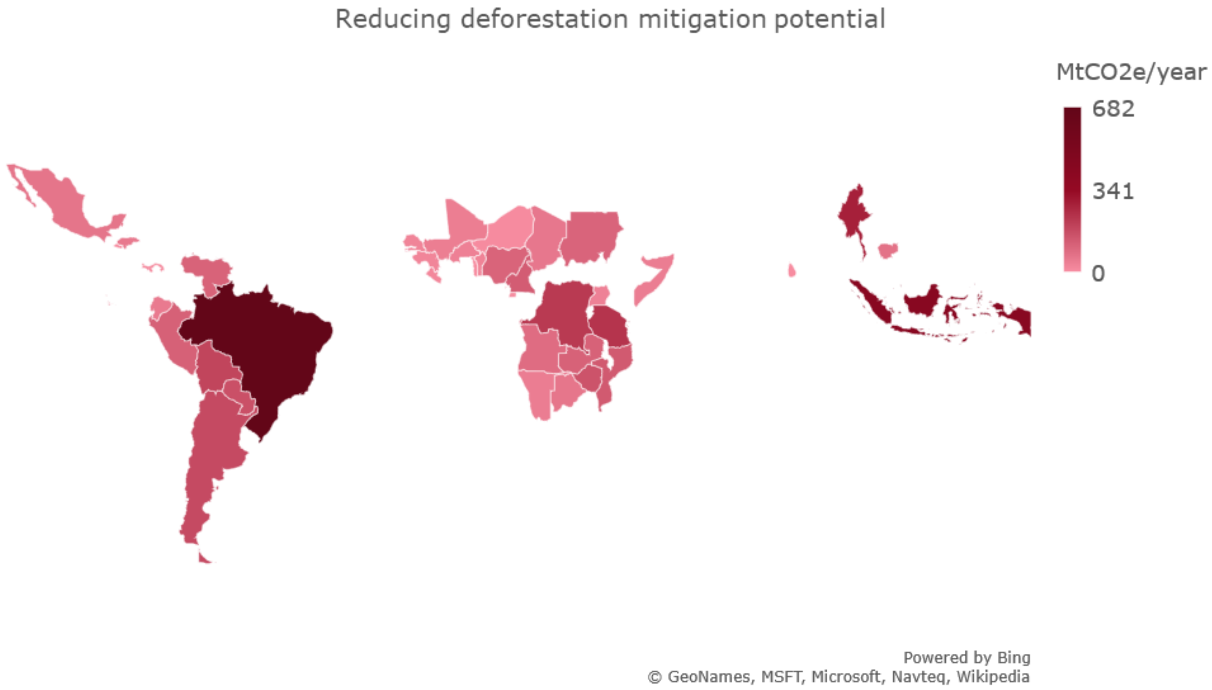

Figure 19. Map of reducing deforestation mitigation potential in 2030.

7.3 Reforestation

In this section the measure reforestation is discussed and analyzed in detail. First, the definition for reforestation will be given followed by the used methodology and literature. Subsequently, the technical and financial mitigation potentials will be given.

7.3.1 Methodology and assumptions

The definitions used for reforestation differ between organizations and various literary sources. The difference between them is often due to inclusion or exclusion of natural regeneration of forest. The FAO (2010) defines reforestation as follows:

> *''Re-establishment of forest through planting and/or deliberate seeding on land classified as forest''*

Furthermore, reforestation implies no change of land use, and includes coppice from trees that were originally planted or seeds. Additionally, reforestation includes planting/seeding of temporarily unstocked forest areas as well as planting and seeding of areas with forest cover. Lastly, the FAO (2010) state that reforestation *excludes* natural forest regeneration. How forest is classified or defined also differs per publication and/or organization. This will be addressed in the methodology section for the reforestation measure.

Reforestation and its activities is beneficial in several ways. For example, reforestation can restore destroyed habitats of flora and fauna and so protect biodiversity and prevent loss of species. Moreover, larger forests mean larger quantities of CO_2 and other GHGs absorbed by forests, which will mitigate global pollution and will enhance the efforts made towards reducing global warming and the problems thereof. Moreover, it will improve the quality of the air. Also, just like reducing deforestation, it will avert soil erosion and the water cycle will be upheld. Lastly, a managed forest, with enough small trees planted and larger older trees harvested will provide a renewable and sustainable source of wood and wood pulp. This will lead to jobs and thus will have a positive financial impact (Afanador *et al.*, 2015).

In this section the used methodology will be discussed. The leading source in the analyses of this measure is Griscom *et al*. (2017). The methodology as well as the results derived using this methodology will be used in the assessment of the final mitigation potential.

Griscom *et al.* (2017) define reforestation as the conversion from non-forest areas to forest areas in ecologically appropriate and desirable areas. Non-forest areas are classified as such when the tree cover is lower than 25 percent, while forest areas are areas with a tree cover which is higher than 25 percent. Afforestation, the planting of forest where that is not the original biome, is excluded. Moreover, croplands are excluded while all grazing lands in forested ecoregions are included. The final extent of the reforestation potential is calculated by modifying a 1km solution map from Atlas of Forest Landscape Restoration Opportunities (Popatov *et al.*, 2011). Then, the total potential forest cover taken from the map is reduced with existing forest, and area which are incompatible with returning to forests.

To circumvent double-counting with the other pathways described in Griscom *et al*. (2017), spatially explicit filters have been applied. Further, boreal areas are excluded in this. The unmapped areas of mangroves and peatlands are deducted from the total potential reforestation area. Additionally, a baseline reforestation rate is taken between 2000 and 2030, which is taken from a UMD dataset

(Hansen *et al*., 2013). Using the methodology as described by Griscom *et al.* (2017) it is possible to determine the potential area for reforestation on country level. Subsequently, the emission factor per hectare of potentially reforested area is calculated on country level using growth rates of natural and plantation forests, in combination with country level percent of re-growth in plantation forests (FAO, 2015).

The potential area is multiplied with the emission factor. In this way, the technical mitigation potential for reforestation on country level is calculated. In the publication, Griscom *et al.* (2017) the economic mitigation potential below \$100 per tCO_2e is determined by multiplying the technical mitigation potential with one of three default cut-off percentages; 30%, 60% or 90%. With regards the measure reforestation, the technical mitigation potential is multiplied with 30%. This choice is based on MACC literature analyses (Griscom *et al.*, 2017). The newly found financial reforestation mitigation potential is now available on national level and can be utilized in the set-up as described in section 3.1 and 3.2 of this thesis.

7.3.3 Reforestation mitigation potential

With the above described methodology, explained in greater detail in the appendix of Griscom *et al*. (2017), it is possible to display and analyze the technical and financial mitigation potential in this section.

The global technical mitigation potential as calculated by Griscom *et al*. (2017) is equal to around 10 $GtCO_2e$ per year in 2030. This mitigation potential has a very high uncertainty, due to a 66% uncertainty assigned to the total amount of area deemed suitable for reforestation, and a 32% uncertainty assigned to the emission factors used. As mentioned before, the technical mitigation potential is reduced to 30% of the total. This means that the global financial mitigation potential is around 3 $GtCO_2e$ per year in 2030. This is close to around 8% of total global CO_2 emission expected in 2030 under the CPS scenario described in the WEO2017.

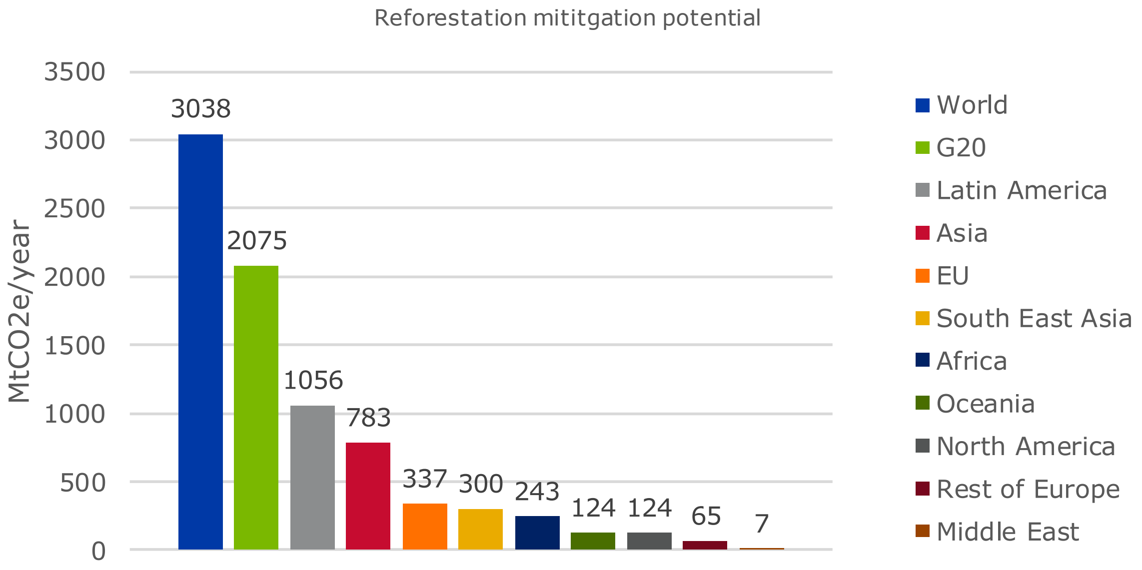

Figure 20. Reforestation mitigation potential in 2030 for the world's regions.

As can be seen in figure 20, the G20 in total represent around 2075 $MtCO_2e$ per year in 2030, which is about 68% of the total global reforestation mitigation potential. The region with the highest mitigation potential is Latin America, with around 1050 $MtCO_2e$. The realization of such a mitigation potential will amount to a 74% reduction of the total emissions, projected to be emitted in 2030 under the CPS (IEA, 2017b). This high potential is largely driven by Brazil with 465 $MtCO_2e$, which is a 91.7% reduction of the country's total emissions. Furthermore, Mexico and Colombia are the second and third largest in Latin America with 155 $MtCO_2e$ and 88.5 $MtCO_2e$, respectively. Asia and the EU are the regions with the second and third largest mitigation potential. China represents around half of Asia's mitigation potential with around 377 $MtCO_2e$, which is equal to a reduction of 3.5% of China's projected emissions in 2030. This is more than the entire EU, which represents around 336 $MtCO_2e$ mitigation potential in the 2030. The reforestation of the EU would lead a 12% reduction of all projected emitted CO_2e. In the EU, the highest potential is in Spain, and is followed by France and the UK. The smallest mitigation potentials regarding reforestation are in the Middle East, the rest of Europe and North America. The regions respectively represent around 7 $MtCO_2e$, 65 $MtCO_2e$, and 124 $MtCO_2e$. For North America that would mean an emission reduction of 2%, when all projected emission in 2030 are taken into consideration. The detailed results for all the regions' mitigation potentials is shown in Table B13, in the appendix.

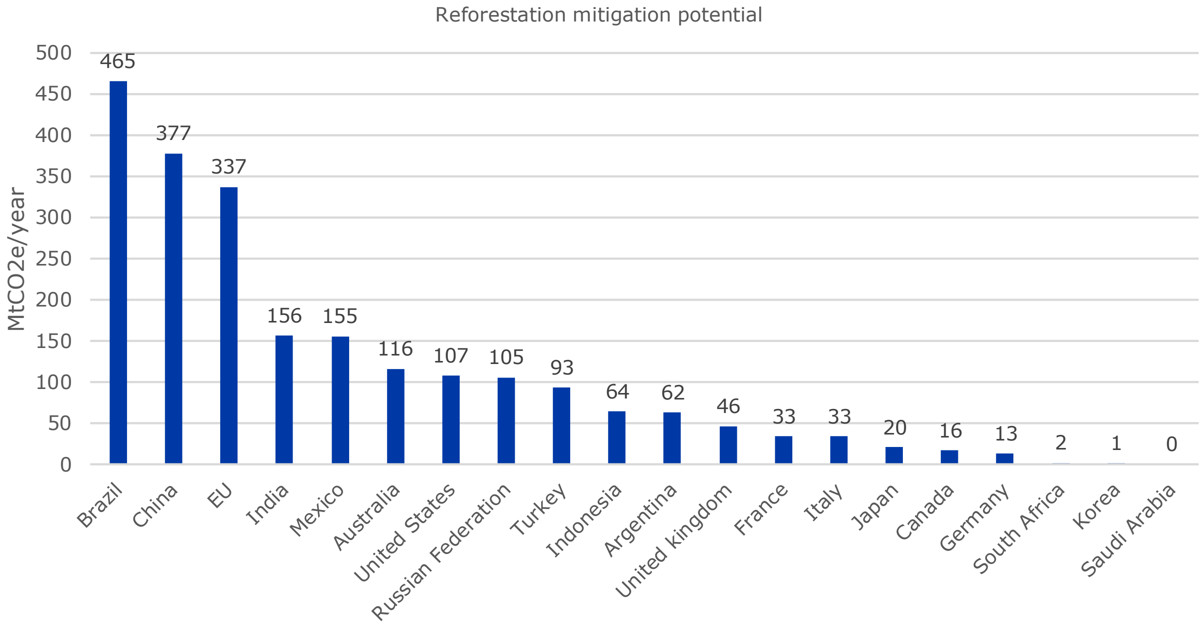

Figure 21. Reforestation mitigation potential in 2030 for the G20.

In the same manner, the results for the reforestation mitigation potential of the G20 can be given and discussed. The mitigation potentials, are displayed in Figure 21. India has a mitigation potential of around 156 $MtCO_2e$ per year in 2030. As mentioned previously, the EU has a reduction potential of around 337 $MtCO_2e$. Australia, the US, and Russia all have a mitigation potential of around 110 $MtCO_2e$ each. Turkey shows that is can mitigate around 90 $MtCO_2e$, while Indonesia and Argentina have a mitigation potential of around 63 $MtCO_2e$ each. The EU G20 member states UK, France and Italy follow with 46 $MtCO_2e$, 34 $MtCO_2e$, and 33 $MtCO_2e$, respectively. Canada has a reforestation mitigation potential of around 16 $MtCO_2e$, and Germany has a potential of 13 $MtCO_2e$. The countries that have almost no mitigation potential are South Africa and South Korea with 1.5 $MtCO_2e$ and 1 $MtCO_2e$. Saudi Arabia has close to zero mitigation potential. The results are shown in Table B14, in the appendix.

As stated earlier, the boreal areas are not included in this analysis, this means that when this area would be included the mitigation potential for countries like Russia and Canada could be higher. In Figure 22, the results for the G20 and all other countries treated in Griscom *et al.* (2017) are visualized in a map of the world. As can be seen by the darkness of the colors the highest, absolute mitigation potentials are situated in Brazil, China, India, Russia, The US, and Australia. However, large results can be achieved if the combined potential of Central and South America, Central Africa, and South-East Asia are realized. The global estimate of around 3 $GtCO_2e$ per year in 2030 is uncertain. It does, however, fit into the range given in the *Emissions Gap Report 2017* (UNEP, 2017; Verdone *et al.*, 2015). In this publication a range from 1.6 to 3.4 $GtCO_2e$ in 2030 is given with a central estimate of around 2.4 $GtCO_2e$.

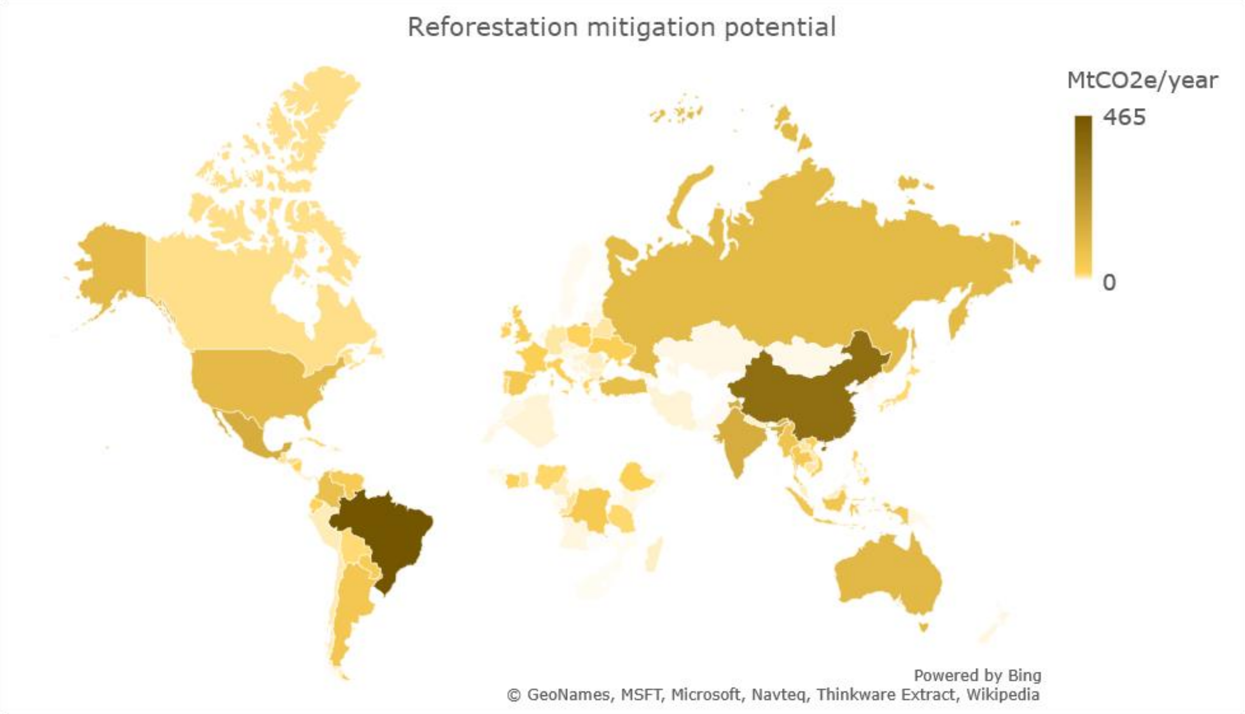

Figure 22. Reforestation mitigation potential in 2030 for the world.

8. Industry

In this section the focus lies on the sector *Industry*. The measure that is to be treated within this thesis and within this sector is *Energy Efficiency – Direct*, as called in the *Emissions Gap Report 2017* (UNEP, 2017). First, the definition and relevance of the sector industry and direct energy efficiency are explained in greater detail. Then, the methodology for the calculation of the mitigation potential is elaborated on, after which the results are presented. Lastly, conclusions regarding the global mitigation potential in comparison with other estimates are drawn.

8.1 Extent of the sector

The industry sector represented about 38% of total final energy consumptions in 2014, amounting up to 154 exajoules (EJ), making it more energy demanding than the transport or buildings sector. Furthermore, the industry sector was responsible for around 24% of energy-related CO_2 emissions in that same year emitting almost 8.3 $GtCO_2$ of direct emissions. Additionally, industry is the largest user of coal, using around 60% of final global coal consumptions. For oil-products this is 28%. Industry further has several highly energy-intensive subsectors (IEA, 2017c). These sectors are iron and steel, cement, chemicals and petrochemicals, pulp and paper, and aluminium. Sometimes, the chemical subsector is divided into high value chemicals and basic chemicals. Additionally, Ammonia and methanol are large end-products in this subsector. Together these energy-intensive subsectors demand around 69% of industries total energy usage. In this chapter, the whole industry sector will be treated, so also smaller sub-sectors not mentioned above.

In the industry sector, efforts have already been made over the last few decades to decrease the dependency on fossil fuels and predominantly oil. These improvements, driven by the want to curtail production cost and risk of price volatility, have been achieved through structural changes, efficiency improvements, and optimization of local sources of energy. According to the IEA (2017), this has led to an 11% decrease in global industry energy efficiency since 2000.

Under the CPS, industry is expected to emit around 19.3 $GtCO_2e$ in 2030. Two of the largest contributors to these expected emissions are direct and indirect use of fossil fuels. The direct use of fossil fuels occurs at the plants or factories and are directly used in the processes. Indirect use of fossil fuels occurs at the power station in the generation of electricity, which is then utilized in industrial processes. An example could be the use of electricity in the steel and iron industry in so-called *Electric Arc Furnaces* (EAF). The furnaces use electricity to melt steel instead of heat generated through the burning of carbon-containing substances and cokes (Proctor *et al*., 2011).

According to Fischedick *et al.* (2014), the emissions in 2030 coming from the industry sector can be decreased by a significant amount through the application of a large variety of mitigation measures. However, it is estimated that most of this mitigation can be achieved by focusing on energy efficiency, non-CO_2 measures, carbon capture and storage (CCS) and renewable heat. According to Akbar *et al.* (2014) the mitigation potential for energy efficiency in the industry sector is around 4.1 $GtCO_2$ in 2030, when it is compared to the CPS. This is in line with estimated made by other authors, such as Worrel & Carreon (2017), and Saygin *et al.* (2011).

8.2 Methodology and assumptions

As mentioned previously, a distinction is made between direct and indirect emissions. In the same way a distinction can be made between the climate measures *energy efficiency – direct* and *energy efficiency – indirect.* In this report the focus is going to be on the direct energy efficiency since the indirect energy efficiency and the related emissions are already treated in the energy sector. The industry sector is a large emitter of CO_2 and other GHGs and is also one of the industries with the highest energy demand. This makes it one of the key sectors to implement changes to improve energy intensity and reduce GHG emissions (IEA, 2017c). In *Energy Technology Perspectives 2017* (IEA, 2017a), direct CO_2 emissions mitigation is divided into four categories of mitigation. They will be treated below

Direct efficiency mitigation types

Material efficiency is the name for processes or approaches which are aimed at reaching the same output of a certain process in terms of energy or resulting material, while using lower amounts of production resources. This approach is adopted to reduce energy demand or to minimize environmental damage. Moreover, it can aid in resource security as well (IEA, 2017c). Material efficiency is useful in all mentioned sub-sectors of industry. There are multiple types of material efficiency which can be interesting for the industry sector. These are *end-use material intensity*, which is focused on reducing overall material consumption, using materials at higher capacities, or using material more intensively. An example is lengthening the lifetime of a product or material change in the end-product. Another form of material efficiency is *manufacturing process material efficiency*. This is mostly focused on increasing production yields in the production of metals. Additionally, there are *inter-industry material synergies*. These are efficiency gains coming from the collaboration of different subsectors. An example hereof is the substitution of clinkers in cement production processes with slag, which is a by-product in the blast furnace route of producing pig-iron. In this way, the highly polluting nature of clinkers in the production of cement can be partly eliminated. Lastly, *post-consumer recycling* focusing on the re-use of materials in other processes, and so decreases the need for newly manufactured materials (IEA, 2017c).

In addition to material efficiency, with the decarbonization of the industry sector in mind, fuel and feedstock switching can offer significant emission mitigation. This is focused on using low-carbon fuels and feedstocks. In some processes this might not be possible due to chemical or process restrictions, but often industrial processes can use energy coming from renewables, such as solar and wind, electricity, waste heat, or biomass. Applying this type of energy efficiency might demand equipment to be updated or retrofitted and can be made difficult by a relative increase in fuel price. Electrification might play a large role in a low-carbon future where renewables deliver a large portion of demanded energy in the form of electricity. This would also add to flexibility of energy demand in the industry sector (IEA, 2017a).

Energy efficiency and best-available-technologies (BAT) deployment are strategies which refer to the implementation of the latest, and most efficient equipment, techniques, or machinery. In this way energy demand is decreased or processes are updated to be more efficient. often site-specific factors make it difficult for plants or factories to reach BAT but trying to implement BAT will significantly help to reduce industry GHG emission. Additionally, energy efficiency can be increased by *energy management systems*. These automated systems monitor the energy use in industrial processes while guaranteeing product quality and safety, at lowest energy cost.

Lastly, innovative processes and predominantly CCS can offer significant improvement with regards to industry's greenhouse gas emissions levels. This category also includes new aluminium, iron, and steelmaking processes such as direct reduction iron and the use of inert anodes for aluminium smelting. Moreover, improvements to cement manufacturing are included such as full-oxy kilns for clinker production. These processes are innovative and often not fully developed, in some cases making them currently not commercially available (IEA, 2017b).

Additionally, the direct energy mitigation potential in the industry sector is assumed to have a marginal abatement cost which is below the financial threshold of \$100/tCO_2e. This assumption is based on the projected emissions reduction and the necessary projected investments as projected by McKinsey (2011).

Now, the methodology and assumptions regarding the calculation of the financial mitigation potential of direct energy efficiency in the world's industry sector will be discussed. First the baseline taken from the *Energy Technology Perspectives 2017* will be discussed, after which two future scenarios will be discussed.

The baseline

For the baseline the *Reference Technology Scenario* with base year 2014, described in ETP 2017 will be used. This scenario considers the current and announced policies and pledges of countries to reduce emissions and advance energy efficiency along their economic sectors. This means that this scenario factors in all individual NDCs made to the Paris climate accord. This also means that this scenario is not a traditional business-as-usual scenario which would assume no changes as of now, and already assumes a significant shift from such a BAU scenario. Even still *Reference Technology Scenario* needs significant policy action and technological development along with emission reductions towards the end of its timeline, which is 2060. It further assumes that temperatures in 2100 would be 2.7℃ above pre-industrial levels and will not be stable for the years after, thus rising even further. This scenario is taken as a baseline since it represents some inevitable change in the direction of a more sustainable future while not assuming too much shifts in energy efficiency and emission reduction. Furthermore, it wouldn't reflect current affairs if a business-as-usual scenario, assuming no change as of 2014 into 2060 would be taken as a baseline.

The *Energy Technology Perspectives 2017*, in which the *Reference Technology Scenario* is described, gives data tables with regards to the energy use and final energy demand of the industry sector of several countries and regions. The final energy demand for the industry sector is further split into the sources of energy. The mentioned countries and regions are World, OECD, non-OECD, ASEAN, EU, Brazil, China, India, Mexico, Russia, South Africa, and the United States. Again, just like in chapter 5, this gives a problem since not all countries within the scope of this thesis, are treated in the *Energy Technology Perspectives 2017*.

To get the final energy demand for the industry sector per energy source for these countries the data from *Energy Technology Perspectives 2017* is combined with data from the IEA balances (IEA, 2018c), in a same manner as in chapter 5. The share in the total energy demand of each source and the growth rate of the final energy demand per energy source from 2014 to 2030 is calculated for each of the countries mentioned above. This growth rate is then applied to the industry energy demand data for each of the missing G20 countries, taken from 2014 data from the IEA balances databases. Additionally, the *Energy Technology Perspectives 2017* gives the direct emissions in the industry sector in 2030. With the total direct emissions and the energy demand per energy source it is possible to calculate the emission factor for each of the countries and regions in 2030. We calculate the marginal emission factor since we assume that fossil fuel intensive energy sources are going to be replaced by renewable sources of energy first, until high levels of RES are reached. The marginal emission factor is calculated by dividing the direct industry emissions of a country or region by the total combined energy demand of coal, oil and gas for industry.

The growth rates and shares within the final energy demand per energy source, as well as the marginal emission factors were assumed to be equal to those of comparable countries or regions, according to geographical situation, comparable economic situations, language and culture. This led to the following assumptions regarding these values:

- Canada is assumed to have equal values to the US
- Argentina is assumed to have equal values to Brazil
- France, Germany, Italy, and the UK are assumed to have equal values to the EU
- Indonesia is assumed to have equal values as ASEAN
- Saudi Arabia is assumed to have equal values to the OECD
- Japan, South Korea, Turkey, Australia are assumed to have equal values to the OECD.

In this way, a baseline for all G20 countries is constructed. This baseline gives the final energy demand in the industry sector for each source of energy and the total for 2030. Emissions for the countries not mentioned in the *Energy Technology Perspectives 2017* were calculated by multiplying their final direct energy demand with the calculated marginal emission factor.

Beyond 2 degrees

The future scenario which will be used to determine the mitigation potential for direct energy efficiency in the industry sector in 2030 is the *beyond two degrees scenario (B2DS)*, described in the *Energy Technology Perspectives 2017.* The B2DS describes a path in which accelerated technology push is assumed which stimulates rapid deployment of low-emission technologies and energy efficiency measures, thereby avoiding a lock-in of energy and carbon intensive technologies. This path assumes that a rise in temperature compared with pre-industrial levels of below 1.75℃ is a technical possibility, although it will need significant efforts and rapid acceleration of global climate action.

The B2DS investigates the possibilities with using current technologies and anticipating technologies which are currently under development and are expected to play a role in the future. Technology efficiency improvements and the deployment of BAT are on the forefront of this scenario. Furthermore, CCS and bioenergy combined with CCS will play a large role, i.e. in the energy and industry sector (IEA, 2017a; Akbar *et al.*, 2014).

Again, as was the case with the baseline mentioned above, only several countries and regions are mentioned in the B2DS. To this end the same method is applied, only this time the growth rates of the energy demand between 2014 and 2030 and share per energy source in the final energy demand of the B2DS are applied to the base year values taken from the IEA balances. Again, the marginal emission factor is calculated for each country in the B2DS in 2030 and multiplied with the direct final energy demand for each of the G20 member states to get the emissions under the B2DS in 2030. The mitigation potential for each of the G20 countries under the B2DS scenario is calculated by deducting the emissions from the emissions as calculated under the *Reference Technology Scenario* (IEA, 2017a).

Since the size of the industry sector within country is strongly linked to the GDP or the relative rise in GDP of that country (Crosthwaite, 2000), the mitigation potential for the world's regions is calculated as follows. The mitigation potential for the G20 member countries within one the regions is combined, and subsequently divided by the percentage of GDP that these member states together represent within their region. This will give the mitigation potential for the whole region, with GDP as the variable. For example, the region Asia, as described in this thesis, entails the G20 member states China, India, Korea, Japan, Russia, and Turkey. Their combined mitigation potential, calculated previously, is then divided by their share of the GDP in Asia. This is around 93%. It is thus assumed that the non-G20 members in Asia represent the other 7% mitigation potential.

As mentioned before, the B2DS scenario will also be highly dependent on the deployment of innovative techniques such as CCS and bioenergy combined with CCS. These techniques offer significant mitigation potential and will most likely play a huge role in the future energy and industry sector since they offer an outcome for the large quantities of emitted CO_2 in the sector processes, which is currently not available. However, these techniques are currently not economically developed enough for it to fall below the \$100/tCO_2 threshold, and it is uncertain as to how this will develop in the future and up to 2030 (Global CCS Institute, 2017). Moreover, in *Energy Technology Perspectives 2017* ''innovative techniques'' and CCS play a crucial role, but it is not stated how much of the mitigation potential is offered by these innovative techniques and how much by CCS, percentage wise. So, the decision has been made to exclude innovative techniques and CCS, as described in the *Energy Technology Perspectives 2017* and the B2DS, from the direct energy efficiency analysis in this thesis. The amount of CO_2 which will be captured via CCS under the *Reference Technology Scenario* and B2DS in 2030 is given in the *Energy Technology Perspectives 2017* for each of the above-mentioned countries.

The amount of captured emissions using CCS in the countries that aren't treated in *Energy Technology Perspectives 2017* are calculated as follows. First, the total amount of captured CO_2 for each country, treated in *Energy Technology Perspectives 2017,* is divided by the total mitigation potential. This percentage is then applied to a comparable country or region. Here the same ''model''-countries are used as in determining the final energy demand per energy source. This can directly be deducted from the calculated mitigation potential under the B2DS.

For comparative reasons a second methodology has been used. This methodology has led to the same global results as well as a similar trend with regards to countrywide mitigation potentials. However, this methodology utilizes unpublished data and therefore not included. The methodology is described in Appendix D

8.3 Direct energy efficiency mitigation potential in the industry sector

In this section the results of the direct energy efficiency mitigation potential, using the methodology described above, are displayed for the G20 member countries and the world's regions. First, the results for the world's regions including the G20 total will be discussed, after which the focus will shift towards the individual G20 members. As explained, assumptions regarding the base year values as well as the energy usage and emissions growth rates have been made. This leads to uncertainty with regards to nationally calculated mitigation potentials for the countries which are not mentioned in the *Energy Technology Perspectives 2017.*

In Figure 23, the mitigation potential for the world's regions is displayed. In total the world's potential is 2550 $MtCO_2e$ per year in 2030. This potential is largely situated in non-OECD countries. In turn, the mitigation potential of the non-OECD is largely situated in countries such as China, India, Russia, and Saudi Arabia. The G20 in total has a mitigation potential of around 2120 $MtCO_2e$ per year in 2030. This means that the G20 represents around 83% of the global total mitigation potential. Asia is by far the region with the largest mitigation potential in 2030, again this is largely due to it containing China, India, Russia, Japan, Korea and Turkey. The Middle East, South East Asia and Africa have a mitigation potential of 180 $MtCO_2e$, 145 $MtCO_2e$, and 144 $MtCO_2e$, respectively. The mitigation potential in the Americas ranges between around 130 $MtCO_2e$ and 105 $MtCO_2e$. The European Union has a mitigation potential which represents around 4% of the global total, amounting to 95 $MtCO_2e$ in 2030. The mitigation potential, as calculated in this report, of Oceania and the rest of Europe are almost insignificant on a global scale. Oceania has a mitigation potential of around 10 $MtCO_2e$, while the rest of Europe has a mitigation potential of around 5 $MtCO_2e$.

The total global mitigation potential calculated represents an emissions reduction of around 17% when compared to baseline in 2030. Russia has the largest reduction of around 26%, while Japan, Turkey and Korea have the lowest relative reduction of around 10%. China's mitigation potential represents a reduction of 19%, while the US' mitigation potential would mean a 14% reduction compared to the baseline in 2030. In the EU, this reduction is 15%.

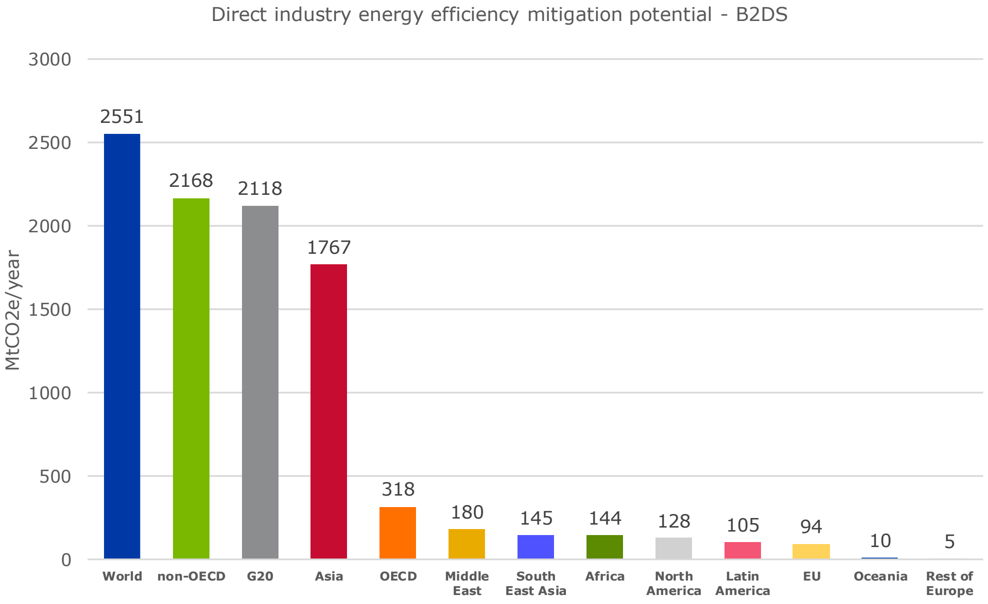

Figure 23. Direct energy efficiency mitigation potential for world's regions' industry sectors in 2030.

The results for the G20 member states is split into two graphs since the difference between the individual countries is so significant that it doesn't allow for specificity below a certain mitigation potential. The results for the member states with the highest mitigation potential are displayed in Figure 24. As can be seen, China by far has the largest mitigation potential when comparing the potential of around 1180 $MtCO_2e$ to the other G20 countries' mitigation potential. China embodies around 46% of the total mitigation of direct energy efficiency improvements in the Industry sector. India has the second largest mitigation potential of around 330 $MtCO_2e$ which is around 13%, while the US and EU together represent around 205 $MtCO_2e$ of mitigation per year in 2030.

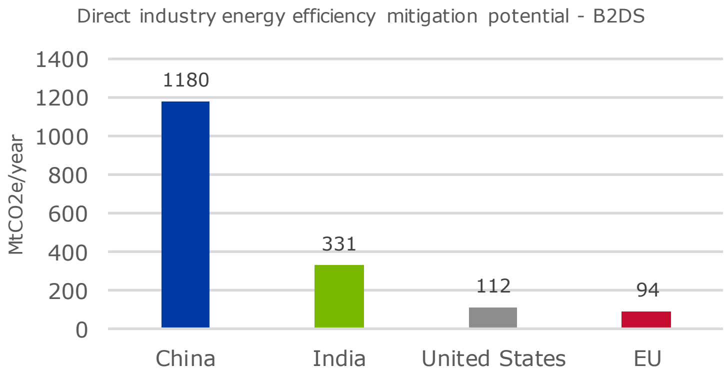

Figure 24. Energy efficiency mitigation potential for the industry sector of selected G20 states in 2030.

The G20 member countries, shown in Figure 25, show significant lower mitigation potentials than the G20 countries shown in Figure 24. Russia is the country with the fifth largest mitigation potential followed by Saudi Arabia. Both countries have a relatively large mitigation potential which is largely based on the large chemical and petrochemical industries which are present. Further, the European countries Germany, France, Italy and the UK together have a mitigation potential of around 52 $MtCO_2e$. This is just more than half, 55%, of the mitigation potential which was calculated for the entire EU in 2030. Additionally, China represents most of the mitigation potential, around 56% of the G20's mitigation potential, while India and the US represents 16% and 5%, respectively. The EU and Russia represent 4%, while the rest of the countries represent 1% or 2%.

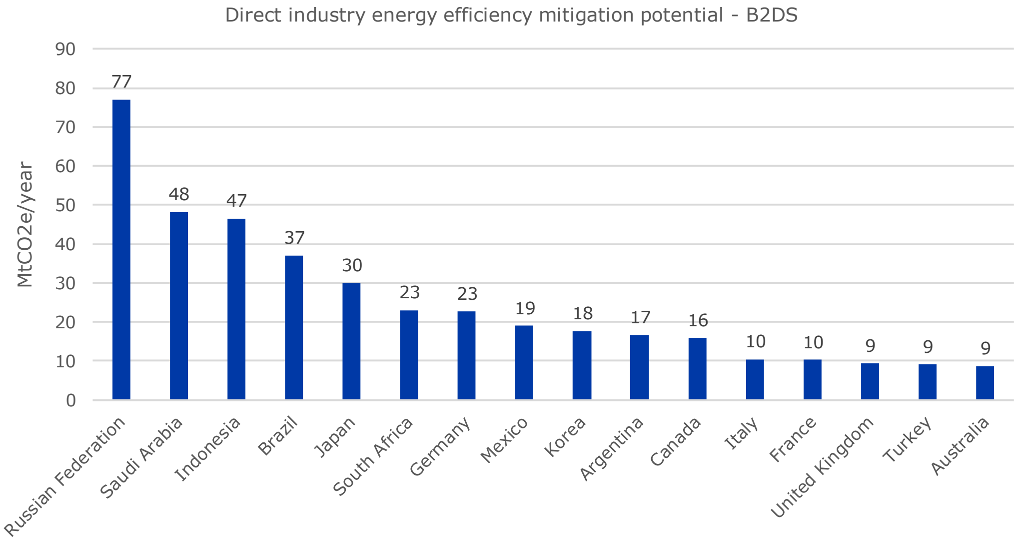

Figure 25. Direct energy efficiency mitigation potential for the industry sector of G20 states in 2030.

9. Transport

In this section the sector *Transportation* is discussed. The measure within this sector that offers the largest mitigation potential according to the *Emissions Gap Report 2017*, is *efficient light duty vehicles (UNEP, 2017).* Before the methodology and the subsequent results and conclusion regarding the mitigation potential of this measure are given, the current situation and extent of the sector is explained. Moreover, other estimates of the potential mitigation of the transportation sector and efficient passenger vehicles are given and discussed.

9.1 Extent of the sector

The transport sector is one of the sectors which has always been one of the main emitters of GHG and pollutants. Since the 1970's the emissions from the transport sector have increased rapidly and in 2010 the emissions from all transport amounted to around 7 GtCO$_2$e of direct emissions (Sims *et al.*, 2014; IEA, 2012) of which around 80% originates from road transport. Moreover, under the *Reference Technology Scenario* mentioned in the *Energy Technology Perspectives 2017*, the global well-to-wheel (WTW) emissions from the transport sector are estimated to be around 11.4 GtCO$_2$e in 2030, with direct emissions of around 9 GtCO$_2$e. Almost 27% of total energy demand in 2014 came from the transport sector. Of this demand, almost 95% was generated by using oil or oil products. Further, biomass and natural gas represented 3% and 1.5%, respectively. On a global scale, the electric energy demand is negligible. This is, however, expected to increase and to gain a larger foothold in the transport sector (IEA, 2017a). Several sources claim that electric vehicles (EVs) will represent a significant part of vehicle sales by 2030 ranging from 7% to 10% (IRENA, 2016; ICCT, 2012; Bloomberg, 2017).

In this thesis, the measure which will be focused on in the transport sector is a shift towards more efficient light duty vehicles. An ICCT report (2012) estimates that by 2030 around 2 GtCO$_2$e of emissions coming from light duty vehicles (LDV) can be mitigated through fuel efficiency. This fuel efficiency includes advances in motor efficiency, modal shifts and the shift to electric vehicles.

In recent years advances have already been made with regards to efficiency and the amount of emitted CO$_2$ per kilometer of passenger vehicles and other LDVs, however, this has not been free of controversy. In 2015, investigation made clear that car manufacturer Volkswagen had installed software, dubbed ''defeat device'' which in testing gave lower amounts of emitted GHGs than it would emit in real road circumstances. This scandal has led to significant loss of face for the company and has made clear that progress which was assumed to be made was not made at all (Tabuchi & Ewing, 2016).

9.2 Methodology and assumptions

In this thesis the measure that will be treated within the transport sector is *efficient light duty vehicles*. With the term efficient light duty vehicles all measures concerning light duty vehicles and 2- and 3-wheelers are included. The term LDV further includes passenger light duty vehicles (PLDV) such as privately-owned cars, but also light commercial vehicles (LCV). The IEA doesn't give a clear definition as to what LCV are, but several definitions are maintained. In the US, LCVs are considered vehicles with a weight, when fully loaded of maximum 3850 kg, while in the EU, and Australia this is 3500 kg. This is in line with ''conventional'' delivery trucks. In this thesis the mitigation potential of these three types of transport will be included, and thus trucks, buses, train, aviation and shipping are not considered.

The reduction in GHG emissions made by the transport sector are shaped by future developments in transport activity, modal shift, and transport technologies. Transport activity refers to the total activity in terms of passenger kilometers of tonne kilometers. Reducing the amount of transport activity reduces the amount of energy necessary in the transport sector. This can be done by making trips shorter or taking away the demand for transport. Modal shift refers to using modes of transport which would require less energy to get there. For example, taking public transit instead of taking your own car or other vehicle would reduce the total amount of energy used and emitted GHGs. Lastly, advances made in terms of technology will reduce the energy demand to travel the same distance. These improvements i.e. include motor or drivetrain efficiency gains, weight reductions and aerodynamic improvements. Additionally, this also includes the move towards more carbon-efficient fuels or even semi-electric of fully-electric vehicles. This principle of reducing the need for transport, traveling more efficient and developing technologies to reduce energy use and emissions in the energy sector is termed as ‘’avoid, shift and improve’’ by the IEA (2017a). Additionally, the marginal abatement cost of shifting to more efficient light duty vehicles is below \$100/tCO_2e. This is based on the marginal abatement cost curve as given by McKinsey (2010).

Now the used methodology of calculating the mitigation potential of direct energy efficiency in the world’s transport sector will be discussed. First the baseline taken from the *Energy Technology Perspectives 2017* will be discussed, after which the future scenarios will be explained. As a baseline for the transport sector the *Reference Technology Scenario* is used. This scenario is described in the *Energy Technology Perspectives 2017* and considers transport policies and regulations which are implemented, are under consideration or have been announced. Moreover, the *Reference Technology Scenario* roughly includes the efforts described in the Paris climate accord and its decarbonization goals. The *Reference Technology Scenario* considers logistic technology improvements, energy efficiency and modal shifts (IEA, 2017a). It should be noted that this is not a continuation of current policies, and already offers improvements versus a scenario where current emission trends are continued. Under the *Reference Technology Scenario,* the direct CO2 emissions related to transport increase from around 7.4 GtCO_2 to 9 GtCO_2 in 2030, while the WTW increases from 9.5 GtCO_2 to 11.4 GtCO_2 in the same timeframe. in 2030, light road transport is responsible for 5.1 GtCO_2, representing around 45% of total WTW emissions.

The *Energy Technology Perspectives 2017* gives data tables which include the amount of passenger kilometers over the years per type of transportation. This data is used to construct a baseline for the countries and regions of interest. In the *Energy Technology Perspectives 2017* a set of countries and regions treated. This set of countries and regions is the same as for the *Buildings* and *Industry* sector and includes World, OECD, non-OECD, ASEAN, EU, Brazil, China, India, Mexico, Russia, South Africa, and the United States. To derive the baseline emissions for the G20 countries and regions that haven’t been included in the *Energy Technology Perspectives 2017* the following has been done.

First, the growth rate in terms of energy use in the transport sector between 2014 and 2030 was calculated for the countries mentioned in the *Energy Technology Perspectives 2017*. This calculation was applied to countries which were assumed to have a similar economic and ecological situation:

- Canada is assumed to have equal values to the US
- Argentina is assumed to have equal values to Brazil
- France, Germany, Italy, and the UK are assumed to have equal values to the EU

- Indonesia is assumed to have equal values as ASEAN
- Saudi Arabia is assumed to have equal values to non-OECD
- Japan, South Korea, Turkey, Australia are assumed to have equal values to the OECD.

The growth rate was multiplied with the historic energy use data for the transport sector in 2014 from the IEA data balances (IEA, 2018d). In this manner the total energy use in 2030 for the transport sector for the countries of the G20 that are not mentioned in the *Energy Technology Perspectives 2017* was constructed. Then the share of the total transport energy that was used for PLDV and LCV was calculated for each country. This was done in the same manner as before, by applying the ''model''-countries split to the other G20 countries. In this way, a transport energy use baseline has been created for 2030.

In this thesis the emission reduction potential for efficient LDVs in 2030 will be calculated using the B2DS, taken from the *Energy Technology Perspectives 2017*. The ambitions of this scenario for the transport sector are such that they are in line with Paris climate accord. Additionally, it is consistent with a 50% probability of keeping temperature rise below 1.75℃ compared to pre-industrial levels. In this scenario, rapid deployment of most efficient technologies and zero-carbon transportation modes and energy carriers are paramount. The goal here is to shift away from fossil-based fuels and transport emissions in the short to medium-term. For this to be accomplished, the B2DS assumes rapid and ambitious legislative and policy action (IEA, 2017a). Under the B2DS, global transport WTW emissions in 2030 are assumed to be 7.94 $GtCO_2$ while light road emissions are responsible for 3.46 $GtCO_2$.

The B2DS shows that WTW GHG emissions will decline significantly over the years, and that there will be a relative shift of energy from passenger transport to freight transport. Further, PLDVs, LCVs and trucks offer most of the emission reduction potential. To reach a highly decarbonized transport sector the B2DS assumes that current state-of-the-art technologies will be widely implemented alongside rigorous policy action. In this way a shift towards more efficient and less carbon intensive transport modes will be achieved. The main energy carrier for short-distance travel will be electricity. LDVs, 2- and 3-wheelers and public transport will be mostly electrified. Long-distance transport, such as freight transportation and aviation will be reliant on low-carbon energy carriers and will reduce emissions by improving efficiency through a stricter regulatory environment. in the long-distance transport sector low-carbon gaseous and liquid biofuels have significant potential, as well as hydrogen although this energy carrier will be more widespread towards 2060.

Overall, the electrification of the transport sector will be the largest source of decarbonization, especially in the short- to medium-distance modes by 2060. In 2030 the share of electric vehicles will be modest with penetration rates of around 15%. It is assumed that the cost, as well as the lifetime, efficiency and dangerous nature of batteries will improve so that it proves to be a more viable option for not only consumers but also governments and car manufacturers. Additionally, hydrogen is assumed to increase foothold in the B2DS in 2060. The range that vehicles with a hydrogen fuel cell can drive is in the same range as the action radius of internal combustion engine vehicles available today. Moreover, hydrogen can be produced through low-carbon processes using CCS or low-carbon energy sources such as solar power electricity (Miller, 2016). According to Papageorgopoulos (2016) fuel cells are estimated to become less costly, reducing total cost of ownership. Hydrogen, however, must overcome some barriers to be more widely implemented, and in 2030 will not play a significant role yet. Electrolysers have low capacity utilization making the economic case difficult. Also, hydrogen-based electricity has lower thermodynamic efficiency compared to other storage technologies.

To calculate the emission reduction potential under the B2DS using the *Reference Technology Scenario* as a baseline, the energy usage of transport and the LDVs and LCVs must be calculated for all G20 countries. This will be done in the exact same manner as has been done under the *Reference Technology Scenario*, only replacing the 2030 energy usage data for B2DS data for the countries treated in the *Energy Technology Perspectives 2017*. Now, there is energy use data for 2030 under the *Reference Technology Scenario*, serving as a baseline, and under the B2DS for each country of the G20 as well as for the world, OECD, non-OECD and South East Asia. The *Energy Technology Perspectives 2017* gives WTW emissions from 2014 to 2030 under the *Reference Technology Scenario* and B2DS. Combined with the energy usage data for light road freight under both scenarios, it is possible to determine an emission factor for each of the treated countries and regions in the ETP. This is done by deducting the energy usage and WTW emissions for 2030 under the *Reference Technology Scenario* by the same energy usage and emissions under the B2DS and then dividing the reduced emissions by the reduced energy. The emissions factor of ''model''-countries is then applied to the other, similar countries. In this way the emissions reduction potential is calculated for 2030. To get the emissions reduction potential for the world's regions the emission reduction of the G20 countries in a certain region is divided by their share in the regions GDP. This method of calculating the regions mitigation potential has been chosen because the measure of transport within a country or region is strongly linked to the size and development of the economy (Liddle & Lung, 2013).

9.3 Technical and financial mitigation potential

With the methodology described in the section above, it is now possible to generate the results found for efficient light duty vehicles' emission reduction potential. First, the results for the world's regions will be given and discussed, after which the results for the G20 countries will be treated. Several assumptions have been made with regards to the base year energy use data and the transport energy use and emissions data, and so the mitigation potential for these countries can be subject to some uncertainty.

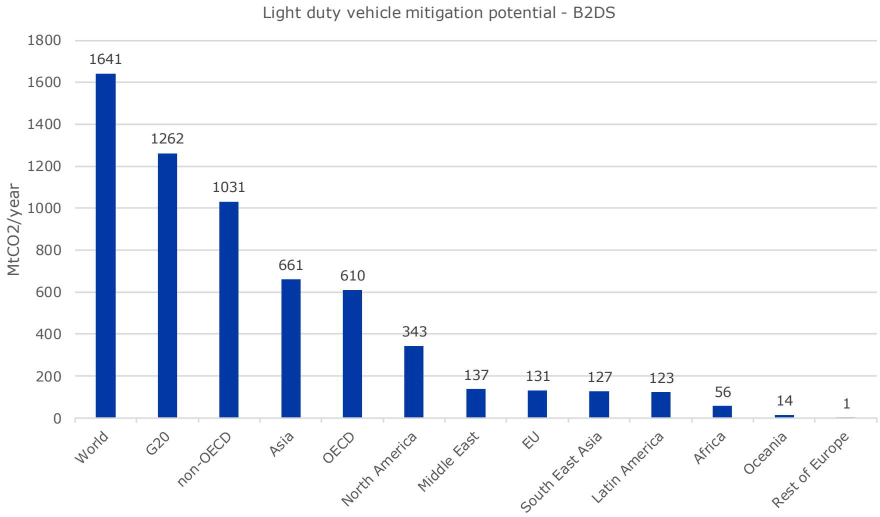

Figure 26. Efficient light duty vehicles emission reduction potential in 2030 for the world's regions.

Asia is the region with the largest mitigation potential. As explained above, this is largely due to it containing countries with large transport sector which are either in a transitioning phase, such as China and India, as well as developed economies with large amounts of transport use such as Japan and Korea. North America is the region with the second largest mitigation potential. The US and Canada have relatively large transport sectors where carbon-intensive energy carriers and inefficient LDVs and LCVs are heavily used. This gives significant room for improvement.

Additionally, the electrification of the transport sector will play an important role in the US under the B2DS, representing about 7% of total transport energy use compared to around 0.9% in the *Reference Technology Scenario*. The Middle East, EU, South East Asia and Latin America all have an emission reduction potential of around 130 $MtCO_2$. The EU currently already has a more efficient vehicle stock, as well as stringent policy action, therefor keeping its mitigation potential relatively small. Africa and Oceania, have a mitigation potential of 56 $MtCO_2$ and 14 $MtCO_2$, respectively. Lastly, the rest of Europe offers hardly any mitigation potential on a global scale, representing around 1 $MtCO_2$ under the B2DS scenario.

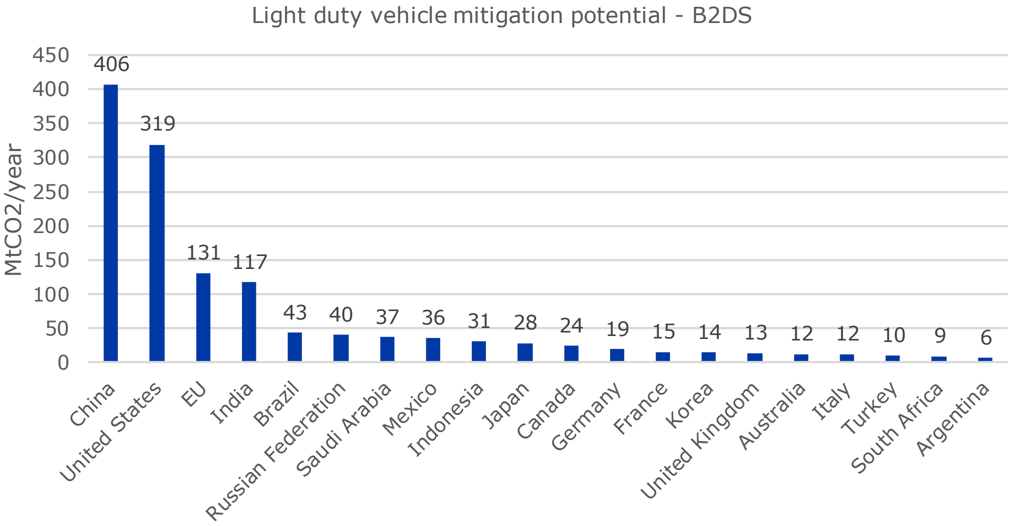

Figure 27. Efficient light duty vehicles mitigation potential of G20 states in 2030.

In Figure 27, the mitigation potential of the G20 member states for efficient light duty vehicles in 2030 is shown. China and the US are the two countries with the largest mitigation potential at around 406 $MtCO_2$ and 319 $MtCO_2$, respectively. In both countries the emission reduction is largely due to a decrease in energy use by PLDVs when compared to the decrease in energy use of LCVs. The EU and India have mitigation potentials of 131 $MtCO_2$ and 117$MtCO_2$, respectively. Although India has more than double the number of inhabitants, the mitigation potential is lower in 2030 when compared with the *Reference Technology Scenario*. Additionally, the EU has newer and more efficient PLDVs and LCVs on average. This shows that the amount of per capita energy use in India in the transport sector is many times lower than in Europe. The other G20 countries have mitigation potentials ranging from 43 MtCO2 in Brazil to around 6 $MtCO_2$ in Argentina, as can be seen in Figure 27.

10. Aggregated results and analysis

In this chapter the goal is to analyze the found results, given in chapter 4 to 9, concerning each of the sectors and their chosen measures. Remarkable results as well as found trends will be discussed and correlations and causalities will be mentioned. To illustrate the results, a table will be given in which all results are given per country or region and per measure. In this way it will be possible to view the total mitigation for a single country or a region in 2030 when considering selected measures.

10.1 Combined mitigation potentials

In Table 3, the financial mitigation for each of the world regions and the G20 member states is given for all the treated measures. The mitigation potential displayed is given in $MtCO_2e$, while the total is displayed in $GtCO_2e$. As can be seen the total global mitigation potential in 2030 for the selected measures is between 19 $GtCO_2e$ and 27 $GtCO_2e$. This range has been determined by adding all the lower bounds of the mitigation potentials for each measure on the one hand, and by adding all the upper bound mitigation potentials on the other hand. If no range is given the single value is taken. The measures with the largest mitigation potential on a global scale are solar PV (2.8 – 5.8 $GtCO_2e$), wind energy (3.6 – 5.0 $GtCO_2e$), efficient appliances (3.1 $GtCO_2e$), reducing deforestation (1.6 – 4.1 $GtCO_2e$) and direct energy efficiency in the industry sector (2.5 $GtCO_2e$). For all the measures treated in this thesis, the mitigation potential per region is calculated as well as per G20 member state. First, the world's regions will be treated, after which the attention will be directed towards the individual G20 countries. In Figure 28, the cumulative results of all the mitigation potentials are shown per region and per measure.

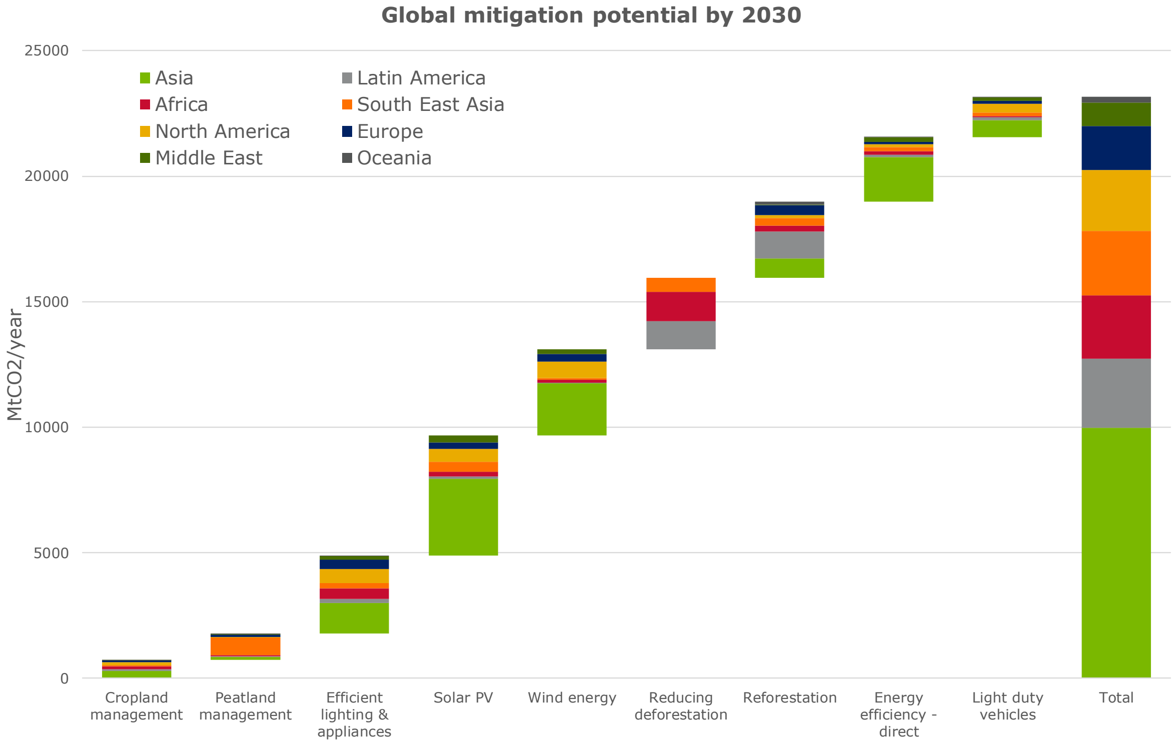

Figure 28. Total global mitigation potential for 2030 per measure per region.

Evidently and expectedly, Asia is the region with the largest mitigation potential in 2030 when the measures under consideration are added. The mitigation potential for the measures solar PV, wind energy and reducing deforestation are the values from the middle of the previously mentioned ranges, and thus the global total ends up around 23 $GtCO_2e$ in 2030.

Asia, containing China, India, Korea, Japan, Russia and Turkey represents 43% of the total global mitigation potential. This potential is largely driven by high mitigation potentials for the measures solar PV, wind energy, direct energy efficiency in industry, as well as efficient appliances and lighting. Latin America amounts to around 2.75 $GtCO_2e$ of mitigation potential which is equal to around 12% of total global mitigation potential. In total, 79% of Latin America's emission reduction potential originates from the forestry sector. Other measures that are of importance are efficient lighting and appliances as well as efficient light duty vehicles. The region with the third largest reduction potential is Africa. Again, the forestry sector is the sector with the largest mitigation potential. Reducing deforestation is responsible for around 47% of Africa's total mitigation potential. Solar PV and wind energy together represent 13% of the reduction potential. This might seem low, considering the vast solar and wind resources present on the African continent including the Sahara Desert. However, the scenario used for the energy sector, the price threshold of 100$/$tCO_2e$ and the relatively short timeframe keep high mitigation potentials in the energy sector of Africa low. Additionally, the African energy sector is relatively small compared with other world regions and is far from well-developed.

For peatland management South East Asia's mitigation potential is by far the highest, representing 67% of total global mitigation potential. This is almost entirely due to high mitigation potentials situated in Indonesia and Malaysia. Besides high emission reduction potentials in the agriculture sector, South East Asia also has high mitigation potentials in the forestry sector. Reduction of deforestation and reforestation combined amount to 850 $MtCO_2e$, which is around 32% of South East Asia's total mitigation potential. North America's total mitigation potential is around 2.4 $GtCO_2e$ when the mid-range values are taken. Respectively, efficient appliances, solar PV and wind energy represent 23%, 20%, and 27% of North America's total reduction potential. Additionally, efficiency improvements with regards to PLDVs and LCVs contribute a total emissions reduction of around 343 $MtCO_2e$ in 2030. In total, Europe has a reduction potential of 1750 $MtCO_2e$ in 2030. With regards to Europe's emission reduction potential, a similar trend as in North America can be seen; the energy sector and efficient appliances and lighting offer high reduction potentials, however, in Europe reforestation offers the highest mitigation potential, amounting to 400 $MtCO_2e$ in 2030.

The Middle East predominantly shows potential in the decarbonization of the energy sector as well as energy efficiency gains in the industry sector. Lastly, the transport sector through more efficient LDVs offers significant potential. The region with the lowest mitigation potential is Oceania. In total it has an emission reduction potential of around 215 $MtCO_2e$ per year in 2030. This is, however, without the inclusion of Solar PV and wind energy potentials. Due to the demarcation is the sources used for the energy sector, the mitigation potential for solar PV and wind energy of Oceania have been allocated to *Asia.* The mitigation potential of Oceania would thus be higher; however, it cannot be said as to how much higher. In the same manner, Asia's mitigation potential should be lower. Though, regarding the size of Oceania this would most probably not have a significant impact the total of Asia.

*Table 3. Mitigation potential for each measure for the world's regions and the G20 in 2030. *For these measures Asia includes Oceania and excludes Russia.*

Region	Cropland management	Peatland management	Efficient lighting & appliances	Solar PV*	Wind energy*	Reducing deforestation	Reforestation	Energy efficiency - direct	Light duty vehicles	Total
	MtCO₂e /year									GtCO2/year
World	725	1060	3100	2880 – 5775	2480 – 4960	1600 – 4110	3040	2550	1640	**19 – 27**
Asia	280	130	1210	1777 – 3551	1346 – 2692	0	780	1770	660	**8.0 – 11.1**
North America	100	12	570	335 – 670	440 – 880	0	125	130	340	**2.0 – 2.8**
Africa	105	40	415	135 – 270	80 – 160	665 – 1710	240	145	55	**1.9 – 3.1**
Europe	80	90	370	170 – 340	210 – 420	0	400	100	130	**1.6 – 1.9**
South East Asia	60	710	220	260 – 520	40 – 80	310 – 790	300	145	130	**2.2 – 3.0**
Latin America	80	15	155	55 – 110	20 – 40	630 – 1610	1060	105	120	**2.2 – 3.3**
Middle East	4	30	135	185 – 370	120 – 240	0	7	180	140	**0.8 – 1.1**
Oceania	7	35	30	0	0	0	125	10	15	**0.2**
G20	500	820	2200	2430– 4860	2405 – 4810	525 – 1350	2075	2120	1260	**14.4 – 20.0**
Argentina	5	0.1	30	4 – 8	10 – 20	70 – 175	60	15	5	**0.2 – 0.3**
Australia	6	1	20	45 – 90	50 – 100	0	115	10	110	**0.3 – 0.4**
Brazil	50	6	60	12 – 25	1	265 – 680	465	40	40	**0.9 – 1.4**
Canada	25	1	60	27 – 55	20 – 40	0	15	15	25	**0.2**
China	75	55	550	945 – 1890	1120 – 2240	0	380	1180	405	**4.7 – 6.8**
EU	60	60	220	120 – 240	150 – 300	0	340	95	130	**1.2 – 1.4**
France	9	1	30	20 – 40	30 – 60	0	30	10	15	**0.2**
Germany	6	8	45	20 – 40	35 – 70	0	15	25	120	**0.2**
UK	3	4	30	10 – 20	35 – 70	0	45	10	15	**0.1 – 0.2**
India	100	1	310	570 – 1140	125 – 250	0	160	330	120	**1.7 – 2.4**
Indonesia	26	640	85	80 – 160	0	165 – 430	65	50	30	**1.1 – 1.5**
Japan	2	1	120	80 – 160	75 – 150	0	20	30	30	**0.4 – 0.5**
Mexico	3	1	50	17 – 35	8 – 15	25 – 65	155	20	35	**0.3 – 0.4**
Russia	60	45	65	40 – 80	220 – 440	0	105	75	40	**0.7 – 0.9**
Saudi Arabia	0.5	0.0	25	50 – 100	50 – 100	0	0	50	40	**0.2 – 0.3**
South Africa	2	0.2	25	45 – 90	50 – 100	0	2	25	10	**0.2**
Korea	1	0.01	50	85 – 170	50 – 100	0	1	20	15	**0.2 – 0.4**
Turkey	13	0.2	40	15 – 30	13 – 25	0	90	10	10	**0.2 – 0.2**
United States	77	12	505	290 – 580	455 – 910	0	110	110	320	**1.9 – 2.6**
Italy	5	0	25	15 – 30	8 – 15	0	33	10	10	**0.1**

The G20's total mitigation potential ranges from 14.4 to around 20.0 $GtCO_2e$ in 2030. In Figure 29, the mid-range values are used to show the mitigation potential of the G20 countries and all measures.

The largest contributors to that potential are China, the US, India, the EU and Indonesia. China has a mitigation range from 4.7 to 6.8 $GtCO_2e$, while the US' mitigation potential ranges from 1.9 to 2.6 $GtCO_2e$. The high potential of China is driven mainly by high mitigation potentials in the energy and industry sector. The two sectors combined represents between 70% and 78% of China's total mitigation potential. Cropland management and peatland management play marginal roles. The US' measures with the largest mitigation potential are Solar PV and wind energy from the energy sector and efficient lighting and appliances from the buildings sector. Together they represent between 1.25 $GtCO_2e$ (65% of US total) and 2 $GtCO_2e$ (76% of US total) of mitigation. For India, the energy sector has the largest mitigation potential. The energy sector's potential, however, is predominantly based on solar PV potential, which by itself represents between 34% and 48% of India's total emission reduction potential. Other large sources of mitigation potential are cropland management, industry direct energy efficiency and efficient appliances and lighting. The EU's mitigation potential is somewhat divided over all the treated measures although peatland management and cropland management represent the lowest mitigation potentials. For Indonesia, the mitigation potential is for the largest part coming from the agricultural sector and the forestry sector. Peatland management in Indonesia has a mitigation potential of approximately 637 $MtCO_2e$, and reducing deforestation has a potential of reducing 167 to 428 $MtCO_2e$ by 2030. Additionally, reforestation has a potential of 64 $MtCO_2e$. Together this equals approximately 0.85 $GtCO_2e$ to 1.1 $GtCO_2e$, which is between 75% and 79% of Indonesia's total mitigation potential in 2030. Brazil's added mitigation potential for the considered measures is between 0.9 and 1.4 $GtCO_2e$ in 2030, of which between 0.7 and 1.15 $GtCO_2e$ is situated in the forestry sector.

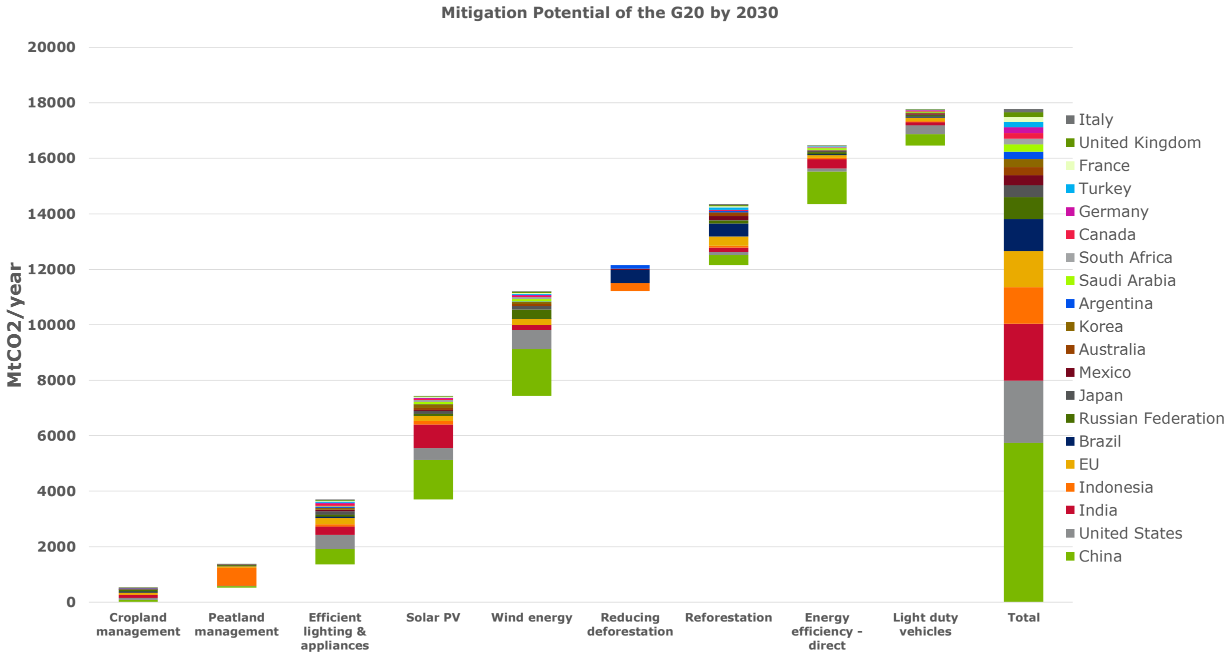

Figure 29. Mitigation potential of the G20 in 2030 for selected measures.

Now that the country and region wide mitigation potentials of the treated measures combined is given in Table 4 and visualized in Figures 28 and 29, the effect of such emission reduction will be focused on in terms of emissions reductions compared to a current policy trajectory. This current policy trajectory is not the homonymous scenario which is portrayed by the IEA in the respective *World Energy Outlook* reports (IEA, 2016;2017b), but the trajectory which is given by PBL, the Dutch environmental assessment agency, IIASA, and NewClimate Institute (Kuramochi *et al.*, 2016).

In this publication, current policy emission estimates by PBL and NewClimate Institute for 2030 are given. Additionally, governmental current policy scenarios up until 2030 are also given, however, this is not done for each country. For consistency, the estimates given by PBL and NewClimate are used in this analysis. Not all these current policy estimates included emissions of Land-use, Land-use change and Forestry (LULUCF). When this was not included, LULUCF emission data was taken from the Climate Action Tracker (CAT, 2018b), and assumed to be constant from the last year that it was available, which was 2015 in all but one case. The countries of which no data was available, France, Germany, Italy and the UK, a current policy scenario was constructed. For Germany, the 2030 emissions projection was taken from the Climate Action Report 2016 (BMUB, 2016), in which a scenario is given that takes into consideration introduced and implemented policies up until 2014. This scenario, however, doesn't include LULUCF emissions, and so the LULUCF emissions for Germany are taken from the UNFCCC greenhouse gas inventory (2018), and assumed to be constant from 2016 onwards. For France, Italy, and the UK a current policy estimates up until 2030 excluding LULUCF, projected by Climate Transparency (2017a; 2017b) is used and is combined with LULUCF emissions data from the UNFCCC (2018), which was assumed to be constant from 2016.

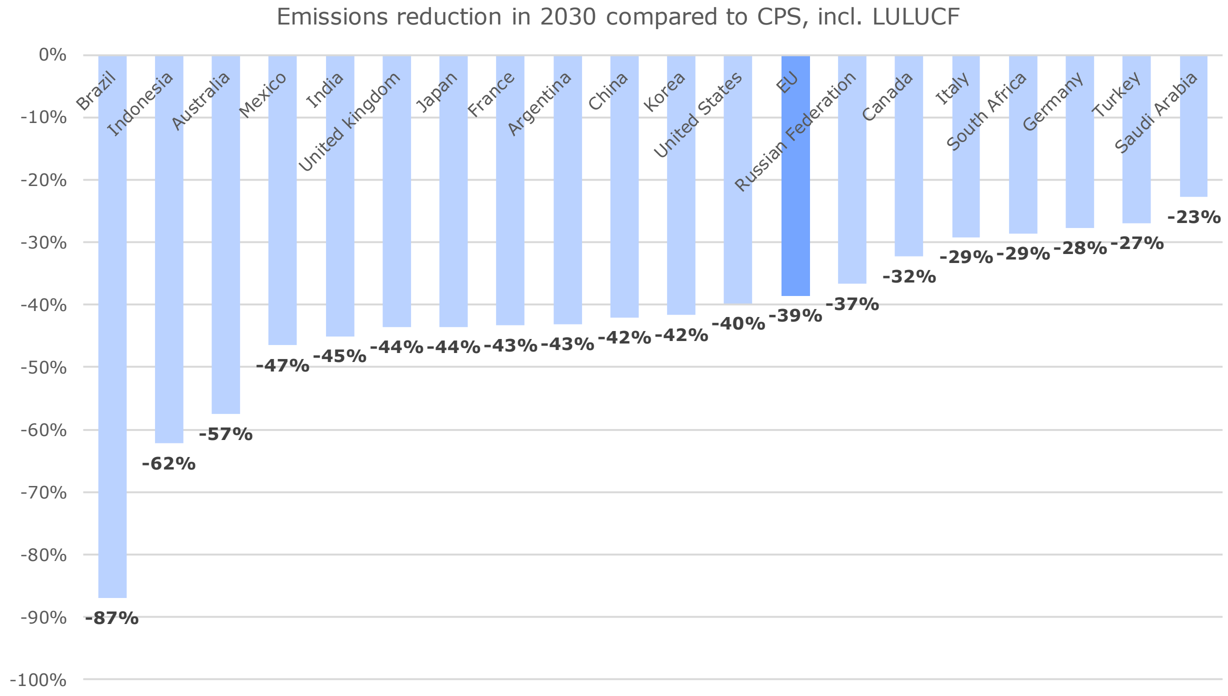

Figure 30. Emission reduction in 2030 per G20 member when compared to a current policy scenario

The combined emissions reduction potentials for each of the G20 countries are then compared with from the current policy trajectory emissions. This yields a reduction compared to the current policy estimate for 2030. The percentage reduction per G20 member country is displayed in Figure 30. The EU, being a composition of several sovereign countries, is given a different color. Note that the LULUCF emissions have been assumed constant, leading to uncertainties in the answers provided in Figure 30mand 31. This has been assumed due to a lack of data availability.

Percentage wise, Brazil has the largest net emission reduction when comparing it to a current policy trajectory. This large reduction is the result of high emission reduction potentials for the measures *reducing deforestation* and *reforestation*. In Indonesia, *reducing deforestation* and *peatland management* are the drivers for the large relative reduction in emissions. Also, for Australia and Mexico the forestry sector is a large contributor to the emission reductions, and thus the large percentage wise emission reduction envisioned against a current policy trajectory. The 4 countries with the largest percentage wise reduction, all have relatively large emission reduction potentials in the LULUCF sectors.

The unweighted average percentage wise reduction compared to the CPS per country is 42%. Saudi Arabia, Turkey, Germany, Italy and South Africa. The reason for their respective low reduction percentages can be manifold. For example, the percentage wise mitigation potential could be relatively low in Germany, since the implemented policies in Germany and Europe which are taken into consideration are much more stringent than they are in the other three countries. Additionally, the emissions of Saudi Arabia and Turkey are expected to increase drastically from 2014 historical emissions levels. Saudi Arabia GHG emissions excluding LULUCF are expected to rise from 630 to 1130 $MtCO_2e$ between 2014 and 2030 (CAT, 2018b). Turkey's total emissions are expected to increase by 86%, from 400 to 745 $MtCO_2e$. Because of this significant increase the respective reductions are relatively low. Also, Canada's reduction is somewhat below average. Canada's emissions are expected to remain close to 2014 levels in the current policy scenario. In the light of this the relatively low percentage wise reduction might give a distorted view.

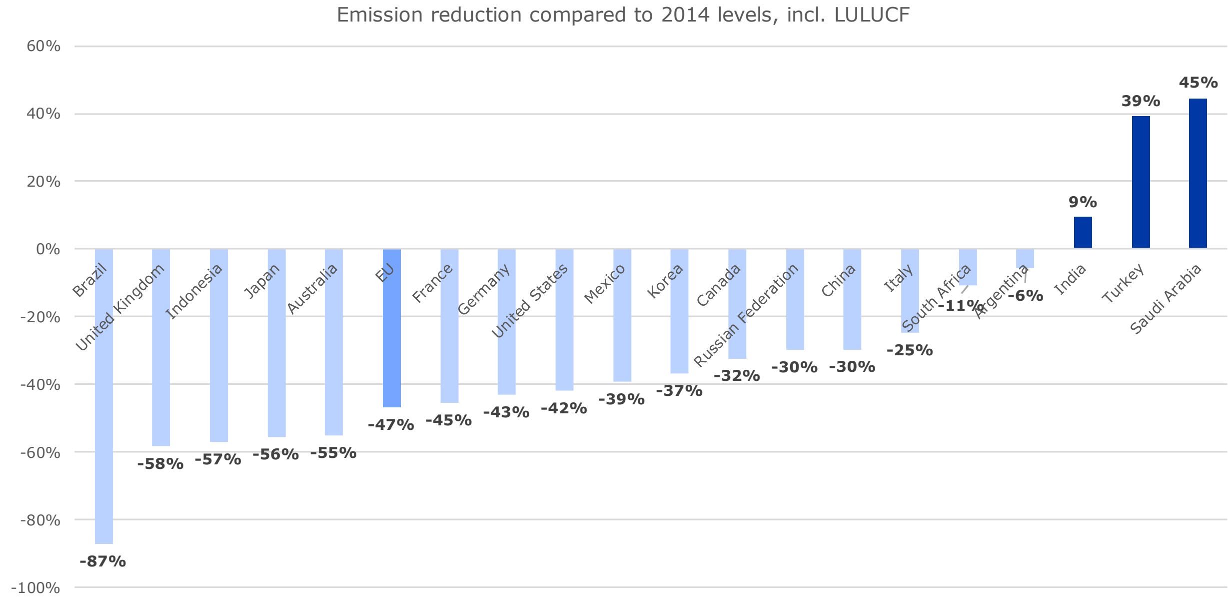

Figure 31. Percentage emission reductions in 2030 when compared to 2014 emissions levels.

To illustrate the effect of the measures mitigation potentials further, the emission levels after deducting the envisioned reductions from the current policy estimates are compared with emission levels in the base year, 2014. The resulting reductions are displayed per country in Figure 31 as percentage wise reductions and in Figure 32 as absolute reductions. In Figure 32 positive values point to an absolute increase in emissions between 2014 and 2030 when all reduction potentials of the treated measures are applied.

When compared to 2014 Brazil is again the country with the largest percentage wise reduction, 87%, followed by the UK (58%), Indonesia (57%), Japan (56%) and Australia (55%). Saudi Arabia, Turkey, and India, compared to 2014, have higher emissions in 2030. For Saudi Arabia this might be counterintuitive. The mitigation potential in this thesis however, only covers 9 measures over six sectors. Saudi Arabia has close to no mitigation potential regarding reducing deforestation, reforestation, cropland management, and peatland management. Furthermore, for solar PV and wind energy the mitigation potential is relatively not substantial. Tough, when looking at Saudi Arabia's energy consumption in 2030 under the assumed scenario solar PV and wind energy represent a large share in the power sector, representing a reduction of 77% in the power sector. The power consumption which is assumed in the scenario used, is simply not high, limiting the mitigation potential of Saudi Arabia's power sector. Moreover the 2030 baseline electricity generation value was assumed, using the entire Middle East as a 'model area' while the actual electricity generation in Saudi Arabia can be higher. This is also the case for Turkey. Additionally, measures that are not treated in this thesis could potentially significantly increase the mitigation potential for Saudi Arabia and Turkey. These measures could be the use of CCS or the reduction of non-CO_2 GHGs coming from the oil and gas industry.

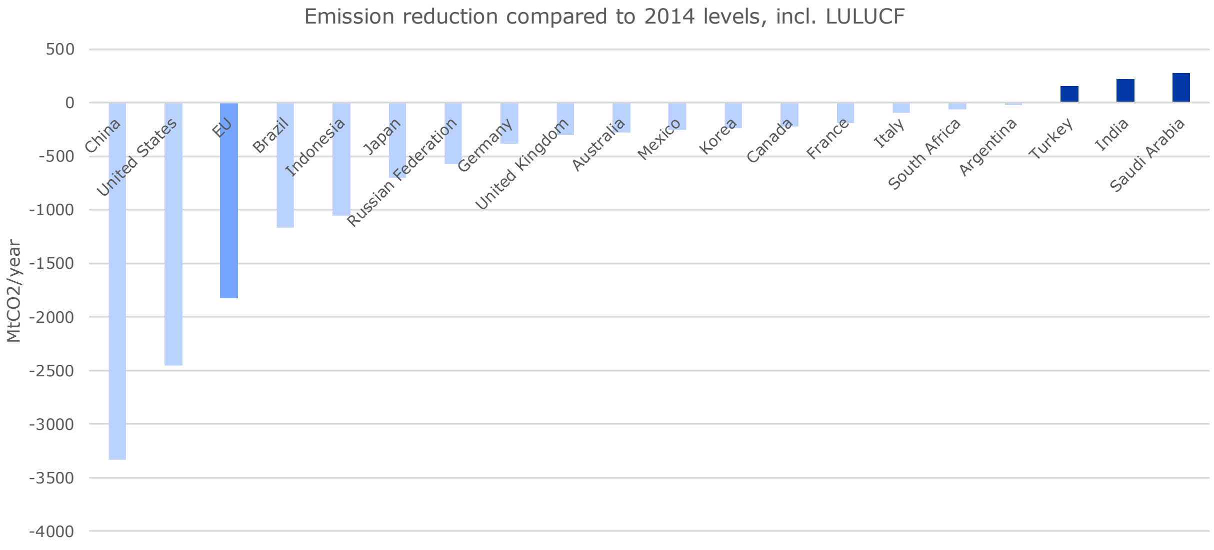

Figure 32. Absolute emission reductions in 2030 compared to 2014 emissions levels.

As said before, these higher emissions can be explained by the substantial increase that is expected in emissions under a current policy trajectory. Turkey has recently announced a doubling of the coal capacity, to minimize risk from foreign politics and decrease dependence on other, external sources of power (Crisp, 2015). India's increase in emissions, despite the envisioned applied potentials, can be explained by a huge population which is increasing rapidly. This is combined with a fast-growing GDP and GDP/capita, driving the need for i.e. electricity, other energy, and transport. To keep up with these developments, India has invested and will invest significant amounts in the expansion of the power system, both renewables- as fossil-based. Saudi Arabia is a country rich in oil, a fossil source of energy, and is thus not the most willing G20 member to shift towards a more renewable power system. Additionally, the oil industry is the largest industry and source of income. For this reason, the climate targets set by Saudi Arabia are not very ambitious and climate policies are not stringent. This all results in 2030 emissions which are 45% or 227 $MtCO_2e$ higher than 2014 levels, despite all the mitigation potentials that have been applied to the current policy trajectory.

10.2 Achieving national determined contributions

All the countries of the G20 have made their intentions regarding the environment known in the form of NDCs which are taken up into the Paris climate accord of 2015. In this section the goal is to see whether the member states of the G20 would fulfill their NDC if the mitigation potentials calculated in this thesis were to be made reality and be deducted from a current policy trajectory.

NDCs and current policy trajectories are signpost of ambition with regards to mitigation and climate action. Subsequently, not all NDCs are equally ambitious and ‘’fair’’. Regarding the fairness and ambition of NDCs the CAT (2018) has given a rating, based on expected global warming if these trends were to continue. Currently, the majority of all G20 members is performing insufficiently. According to CAT, Australia, Brazil, the EU, and Mexico are classified as ‘’insufficient’’. This means that if all countries of the world were to continue this level of action the temperature would increase 2℃ to 3℃ compared to pre-industrial levels. Additionally, Argentina, Canada, China, Indonesia, Japan, Korea and South Africa are performing ‘’highly insufficient’’, meaning temperatures on earth would increase with up to 4℃ compared to pre-industrial levels if this level of effort would be made on a global scale. Russia’s, Saudi Arabia’s and the US’ efforts are categorized as ‘’critically insufficient’’. This means that if all governments had this level of target and action, the temperature would rise more than 4℃ compared to pre-industrial levels. On the other hand, India’s targets and efforts are such that it is in line with a ‘’2℃ compatible’’ pathway, which means that if all governments were to take the same level of action temperature increase would be limited to 2℃.

The results of this analysis can be seen in Table 4. The G20 member states and their respective NDCs are translated to a threshold emission level which is to be reached in 2025 or 2030. As can be seen in the table, all can reach their respective NDCs if the mitigation potentials for each of the treated measures in this thesis were to be implemented. The NDC for China is that peak emission levels are reached in 2030 and that subsequently emissions will decrease thereafter. This can however not be assessed with the application of the mitigation potential, and therefor has N/A in the ‘’NDC Achieved’’ column. The current policy projection of the CAT, however, assumes that the emissions peak will be reached in 2030 and will range between 12.75 $GtCO_2e$ and 13.8 $GtCO_2e$. Additionally, even the conditional NDCs of Argentina, Indonesia, and Mexico will be reached in the scenario in which all the emissions from the six treated sectors are mitigated. For these conditional NDCs, the countries want and need help from other countries, in the form of finance and trade, regulation, or knowledge. Furthermore, The NDC of individual EU members Germany, France, Italy and the UK are equal to that of the EU.

Table 4. Emission levels of NDCs in 2025 and 2030 for the G20, and the achievability of these NDCs with implementation of mitigation potentials for the treated measures.

Country	Type of NDC	NDC	Translated NDC	Year of target	2030 emissions with envisioned reduction (MtCO2/year)	Is NDC achievable?
Argentina	Unconditional	483 MtCO$_2$e /year by 2030	Below 483 MtCO$_2$e /year	2030	347	Yes
	Conditional	369 MtCO$_2$e /year by 2030	Below 369 MtCO$_2$e /year	2030	347	Yes
Australia	Unconditional	26 - 28% below 2005 by 2030	Below 417 to 428 MtCO2e/year	2030	229	Yes
Brazil	Unconditional	Max. 1.2 GtCO$_2$e /year by 2025	Below 1.2 GtCO$_2$e /year	2025	173	Yes
Canada	Unconditional	30% below 2005 by 2030	Below 479 MtCO$_2$e /year	2030	459	Yes
China	Unconditional	Peak emissions by 2030	Peak Emissions by 2030	2030	7902	N/A
EU	Unconditional	Min. 40% below 1990 levels by 2030	Below 3181 MtCO$_2$e /year	2030	2081	Yes
France	Unconditional	Min. 40% below 1990 levels by 2030	Below 336 MtCO$_2$e /year	2030	231	Yes
Germany	Unconditional	min 40% below 1990 levels by 2030	Below 726 MtCO$_2$e /year	2030	503	Yes
India	Unconditional	33-35% below 2005 emissions intensity of GDP by 2030	Not exceed 1.32 to 1.36 MtCO$_2$e /billion GDP	2030	0.251 MtCO$_2$e /billion GDP	Yes
Indonesia	Unconditional	29% below NDC BAU by 2030	Below 2037 MtCO$_2$e /year	2030	793	Yes
	Conditional	38% below NDC BAU by 2030	Below 1780 MtCO$_2$e /year	2030	793	Yes
Italy	Unconditional	Min. 40% below 1990 levels by 2030	Below 307 MtCO$_2$e /year	2030	290	Yes
Japan	Unconditional	26% below 2013 by 2030 (18% below 1990 by 2030)	Below 970 MtCO$_2$e /year	2030	563	Yes
Korea	Unconditional	37% below BAU by 2030	Below 535 MtCO$_2$e /year	2030	404	Yes
Mexico	Unconditional	22% below NDC BAU by 2030	Below 759 MtCO$_2$e /year	2030	399	Yes
	Conditional	36% below NDC BAU by 2030	Below 623 MtCO$_2$e /year	2030	399	Yes
Russia	Unconditional	25-30% below 1990 by 2030	Below 2640 to 2830 MtCO$_2$e /year	2030	1358	Yes
Saudi Arabia	Unconditional	Reach 130 MtCO$_2$e /year reduction in 2030	130 MtCO2e/year reduction	2030	898	Yes
South Africa	Unconditional	Emissions between 398-614 MtCO$_2$e /year over 2025-2030	Below 398 to 614 MtCO$_2$e /year	2025 - 2030	496	Yes
Turkey	Unconditional	21% below NDC BAU by 2030	Below 929 MtCO$_2$e /year	2030	557	Yes
UK	Unconditional	Min. 40% below 1990 levels by 2030	Below 475 MtCO$_2$e /year	2030	217	Yes
US	Unconditional	26-28% below 2005 levels in 2025	Below 4655 to 4784 MtCO$_2$e /year	2025	3399	Yes

As can be seen in Table 4, some countries can reach their NDC by a larger margin than another country. This is dependent on the level of ambition of the respective NDCs and the level of mitigation potential envisioned in this thesis. For example, Saudi Arabia and Argentina have similar emission reduction potential for the measures treated in this thesis, while Saudi Arabia has double the emissions in 2030 according to current policy projections (Kuramochi *et al.*, 2016). Additionally, the reduction needed to reach their respective NDCs is around 130 $MtCO_2e$ for both countries. Clearly, not all efforts are of the same magnitude and fairness, thus, the achievement of the NDCs under envisioned reductions should be judged qualitatively instead of quantitatively.

10.3 Closing the emissions gap

With the total emission reduction potentials under 100$/$tCO_2e$ are known for the measures within the scope of this thesis, it is possible to say something about the effects of these mitigations on a global scale and with regards to the in chapter 2 mentioned *Emissions Gap*. In this section the results will be compared to the emissions gap as portrayed by CAT (2017), shown in Figure 33.

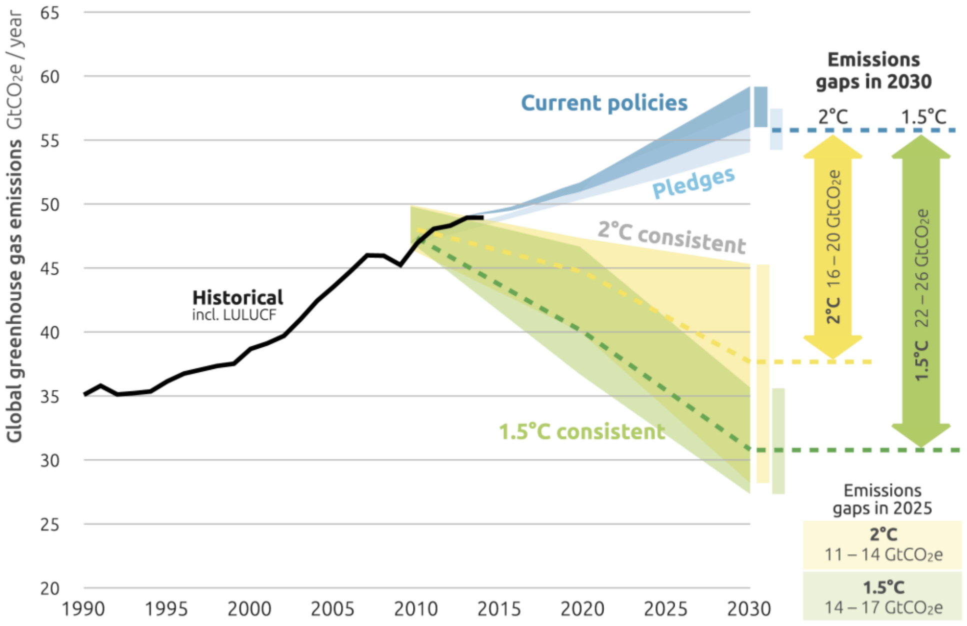

Figure 33. The emissions gaps portrayed by the Climate Action Tracker

In Figure 33, the emissions gaps including LULUCF are shown with regards to a below 2℃-pathway with an 80% probability and a below 1.5℃ pathway with a 50% minimal probability. The graph further shows the historical emissions and projected emission ranges for a current policy scenario and a ‘’pledges’’ scenario in which all the pledges of the NDCs, submitted to the UNFCCC, are included. According to CAT (2017) the emissions gap between the combined pledges made in the NDCs and a below 2℃-pathway is in the range of 16 to 20 $GtCO_2e$ in 2030. Moreover, the same emission gap for a 1.5℃ pathway is even higher and ranges from 22 to 26 $GtCO_2e$ in 2030. However, currently implemented policies are not ambitious enough to achieve all the pledges made in the NDCs under the Paris climate accord (CAT, 2017). To account for this the current policies scenario predicts higher emissions in 2030 than the ‘’pledges-scenario’’ shown in Figure 33. Subsequently, the emissions gaps become 1-2 $GtCO_2e$ higher for both temperature pathways. Consequently, the emissions gaps in 2030 are estimated to be 18 to 22

$GtCO_2e$ for a 2℃-pathway and 24 to 27 $GtCO_2e$ for a 1.5℃ pathway. As shown in Table 4, the global mitigation potential for the 9 measures treated in this thesis is between 19.1 and 27 $GtCO_2e$ in 2030. Thus, the emission gaps as portrayed by CAT for 2030 have a large chance to be (partially) closed by 2030 by focusing on the treated measures, at or below 100$/$tCO_2e$. With current results it is highly likely that a large portion of the emissions gap can be closed by 2030 if efforts are made and prolonged and the necessary investments are made by respective governments. The range of the envisioned mitigation potential is substantial, which makes it difficult to say exactly as to how much the emissions gap could be bridged, but it gives an indication as to what could be done, and what the effects thereof could be. Additionally, the results found in this thesis are compared to the *Emissions Gap Report 2017*, which was used as point of reference. This can only be done on global level since this was the focus of the *Emissions Gap Report 2017*. The global mitigation potential in 2030, given in the *Emissions Gap Report 2017* for the measures that were treated in this thesis ranged from 19.4-25.7 GtCO2e/year. Compared to the range in this thesis (19.1-27.0 GtCO2e/year) it can be observed that they are in the same order of magnitude and overlap entirely. The largest differences are in the upper bounds of wind energy and reforestation. In the *Emissions Gap Report 2017* the upper bound of wind energy and reforestation are 4.1 GtCO2e 3.4 GtCO2e, respectively, while this is 5.0 GtCO2e and 4.1 GtCO2e in this thesis. The higher wind energy mitigation potential comes from the scenario used in the energy sector being very ambitious. For reforestation this can be explained because more countries have been included in this thesis, leading to a larger potential. Additionally, industry efficiency is 0.3 GtCO2e higher in this thesis, while efficient LDVs mitigation potential is 0.4 GtCO2e lower.

In Figure 34, the number MtCO2e of envisioned reduction per billion of GDP in 2030 is given. For this, the total projected GDP for 2030 was taken from the World Economic Outlook Database (IMF, 2016). This publication gave the data for the projected 20 largest economies. This top-20 did not include Argentina and South Africa and so the projected GDP in 2030 for these countries was taken from the *International Macroeconomic Data Set* (USDA, 2017). Furthermore, the EU was not included in this analysis since it includes 28 countries and not for all countries mitigation potentials are calculated in this thesis. The projected total mitigation per country in 2030 is divided by the predicted GDP in 2030 for that country. The results are displayed below.

As can be seen, Indonesia relatively has the highest $MtCO_2e$ of reduced emissions in 2030 per billion of GDP. This is due to the relatively high mitigation potential of the measures such as peatland management, reforestation and reducing deforestation, and the relatively small projected GDP in 2030. In total, Indonesia can mitigate between 1.1 and 1.3 $GtCO_2e$ and has a projected GDP of around 2.5 Trillion USD, in 2030 (IMF, 2016). Additionally, Argentina, South Africa, Brazil, Russia, India and China have relatively high values as well. Strikingly, the most developed countries are situated more to the right of the chart, indicating lower values. A country with high values of projected mitigation potential per GDP has a more strenuous task ahead of it in comparison with other more developed G20 countries with lower values. It raises the question if this is fair, and if such a country should be responsible for the cost which is inherent to the envisioned mitigation of emissions, especially if it is a global problem.

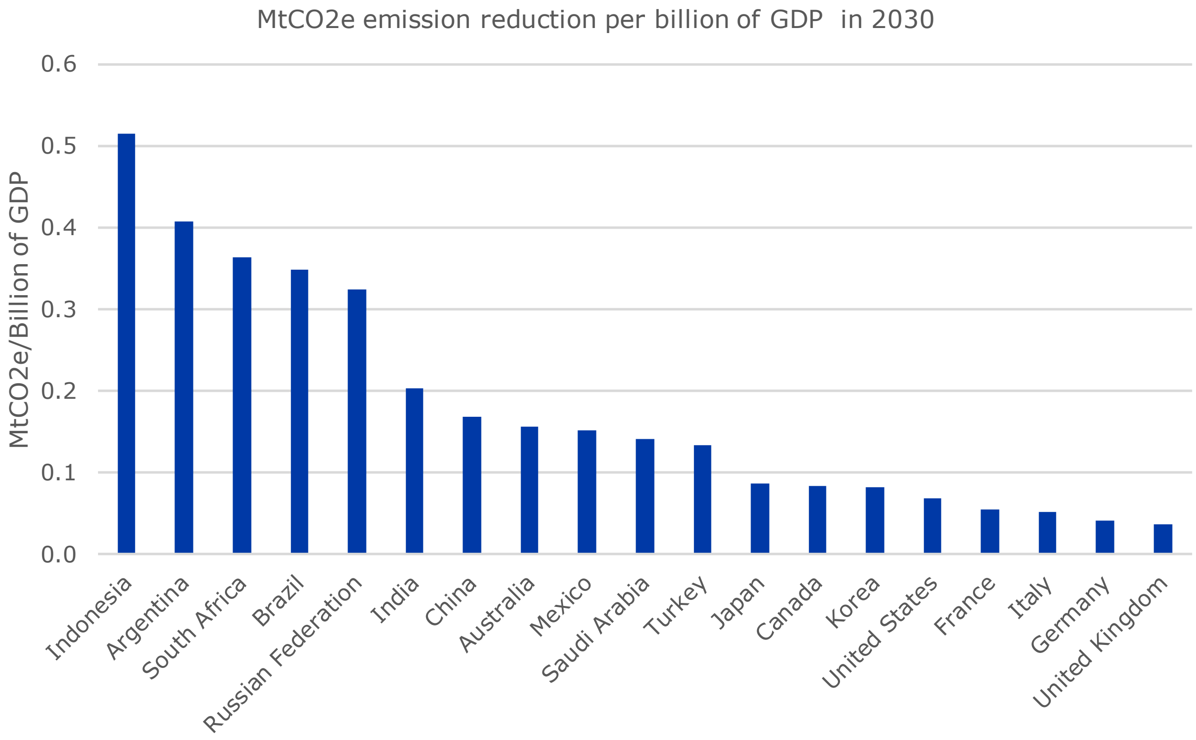

Figure 34. Number of billions GDP per MtCO$_2$e emission reduction potential in 2030.

Additionally, GHGs don't recognize borders and for example, the rainforests in the (sub-)tropical regions act as a carbon sink, taking up carbon from the atmosphere likely produced otherwise. To this end, conditional NDCs are put in place, which are to be achieved with (financial) aid from abroad. Expecting countries like Indonesia and Argentina to be responsible for most of this cost is not realistic and will not lead to a rapid and complete decarbonization necessary to keep temperature rise wanted levels. Developed countries such as the UK, France, Germany, the US and Korea and other industrialized countries could aid less economically developed countries mitigate emissions and decarbonize. This can be done to stop environmental issues, but also because emissions from the production of products are not always allocated to where these products are used (Carbon brief, 2017). Low income countries are more often net carbon exporters than importers due to their relatively cheap labour, and the subsequent allocation of production there.

According to Wiebe & Yamano (2016) the EU, USA, Australia, Japan, Brazil, Mexico and Turkey have more consumption-based emissions than production-based emissions, thus importing emissions. On the other hand, China, India, South Africa, and Russia are net exporters of emissions. These findings are backed by the Carbon brief (2017). This import or export of emissions, however, is often not accounted for, giving a distorted image of reality.

Lastly, developing economies often do not prioritize climate goals, but do their best to keep up with their growing economic systems and often see no other choice than to invest in the cheapest, most effective method or technology for producing products or energy, often utilizing relatively cheaper fossil fuels. More intergovernmental cooperation flowing towards the developing economies could help in the improvement hereof.

11. Discussion

The mitigation potentials calculated in this thesis have shown that the 9 selected climate measures with a marginal abatement cost below a 100$/tCO$_2$e are fully or to a large extent capable of closing the emissions gap to limit temperature rise below 2℃ and even 1.5 ℃. The G20 has a large part in this, and subsequently all its member states achieve their NDCs under envisioned emissions reductions. Additionally, this thesis has given an overview of technically possible mitigation potential for the G20 and their subsequent regions in 2030, to close a knowledge deficit existing with regards to the emission gap, explained in chapter 2. There are, however, several limitations in this thesis. The most important limitation of this research is the focus on technical possibilities without making a detailed feasibility study on a technology and regional level. Therefore, this study only concludes the technical mitigation potential of 9 measures across 6 sectors. To be able to perform a feasibility study for implementation two main uncertainties of this thesis need to be addressed. These two limitations are the limitations regarding the used *sources* and the *availability of data given in these sources*. In Table 5, the uncertainties and the recommendation for future research is specified per limitation per sector.

Sources

There are three main uncertainties with the used sources. First this thesis uses secondary data only. Secondly, there is no knowledge with regards to the implementation of the scenarios used in this thesis. Lastly, the geographical division in the used sources differ significantly from one another. These limitations will be discussed below.

In a bottom-up fashion, explained in chapter 2.4, the mitigation potentials were assessed using available literature. This is directly a limitation since, in this manner, only secondary data is used and factors such as credibility and age of the publication are involved. To moderate this, high standard publications by leading institutions and organizations, found in i.e. the *Emissions Gap Report 2017*, have been assessed on their regional and national data availability and have subsequently been used in this research, as explained in chapter 3.2. This in turn, has led to the selection of the in thesis treated measures. The selected measures do not entail all possible mitigation possibilities present in the six treated sectors since mitigation measures are numerous and a study treating all measures would require extensive amounts of time. In addition, currently chosen measures represent the bulk of the mitigation potential given in the *Emissions Gap Report 2017*. In the case of contradictory mitigation potentials, emissions factors or other assumptions, the most recent source is used. Additionally, contact has been made with the authors of publications when there was uncertainty regarding which source to use or data (Chapter 4.3.1).

In addition, the sources used in this thesis contain scenarios of which no knowledge is present on how to achieve these simulated futures. This thesis does not aim to determine how to implement measures and to what extent specific mitigation measures can be implemented. This is a complex exercise since it includes factors such as the political situation and societal support within a country. For this thesis such factors are out of scope and are thus not considered. If a government wishes to further specify and understand the impact of the 9 selected measures within its country, a follow-up feasibility study with regards to implementation cost, public acceptance and environmental impact would be recommended.

As explained previously, the data found didn't always cover all regions and countries within the scope of this thesis. Moreover, the separate literary sources used in this thesis often demarcate areas differently when giving regional data. Without the availability of national data, this leads to disparity between datasets. The standard regional demarcation used in this thesis and described in chapter 3, tries to mitigate this. Where possible, the datasets have been processed in such a way that the data fits this demarcation, given in chapter 3. However, not in all cases this has been successful. For solar PV and wind energy in the energy sector this has led to a distorted image, which causes Oceania to have no mitigation potential, as is explained in chapter 6. Additionally, a second source was used to create a range for solar PV and wind energy. The results, however, proved to be unrealistic and thus the decision has been made to not use these results. This has led to the installment of a lower bound for solar PV and wind energy which reflects the large uncertainty of the above. The uncertainty has been assumed to be 50%. Further, uncertainty exists regarding the other sectors for which extrapolations had to be made. This is discussed in the following section.

To conclude, this thesis gives a clear overview on the geographical whereabouts of the mitigation potentials of 9 measures across 6 sectors, and that subsequently the emissions gap can be closed. This thesis, however, does not provide information or recommendations regarding implementation for policy makers. To do so, the above limitations should first be addressed.

Availability of data

There are three main uncertainties regarding the used data. Firstly, in this thesis incomplete data is used with regards to the scope of this thesis. This has led to the inter- and extrapolation of data based on several assumptions. Secondly, assumptions have bene made with regards to the baselines used in this thesis. Lastly, lack of available data has led to the use of methodologies and emissions factor for the forestry and agriculture sector based on several assumptions. These three main uncertainties will be explained below.

Firstly, for the sectors buildings, energy, industry and transport methodologies have been used which utilize publications containing energy use, electricity generation, and emission output data. These publications however do not contain data for all G20 countries and so growth rates, emission factors and subsequent reduction potentials have been assumed according to similar regions or countries, which can be read in the respective methodology sections of the mentioned sectors. This methodology has been applied for the countries Argentina, Australia, Canada, France, Germany, Italy, the UK, Indonesia, Japan, Korea, Turkey, and Saudi Arabia. This creates extra uncertainty regarding the mitigation potentials for these countries in these sectors, since applying assumed growth rates, emissions factor or reduction potentials to these countries doesn't reflect reality and ignores country specific aspects.

Additionally, the base year energy use values are taken from different databases, the IEA balances and the *Energy Technology Perspectives 2017,* and so differ from each other leading to uncertainties. When comparing the global base year energy use values for both data bases, discrepancies of 11.5%, 4,7%, 2,7% are found for industry, buildings, transport, respectively. It is not clear how these discrepancies have effect on the eventual mitigation potential for the measures in these sectors on a national level since these percentages are not country specific but an uncertainty of 5% to 10% is maintained. To come to a result with more precise mitigation potentials for these measures in these countries it would be interesting to look at country specific electricity generation, energy use, and emissions output data. This would eliminate the need to use different data sets and to extrapolate.

Furthermore, for the sectors industry and transport the nationally generated mitigation potential data was upscaled with GDP as the decisive variable to extrapolate the mitigation potential for the world regions. This decision has been made since the size of the industry and transport sector are linked to GDP. Unclear, however, is the precise relation between GDP and energy use in these sectors leading to uncertainty in the final mitigation potential of the world regions, and so further research into the correlation between industry and transport energy use and GDP is recommended. At first, not GDP but energy use has been considered as the used extrapolation variable. This however, proved difficult since not for all countries the energy use in 2030 under the B2DS was available. Further, the mitigation potential of efficient lighting and appliances in 2030 is based on the successful implementation of MEPS while currently only a relatively small share of countries have shown the intent to implement such climate policy. Although this research reflects the potential emissions reduction in 2030, it is highly dependent on political interest and action as well as public acceptance, which are not considered in this thesis. For this reason, the mitigation potential might be optimistic.

Secondly, for the sectors industry, transport and buildings, instead of a current policy scenario as described by the *World Energy Outlook 2017,* the *Reference Technology Scenario was used.* This scenario considers the NDCs of the individual countries. This means that the mitigation potentials calculated for the measures in these sectors are too pessimistic if with the current policies countries are not on track to achieve their NDCS. The gap between the NDCs scenario and the current policy scenario is around 1-2 $GtCO_2e$ in 2030 for all climate measures. Considering, that the *Reference Technology Scenario* was used only for three measures it can be noted that this would only marginally increase the mitigation potential. Furthermore, For the sectors agriculture and forestry uncertainties exists regarding the baselines used in the methodologies. For example, for the forestry sector a constant deforestation baseline is assumed since high uncertainties surround this baseline in literature and there is no better alternative. Additionally, the baselines in literature are often based on relatively old, assumed data.

Thirdly, for cropland management and peatland management this research used only the emissions factor per area of crop- or peatland. This is a limitation since it assumes no achieved mitigation to date. Research could be focused on the achieved mitigation potential concerning cropland management and peatland management. Further, in the methodologies used in the agriculture sector, climate zones have been used to determine the emissions factor used for a certain country. This, however, leads to uncertainty in some cases since entire countries are assumed to be within a single climate zone while this is not always true, as is the case for i.e. Argentina, and the US. Setting up a database stating how much of a countries' surface, cropland and peatland is within a climate zone would reduce uncertainty, and this would thus be a recommendation for further research. Likewise, for the area of cropland in 2030 a growth rate has been constructed, as can be seen in chapter 4. This growth rate has been evenly distributed over the globe while this might not be realistic with regards to i.e. higher population growth in regions such as China, Africa, and South East Asia than in Europe, Oceania or North America. Research into nationally or regionally growth rates of cropland area would make it possible to construct a more realistic overview of cropland area in 2030 and thus a more specific and realistic overview of cropland management mitigation potentials.

Furthermore, there is uncertainty in literature regarding the effect of reducing deforestation and whether all mitigation potential should be attributed hereto. Additionally, since no distinction could be made between forest and soil types the entire range of the emission factor for reducing deforestation has been used for the identified areas of forest, creating large uncertainty. A recommendation would be to investigate the long-term effect of reducing deforestation, its emission factors, and whether all mitigation can be ascribed to it. Further, a more specific forest and soil type database could help in reducing this uncertainty.

Moreover, for the calculation of a mitigation potential for the measure reducing deforestation a best-in-class approach has been used. This approach has been used since there is a lack of usable data with regards to reducing deforestation. Brazils recent decrease in deforestation up until 2014 has been used to show the mitigation elsewhere if similar results were to be achieved. The question here is to what extent this is realistic. Brazil has shown a very large reduction in deforestation rates over a relatively short period. This has been achieved by extensive policy action and funds allocation. Many of the countries in the subtropical and tropical belt are low to middle income countries where many factors such a poverty, corruption and malmanagement make reducing deforestation difficult. Meanwhile, while the deforestation rate has decreased in Brazil, it has gone up elsewhere, like Indonesia and Central Africa. In other words; the deforestation of tropical forests hasn't decreased, it has shifted. Additionally, several sources report increased deforestation rates in Brazil in recent years. Research into the feasibility of implementation of Brazil's policy action in the other in chapter 7.2 treated countries would decrease uncertainties regarding reducing deforestation mitigation potentials as calculated in this thesis.

Table 5 shows the specific limitations that exists for the treated sectors and gives recommendations to mitigate these limitations. It is paramount to have more complete sectoral data at your disposal to generate more detailed mitigation potential, and to subsequently eliminate the limitations as given in the table. If all these recommendations were to be achieved, the resulting data gap that would be filled would lead to clearer mitigation potentials. On a global scale the mitigation potential can be calculated, as has been done in this thesis. For the regions or countries, however, several assumptions have been made, as discussed above, making the analysis a high-level overview of technical possibilities but not taking sector specific limitations into account in the quantification of the mitigation potential. For example, if a more sophisticated baseline was available for reforestation or reducing deforestation that would lead to a more precise mitigation potential per country. In the same manner, if energy use and emissions output data was available for all G20 countries and world regions, no assumptions would have to be made with regards to growth rates or the used emission factors, leading to more certain mitigation potentials. To map the full decarbonization potential for each sector, a deep dived sector analysis is need. Table 5 provides recommendations for each sector to do so. Where possible, based on the used data, this thesis has already provided uncertainties and has quantified ranges in the mitigation potentials where possible.

Table 5. Per sector scenario and data limitations of this thesis with recommendations for future research.

Sector	Type	Limitation	Recommendation for further research
Overall	Scope	• Geographical setting • Treated measures	• N/A • N/A
	Data	• Secondary data	• N/A
Agriculture	Scenario	• Assumption no mitigation has been achieved to date • Cropland growth rate assumed homogeneous	• Currently achieved cropland management and peatland management mitigation • Regional or national estimated cropland growth rate data towards 2030
	Data	• Arbitrary climate zones	• Setting up a database with more specific national climate zones in combination with highly specific peatland or cropland data
Buildings	Scenario	• Assumption successful implementation MEPS	• Action plan for MEPS including policy gap analysis on national level
	Data	• Incomplete data, extrapolation	• Electricity generation and emissions output data for missing countries or regions
Energy	Scenario	• Uncertainty about scenario, thus results not used	• N/A
	Data	• Incomplete data, extrapolation	• Electricity generation and emissions output data for missing countries or regions
Forestry	Scenario	• Unsure baseline • Use of best-in-class reducing deforestation • Focus on sub-tropical and tropical belt reducing deforestation	• Create baseline of deforestation/forest cover towards the future in (sub)-tropical belt • Feasibility study for best-in-class approach in other countries • Focus on countries outside sub-tropical and tropical belt
	Data	• Uncertainty mitigation effect reducing deforestation • Unspecific emission factor	• Long-term effects of reduction deforestation on climate mitigation and ecosystem • Setting up database for emission factors with smaller range according to soil/forest type in combination with precise forest/soil type database
Industry	Scenario	• Incomplete data, extrapolation • Exclusion CCS	• Electricity generation and emissions output data for missing countries or regions • Future feasibility study CCS focusing on price
	Data	• GDP used as variable for upscaling	• Correlation study between Industry energy use and GDP or other variable(s)
Transport	Scenario	• Incomplete data, extrapolation	• Electricity generation and emissions output data for missing countries or regions
	Data	• GDP as variable for upscaling	• Correlation study between Transport energy use and GDP or other variable(s)

Discussion of results

This thesis shows that only 9 measures are needed to be able to mitigate between 19 $GtCO_2e$ and 27 $GtCO_2e$ in 2030. However, this thesis does not say that this technical mitigation potential is easily achievable. There are reasons for this. Firstly, that socio-economic factors are not considered in this thesis. Secondly, other technical development factors such as shifts towards a different power system and infrastructure are not discussed. Thirdly, the availability of financial resources in poorer countries with high calculated mitigation potentials creates unfairness in climate mitigation action and targets.

First, as discussed above, social, political and economic factors, apart from the threshold of $100/$tCO_2$, are not taken into consideration. This thesis only focused on the technical potential. In reality, not all global politics and national governments are aiming at mitigating greenhouse gas emissions to keep temperature rise below 2℃, and further 1.5℃. Factors such as poverty, political unrest, war, climate change denial and corruption are not considered in this thesis but do influence the feasibility of implementation of the technical potential since all these factors would surely delay if not hinder the realization of the calculated mitigation potentials. As mentioned in chapter 2.2, the US is withdrawing from the Paris climate accord is a poignant example of a lack of environmental priority in some countries. Moreover, according to the *Climate Action Tracker* hardly any developed economy is doing sufficient to reach their NDCs. Assuming these developed countries have the most knowledge, environmental budget and political support it is possible to imagine the low extent of political and economic will or ability that exists in less developed countries to mitigate climate change.

Secondly, in this thesis no attention is given to the strength of lobbies, or the level of system lock-in in which there is reluctance to switch to a new technology or method since everything is designed to fit the needs of the current technology. This is the case, for example, with the use of fossil fuels in the transport sector. This sector, in the last century, has been designed almost entirely around the use and distribution of fossil-based fuels. Electric vehicles are only recently slightly changing this image in developed economies, with aid of governmental tax breaks. Moreover, fossil-based fuels such as coal and oil are still being subsidized more than renewable energy. This creates a situation in which fossil-based energy is often cheaper than renewable energy, despite recent technological advancements. Combined with potential high-initial cost to renewable energies, such as solar panels, limits the large-scale implementation of such technologies. Another economic and technical obstacle is that a more sustainable energy system is more reliant on electricity than now. This leads to problem regarding the power grid. Expanding this grid is a costly affair and an alternative could be the extensive use of short-term storage devices such as batteries. These, however, are also very expensive, largely inhibiting the possibility of a large-scale shift to a more electrified system.

Thirdly, in chapter 10 attention is also given to the amount of GDP per $MtCO_2e$ in 2030 for each country. It is seen in Figure 34, that richer countries are situated to the right indicating higher levels of GDP per $MtCO_2e$. Subsequently, countries like Indonesia, Argentina, South Africa and Brazil are poorer countries who have a disproportionate amount of envisioned emissions reductions when compared to the western or developed countries. It makes you wonder if richer countries and regions such as the US, Korea and the EU should contribute to or pay for the mitigation of emissions in the relatively poorer countries. This is a fair question with respect to the G20, but more so for the poor countries which are not within the scope of this thesis. These countries often don't have climate mitigation as their top priority due to factors such as political unrest or instability and poverty. Moreover, the climate problematic is a global cause.

Additionally, several arguments can be made for a situation in which richer countries pay relatively more for the made ecological damage. Firstly, it could be argued that the developed countries owe thanks to the sacrifice of the environment for their development over the last two centuries. In this time, these countries have used enormous quantities of natural resources, leading to the emission of huge amount of GHGs. This creates a sort of historical debt. Secondly, developed countries account for a smaller portion of the global population but use a majority of the energy and natural resources. In a form of ecological imperialism, the developed countries have moved their polluting and resource exhaustive industries and production to poorer, developing countries. Thirdly, the developed countries simply have more resources which could aid in the betterment of the environment, economically as well as scientifically.

When comparing the results of this thesis to the results in the publication that was used as a basis, the *Emissions Gap Report 2017*, similar results are presented. Naturally, differences exist between the mitigation potential of individual measures calculated in this thesis and the *Emissions Gap Report 2017*, but overall the mitigation potential is of the same magnitude and similar trends are seen. This thesis' goal was to show where the mitigation potentials are located and to (partially) close a knowledge gap so that policy makers can focus more specifically on certain measures. The mitigation potentials as calculated in this thesis are ambitious but are technically possible if the right amount of attention, resources, and policy action are allocated to them. 2030 is only 12 years away, and many large steps must be made to stay below a 2℃-temperature increase. This document contributes to the timely achievement of that goal, by making a first step into mapping the mitigation potentials on a regional and national level, so that policy makers can act on that information.

With the above in mind it is possible that the results presented in this thesis are somewhat optimistic. On the other hand, the results are only for 9 measures. In the *Emissions Gap Report 2017* a total of 39 measures are considered. The total global mitigation potential will thus be significantly higher and might still be able to close the emissions gap. This, and the above factors, were not included in the scope of this thesis a so, a recommendation is to do research regarding the effect of (socio-)economic factors on the calculated mitigation potentials. Further, the mitigation potential for the other 30 measures treated in the *Emissions Gap Report 2017* could be investigated on a regional and national level.

Concludingly, the hope is that by showing that it is technically possible to combat climate change below a reasonable price threshold, the focus of the debate surrounding it will no longer be if we can achieve it, but how we can achieve it and that there will be subsequent steps towards a renewable future.

12. Conclusion

In this chapter the questions that were posed in the introduction of this thesis will be answered. The main questions in this thesis are:

''What are the sectoral emission reduction potentials for the considered measures that can be utilized, at or below 100$/t$CO_2$e for the G20 and world regions in 2030? Further, can NDCs be achieved so that the emission gap can be closed to achieve the Paris agreement's goal to stay well below 2℃ above pre-industrial levels, and additionally try to limit temperature rise to 1.5℃?''

The are several main findings in this thesis.

- Firstly, the total mitigation potential in 2030 for the treated 9 measures ranges from 19 GtCO_2e to 27 GtCO_2e.
- Secondly, the envisioned mitigation potential of only the 9 treated measures in 2030 is enough to close the *emission gaps.*
- Thirdly, with the envisioned mitigation potentials the NDCs of all G20 countries can be achieved by a large margin.

Regionally, Asia has the largest part in the global mitigation potential, discussed above, representing around 44%. Asia is followed by North America and Africa. Regions with lower mitigation potentials are Europe, the Middle East, and Oceania. Asia's mitigation potential, is predominantly coming from China, India, and Russia. China by far has the largest potential and represents around 25% of the global total mitigation potential for the measures treated in this thesis. Furthermore, the measures with the largest mitigation potentials are solar PV, wind energy, and reducing deforestation. The G20 has a mitigation potential ranging from 14.4 GtCO_2e to 20 GtCO_2e. The G20 member states with the highest mitigation potentials are China, The US, India, Indonesia and Brazil. Indonesia and Brazil have large mitigation potentials due to the forestry sector. Additionally, peatland management is the reason for Indonesia's high mitigation potential, which represents around 60% of the global total peatland management mitigation potential in 2030.

The emissions gap for a scenario in which temperature rise stays below 2℃ compared to pre-industrial levels was determined to be 18-22 GtCO_2e in 2030. Similarly, between a current policy scenario and a 1.5℃ pathway, the emissions gap is determined to be between 24 GtCO_2e and 27 GtCO_2e in 2030. When compared with the mitigation potential mentioned above it can be said that when the envisioned mitigation potentials for only the 9 treated measures are realized in 2030, it is very likely that a pathway in which temperature rise will be limited to below 2℃ is achievable. Moreover, a 1.5℃ pathway could be achieved, although, this can be said with less certainty due to the ranges not totally overlapping

After comparing the NDCs, translated to emissions, of the G20 member states with envisioned emission reductions it can be concluded that all NDCs would be achieved well within the set time limit when only considering the 9 measures treated in this thesis. Moreover, most of the NDCs would be achieved by a large margin. An overview of the NDCs, emission levels, and the emission levels under envisioned mitigation is shown in Table 4.

Concludingly, this thesis has shown that staying below a temperature rise of 2℃, and 1.5℃ is technically possible below 100$/t$CO_2$e by realizing mitigation potentials for just 9 measures. Additionally, with such emission reductions all G20 members are in line with their NDCs. Lastly, considering the G20, it can be said that it has a significant part in the decarbonization of our future.

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Appendix A. Regions and country tables

Table A1. Countries located within regions of the world as used in this thesis, unless stated otherwise.

Region	Countries
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi. Cabo Verde, Cameroon, Central African Republic (CAR), Chad, Comoros, the Congo, Cote d'Ivoir, Democratic Republic of the Congo (DRC), Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of South Africa (RSA), Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
Asia	Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, China, Georgia, India, Japan, Kazakhstan, Kyrgyzstan, Maldives, Mongolia, North-Korea, Nepal, Pakistan, Russian Federation, South Korea, Sri Lanka, Tajikistan, Taiwan, Turkey, Turkmenistan, Uzbekistan
EU	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, The United Kingdom
Europe	Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Lithuania, Luxembourg, Macedonia, Malta, Moldova, Montenegro, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom
Latin America and The Caribbean	Antigua & Barbuda, Argentina, Barbados, Bahamas, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Guatemala, Grenada, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts & Nevis, St. Lucia, St. Vincent & Grenadines, Suriname Trinidad and Tobago, Uruguay, Venezuela
MENA	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Syria, Tunisia, UAE, Yemen.
Middle-East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, UAE, Yemen
North America	Canada, The United States of America
Oceania	Australia, Fiji, Kiribati, Marshall Islands, Micronesia, Nauru, New Zealand, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu
South-East Asia	Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, The Philippines, Singapore, Thailand, Timor-Leste, Vietnam

Table A2. Country groupings as used in WEO2017 (IEA, 2017b).

Region	Countries
North America	Canada, Mexico, United states of America
Central and South America	Argentina, Bolivia, Venezuela, Brazil, Chile, Colombia, Costa Rica, Cuba, Curacao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Bonaire, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, Saba, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Saint Maarten, Turks and Caicos Islands.
Africa	Algeria, Egypt, Libya, Morocco and Tunisia, Angola, Benin, Botswana, Cameroon, Republic of the Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania, Togo, Zambia, Zimbabwe, Burkina Faso, Burundi, Cabo Verde, Central African Republic, Chad, Comoros, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Réunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Swaziland, Uganda and Western Sahara.
Middle East	Bahrain, the Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, the Syrian Arab Republic, the United Arab Emirates and Yemen.
Europe	The EU and Albania, Belarus, Bosnia and Herzegovina, Gibraltar, Iceland, Israel5, Kosovo, Montenegro, Norway, Serbia, Switzerland, the Former Yugoslav Republic of Macedonia, the Republic of Moldova, Turkey and Ukraine.
EU	Austria, Belgium, Bulgaria, Croatia, Cyprus1,2, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, the Slovak Republic, Slovenia, Spain, Sweden and the United Kingdom.
Eurasia	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Russian Federation
Asia Pacific	Australia, Bangladesh, China, Chinese Taipei, India, Japan, Korea, Democratic People's Republic of Korea, Mongolia, Nepal, New Zealand, Pakistan, Sri Lanka, Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, the Lao People's Democratic Republic, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste and Tonga, Vanuatu, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam.

Table A3. Regions as given in WEO2017, and differently labelled same geographic area as given by WEO2014

WEO 2017	WEO 2014
Global	Global
Asia Pacific	China, India, Other Asia, OECD Asia Oceania
North America	OECD North America
Eurasia	Eastern Europe/Eurasia
European Union	OECD Europe
Middle East	Middle East
Africa	Africa
Central and South America	Latin America

Table A4. Regions and countries of the world, as described in the WEO 2014.

Region	Countries
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, , Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Swaziland, united Republic of Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe
Other Asia	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Chinese Taipei, Cook Islands, East Timor, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Macao, Malaysia, Maldives, Mongolia, Myanmar, Nepal, New Caledonia, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu, Vietnam
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Israel, Luxembourg, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
Eastern Europe/Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kosovo, Kyrgyz Republic, Latvia, Lithuania, Montenegro, Romania, Russia, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, Gibraltar and Malta.
Latin America	Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Bermuda, Bolivia, brazil, British virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, Saint Lucia, St. Pierre et Miquelon, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, Uruguay, Venezuela
Middle East	Bahrain, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
OECD North America	Canada, Mexico, United States of America
OECD Asia Oceania	Australia, Japan, Korea, New Zealand

Table A5. Regions and countries of the world, as described by Ram et al. (2017).

Region	Countries
North America	Canada, Mexico, United states of America
South America	Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala, Belize, Colombia, Venezuela, Guyana, French Guiana, Suriname, Ecuador, Peru, Bolivia, Paraguay, Brazil, Argentina, Uruguay, Chile
Sub-Saharan Africa	Gambia, Cape Verde, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Senegal, Sierra Leone, Benin, Burkina Faso, Cote d'ivoir, Ghana, Togo, Chad, Niger, Nigeria, Sudan, Eritrea, Ethiopia, Somalia, Djibouti, Kenya, Uganda, Tanzania, Rwanda, Burundi, Cameroon, Central African Republic, Equatorial Guinea, Gabo, Sao Tome and Principe, Congo, democratic republic of the Congo, Angola, Botswana, Namibia, South Africa, Lesotho, Malawi, Mozambique, Swaziland, Zambia, Zimbabwe, Comoros, Madagascar, Mayotte, Seychelles, Mauritius
MENA	Algeria, Bahrain, Qatar, Egypt, Iran, Iraq, Israel, Jordan, Palestine, Kuwait, Lebanon, Libya, Morocco, Oman, Saudi Arabia, Tunisia, UAE, Yemen, Syria
Europe	Norway, Denmark, Sweden, Finland, Iceland, Estonia, Lithuania, Latvia, Poland, Portugal, Spain, Gibraltar, France, Monaco, Andorra, Belgium, Netherlands, Luxembourg, Ireland, UK, Isle of man, Guernsey, Jersey, Germany, Czech Republic, Slovakia, Austria, Hungary, Slovenia, Croatia, Romania, Bulgaria, Greece, Bosnia and Herzegovina, Serbia, Montenegro, Macedonia, Albania, Italy, San Marino, Vatican, Switzerland, Liechtenstein, Turkey, Cyprus, Ukraine, Moldavia
SAARC	Afghanistan, Pakistan, India, Nepal, Bhutan, Bangladesh, Sri Lanka
Eurasia	Russia, Belarus, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan
Northeast Asia	China, Japan, Korea, North-Korea, Mongolia
Southeast Asia	Myanmar, Malaysia, Brunei, Singapore, Indonesia, Thailand, Laos, Vietnam, Cambodia, Philippines, Australia, New Zealand

Appendix B. Mitigation potential tables

Table B1. Mitigation potential for the measure cropland management mitigation potentials in 2030 for the world's regions.

Region	Technical mitigation potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
World	1329.32	**727.63**
Non-OECD	989.00	548.18
OECD	340.32	179.45
G20	908.42	502.05
Asia	501.28	283.16
Africa	196.80	105.40
North America	186.38	101.63
Latin America	149.88	79.46
South-East Asia	110.29	65.23
European Union	105.70	59.02
Rest of Europe	41.92	22.86
Oceania	22.25	6.78
Middle East	14.81	4.10

Table B2. Mitigation potential for the measure cropland management in 2030 for the G20.

Country	Technical mitigation potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
India	170.86	101.04
United States of America	141.36	77.08
China	126.14	74.60
Russian Federation	110.63	60.33
European Union	105.70	59.02
Brazil	80.45	47.58
Canada	45.02	24.55
Indonesia	44.24	26.16
Turkey	22.21	13.14
Australia	20.19	5.58
Argentina	17.72	4.90
France	16.65	9.08
Mexico	11.22	3.10
Germany	10.48	5.72
Italy	8.47	5.01
South Africa	5.64	1.56
United Kingdom	5.16	2.81
Japan	3.96	2.16
Saudi Arabia	1.63	0.45
Republic of Korea	1.47	0.80
G20	908.42	502.05

Table B3. mitigation potential for the measure peatland management for the world's regions in 2030.

Region	Technical mitigation potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
World	1558.90	1064.49
non-OECD	1423.67	990.32
OECD	135.23	74.18
G20	1186.52	812.94
South-East Asia	990.48	716.22
Asia	223.55	133.83
EU	97.06	52.45
Africa	69.61	43.06
Rest of Europe	48.45	27.16
Oceania	45.40	33.32
Middle East	36.58	31.43
Latin America	25.46	1064.49
North America	22.31	990.32

Table B4. Mitigation potential for the measure peatland management for the G20 in 2030.

Country	Technical mitigation potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
Indonesia	878.09	637.46
China	78.79	55.66
European Union	97.06	52.45
Russian Federation	91.07	44.58
United states of America	21.12	11.62
Germany	17.41	8.36
Brazil	10.49	5.77
United Kingdom	6.91	3.80
Australia	2.71	1.39
Japan	2.47	1.19
France	1.81	1.00
India	1.75	0.96
Canada	1.19	0.66
Mexico	0.60	0.53
South Korea	0.56	0.27
Italy	0.35	0.19
Turkey	0.34	0.18
South Africa	0.16	0.14
Argentina	0.12	0.08
Saudi Arabia	0.00	0.00
G20	1186.5	812.9

Table B5. Mitigation potential for residential and commercial efficient appliances and lighting for the world's regions in 2030

Region	Residential mitigation potential (MtCO2/year)	Commercial mitigation potential (MtCO2/year)	Total mitigation potential (MtCO2/year)
World	2381	721	3103
G20	1672	542	2214
Non-OECD	1518	248	1766
OECD	864	473	1337
Asia	994	216	1209
North America	366	202	568
Africa	393	22	415
Europe	259	114	373
EU	150	67	217
South-East Asia	182	38	220
Latin America ^ Caribbean	120	35	155
Middle East	105	29	134
Oceania	18	10	28

Table B6. Mitigation potential residential and commercial efficient appliances and lighting for the G20 in 2030

Country	Residential mitigation potential (MtCO2/year)	Commercial mitigation potential (MtCO2/year)	Total mitigation potential (MtCO2/year)
China	482	68	550
United States	324	181	505
India	282	27	309
EU	150	67	217
Japan	59	58	117
Indonesia	78	6	84
Canada	42	21	63
Russia	48	19	67
Brazil	40	21	61
Mexico	44	7	51
Korea	26	24	50
Germany	29	16	45
Turkey	27	14	41
France	21	11	31
Argentina	22	7	29
UK	20	8	28
Saudi Arabia	16	8	24
Italy	17	7	24
South Africa	19	5	24
Australia	14	8	22
G20	1672	542	2214

Table B7. Mitigation potential for solar PV and wind energy in 2030 for the world's regions, using Ram et al. (2017)

Region	Wind mitigation potential (MtCO2/year)	Solar PV mitigation potential (MtCO2/year)	Total mitigation potential (MtCO2/year)
World	5775	4966	10741
Asia Pacific	4073	2772	6845
North America	672	875	1547
Europe	340	418	757
Eurasia	124	503	628
Middle East	369	235	604
South-East Asia	522	80	602
EU	236	305	541
Africa	275	159	434
Central and South America	108	37	146

Table B8. Mitigation potential for solar PV and wind energy in 2030 for the G20, using Ram et al. (2017)

Country	Wind mitigation potential (MtCO2/year)	Solar PV mitigation potential (MtCO2/year)	Total mitigation potential (MtCO2/year)
China	1891	2242	4133
US	574	912	1486
India	1143	248	1390
EU	236	305	541
Russia	78	444	523
Japan	164	151	315
Korea	173	100	274
Saudi Arabia	104	103	207
Australia	92	99	191
South Africa	89	97	186
Indonesia	162	0	162
Germany	39	68	107
France	43	60	103
Canada	55	44	99
Mexico	62	31	93
UK	18	69	87
Turkey	27	25	53
Italy	31	16	47
Argentina	8	22	30
Brazil	23	1	25
G20	4881	4825	9707

Table B9. Mitigation potential for solar PV and wind energy in 2030 for the world's regions, using Teske et al. (2015)

Region	Wind mitigation potential (MtCO2/year)	Solar PV mitigation potential (MtCO2/year)	Total mitigation potential (MtCO2/year)
World	1321	2017	3339
Asia Pacific	676	1020	1696
North America	273	393	665
Middle East	156	105	261
South-East Asia	89	134	222
Africa	120	101	221
Eurasia	35	112	147
EU	28	65	94
Central and South America	24	46	70

Table 10. Mitigation potential for solar PV and wind energy in 2030 for the G20, using Teske et al. (2015)

Country	Wind emission reduction potential ($MtCO_2$/year)	Solar PV emission reduction potential ($MtCO_2$/year)
India	242	408
US	265	381
China	195	312
Russia	25	80
EU	28	65
South Africa	50	42
Korea	35	53
Canada	35	50
Saudi Arabia	50	34
Japan	26	39
Indonesia	24	36
Australia	16	25
Mexico	16	23
Germany	6	13
France	5	11
UK	3	7
Italy	3	6
Argentina	3	5
Brazil	2	3
Turkey	1	1
G20	1013	1557

Table B11. Mitigation potential for reducing deforestation in 2030 for the tropical and sub-tropical belt.

Country	Low mitigation potential (MtCO2/year)	High mitigation potential (MtCO2/year)
Brazil	265.37	683.14
Indonesia	166.58	433.11
Myanmar	109.66	286.38
Tanzania	90.00	236.84
DRC	83.99	217.66
Bolivia	73.31	188.94
Argentina	67.86	174.49
Paraguay	61.94	162.27
Zimbabwe	59.19	156.43
Mozambique	52.35	136.55
Cameroon	49.63	128.32
Peru	44.97	117.95
Zambia	43.82	115.68
Venezuela	43.09	113.63
Nigeria	42.00	109.92
Sudan	41.45	108.96
Angola	33.55	88.77
Cambodia	28.03	72.41
Mexico	24.99	65.11
Botswana	24.02	61.97
Chad	22.53	58.32
Honduras	20.98	54.48
Ecuador	19.62	50.91
Somalia	17.32	45.47
Namibia	17.03	44.53
Mali	16.42	42.75
Burkina Faso	13.70	36.32
Uganda	13.11	34.54
Benin	11.37	30.11
Senegal	10.26	27.40
Guinea	9.09	24.14
Liberia	7.38	19.62
Panama	4.30	11.46
Niger	2.86	7.61
Equatorial Guinea	2.83	7.52
Sri Lanka	1.74	4.63
Togo	1.10	2.95
El Salvador	0.91	2.43

Table B12. Mitigation potential for reducing deforestation in 2030 for the world's regions

Region	High Mitigation potential (MtCO2/year)	Low Mitigation potential (MtCO2/year)
Africa	663.90	1739.44
Latin America	529.05	1370.84
South-East Asia	307.12	799.48
Total	1500	3910

Table B13. Mitigation potential for reforestation in 2030 for the worlds' regions

Region	Technical Mitigation Potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
World	10128.14	3038.44
non-OECD	7336.60	2200.98
G20	6917.97	2075.39
Latin America	3520.23	1056.07
OECD	2791.54	837.46
Asia	2609.36	782.81
EU	1121.83	336.55
South-East Asia	998.90	299.67
Africa	811.09	243.33
Oceania	414.06	124.22
North America	412.56	123.77
Rest of Europe	216.07	64.82
Middle East	24.04	7.21

Table B14. Mitigation potential for reforestation in 2030 for the G20

Country	Technical mitigation potential (MtCO2/year)	Financial mitigation potential (MtCO2/year)
Brazil	1549.72	464.9
China	1256.71	377.0
European Union	1121.83	336.5
India	519.47	155.8
Mexico	516.96	155.1
Australia	385.67	115.7
United states of America	357.98	107.4
Russian Federation	351.33	105.4
Turkey	308.96	92.7
Indonesia	212.02	63.6
Argentina	207.41	62.2
United Kingdom	153.05	45.9
France	111.50	33.5
Italy	111.47	33.4
Japan	67.06	20.1
Canada	54.58	16.4
Germany	42.00	12.6
South Africa	5.03	1.5
South Korea	3.24	1.0
Saudi Arabia	0.00	0.0
Total G20	6918.0	2075.4

Table B15. Mitigation potential for direct energy efficiency in the industry sector in 2030 for the G20

Region	**Technical mitigation potential (MtCO2/year)**
World	2551.0
non-OECD	2168.0
G20	2118.3
Asia	1767.3
OECD	318.0
Middle East	179.9
South East Asia	144.5
Africa	144.3
North America	127.8
Latin America	104.5
EU	94.0
Oceania	10.1
Rest of Europe	4.5

Table B16. Mitigation potential for direct energy efficiency in the industry sector in 2030 for the G20

Country	Technical mitigation potential (MtCO2/year)
China	1180.0
India	331.0
United States of America	112.0
European Union	94.0
Russian Federation	77.0
Saudi Arabia	48.1
Indonesia	46.5
Brazil	37.0
Japan	29.9
South Africa	23.0
Germany	22.7
Mexico	19.0
Korea	17.6
Argentina	16.7
Canada	15.8
Italy	10.4
France	10.2
United Kingdom	9.4
Turkey	9.1
Australia	8.7
Total G20	2118.3

Table B17. Mitigation potential for efficient light duty vehicles in 2030 for the G20

Region	Technical mitigation potential (MtCO2/year)
World	1641.0
G20	1262.1
non-OECD	1031.0
Asia	660.8
OECD	610.0
North America	342.7
Middle East	136.6
EU	131.0
South East Asia	127.0
Latin America	122.8
Africa	56.5
Oceania	14.0
Rest of Europe	1.0

Table B18. Mitigation potential for efficient light duty vehicles in 2030 for the G20

Region	Technical mitigation potential (MtCO2/year)
China	406.0
United States of America	319.0
European Union	131.0
India	117.0
Brazil	43.0
Russian Federation	40.0
Saudi Arabia	36.6
Mexico	36.0
Indonesia	30.6
Japan	28.0
Canada	23.7
Germany	18.9
France	14.8
Korea	14.0
United Kingdom	13.5
Australia	12.0
Italy	12.0
Turkey	9.9
South Africa	9.0
Argentina	6.4
Total G20	1262.1

Appendix C. Auxiliary tables

Table C1. Emission factors for cropland management activities in the 4 climate zones, according to Smith (2007)

Climate zone	Sub-measure	Emission factor	Average emission factor
Cool-dry	Agronomy	0.39	0.30
	Nutrient management	0.33	
	Tillage & residue management	0.17	
Cool-moist	Agronomy	0.98	0.71
	Nutrient management	0.62	
	Tillage & residue management	0.53	
Warm-dry	Agronomy	0.39	0.357
	Nutrient management	0.33	
	Tillage & residue management	0.35	
Warm-moist	Agronomy	0.98	0.77
	Nutrient management	0.62	
	Tillage & residue management	0.72	

Table C2. Cropland growth rates calculation using Meyfroidt & Lambin (2010), and UN (2015) & FAOSTAT (2015).

Period	**Low (Mha)**	**High (Mha)**	**Average (Mha)**
2000 (Lambin & Meyfroidt, 2010)	1510	1611	1560.5
2015 (Lambin & Meyfroidt, 2010)	1550.5	1.684.5	1.617.5
2030 (Lambin & Meyfroidt, 2010)	1591	1758	1674.5
Cumulative change 2000 - 2030 (%)	+5.36	+9.12	+7.31
2015 (UN & FAOSTAT)			1638
Cumulative change 2000 - 2015 (%)			+4.97

Table C3. Share of mitigation potential that remains for cropland management below \$100/tCO$_2$.

Climate zone	Financial mitigation share
Cool-dry	-
Cool-moist	54.53%
Warm-dry	27.65%
Warm-moist	59.14%

Table C4. Efficient lighting and appliances energy use reduction potential in 2030.

	Residential		Commercial	
	Lighting	Appliances	Lighting	Appliances
China	-57%	-59%	-16%	-19%
EU	-54%	-47%	-11%	-20%
India	-59%	-53%	-16%	-19%
RSA	-62%	-71%	-18%	-17%
United States	-60%	-51%	-4%	-18%
ROW	-62%	-63%	-18%	-20%
World	-60%	-58%	-14%	-18%

Appendix D. Industry mitigation potential – alternative

In this methodology the mitigation potential for efficient industry sector is calculated using data from several different sources. Firstly, the *Energy Technology Perspectives 2017* data is used to calculate emissions factors using energy use and emissions output data. Furthermore, the *Energy Technology Perspectives 2017* is used for its national and regional energy data in the year 2030. Furthermore, the IEA energy balances are used for the base year energy use in case the country is not mentioned in the *Energy Technology Perspectives 2017*. Secondly, the *International energy outlook 2016* (EIA, 2016) is used since it contains the share of industry sub-sector energy use in 2012 and 2040. The shift in this share is assumed linear between 2012 and 2040 and so, the sub sector share can be calculated for 2030. In the same manner the division of industry energy use between the OECD and non-OECD is given for 2012 and 2040 and is calculated for 2030. Lastly, *the Hitchhiker's guide to energy transition within 1.5 degrees* (van Exter, 2018) is used. This research provides energy efficiency reduction potential in 2014 and 2050 per industry sub-sector under a 1.5℃ pathway. Again, this is assumed to be linear between these two years, and so the reduction potential in 2030 can be calculated.

The 2030 energy use, for each country, is then divided according to the sub sector share provided by the EIA (2016), yielding subsector energy use in 2030, providing a baseline. This baseline is then used to calculate the mitigation potential using the energy use reduction potential given by van Exter (2018). The found baseline values are multiplied with these reduction potentials, resulting in a 1.5℃ compatible pathway. The energy use differences in 2030 between the constructed baseline and the 1.5 degrees compatible pathway are multiplied with the region or country specific emissions factor, calculated using *Energy Technology Perspectives 2017* data (IEA, 2017). This results in per country and regional mitigation potentials of industry energy efficiency in 2030. The results are displayed below

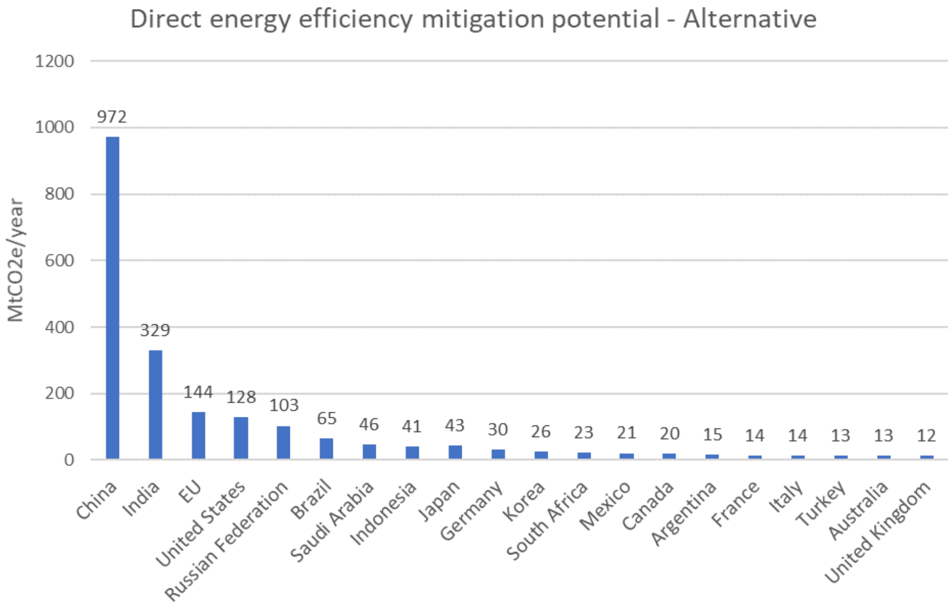

Figure D1. Direct energy efficiency mitigation potential for the G20 in 2030.

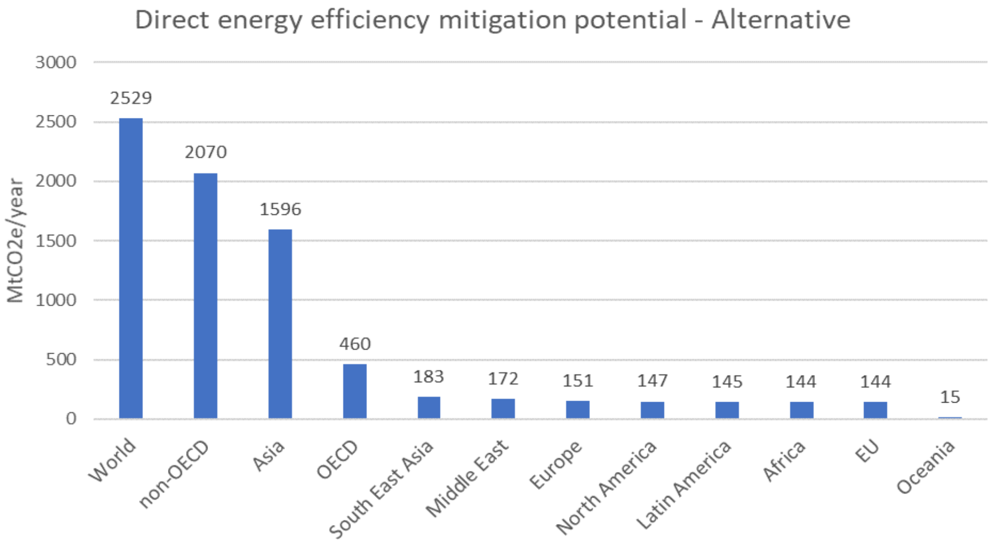

Figure D2. Direct energy efficiency mitigation potential for the worlds regions in 2030.

Figure D1 and D2 show the mitigation potential in 2030 for the G20 and the world regions respectively. As can be seen again China by far has the largest mitigation potential, followed by India the EU and the US. Furthermore, the other G20 countries have relatively lower mitigation potentials. Moreover, the global mitigation potential is 2529 $MtCO_2e$ in 2030. This is within the same range as the mitigation potential calculated in chapter 8.

There are some uncertainties regarding this methodology which have led to the decision not to include the results in the main report.

- The data by van Exter (2018) is given in an unpublished thesis research.
- Assumed 2030 energy use and emission factors taken from the *Energy Technology Perspectives 2017* and the energy balances (IEA, 2017;2018)
- Subsector share, energy split between OECD and non-OECD, and energy use reduction potential in 2030 linearly assumed.

These are assumptions leading to the methodology being relatively uncertain. The found result however, indicated that the mitigation potential calculated in chapter 8 is somewhat accurate or in the right direction.