SUOMEN ILMASTOPANEELI
The Finnish Climate Change Panel

AN APPROACH TO NATIONALLY DETERMINED CONTRIBUTIONS CONSISTENT WITH THE PARIS CLIMATE AGREEMENT AND CLIMATE SCIENCE: APPLICATION TO FINLAND AND THE EU

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PREFACE

This report provides a continuation of the analysis that the Finnish Climate Change Panel conducted on the long-term emissions reduction target for Finland. This analysis was originally developed as background material for answering questions Minister Tiilikainen posed to the Panel concerning the long-term emissions reduction target for Finland. The specific questions given to the Panel for consideration were

1) Considering current long-term climate policy commitments and the scientific views on reaching the Paris Agreement goals, what could be a sufficiently ambitious reduction target for Finland for 2050?
2) How does the Panel view the preciseness of setting a target and possible milestones towards reaching it? Taking into account uncertainties and other factors, is there reason to consider a target range instead of a specific target? Are there grounds for defining an emissions reduction pathway towards 2050 targets?
3) Does the Panel see carbon neutrality as part of the emissions reduction target or as a parallel goal? How could these targets work together coherently?
4) What kind of role should flexibilities have, in the Panel's opinion, when defining reduction targets and carbon neutrality? How does the Panel see flexibilities relative to cost-efficiency, risk management and increasing ambition?
5) Which other points should be considered in the Panel's opinion, when setting the long-term emissions reduction target?

Given that the notion of responsible or fair contribution to the global efforts to mitigate climate change is normative, the Finnish Climate Change Panel developed an approach that drew on the recent climate research employing equity criteria on one hand and global carbon budgets on the other. The IPCC's report "Global Warming of 1.5 °C" provides new estimates of global carbon budgets. This report updates the previous analysis to reflect these estimates and explores their implications to the fair and responsible contribution of Finland, the EU, Germany and Sweden to global efforts to restrict the increase in the global mean temperature to 1.5 degrees.

Helsinki, October 3rd 2019

Markku Ollikainen
Chair of the Finnish Climate Change Panel

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Introduction

The Paris Agreement defines the goal of keeping the increase in global average temperatures to under 2 °C while striving for 1.5 °C compared to preindustrial levels. The Agreement requires its parties to start decreasing global emissions as soon as possible and achieve a balance of emissions and removals during the second half of this century. Emissions reductions under the Paris Agreement are based on voluntary national contributions, which are viewed collectively and their adequacy relative to the Agreement judged every five years. This system aims to ensure that each country's efforts are in line with the agreed long-term goal. The EU and its member states have committed to the Paris Agreement and its targets. Under the Agreement, its Parties should communicate a mid-century, long-term low greenhouse gas emission development strategy by 2020 to the UNFCCC, which the EU is currently preparing.

Decisions on national mitigation efforts according to the Paris Agreement process are presumably guided by each country's views on their fair share in climate action and their technical and economic capabilities to decrease net emissions, meaning the balance of fossil fuel and process-based greenhouse gas emissions and carbon sequestration in the LULUCF (Land-use, Land-use change and Forestry, from now on land-use sector) sector. The ideas of global equity or sufficient ambition are normative by nature and can be systemised for public discussion by utilising extensively applied equity criteria from scientific literature[1]. The discussion on the implementation of the Paris Agreement has most often applied equality, ability to pay and historic responsibility as equity principles and in this report we apply these principles to the determination of national mitigation efforts and the path of nationally determined contributions to the Paris Agreement.

Our approach is also in line with the fundamental spirit of the United Nations Framework Convention on Climate Change of 1992, which states:

"The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities."

The principle of 'common but differentiated responsibilities' (CBDR) has always played a key part in negotiation and compromise in climate policy. The clear division most famously in the Kyoto Protocol of developed and developing countries is shifting and the field is open to a more versatile interpretation of responsibility. A selection of equity principles as measures for responsibility is thus worth examining, as every nation has differing circumstances politically, historically, geographically and socially.[2]

Drawing on another United Nations body, the Intergovernmental Panel on Climate Change (IPCC) provided an alarming report on "Global Warming of 1.5 °C" in October 2018 outlining the increase in climate risks resulting from an increase in global warming from 1.5 degree to 2 degrees. The report also outlined the required emissions reduction pathways for achieving the 1.5 degree target. The IPCC stresses the need for a rapid and radical reduction of emissions and removing carbon dioxide from the atmosphere. The IPCC's approach requires a consistent and simultaneous analysis of reducing fossil and process-based emissions and increasing carbon sinks.

Keeping all of these aspects in mind, our approach is to combine new estimates of global carbon budgets and operational equity criteria to examine any countries' fair share in global climate mitigation. While this approach is founded in scientific literature, thus far the literature has focused on groups of countries instead of a single country (for example in Bretschger, 2013 and Höhne et al., 2014). Focusing on a single country makes a challenging task, as carbon budgets are global and contain no country-specific assumptions on the

[1] Se e.g. Höhne et al. (2014), Mattoo and Subramanian (2012), Pan et al. (2017) and Raupach et al. (2014)

[2] Brunnée, J. and Streck, C., 2013. The UNFCCC as a negotiation forum: towards common but more differentiated responsibilities. Climate Policy, 13(5), pp.589-607.

evolvement of emissions and carbon sinks. In addition, carbon budgets are typically expressed for carbon dioxide only with external assumptions for other GHGs, while climate policies often focus on carbon dioxide equivalent emissions.

Nevertheless, our chosen approach has the merit of providing consistent framework for a simultaneous treatment of all GHG emissions as well as carbon sinks, while considering global carbon budgets. The results provide a useful basis for discussion on fair national long-term goals and emissions reduction efforts. Our approach resembles the analyses provided by the PBL Netherlands Environmental Assessment Agency (2017)[3] and Pan, den Elzen, Höhne, Teng, and Wang (2017)[4] among others.

A framework for national climate ambition

For us to be able to address national climate policy while accounting for global responsibility, we start with the introduction of global carbon budgets as the foundation of our framework. Next we will examine selected equity approaches to bring in the aspect of fairness to the mix. After these two main elements are introduced, we examine what adjustments are needed before moving on to our case studies, to reflect the policy context. Lastly, all data used for this report is presented concisely before moving on to the actual case studies and their results.

Carbon budgets

The Paris Agreement's goals of containing global warming to 2 °C while aiming for 1.5 °C can be calculated into carbon budgets, which are an estimation of the amount of cumulative carbon emissions allowed over time to keep in line with given temperature targets.[5] New estimates of the remaining carbon budgets have now been published in the IPCC Special Report (SR15) on Global Warming of 1.5 °C (IPCC, 2019). The estimated budgets are larger than previous estimates, which is partly explained by the change in the calculation methods. The previous carbon budgets in the AR5 report in 2011 (IPCC, 2011) were derived from models of intermediate complexity and their results. The SR15 estimates use observations to adjust its evaluation of the remaining carbon budget in addition to the Earth-system models. Secondly, it calculates the remaining budget as additional warming to the 2006–2015 base period. Further research will tell us how this base period compares with long-term trends and thus affects the presented budget estimates. Drawing on SR15, the new expected carbon budgets for 1.5 °C and 2 °C from 2018 are

- **420 Gt CO_2** for a 66% probability of limiting global warming levels to 1.5 °C
    - 580 Gt CO_2 for 50% probability of limiting global warming levels to 1.5 °C
- **1170 Gt CO_2** for a 66% probability of limiting global warming levels to 2 °C
    - 1500 Gt CO_2 for a 50% probability of limiting global warming levels to 2 °C

After the publication of the SR15, we now know that restricting the increase of the global temperature to 1.5 °C reduces damages considerably relative to 2 °C. Thus we will focus on the 1.5 °C carbon budget and only examine the 2°C budget in the section for sensitivity analysis. As these budgets were from 2018 onwards, emissions of 2018 must be decreased from the budgets to see how big the carbon budget is for 2019 onwards. Based on information from the Global Carbon Project[6], we estimate these emissions to be 42 Gt, thus making the carbon budget for 1.5 °C **378 Gt** (and 1128 Gt for 2 °C)**.**

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[3] The implications of the Paris Climate Agreement for the Dutch Climate Policy objectives (2017). Detlef P. van Vuuren, Pieter A. Boot, Jan Ros, Andries F. Hof and Michel G.J. den Elzen

[4] Pan, X., den Elzen, M., Höhne, N., Teng, F. and Wang, L., 2017. Exploring fair and ambitious mitigation contributions under the Paris Agreement goals. Environmental Science & Policy, 74, pp. 49-56.

[5] see e.g. Meinshausen et al., 2009, Matthews et al., 2009, Allen et al., 2009 and Friedlingstein et al., 2014

[6] Projected fossil-based emissions for 2018 are 37.1 Gt CO2 an estimated land-use change emissions were approximately 5 Gt in 2017. Global Carbon Project (2018) Carbon budget and trends 2018. [www.globalcarbonproject.org/carbonbudget]

The IPCC budgets contain external suppositions of non-CO_2 emissions pathways and consider carbon sinks inherently.[7] As neither of these effects can be extracted out of the budgets on a country-level, we have utilised a balancing approach to be able to examine all sectors jointly, including LULUCF:

1. Even though the IPCC carbon budgets have external assumptions of non-CO_2 emissions pathways, we have used them as CO_2 equivalent budgets. This leads to double accounting for non-CO_2 emissions, resulting in stricter than necessary targets.
2. The climate models use assumptions of the land-use sector's effect on the carbon cycle for calculating carbon budgets. Both the EU and Finland have been a net sink for carbon, and for this analysis, we use the net land-use sector carbon sink as wholly or partially interchangeable for emissions when defining net emissions, leading to less strict targets than necessary.

Whether or not these effects roughly balance each other out, our approach and calculations provide a reasonable approximation of the implications of equity criteria and carbon budgets. Calculating global carbon budgets is never a simple task and all estimates have high uncertainty.[8] It is not strictly correct to translate carbon budget into CO_2 equivalent budgets, but as budgets have high uncertainty, the adding of non-CO_2 gases and a level of carbon sink offsets to this examination is not a gross misuse of carbon budgets, as we are solely looking for country-level guiding principles rather than commenting on global emissions. Thus, from now on, we use these carbon budget estimates in the form of CO_2 equivalent (CO_2e) budgets, as this is an illustrative calculation for policy, not a study on the chemical and biological reality of greenhouse-gas forcing in the atmosphere.

Equity principles

Climate science provides us with estimations of the size of carbon budgets and necessary emissions reductions on a global level, but allocating efforts out to individual countries or regions requires economic, legal, political and moral analysis. Per international law, the Paris Agreement does not contain any specifics on how ambitious countries' individual targets should be. Furthermore, the design of the Agreement is "bottom-up" requiring countries to provide unilaterally their nationally determined contributions to the global mitigation efforts. One way of looking at national ambition levels is to examine an established idea of 'fair' or 'equitable' shares in global mitigation efforts for any country. Therefore, it is worth examining what kind of equity criteria scientific literature provides us with for determination of the path of nationally determined contributions.

Several equity principles have been scrutinized by the scientific community[9] in the climate policy context, including the resulting per country (cumulative) emissions which would be compatible with the global carbon budget. We do not assess the "goodness" of these criteria but examine what implications following each would have on the path of net emissions and thus for the nationally determined contributions. An alternative is to use a mix of equity criteria, for combining two or more (weighted) equity principles.[10] However, in this report we focus on the three most basic criteria commonly used in the context of climate policy, such as presented in Bretschger (2013), and Mattoo and Subramanian (2012).[11] Two of them are a variation of egalitarian thinking: all people around the world have a right to the same per capita emissions; and all people have the same right to affect the atmosphere (including both past and present per capita emissions). The third one accounts for economic performance of countries and requires that mitigation efforts are divided by countries' ability to pay (GDP) or development potential (reverse GDP). The idea is that the more one can afford to contribute the more one should, which as an idea is similar to progressive taxation.

[7] Rogelj, J., Schaeffer, M., Friedlingstein, P., Gillett, N.P., Van Vuuren, D.P., Riahi, K., Allen, M. and Knutti, R., 2016. Differences between carbon budget estimates unravelled. Nature Climate Change, 6(3), p.245.
[8] See e.g. Rogelj et al. (2016)
[9] E.g. Rose, Adam, Brandt Stevens, Jae Edmonds, and Marshall Wise. "International equity and differentiation in global warming policy." Environmental and Resource Economics 12, no. 1 (1998): 25-51.; and Metz, B., 2000. International equity in climate change policy. Integrated assessment, 1(2), pp.111-126.
[10] See e.g. Raupach et. al. (2014)
[11] Bretschger also provides economically sophisticated alternatives and Rose et al. a broader view on how equity has been applied.

Drawing on literature, we formulate the allocation-based principles and their implications of sharing mitigation efforts as follows:

1. **The equality principle**: Everyone has the equal right to the remaining emissions, which means the remaining GHG budget is divided by the global population. This results in a per capita GHG budget, which can be aggregated to a national level by multiplying the per capita GHG budget and the national population.

2. **The ability to pay principle:** The share of the remaining per capita GHG budget is defined by of ability to pay for mitigation. One way of calculating this is to compare the purchasing power adjusted global average per capita gross domestic product (GDP) to the national per capita GDP. From this follows that smaller shares of the per capita GHGn budget are allocated to wealthier than average countries leading to higher mitigation rates for them, and vice versa.

3. **The historic responsibility principle**: Everyone has the equal right to the remaining emissions but must also take responsibility for past emissions. This principle is also called the historic responsibility principle, for which high past emissions lead to a smaller share of the remaining per capita GHG budget, and vice versa. We have selected 1990 as the year for the starting point for taking responsibility, since 1990 can be thought to be the year when we knew enough about climate change and its causes to take action.

These equity principles differ from each other, while having the same fundamental in the per capita equality approach. Unsurprisingly, all of these criteria can and should be criticised from many perspectives.[12] For example, an equality approach is not sensitive to differences in countries' economic structure or other national circumstances, such as accounting for the fulfilment of basic needs. It is worth noting that when applying historic responsibility as an equity principle, it disregards that the countries, who have emitted most emissions, have also produced technological advances for themselves and others to mitigate carbon. Dividing mitigation efforts according to the ability to pay does not account for differences in mitigation costs and does not inherently lead to an economically efficient allocation of mitigation efforts.

Different timeframes have been presented for the analysis of historic responsibility in scientific literature and climate policy discussion (see for example Müller et al., 2009 and Den Elzen et al., 2005). If the entire history of fossil-based emissions would be accounted for, a budget per capita for the period of 1750 or 1850 to 2050 can be selected. On the other hand, if the emphasis is preferred to be on the relatively late understanding and consensus on climate change, the period of 1990-2050 can be selected for the per capita GHG budget. In this report we will examine the latter of these cases, as data on country-level emissions is more readily and reliably available from 1990 onwards and the warming effect of GHGs emissions were widely known.

So, despite their simple nature, these principles have had and will continue having a role in climate policies. To our knowledge, the 80% reduction target of the EU was originally adapted from the United Kingdom's own target, which was actually based on an equity calculation, in which all people in the world were allowed the same amount of emissions. The point of this report is not to judge the criteria on how good they are, instead to examine whether they lead to similar or differing results and fair shares of global responsibility, as a way to achieve the commitments in the Paris Agreement.

[12] E.g. Lange, Andreas, Carsten Vogt, and Andreas Ziegler. "On the importance of equity in international climate policy: An empirical analysis." Energy Economics 29, no. 3 (2007): 545-562.

Application and adjustments

The need for reducing fossil and process based emissions is reasonably straightforward, as this is what burden-sharing analyses have usually focused on. We add to this by approaching the land-use sector too. For our analysis to be relevant, we need to make a few adjustments and clarifications to how we address both of these, so before moving on to analysis we will present these adjustments and application methods.

Emissions

The starting point for each case study is the current level of emissions. We assume linear pathways, since for example EU climate policy is designed as linear reduction pathways and targets. We do not take any stands on specific sectors, as we are looking for a sector-wide coherent guideline. However, we do take note that it currently seems implausible that all emissions can be abated. Thus, the linear reduction pathways up to a point where emission levels are 90% to 95% lower than 1990 levels, after which emissions plateau and remain at this level consistent with e.g. many European countries' and the EU's long-term targets.

Sinks

The Paris Agreement states that the goal of the agreement is "[…].to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". It is not yet clear what the key word of 'anthropogenic' means in this context and the debate over it is ongoing in both the scientific and diplomatic communities. In this report, we sidestep the 'anthropogenic' problem by approaching the Paris Agreement and its temperature target with the help of carbon budgets, rather than take part yet in the debate over what is meant by this sentence.

In line with global carbon budgets, we include forest sinks and land-use emissions in our calculations and discuss net emissions. In this way, we can simultaneously examine sinks and all emissions in a coherent way under any given equity criterion. The land-use sector's net sink is a key factor in all calculations presented in this report, as it offsets emissions. When we discuss the net land-use sector sink, we mean the biological sink, i.e. the sum of emissions in the land-use sector and sinks from forests and harvested wood products.

The net sink effect of the land-use sector presumably fluctuates during 2019-2050, depending on economic and climatic conditions. Also, as is well known, there is much uncertainty concerning the size of the carbon sink and soil emissions and this should also be taken into account. Thus we select a constant baseline for the land-use sector net sink, which is a conservatively assumed average for the time period 2019-2050. This is to simplify our analysis, as there are high annual fluctuations in emissions and sinks in the land-use sector, which would make clear presentation difficult.

In some cases of our analysis, additional emissions removals are needed on top of the net sink for net emissions to remain within the GHG budget. Additional removals mean negative emissions technology or other GHG absorbing activities, such as increased land-use sector sinks on top of the baseline level. Since our framework is designed for the policy context, we want to provide policy guidelines for emissions removals and the land-use sector, too. For this purpose, we have selected 2031 as the year from which additional emissions removals commence, rather than 2019 with the traditional emissions reductions. There are two main reasons for this:

1. If additional emission removals come from the land-use sector, there is a lag in in the actual effect. Most measures implemented today will only take effect later, e.g. steps to decrease emissions from soils or planting trees. If they come from other negative emission technology, it doesn't yet exist at a feasible scale, and thus is in use at the earliest from 2030 onwards.[13]

[13] Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N. and Le Quéré, C., 2014. Betting on negative emissions. Nature climate change, 4(10), p.850.; Anderson, K. and Peters, G., 2016. The trouble with negative emissions. Science, 354(6309), pp.182-183.

2. Comprehensive climate policy in the land-use sector is in place for the first time in the EU for the period of 2021-2030. Initiating additional removals from 2030 can be seen as ramping up of climate targets in the EU for the second phase of land-use climate policy, in line with the Paris approach of increasing ambition.

As our main focus is on Finland, we will now elaborate its land-use sector conditions a little further before moving on to the data we have used for our calculations. The net sink of Finland from 1990 to the present has fluctuated between -34 and -14 Mt CO_2e/a. It has been predicted that the boost in logging from 'bioeconomy' growth or forest loss due to extreme weather or pests will decrease the net carbon sink of the land-use sector in the future. At the same time, projections from forest growth models predict higher growth levels, so this would then increase the net carbon sink of the land-use sector. We do feel confident that the land-use sector in Finland, and also in the other case studies, will remain as a biological carbon sink, but how much of this can be used for offsetting emissions is debatable. There is a strong case for only a part of the carbon sink to be interchangeable with emissions, either politically (e.g. LULUCF regulation) or scientifically (contained within the carbon budget or replacing past deforestation). In the case of Finland, these contingencies will be examined by using two different average levels of carbon sinks. We will use -21 Mt or -14 Mt CO_2e as the average base value for the entire period of 2019 to 2050. The -21 Mt value corresponds to past average net LULUCF sink per year between 1990 and 2018. The -14 Mt net sink level accounts for the uncertainty factors mentioned previously and discussed further in the Appendix. For example, a 30% uncertainty in the -21 Mt average net sink results in a -14 Mt net sink. In the cases of the EU, Sweden and Germany we will only look at the average net sink value between 1990 and 2018 for the sake of simplicity.

Data

The data for this analysis has been compiled from various sources. We have used national or EU emissions statistics when available, and for global emissions a selection of sources, namely the Food and Agriculture Organization of the UN for land-use emissions and PBL Netherlands Environmental Assessment Agency for other emissions. Purchasing power adjusted average GDP figures were retrieved from the World Bank database and population projections from the UN World Population Prospects online database. Table 1 shows all the figures used in the analyses in the following chapters of this report.

Table 1. Figures and statistics used in the framework analysis

	World	EU	Finland	Sweden	Germany
Most recent annual emissions Gt/Mt CO_2e (2016, 2017 or 2018) [14]	50.86 Gt	4 291 Mt	57 Mt	53 Mt	936 Mt
Most recent LULUCF Gt/Mt CO_2e (2016, 2017 or 2018) [15]	2.95 Gt	-248 Mt	-14 Mt	-44 Mt	-15 Mt
Net emissions Gt/Mt CO_2e (2016, 2017 or 2018)	53.81 Gt	3 990 Mt	42 Mt	9 Mt	921 Mt
Emissions per capita t CO_2e, (2016, 2017 or 2018) with future average population, without LULUCF	5.79 t	8.18 t	9.76 t	4.68 t	11.14 t
Net emissions per capita t CO_2e (2016, 2017 or 2018) with future average population, with LULUCF	6.12 t	7.60 t	7.31 t	0.79 t	10.96 t
Emissions in 1990 Gt/Mt CO_2e	32.91 Gt	5 720 Mt	71 Mt	71 Mt	1 052 Mt
LULUCF in 1990 Gt/Mt CO_2e	4.08 Gt	-260 Mt	-15 Mt	-34 Mt	-31 Mt
Net emissions in 1990 Gt/Mt CO_2e	36.99 Gt	5 460 Mt	57 Mt	37 Mt	1 021 Mt
Emissions per capita t CO_2e 1990, with future average population, without LULUCF	3.74 t	10.90 t	12.32 t	6.34 t	12.52 t
Net emissions per capita t CO_2e 1990, with future average population, with LULUCF	4.21 t	10.41 t	9.76 t	3.28 t	12.15 t
Average LULUCF net sink 1990-2018		-294 Mt	-21 Mt	-37 Mt	-22 Mt
Cumulative net emissions Gt/Mt CO_2e, 1990-2018	1298.52 Gt	136 029 Mt	1 431 Mt	796 Mt	29 696 Mt
Average population in billions/millions 2019-2050 [16]	8.819 billion	524.69 mil.	5.79 mil.	11.24 mil.	84.04 mil.
GDP, $ PPP adjusted 2017 [17]	$ 17 100	$ 42 517	$ 46 344	$ 51 405	$ 52 556

[14] World: Olivier J.G.J. and Peters J.A.H.W. (2018), Trends in global CO2 and total greenhouse gas emissions: 2018 report. Report no. 3125. PBL Netherlands Environmental Assessment Agency, The Hague.; EU&Germany: Greenhouse gas emissions by source sector (source: EEA) [env_air_gge]; Sweden: Statistikdatabasen; Finland: Statistics Finland.

[15] World: FAOSTAT, http://www.fao.org/faostat/en/#data/GL/metadata; EU&Germany: Greenhouse gas emissions by source sector (source: EEA) [env_air_gge]; Sweden: Statistikdatabasen; Finland: Statistics Finland.

[16] World: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, custom data acquired via website; EU, Sweden & Germany: Eurostat [proj_15npms]; Finland: Statistics Finland

[17] GDP per capita, PPP (current international $), World Bank, International Comparison Program database.

Globally fair pathways of reducing net emissions: The case of Finland

We will now put our framework to the test by combining all aspects previously introduced. As we now have the GHG budget of 378 Gt for 2019-2050 for 1.5 °C global warming, we can take a look at how to divide it according to equality, ability to pay and responsibility. For Finland we assume a 90% reduction target, leaving emission at 7 Mt levels, which translates into 1.2 t CO_2e per capita.

Equality: Everyone has the equal right to shares in remaining emissions

The case of equality is simple to calculate. We use the expected average value of global population between 2019 and 2050, which is 8.82 billion people[18], to calculate per capita allowed emissions. Thus the cumulative emissions per capita allowed from 2019 up to 2050 are **43 t per person.**

Table 2 compares this per capita budget with Finland's potential cumulative emissions per capita, when drawing on demographic projections and emissions are assumed to decrease linearly from one year to the next. The two sink levels and a case of no sinks is presented to show the effect of sinks on cumulative net emissions.

Table 2. Alternative reduction targets for Finland for 2050 and resulting cumulative per capita emissions

Reduction targets for 2050	Remaining CO_2e levels in 2050, without sinks	Cumulative net emissions per capita (t) 2019-2050		
		Without sinks	National net sink -14 Mt CO_2e/a	National net sink -21 Mt CO_2e/a
80 %	14.3 Mt CO_2e	196 t	118 t	79 t
85 %	10.7 Mt CO_2e	186 t	108 t	70 t
90 %	7.1 Mt CO_2e	176 t	98 t	60 t
95 %	3.6 Mt CO_2e	166 t	89 t	50 t
100 %	0 Mt CO_2e	156 t	79 t	40 t

Table 2 shows that carbon sinks are significant for reaching cumulative net emissions targets. Without sinks, even at 100% emissions reduction Finland's per capita emissions are over three times as large as the fair share according to equality in a 1.5 °C scenario. So what would a 43 t CO_2e per capita GHG budget look at the national level for Finland?

Figure 1 below shows that for the 1.5 °C target the assumed net sink of -14 Mt CO_2e/a does not provide enough negative emissions for remaining within the GHG budget. GHG neutrality would be achieved in 2037 and the emissions reduction rate would have to be 2.24 Mt each year leading to a 103% total emissions reduction by 2050. The 103% reduction target is calculated from the sum of remaining emissions and additional removals in 2020 and compared to 1990 levels of emissions. In this case, additional removals are -9.43 Mt and together with the 10% of emissions left (7 Mt) lead to -2 Mt, which in turn is 103% lower than the 1990 emissions of 71.31. Mt.

[18] According to United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, custom data acquired via website. An average figure is used, as the emissions reduction pathways will be linear.

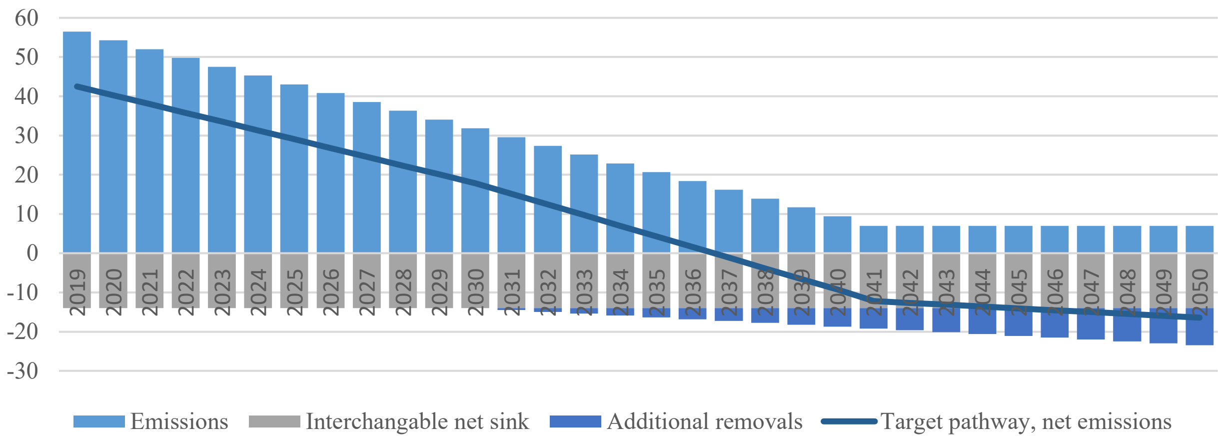
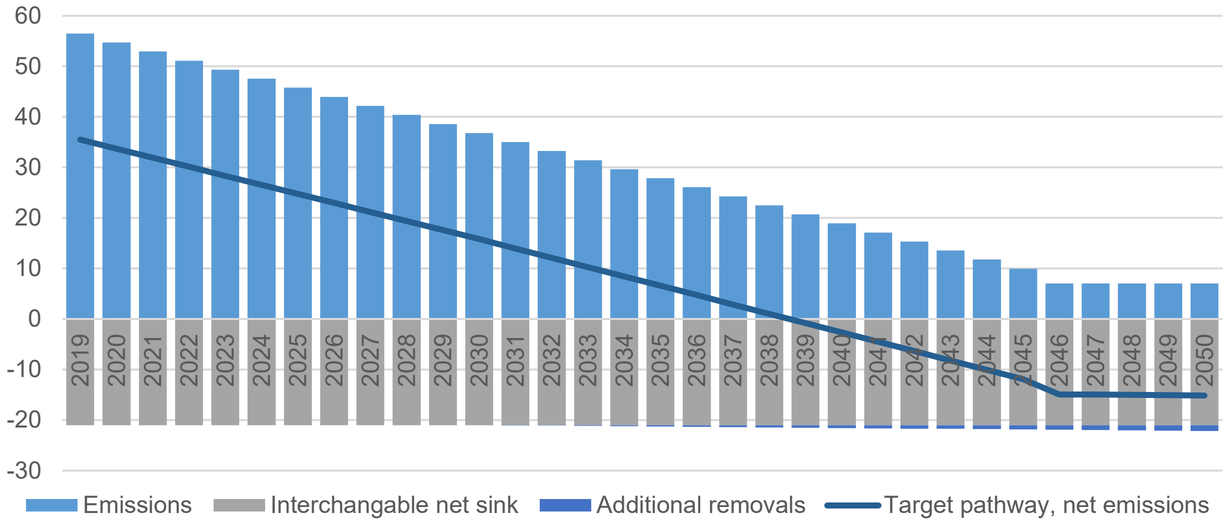


Figure 1. The emissions reduction pathway 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -14 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided equally per capita. Emissions are reduced at an annual rate of 2.24 Mt leading to a 103% reduction in 2050. Additional removals of -0.47 Mt per year result in –9.43 Mt in 2050. What we call 'GHG neutrality'[19] is achieved in 2039, and emissions plateau in 2041.

If we look at a baseline net sink of -21 Mt, the reduction pathway is less steep and less additional removals are required, as we can see from Figure 2 below.



Figures 2. The emissions reduction pathway 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -21 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided equally per capita. Emissions are reduced at an annual rate of 1.79 Mt leading to a 92% reduction in 2050. Additional removals of -0.06 Mt per year result in –1.15 Mt in 2050. GHG neutrality is achieved in 2038, and emissions plateau in 2046.

Figures 1 and 2 show how the land-use sector net sink affects required emissions reductions. We can however draw the same conclusions: if we apply equality as an equity principle, Finland should already be net negative in the late 2030s, but the required additional removals are achievable with present day practices. Emissions should be at the 10% level for most of the 2040s. This may be a challenge for mitigating emissions in some of sectors, providing incentives for innovation in industry and developing negative emissions technologies. Next, we will further the analysis by adding the element of ability to pay to this base case of equality.

[19] All GHG emissions and sinks are in balance, Finland's emissions are net zero.

Ability to pay: Everyone has an equal right to remaining emissions while adjusting for ability to contribute to mitigation efforts

GDP per capita is the metric traditionally used to describe countries' ability to pay or ability to contribute to mitigation efforts. Under this principle each country receives a portion of the per capita GHG budget, which is defined by the ratio of the world average per capita GDP to a country's per capita GDP. In 2016 Finland's purchase power (PP) adjusted per capita GDP was $46 344 and the world average $17 100.[20] From these values we get as Finland's portion of the global per capita budget 17 100/46 344 = 0.369. This index defines the equitable portion of the per capita GHG budget. The results for Finland are presented in Table 3.

Table 3. GHG budgets for Finland according to the ability to pay principle

1.5 °C target	
Global equal share per capita GHG, t CO_2e	42.862 t
Finland's portion of the per capita budget	0.369
The resulting cumulative per capita budget for Finland, t CO_2e per capita	15.82 t
The resulting cumulative total budget for Finland Mt CO_2e	91.57 Mt

With this equity principle, Finland's GHG budget is naturally smaller than in the case of equality. To put into context, Finland's 2018 levels of emissions are approximately 57 Mt, so this total allocation of 92 Mt for the following three decades clearly means the need for emission removals will be higher than in the previous case. Figures 3 and show the emissions reduction pathways required for the 1.5 °C target with average net sink values of -14 Mt and -21 CO_2e/a, and what follows from these.

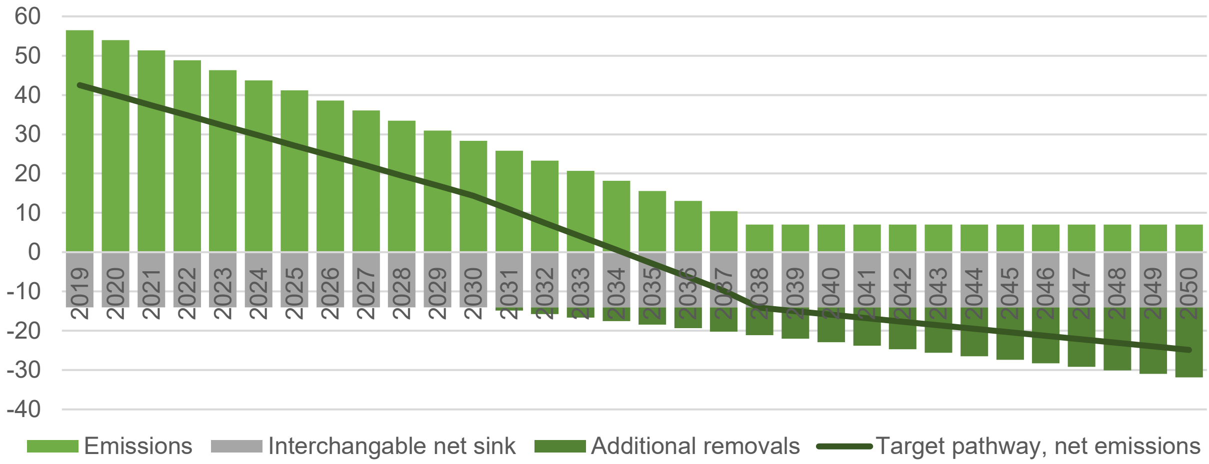


Figure 3. Emissions reduction pathway for 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -14 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided according to ability to pay. Emissions are reduced at an annual rate of 2.56 Mt leading to a 115% net reduction in 2050. Additional emissions removals are -0.9 Mt per year and -22.78 Mt in total in 2050 on top of the net sink. GHG neutrality is achieved in 2036 and emissions plateau in 2038.

[20] Source for GDP values: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD

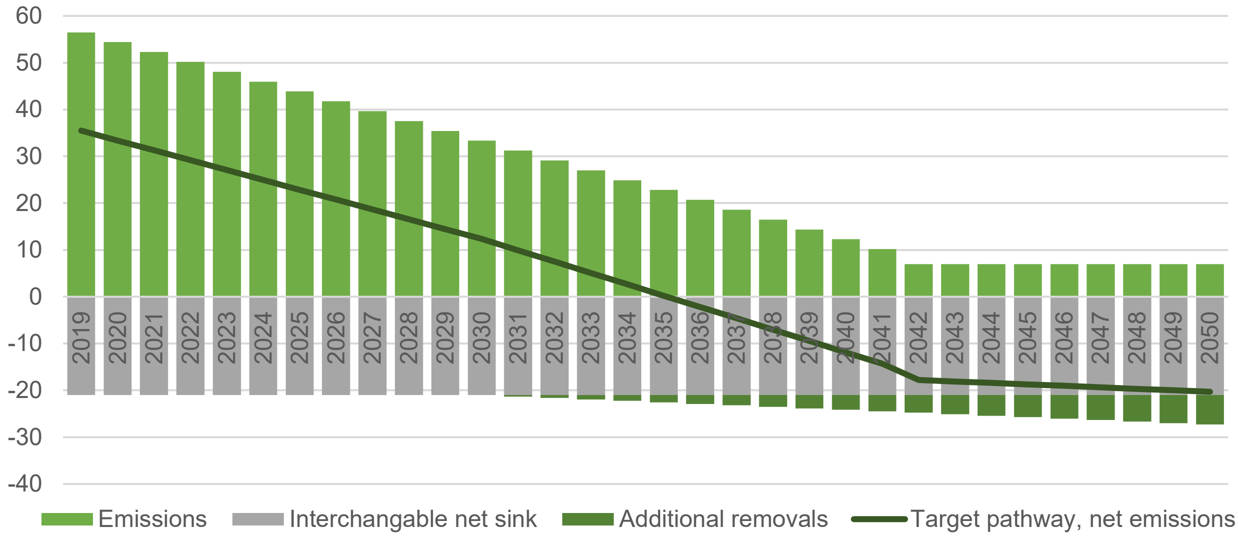


Figure 4. Emissions reduction pathway for 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -21 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided according to ability to pay. Emissions are reduced at an annual rate of 2.11 Mt leading to a 99% net reduction in 2050. Additional emissions removals are -0.32 Mt per year and -6.3 Mt in total in 2050 on top of the net sink. GHG neutrality is achieved in 2035 and emissions plateau in 2042.

According to Figure 3, Finland should be GHG neutral by 2034 and emissions plateau in 2038. In Figure 4, Finland should be GHG neutral by 2035 and emissions plateau in 2042. Figures 3 and 4 also provide a good opportunity to evaluate current 2030 targets. In 2030, emissions in Finland should reach approximately 28 to 33 million tonnes. A reduction of 19 to 24 million tonnes would be required during the next 11 years, which translates into a 54 to 60% reduction compared to 1990 levels.

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Historic responsibility: All citizens of the world have the equal right to shares in the sum of past and remaining emissions

Past emissions affect present and future global warming, since greenhouse gases remain in the atmosphere for a long time. This effect of past emissions, or levels of climate action, can be accounted for by looking at historic contributions of past and present emissions by nations. One way of calculating this type of historic responsibility is to appoint equal portions of GHG budgets for all people over a certain time period. This means that each person has the same emissions space over time, so past larger than average emissions decrease the opportunity for emitting in the future. In reverse, smaller than average emissions in the past provide for higher portions of future emissions space.

From 1990 to 2019 Finland's cumulative per capita emissions were **247 t**[21] including the land-use sector net sink, when the estimated emissions from both fossil-fuels and land-use for the world according to PBL and FAOSTAT was **147 t**[22] per capita.

Table 4 presents cumulative per capita emissions for Finland and total emissions in the case of historic responsibility from 1990 onwards. These are calculated as the sum of past per capita emissions and possible future emissions per capita according to the GHG budgets. Thus, the global per capita GHG budget for 1990 to 2050 in the case of 1.5 °C is the sum of 147 t and 43 t, which is 190 t. We can see that Finnish past per capita emissions of 247 t already exceed this by 57 t. Thus if historic responsibility is reached to 1990, Finland has already significantly exceeded its allowed allocation for remaining within 1.5 °C. This results in a negative budget for 2019-2050. To calculate the GHG budget according to historical responsibility:

Remaining GHG budget + (Global past average – national past average) = 43 t + (147 t – 247 t) = **-57 t**

Table 4. Cumulative per capita (t CO_2e) and total emissions (Mt CO_2e) for Finland with 1.5 °C and 2 °C temperature target budgets according to historic responsibility.

Global warming limit	1.5 °C
Cumulative emissions t CO_2e per capita 2019-2050	-57 t
Cumulative emissions Mt CO_2e, Finland total 2019-2050	-330 Mt

Figure 5 illustrates the linear pathway for 2019-2050 compatible with the 1.5 °C GHG budget, when historic responsibility accounts for emissions from 1990.

[21] In 2015 Finland's per capita emissions were 4.86 t, Sweden's 0.9 t, while the EU average was 7.88 t. Cumulative emissions per capita for 1990-2015 were 235.50 t for Finland, 83.38 t for Sweden and EU average at 252.98 t. The figure 247 t for Finland is from Statistics Finland's data from 1990 to 2018.

[22] Emissions from fossil fuel and industry and land-use change added up from 1990 to 2017 with emissions in 2018 assumed to be equal to 2017, divided by the expected average value of global population between 2019 and 2050.

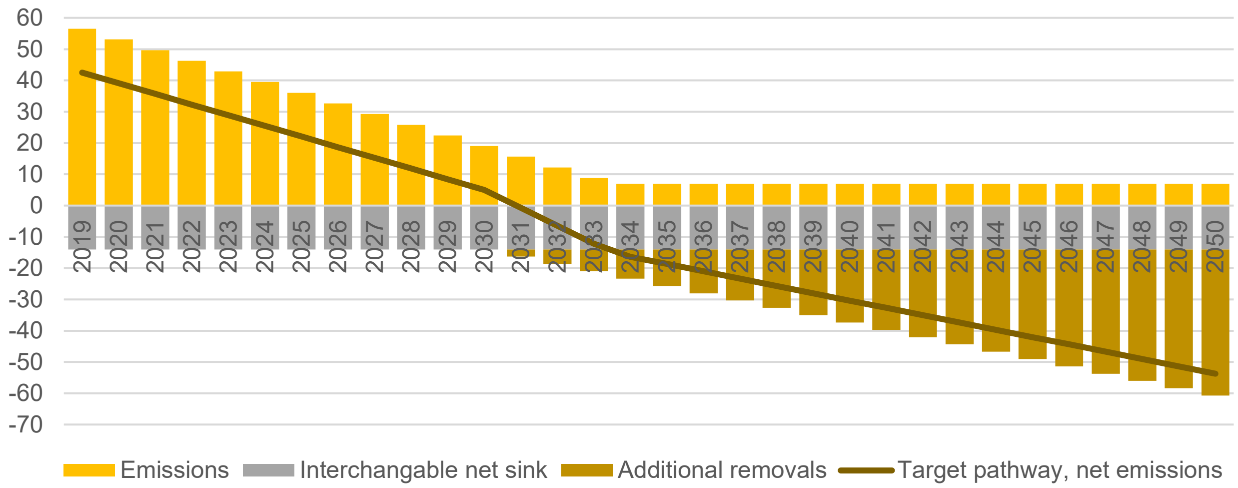

Figure 5. Emissions reduction pathway for 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -14 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided according to historic responsibility. Emissions are reduced at an annual rate of 3.41 Mt leading to a 156% net reduction in 2050. Additional emissions removals are -2.34 Mt per year and -46.75 Mt in total in 2050 on top of the net sink. GHG neutrality is achieved in 2031 and emissions plateau in 2034.

Figure 5 shows that emissions should plateau just after reaching GHG neutrality in 2030. Negative emissions are increased from 2030 on at a rate of over 2 Mt each year. The annual mitigation rate of 3.41 Mt equals to 5% of total emissions or to half on industry emissions in Finland in 2017. Additional removals in 2050 approximately equal to all current CO_2 emissions, to bring into context the level of emissions removals required. Figure 6 below demonstrates the case of historic responsibility and a -21 Mt CO_2e average net sink.

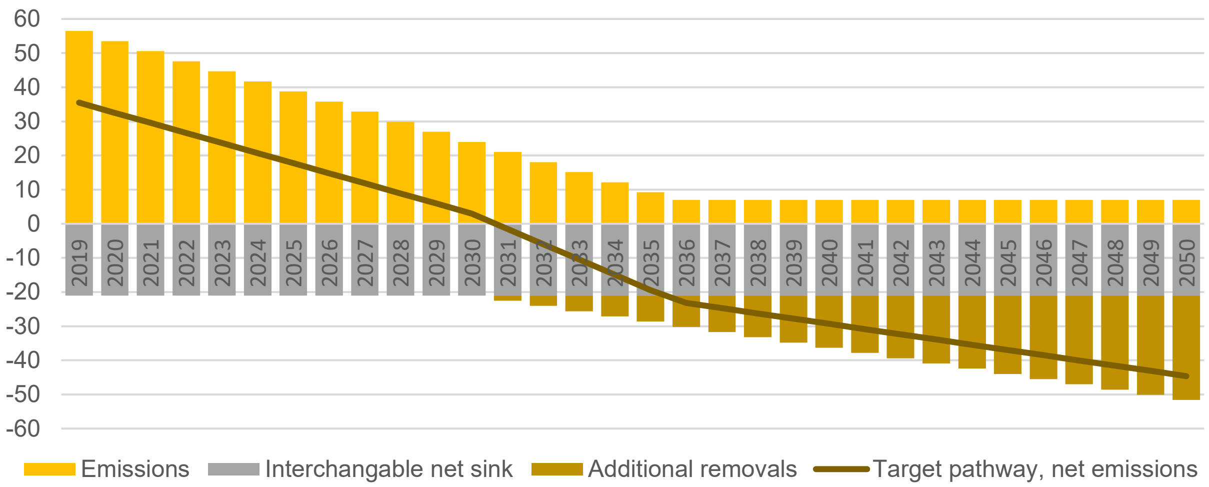

Figure 6. Emissions reduction pathway for 2019-2050, the land-use sector and negative emissions, when the average net land-use sink is assumed to be -21 Mt CO_2e/a and the remaining cumulative 1.5 °C budget is divided according to historic responsibility. Emissions are reduced at an annual rate of 2.96 Mt leading to a 133% net reduction in 2050. Additional emissions removals are -1.53 Mt per year and -30.63 Mt in total in 2050 on top of the net sink. GHG neutrality is achieved in 2030 and emissions plateau in 2035.

In the case of historic responsibility reaching to 1990, even with the larger net sink as in Figure 6, a reduction target of significantly over 100% is required for Finland to remain within the 1.5 °C budget. High levels of emissions removals in addition to a steep and speedy reduction of emissions is required. The level of emission removals may not be achievable with natural solutions, therefore the need of negative emissions technology is imperative.

Sensitivity analysis: The effects of uncertainty over the global carbon budget with variations on the interchangeable net carbon sink

Recent scientific research reveals that there is variation in the scientifically based approximations of the remaining carbon budget, as discussed previously. So, we have added to our analysis by examining a suitable range (-420 to + 380 Gt CO_2e and the 1170 Gt for 2 °C) of alternative global GHG budgets for sensitivity analysis. In this sensitivity analysis, we examine linear pathways and the elimination of all emissions for the sake of simplicity. Our goal is to see how results alter qualitatively rather than quantitatively. Therefore, the table below show the magnitude of change for Finland in different cases.

Table 5. Sensitivity analysis on required reduction targets (%) with six different global GHG budgets, five national interchangeable land-use sector net carbon sinks and selected equity principles.

Global carbon budget	Average net sink per year	Equality				Ability to pay				Historic responsibility			
		% in 2050 vs. 1990	Reduction Mt CO_2e/a	% in 2030 vs. 1990	GHG neutrality	% in 2050 vs. 1990	Reduction Mt CO_2e/a	% in 2030 vs. 1990	GHG neutrality	% in 2050 vs. 1990	Reduction Mt CO_2e/a	% in 2030 vs. 1990	GHG neutrality
0 Gt		<u>0</u> Mt CO_2e				<u>0</u> Mt CO_2e				<u>-578</u> Mt CO_2e			
	-6 Mt	162 %	3.26	71 %	2033	162 %	3.26	71 %	2033	213 %	4.42	89 %	2029
	-14 Mt	140 %	2.74	63 %	2033	140 %	2.74	63 %	2033	191 %	3.91	81 %	2029
	-20 Mt	123 %	2.36	57 %	2033	123 %	2.36	57 %	2033	174 %	3.52	75 %	2028
	-28 Mt	101 %	1.84	49 %	2033	101 %	1.84	49 %	2033	152 %	3.01	67 %	2027
	-34 Mt	84 %	1.46	43 %	2033	84 %	1.46	43 %	2033	135 %	2.62	61 %	2027
200 Gt		<u>104</u> Mt CO_2e				<u>39</u> Mt CO_2e				<u>-475</u> Mt CO_2e			
	-6 Mt	153 %	3.05	68 %	2035	159 %	3.18	70 %	2034	204 %	4.22	86 %	2030
	-14 Mt	131 %	2.53	60 %	2035	137 %	2.66	62 %	2034	182 %	3.70	78 %	2029
	-20 Mt	114 %	2.15	54 %	2035	120 %	2.28	56 %	2034	165 %	3.31	72 %	2029
	-28 Mt	92 %	1.63	46 %	2035	97 %	1.76	48 %	2034	142 %	2.80	64 %	2028
	-34 Mt	75 %	1.25	40 %	2036	81 %	1.38	42 %	2034	126 %	2.41	58 %	2027
420 Gt		<u>248</u> Mt CO_2e				<u>94</u> Mt CO_2e				<u>-330</u> Mt CO_2e			
	-6 Mt	141 %	2.76	63 %	2036	154 %	3.07	68 %	2034	191 %	3.92	81 %	2031
	-14 Mt	118 %	2.24	55 %	2037	132 %	2.55	60 %	2035	169 %	3.41	73 %	2030
	-20 Mt	101 %	1.86	49 %	2038	115 %	2.17	54 %	2035	152 %	3.02	67 %	2030
	-28 Mt	79 %	1.34	41 %	2039	93 %	1.65	46 %	2035	130 %	2.51	59 %	2029
	-34 Mt	62 %	0.95	35 %	2042	76 %	1.26	40 %	2036	113 %	2.12	53 %	2029
650 Gt		<u>399</u> Mt CO_2e				<u>152</u> Mt CO_2e				<u>-179</u> Mt CO_2e			
	-6 Mt	127 %	2.45	59 %	2039	149 %	2.95	66 %	2035	178 %	3.62	77 %	2032
	-14 Mt	105 %	1.94	51 %	2040	127 %	2.44	58 %	2035	156 %	3.10	69 %	2032
	-20 Mt	88 %	1.55	45 %	2042	110 %	2.05	52 %	2036	139 %	2.72	63 %	2031
	-28 Mt	66 %	1.04	37 %	2045	88 %	1.54	44 %	2037	117 %	2.20	55 %	2031
	-34 Mt	49 %	0.65	31 %	-	71 %	1.15	38 %	2038	100 %	1.82	49 %	2030
800 Gt		<u>498</u> Mt CO_2e				<u>189</u> Mt CO_2e				<u>-81</u> Mt CO_2e			
	-6 Mt	119 %	2.26	56 %	2040	146 %	2.88	65 %	2036	170 %	3.42	74 %	2033
	-14 Mt	96 %	1.74	48 %	2042	123 %	2.36	57 %	2036	147 %	2.91	66 %	2033
	-20 Mt	80 %	1.35	42 %	2045	107 %	1.98	51 %	2036	130 %	2.52	60 %	2032
	-28 Mt	57 %	0.84	34 %	-	84 %	1.46	43 %	2038	108 %	2.00	52 %	2032
	-34 Mt	40 %	0.45	28 %	-	67 %	1.07	37 %	2039	91 %	1.62	46 %	2032
1170 Gt		<u>741</u> Mt CO_2e				<u>282</u> Mt CO_2e				<u>162</u> Mt CO_2e			
	-6 Mt	98 %	1.77	48 %	2047	138 %	2.69	62 %	2037	148 %	2.93	66 %	2035
	-14 Mt	75 %	1.25	40 %	-	115 %	2.18	54 %	2038	126 %	2.42	58 %	2036
	-20 Mt	58 %	0.86	34 %	-	99 %	1.79	48 %	2038	109 %	2.03	52 %	2036
	-28 Mt	36 %	0.35	26 %	-	76 %	1.27	40 %	2040	87 %	1.51	44 %	2037
	-34 Mt	-	-	-	-	59 %	0.89	34 %	2043	70 %	1.13	38 %	2038

Table 5 presents the results of six different options on the global GHG budgets[23] and five variations on national average net land-use sector sinks. The range of global carbon budgets is selected to represent an uncertainty range for the 420 Gt 1.5 °C budget up to the estimated 2 °C budget of 1170 Gt. Each equity principle is applied, and the resulting reduction targets are presented in the first column of each section. Table 5 also shows when the linear target pathways would lead to GHG neutrality, the resulting intermediary 2030 target, and how large the annual mitigation rate would need to be.

From Table 5 we can clearly see that the size of the carbon sink is significant to emissions reduction targets. If the land-use sector's net interchangeable sink is -14 Mt, required emissions reduction targets only remain under 100% in the case of equality and when the GHG budget is almost triple that of the 1.5 °C budget, or equal to the 2 °C budget. In light of other equity criteria, reduction targets are always 100% or more with a -13 Mt interchangeable net sink. If the carbon sink is -13 Mt CO_2e/a, the required high levels of emission reduction lead to achieving GHG neutrality earlier than in the case of larger sinks. When climate policy targets are set according to limiting warming to 1.5 °C (e.g. carbon budgets 0 to 762 Gt), GHG neutrality is achieved before the 2040s in all cases, except in the case of equality and the largest budget. The GHG neutrality target in the Finnish Medium-Term Climate Policy Plan[24] is fulfilled in most of the cases in Table 4, but this analysis suggests a significantly earlier target for GHG neutrality is needed.

With the midpoint value for the net sinks, -20 Mt CO_2e/a, required reductions by 2050 for 1.5 °C are close to or over 100%. Annual mitigation rates range from 1 to 4 Mt CO_2e per year and GHG neutrality is reached in the 2030s. The year GHG neutrality is achieved is earlier than in the case of higher net sinks of -27 and -34 Mt in many of the -20 Mt cases, as a smaller interchangeable net sink requires higher mitigation rates for reaching set GHG budgets. Therefore, GHG neutrality is not a goal in itself, instead cumulative net emissions are the key issue for consideration.

If the net sink is increased to -34 Mt, emissions reduction targets would decrease notably, but this alternative remains improbable as the total land-use net sink is unlikely to be interchangeable with emissions and levels of future sinks remain uncertain. Based on the information in Table 4, we can calculate that a decrease in the annual net sink of 1 Mt CO_2e results in an approximately 3 percentage points tightening to the 2050 reduction target. Respectively, an increase of 1 Mt CO_2e to the annual net sink leads to a 3 percentage-point lightening of the 2050 reduction target.

In conclusion, our analysis in the previous section can be seen as strong enough for setting policy guidelines.

[23] From which estimated global emissions of 2018 have been decreased except for the 0 Gt budget, so the values we used for calculation were 0 Gt, 158 Gt, 378 Gt, 608 Gt, 758 Gt, and 1128 Gt

[24] https://www.ym.fi/en-US/The_environment/Climate_and_air/Mitigation_of_climate_change/National_climate_policy/Climate_Change_Plan_2030

Globally fair pathways of reducing net emissions – additional case studies

To see how our framework works for different types of countries, we will next take a look at Germany, with a large population and high past emissions, and Sweden, a similar country to Finland, but with lower per capita emissions and larger net sinks. First however, we will examine the EU on the whole, since the EU as a whole is a party to the Paris Agreement and mitigation efforts are shared between its member states. It is thus worth examining what kind of targets the EU should have and how this would affect member states, such as Finland, Germany and Sweden.

Long-term target for the EU according to equity and the Paris Agreement

The EU is on track for reaching its 2020 climate targets, but the long term 2050 target is not yet set beyond the ambiguous targets of 80-95% reduction and climate neutrality by 2050. So, we will use our carbon budget and equity framework to see what kind of policy guidelines would be the result and how they compare to these current targets after first addressing some of the figures used for this calculation.

The net land-use sector sink for the EU on the whole offsets significantly less of the fossil and process based emissions than in the case of Finland. Thus we presume that the EU needs to reduce its emissions 95% compared to 1990 levels, rather than 90% as in the case of Finland, due to less opportunities for offsetting emissions. This leads to EU emissions to plateau at 286 Mt, which translates into 0.55 t CO_2e per capita. The base assumptions are otherwise the same: emissions are reduced linearly until a set reduction target is met and the land-use sector sink or other negative emission are increased from 2031 onwards. Table 6 below shows the figures used for the EU calculations

Table 6. Data used for EU calculations

1990 emissions, including international aviation	5 723 Mt
2017 emissions, starting point for analysis	4 483 Mt
1990-2017 average net land-use sector sink used for base level	-294 Mt
Cumulative net emissions 1990-2018	139 987 Mt
GDP PP, 2016	42 517 $
Population average 2019-2050	524.69 mil.

The results of our calculations can be demonstrated graphically, as in the Finnish case study. We start with the case of equality and move on to ability to pay and historical responsibility. These calculations are for the EU28, including the United Kingdom.

Equality as the equity measure

In the case of equality, the emission budget is 22 489 Mt for 2019-2050. If emissions remain at 2017 levels, this would mean the budget would run out in 5 years. Thus, required mitigation rates are high. Figure 7 shows the emissions reduction pathway, which demands annual reductions of 225 Mt until 2038. From 2038 onwards emissions plateau at 286 Mt, which is equal to a 95% reduction compared to 1990. From 2031 removals are increased by -88 Mt each year. GHG neutrality is achieved in 2036 and addition removals in 2050 need to be -1 766 Mt, which when added to the 286 Mt of emissions remaining can be calculated into a 126% reduction target.

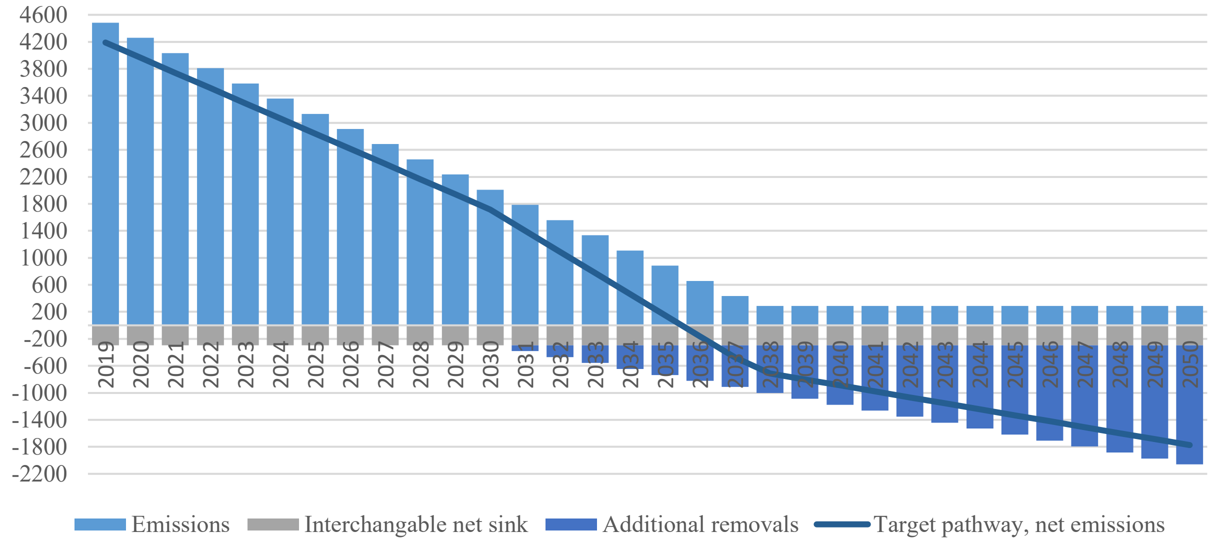

Figure 7. EU long term mitigation pathway according to the 1.5 degree target and equality as the applied equity measure.

Ability to pay as the equity measure

The ability to pay metric for the EU is the ratio of the average global PP adjusted GDP to the EU average, which is \$17 100 / \$42 517 = 0.402. This means that the emissions budget of 9 045 Mt according to ability to pay is approximately 40% of the equality budget. This budget would be used up in just over 2 years at current emission levels. Figure 8 demonstrates the necessary mitigation pathway and key target years for staying in line with ability to pay.

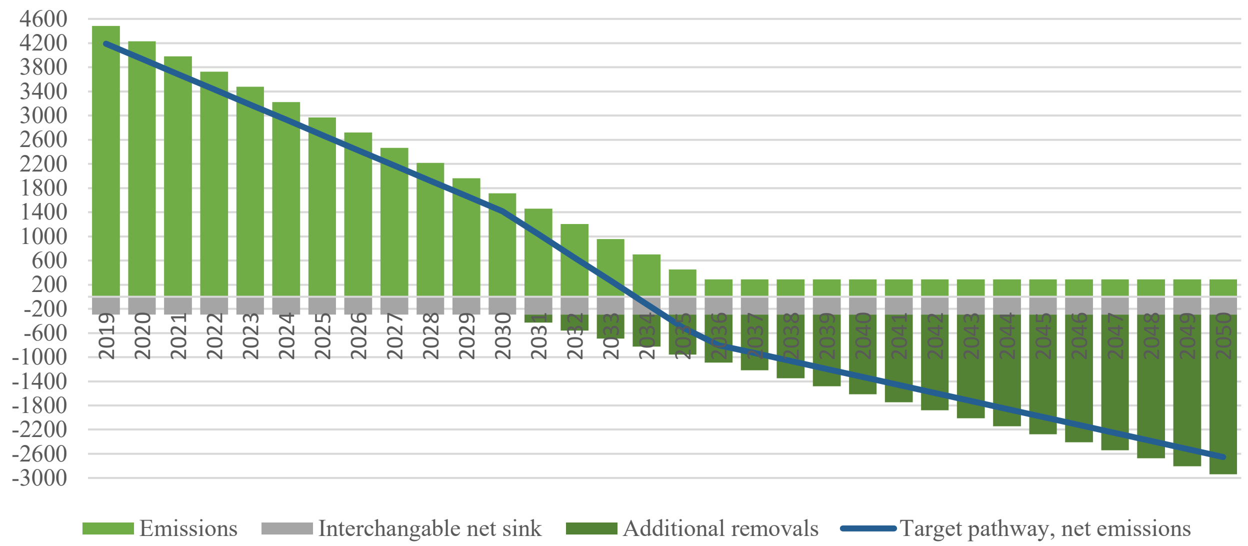

Figure 8. EU long term mitigation pathway according to the 1.5 degree target and ability to pay as the applied equity measure.

The key years for reaching this emissions budget are 2034 and 2036. In 2034 the EU should be GHG neutral, and emissions are decreased annually by 252 Mt up to 2036. Additional removals in 2050 are -2545 Mt, which can be calculated into a 141% emissions net reduction. This would mean increasing removals at a rate of -132 Mt per year from 2030 onwards.

Historic responsibility as the equity measure

To take responsibility for GHG emissions produced while in full knowledge of their effect on global warming, an emission budget including past emissions can be calculated. The EU net emissions during 1990-2018 can be calculated as 267 tCO2e, while the global average was 147 tCO2e. This means the overuse of emissions space in the past needs to be compensated for in the future, leading to an even stricter emission budget than in the previous cases. However, historical emissions especially at the global scale contain high uncertainty, so these calculations are just an example to show the direction and scale in which applying this criteria would affect climate targets of developed nations. Figure 9 shows the dramatic reduction required to fulfil this most stringent equity criterion.

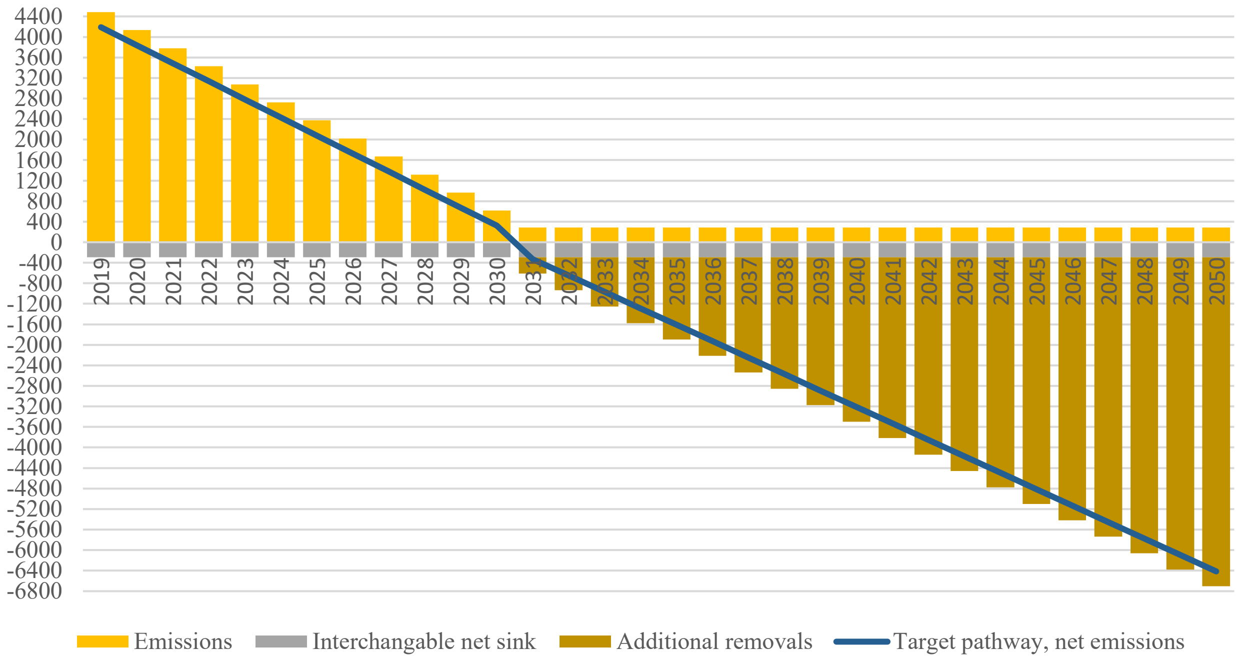

Figure 9. EU long term mitigation pathway according to the 1.5 degree target and historic responsibility from 1990 onwards as the applied equity measure.

The required emissions reduction rate would be 351 Mt per year up to 2031, after which removals would need to increase by -320 Mt each year. Additional removals would be -6397 Mt in 2050, which together with the 286 Mt of emissions left results in a reduction target of 207%. We can see how this alternative is unrealistic as a policy guideline.

Comments and conclusions

The results from the three analyses presented can be summarised into key numbers and years, which are provided in Table 7 below.

Table 7. Results from equity analyses for the EU

	Reduction target for 2050	Annual mitigation rate	Year 95% is achieved	GHG neutrality	Additional removals in 2050
Equality	126 %	225 Mt	2038	2036	-1766 Mt
Ability to pay	141 %	252 Mt	2036	2034	-2646 Mt
Historical	207 %	351 Mt	2031	2030	-6397 Mt

At a glance, it is clear the current EU targets and policies need revising. For example, according to our analysis GHG neutrality is required in the early to mid-2030s. In the light of this result, the climate neutrality target for 2050 is highly insufficient and should be brought forward. To compensate for high emissions, even with substantial mitigation rates, land-use and forest policies need to be in place to increase the sink capacity of forests and lands in the EU. However, the required emissions removals are at a speed and scale inconceivable for the EU to reach. This means significant technological sinks will be required for the EU to be in line with the Paris Agreement and the 1.5 degree target. In addition, if proactive policies and innovation are insufficient, international offsets may be required once trading rules are set.

Long-term target for Germany according to equity and the Paris Agreement

Germany is a very different type of country compared to Finland. The population of Germany is over 16 times that of Finland, which intuitively leads to a higher aggregate national GHG budget. On the other hand, even though the national net carbon sinks are at almost equal levels to Finland, in Germany the same size net sink is compensating for emissions of millions of more people. Thus, net emissions per capita in Germany are not much different from emission without the land-use net sink, unlike in Finland and as we see next, in Sweden. For Germany, this means a more urgent need to increase emission removals than in the cases of Finland and Sweden. We will next examine all three cases of equality, and how this would guide climate targets for Germany.

Equality as the equity measure

When we apply the equality per capita budget of 43 t to Germany, we get a national GHG budget of 3 602 Mt for the 2019-2050 period. Applying the same principles as in the case of the EU of emissions plateauing at 5% and the net average sink estimated at the historical average, we get the results presented in Figure 10 below.

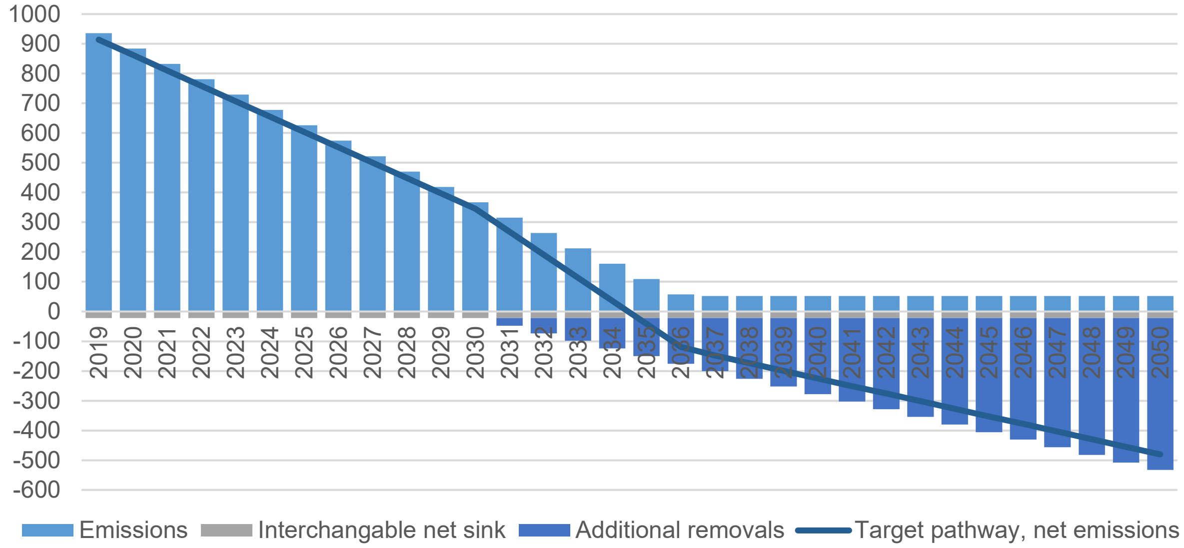

Figure 10. The long-term mitigation pathway for Germany according to the 1.5 degree target and equality as the applied equity measure

Emissions are required to reduce at an annual rate of approximately 51.7 Mt up to the year 2036, when emissions plateau at 53 Mt. GHG neutrality is reached just before that, in 2035. Unlike in the case of Finland, where the emissions removal rate was moderate, in this case we see that the annual rate of increased removals is -26 Mt. With the average net sink being -22 Mt, this means more than doubling the net sink just in the first year. In 2050 additional removals are -511 Mt. Combining the additional removals and the remaining 53 Mt of emissions, the net emissions reduction compared to 1990 is 163%.

Ability to pay as the equity measure

In the case of ability to pay for Germany, the GHG budget decreases compared to the case of equality. We can calculate the fair share as

($52 556 / $17 100) × 43t = 0.3254 × 43t = **13.95 t per capita**

Aggregated to the national levels it becomes **1 172 Mt** for the 2019-2050 period. This would be just over one year of current emissions. Figure 11 below shows the resulting reduction pathway for Germany, and the large amount of emission removals required.

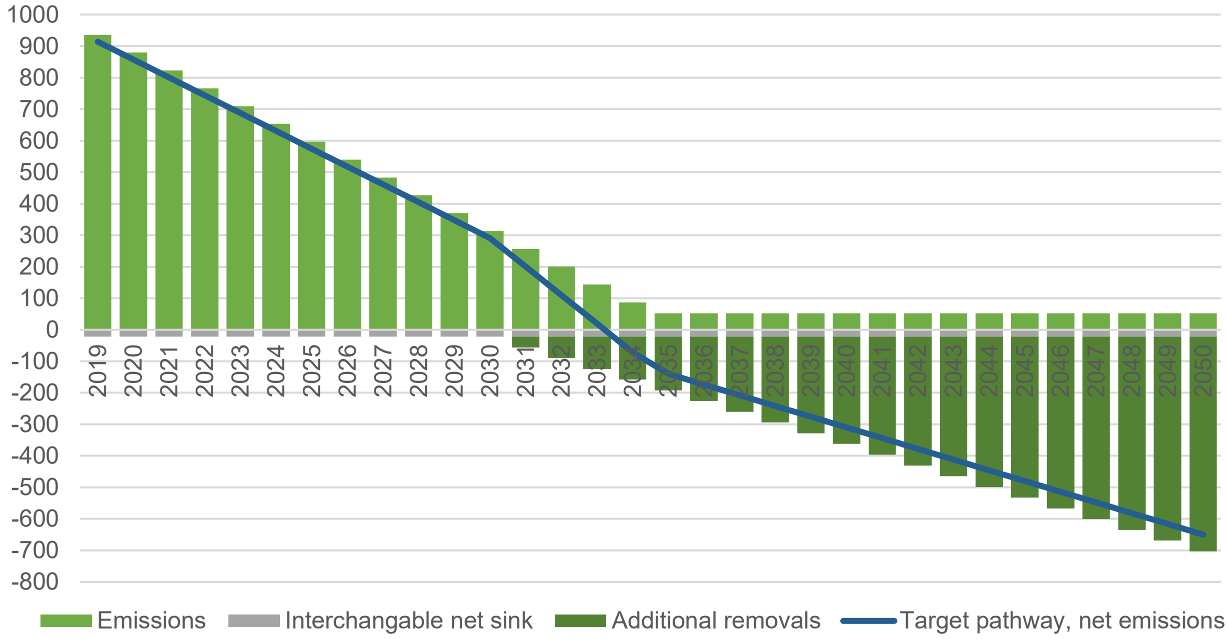

Figure 11. The long-term mitigation pathway for Germany according to the 1.5 degree target and ability to pay as the applied equity measure.

The annual mitigation rate in this case is 56.6 Mt and the rate of additional removals -34 Mt per year. GHG neutrality and the stabilisation of emissions is achieved in the early 2030s, and the net emission reduction compared to 1990 is 178%.

Historic responsibility as the equity measure

To calculate the per capita budget according to historic responsibility, we need to take a look at past emission during 1990-2018. In Germany they were **353 t per capita**. Recalling that the global average past per capita emissions were 147 t and the remaining GHG budget 43 t:

147 t -353 t + 43 t = **-163 t per capita**

Aggregated to the national levels it becomes **-13 692 Mt** for the 2019-2050 period. As Figure 12 shows, this is a completely unrealistic scenario. The 2050 net reduction would be 266% containing approximately -1 900 Mt of additional removals in that year. The mitigation rate to 2029 is 87 Mt, and emissions plateau before GHG neutrality is even reached.

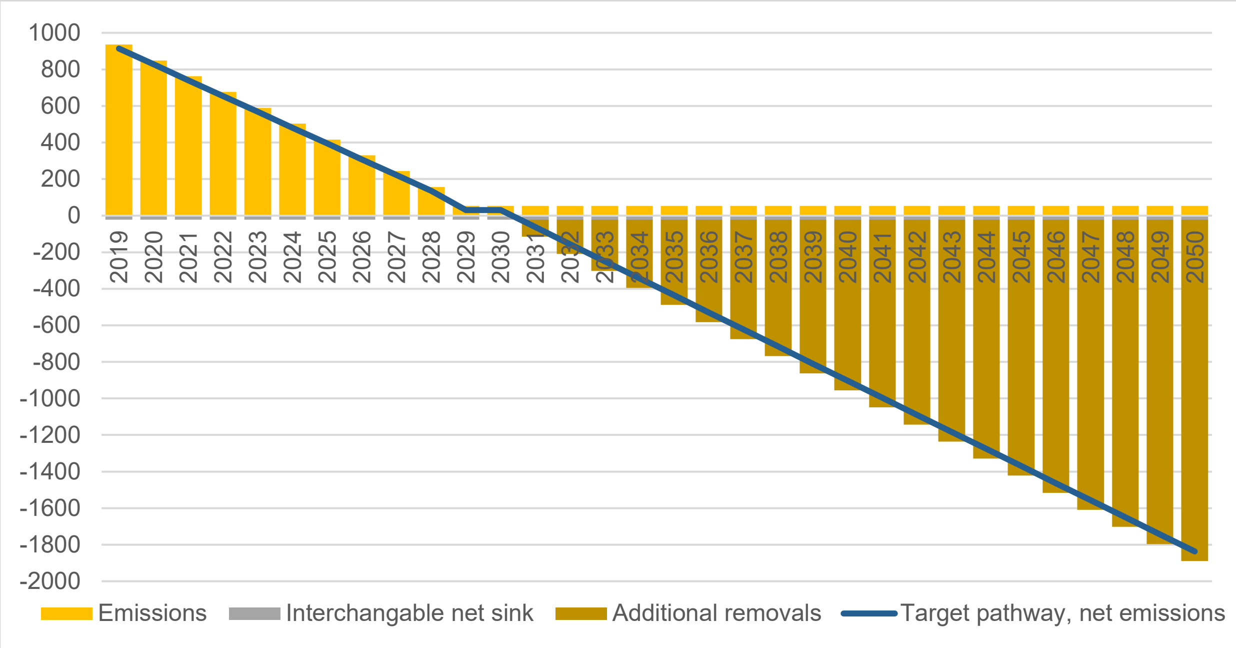

Figure 12. The long-term mitigation pathway for Germany according to the 1.5 degree target and historic responsibility as the applied equity measure.

Conclusions and comments

The results from the three analyses presented can be summarised into key numbers and years, which are provided here in Table 8.

Table 8. Results from equity analyses for Germany

	Reduction target for 2050	**Annual mitigation rate**	**Year 95% is achieved**	**GHG neutrality**	**Additional removals in 2050**
Equality	163 %	52 Mt	2036	2034	-511 Mt
Ability to pay	178 %	57 Mt	2033	2034	-680 Mt
Historical	266 %	87 Mt	2029	2030	-1 868 Mt

Due to the small per capita net sink, and large past emissions in the case of historic responsibility, the results of this analysis for Germany are unrealistic. If biological sinks are ambitiously and proactively increased alongside innovative technological emissions removals, Germany could have a chance of reaching the equality GHG budget of 3 602 Mt.

Long-term target for Sweden according to equity and the Paris Agreement

Sweden is a similar country to Finland, with cool temperatures, vast forests and high per capita GDP. However, there is a key difference in emissions – the population of Sweden is almost double to Finland's, but national emissions are at the same level. Also, the net land-use sector sink has been significantly larger. According to 2017 statistics, Sweden had one of the lowest per capita net emissions levels: an astounding 0.8 t CO_2e. The average EU per capita emissions in the same year were 8.1 t, in Finland 8.3 t and in Germany 11 t. We will nest take a look at how our equity framework works for Sweden.

Equality as the equity measure

In the case of equality, the 43 t per capita budget results in a national budget of 482 Mt. In Figure 13, we have shown what this would mean for Sweden – the average land-use sector net sink provides enough emission removals so that no emission reductions would be necessary. Because of the population of 11 million giving a GHG budget of double that of Finland, and small net emission to start with, in this case of equity Sweden would just need to keep up the good work.

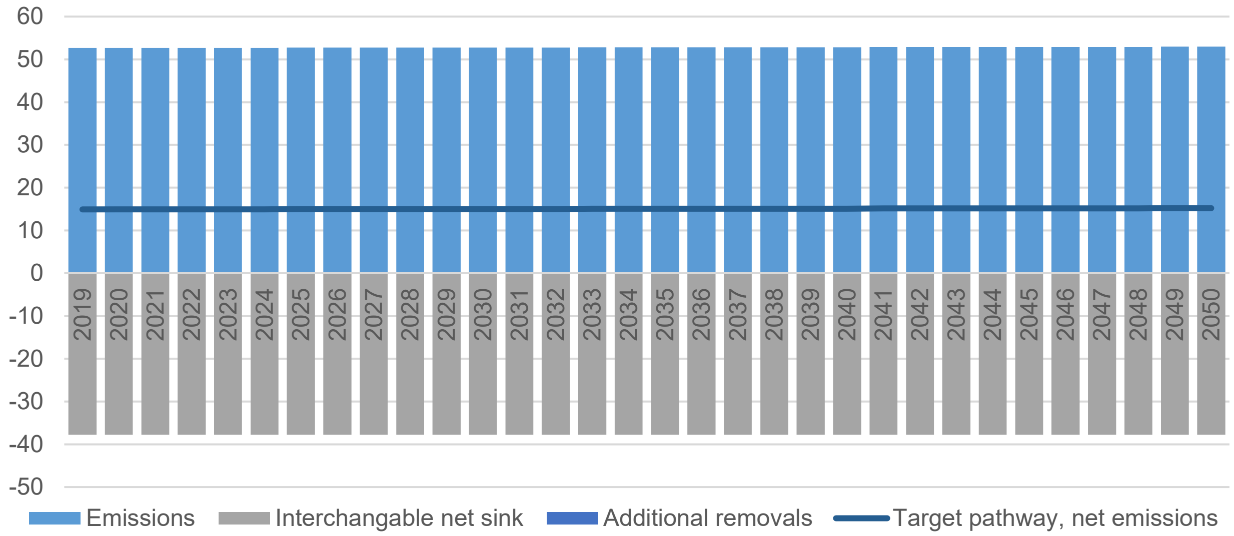

Figure 13. The long-term mitigation pathway for Sweden according to the 1.5 degree target and equality as the applied equity measure

Ability to pay as the equity measure

Moving on to ability to pay, we can assume a tightening of the GHG budget. The calculation for Sweden

$17 100 / $51 405 × 43 t = 0.3326 × 43 t = **14.3 t per capita**

This adds up to approximately 160 Mt for the whole of Sweden for the 2019 to 2050 period. Figure 14 below demonstrates what this would mean in practice.

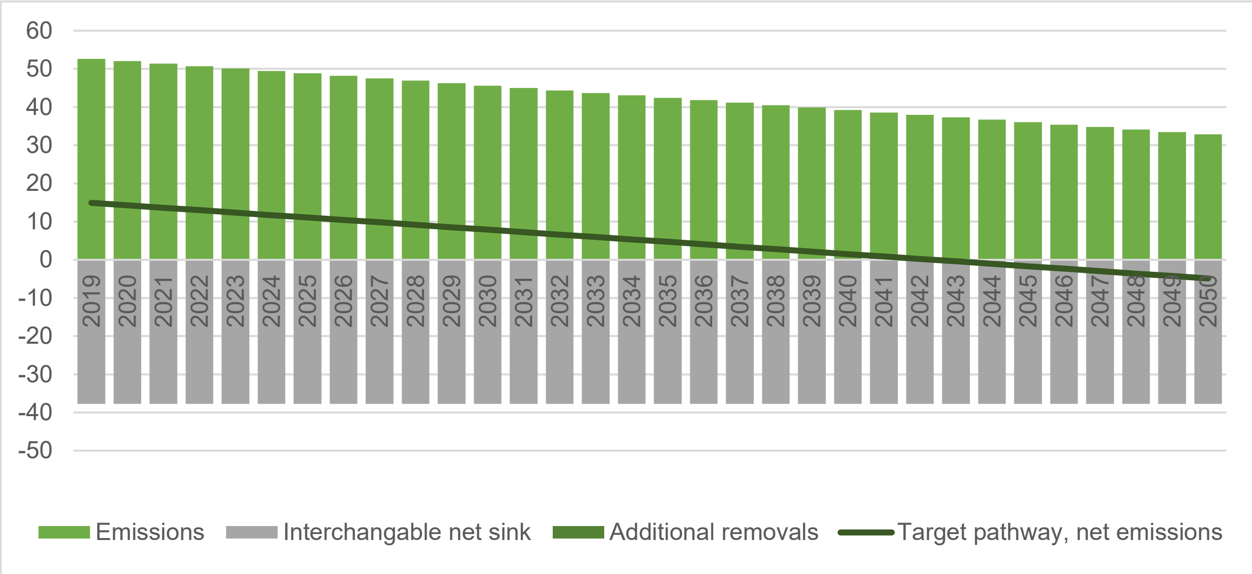

Figure 14. The long-term mitigation pathway for Sweden according to the 1.5 degree target and ability to pay as the applied equity measure.

We can see from Figure 14 that in this case Sweden must reduce emissions. GHG neutrality is achieved in 2040, but no additional removals are required. The annual mitigation rate is 0.64 Mt, but as the 2050 target is 54% compared to 1990 levels, emissions do not need to plateau at any level.

Historic responsibility as the equity measure

Conversely to the previous cases, where historic responsibility brought extraordinary reduction demands, in the case of Sweden, emissions would actually be allowed to increase. Past per capita emissions are 75 t, while the global average is 147 t. This means Sweden has had below average per capita emissions. We can see this by calculating the per capita allocation according to this equity principle:

147 t -75 t + 43 t = **114 t per capita**

We now have a per capita GHG budget, which is higher than in the two previous cases. The results of this are presented in Figure 15. Exceptionally, Sweden could increase its emissions and remain in the GHG budget, for which previous case studies seemed almost impossible.

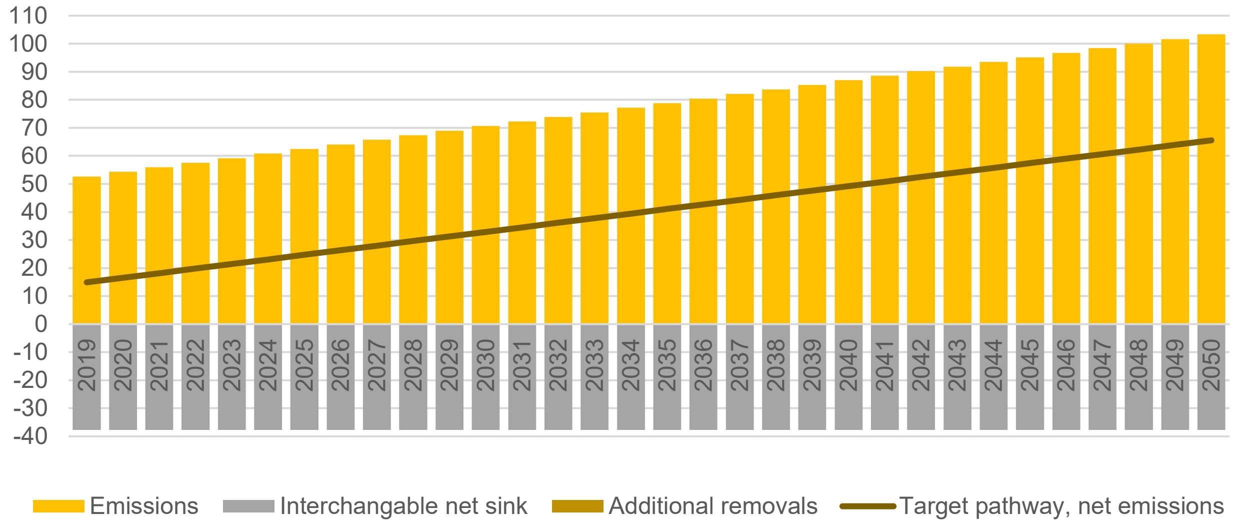

Figure 15. The long-term mitigation pathway for Sweden according to the 1.5 degree target and historic responsibility as the applied equity measure.

Conclusions and comments

The results of this equity analysis are presented in Table 9. Compared to our previous cases, these results are surprising, since only the case of ability to pay provides a reduction target compared to current levels. Such as in the case of Germany, these results are unrealistic – but for very different reasons. Looking at this analysis, we can conclude that the effect of sinks is very significant and dominates in the Swedish case study. However, as we discussed previously and also in the Appendix to this report, the land-use sector net sink has its own problems.

Table 9. Results from equity analyses for Sweden

	Reduction target for 2050	Annual mitigation rate	Year 95% is achieved	GHG neutrality	Additional removals in 2050
Equality	26 %	-	-	-	-
Ability to pay	54 %	0.64 Mt	-	2040	-
Historical	-	-	-	-	-

Conclusions

This framework analysis brings together climate science for remaining within the 1.5 C budget, the concept of equality of the UNFCCC and the Paris Agreement, and all three GHG sectors into one coherent analysis. Our goal of producing background for policy guidelines was tested with sensitivity analysis, and potential for proactive land-use sector policies were considered, as well as the reality of some emissions being impossible to mitigate.

So how do current targets compare to our equity analysis? The results for Finland are clear in all cases. Finland should be GHG neutral during the early 2030s and clearly net negative from 2040 onwards. This translates into an over 100% reduction target for 2050, meaning that the 80% minimum reduction target in the Finnish Climate Change Law is highly insufficient. Proactive policies for increasing carbon sinks are also needed to achieve the required levels of emissions removals.

In the case of the European Union, the Commission's suggested target of climate neutrality: according to our analysis, GHG neutrality in the EU should be achieved in the mid-2030s alongside emissions reduction of 95%. In the light of this result, the climate neutrality target for 2050 is highly insufficient and should be brought forward. To compensate for high emissions, even with substantial mitigation rates, land-use and forest policies need to be in place to increase the sink capacity of forests and lands in the EU.

The required emissions removals are at a speed and scale inconceivable for the EU to reach solely within its borders with biological sinks. The possibility of utilising international offsets may have to be turned to once trading rules have been agreed on internationally. However, there is a strong case to be made on focusing efforts in the field of technological sinks. The benefit of technological removals is their transparency in national GHG accounts, permanency and environmental integrity – unlike in the case of carbon stored in forests, there is no incentive to release technologically stored carbon. Technological innovation for emissions removals is difficult to predict, but knowing that there is a colossal global demand for removing CO_2 from the atmosphere, it provides a promising field for research and development.

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Appendix

How to approach land-use emissions

Our calculations provide normative criteria against which the 80% minimum reduction target written in the Finnish Climate Law and the conclusions of 80 to 95% or climate neutrality targets by the Council of Europe can be evaluated as a fair share of global effort. Early decisions on reduction targets concerned only fossil-based emissions, but sinks will be part of EU and Finnish climate policy from 2021 onwards. Thus, the land-use sector, including the net effect of forest sinks and land-use emissions, is included in these calculations. In this way, we can simultaneously examine sinks and emissions in a coherent way under given equity criteria. The calculations are based on the previously described carbon budget estimates by the IPCC, which are based on information from the IPCC 1.5°C report while taking into account emissions since, and additional calculations.

Net emissions from the land-use sector fluctuate in cycles. We cannot account for this in the following simplified calculations; instead we use an average for 2019 to 2050 for the land-use sector net sink. Due to uncertainty in the estimation models[25] and in statistical reporting[26], we take a conservative base estimate for the average net land-use sink of -21 Mt, which corresponds to the average level between 1990 and 2018. Statistics Finland reported the land-use sector net sink of 2018 decreased to -14 Mt, so the other core value for us to examine is set to be -14 Mt.

In addition to recent sink development, the reason for using -21 and -14 Mt in our analysis is based on the precautionary principle due to the uncertainty factors mentioned. If we look at how emissions and sinks are calculated to form land-use sector (forest land, grassland, cropland, wetland and settlements) net emissions or sinks):

$$LU_{sinks} + LU_{emissions} = LU$$

LU_{sinks}: Carbon sequestered in living plant biomass, in dead organic matter and soil organic matter and in harvested wood products (HWP)
$LU_{emissions}$: GHGs emitted from e.g. organic and mineral soils, nitrogen fertilisation, fire damage and controlled burning, wetland management, peat extraction and land conversion.

For example, in the National Inventory Report (NIR)[27] there are more detailed descriptions on the large range of uncertainty factors in reporting emissions and sinks, including the LULUCF sector. Based on a simplification of the information on uncertainties in the NIR, we consider a 30% uncertainty - what if sinks were 30% smaller and emissions 30% larger? For emissions the uncertainty factor is $UF_e = 1 + 0.3 = 1.3$ and for sinks $UF_s = 1 - 0.3 = 0.7$ to hold with the precautionary principle.

$$UF_s * LU_{sinks} + UF_e * LU_{emissions} = LU_{uf}$$

We can take a look at an example from 2017[28] to see how uncertainty would affect the resulting net land-use sector sinks. The reported total net sink from forestland and HWPs was -37.7 Mt. Reported total net emissions from other subsectors[29] were 10.8 Mt. Net emissions were thus

[25] Kalliokoski, T., Heinonen, T., Holder, J., Mäkelä, A., Minunno, F., Lehtonen, A., Packalen, T., Peltoniemi, M., Pukkala, T., Salminen, O. and Scehlhaas, M.J., 2019. Skenaarioanalyysi metsien kehitystä kuvaavien mallien ennusteiden yhtäläisyyksistä ja eroista. Suomen ilmastopaneelin raportti 2/2019.
[26] https://tilastokeskus.fi/til/khki/2017/khki_2017_2018-05-24_laa_001_fi.html
[27] Greenhouse gas emissions in Finland 1990 to 2017, National Inventory Report under the UNFCCC and the Kyoto Protocol, Submission to the European Union. 15 March 2019
[28] These figures are now outdated, an update to the statistical database decreased the net land-use sector net sink to -21 Mt
[29] Cropland, grassland, wetlands and settlements

$$LU = -37.7 + 10.8 = \mathbf{-26.9}$$

If we account for moderate uncertainty of 30%:

$$LU_{uf} = 0.7(-37.7) + 1.3(10.8) = \mathbf{-12.4}$$

Thus, even moderate uncertainty changes the result drastically. Accounting for emissions in LULUCF is very difficult but improving continuously. We know there is higher uncertainty in emissions from soils and lower uncertainty for plant biomass. The IPCC guidelines are to use a 51% uncertainty factor for the whole of the land-use sector, making our 2017 example to be approximately -13 Mt.[30] So, whether we consider our simplification of a moderate 30% or the IPCC 51%, we gain similar results and thus we consider useful to examine -14 and -21 Mt annual net land-use sector sinks as our primary cases.

[30] (1-0.51) * 26.9 Mt