EU Greenhouse Gas Emission Budget: Implications for EU Climate Policies

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Key messages

Estimates of the EU's greenhouse gas emission budgets for the rest of the century vary considerably but have one thing in common: The EU's emission budget is very small and shrinking rapidly. If the EU's emission budgets were based only on least-costs considerations, it would range between meagre 50 Gt (in 1.5°scenarios) or 90 Gt (in 2°C scenarios) for the period 2020 and 2100. With current annual emissions of about 4 Gt, the EU would have used up its 1.5°C budget by about 2032. In 2° scenarios, the EU budget could be exhausted by around 2042. If, instead, the budget were distributed purely on the basis of equity considerations, the EU emission budget would be much smaller. If, for example, the EU's emission budgets were based on expected EU's share in the global population in 2050, the budget for the period 2021 and 2100 would be 6.9 Gt in 2°C scenarios; the EU would have already exceeded its 1.5°C budget by 10.3Gt in 2020. It is noteworthy that the Paris Agreement (PA) requires emission reductions based on equity but does not refer to least cost considerations.

To have a reasonable chance to stay within the 1.5°C scenario emission budget, the EU should reduce its greenhouse gas emissions by 71% by 2030 and at least 95% by 2050 (compared to 1990) – if the emission budget is calculated based on least cost considerations. Reductions of this scale would require the EU to reduce emissions up to 2030 at an annual rate of 293 Mt and between 2031 and 2050 at an annual rate of 69 Mt. To stay within emission budgets that are based on the EU's share in the global population in 2050, the complete decarbonisation of the EU economy as soon as 2023 would be necessary (2°C scenarios). In either case, the current EU 2030 target of reductions of 40% (compared to 1990) is clearly insufficient. It undermines the long term reduction efforts of the EU.

Executive Summary

Around 400 ppm – this was the atmospheric greenhouse gas (GHG) concentration measured in March 2017. It is the **highest GHG concentration in the atmosphere in at least the last 800.000 years**. GHG concentrations must remain below 430 ppm CO_2eq to have a 50% chance of keeping temperature increases below 1.5 °C by 2100. For a 66% likelihood of keeping temperature increases below 2 °C, concentrations should not rise above 450 ppm. In other words, GHG concentrations can only increase by an additional 30 ppm until 2100 to retain a 50% chance of keeping temperature below 1.5°C. Concentration may only grow by an additional 50 ppm to have a 66% chance of staying below 2°C. **Staying below these atmospheric GHG concentrations requires that only a relatively small amount of GHG is emitted between now and 2100. Current estimates range between 680 Gt CO_2eq for 1.5 °C (>50% probability) and 1440 Gt CO_2eq for 2°C (>66% probability) – for the period between 2010 and 2100.**

With global greenhouse gas emissions (incl. LULUCF) of about 52 Gt in 2016, **these emission budgets are shrinking rapidly**. To stay within the budgets and to avoid the effects of uncontrolled global warming on human economies and societies, emissions have to decrease immediately and much more drastically. That means that even with a full implementation of all Nationally Determined Contributions (NDCs), emissions would well exceed the remaining emission budget for a 2°C scenario, let alone 1.5°C scenarios. Since it is difficult to conceive of such drastic emission reductions, most 2°C or 1.5°C scenarios rely on overshooting in average temperature and the active and permanent removal and storage of CO_2 from the atmosphere through Carbon Dioxide Removal technologies (CDR) – so-called **negative emissions**. Yet this is highly problematic and ultimately irresponsible: currently, no CDR technology is a safe, realistic, technologically and economically feasible option to remove very large quantities of CO_2 from the atmosphere. **Future technological innovation could change this, but it is an extremely risky bet whether the necessary technological changes will materialise within the required time spans.**

While estimates of global emission budgets are largely based on science, **the distribution of these budgets among countries is a political decision**. This decision typically involves a number of criteria, such as cost-effectiveness (mitigation costs and potential) and equity considerations (historic emissions, per capita emissions or GDP). Depending on the weighting and combination of these criteria, emissions budgets for countries differ considerably. Effort-sharing proposals largely based on equity considerations arrive at a different distribution of the remaining emission budget than proposals that are primarily based on least cost assumptions.

Depending on the criteria, the **EU's remaining emission budgets** vary considerably. Even in least-cost approaches, which unfairly favour the EU and other industrial countries, the EU emission budget between 2010 and 2100 ranges between 100 Gt in 1.5°C scenarios and 140 Gt in 2°C scenarios. Crucially, the EU has already used up 28 Gt of this budget between 2010 and 2015. Moreover, it will be reduced by an additional 22 Gt by 2020 if current emission trends continue. This leaves the EU with an emission budget of a meagre 50 Gt (in 1.5°C scenarios) or 90 Gt (in 2°C scenarios) for the for the period 2020 and 2100. Crucially, this approach leaves the rest of the world with only about 120 Gt in 1.5°C scenarios and 840 Gt in 2°C scenarios for the period 2020-2100, if current trends continue. In other words, pure least costs approaches would grant the EU about 10-29 % of the remaining global emission budget, while its population in 2050 is expected to be only 5.4% of the world's total population. With current annual emissions of about 4 Gt, the EU would have used up

its 1.5°C budget by about 2032. In 2°C scenarios, the EU budget could be exhausted by around 2042. Any ton of GHG emissions would then have to be compensated. **Crucially, equity approaches require the EU to reduce emissions drastically more than least costs approaches, requiring zero emissions as soon as 2023 – if the EU's emission budget is based on 2050 population shares.** It is noteworthy that the Paris Agreement requires emission reductions based on equity but does not refer to least cost considerations (Articles 2 and 4.1).

Against this background, the EU should reduce its GHG emissions by around roughly 71% by 2030 and at least 95% by 2050 (compared to 1990) if the emission budget is based on least cost considerations (1.5°C scenario). If, instead, the global emission budget is distributed on the basis of equity, EU reductions would have to be even higher. In either case, the current **EU 2030 target of reductions of 40% (compared to 1990) is insufficient and would undermine the long term efforts of the EU**. Reductions of roughly 71% by 2030 and 95% by 2050 would require the EU to reduce emissions at an annual rate of 292 Mt between 2021-2030 and of 69 Mt between 2031-2050.

As its contribution to these reductions, the **sectors under the Emission Trading Scheme (ETS)** would have to reduce their emissions by roughly 81% by 2030 and 100% by 2050 compared to 2005 – if the proportional distribution between ETS and non-ETS continues that the Low Carbon Economy Roadmap and the European Council adopted. This would result – as one possible option – in a linear reduction factor of 6.25% or an annual reduction of 137 Mt CO_2eq from 2021 to 2030. From 2031 to 2050, the linear reduction factor would be 1% (annual reduction of 22 Mt CO_2eq). The **non-ETS sector** would have to reduce emissions by around 44% by 2030 and of 90% by 2050. If reduction efforts are equally distributed between the ETS and non-ETS sectors, the ETS sectors would have to reduce their GHG emissions by at least 60% by 2030 and by 95% by 2050 (compared to 2005). This entails that the linear reduction factor for the period of 2021 to 2030 would increase from 2.2% to 4%; from 2031 to 2050 the linear reduction factor would amount to 1.85%. The non-ETS sector would reduce emissions by around 60% by 2030 and of 94% by 2050. Steeper reductions between 2021 and 2030 are sensible as they help to meet long term targets and avoid to lock-in carbon intensive investments.

In light of these required reductions, **the level of ambition of the ETS reform and reform of the Effort Sharing Decision (ESD) are inadequate.** The revised ETS could amount in accumulated emissions of up to 15.5 Gt in 2030 and the reformed ESD (Climate Action Regulation (CAR)) would amount in accumulated emissions of 23.4 Gt. With no flexibilities, accumulated emissions under the CAR would amount to 22.5Gt.

The EU's permissible emission budget could increase as **CO_2 removal** technologies mature and are applied. But at this point in time there are no removal technologies that are safe, sustainable, affordable and socially acceptable: And it is far from clear that such technologies can be developed in the remaining time. In optimistic scenarios the potential cumulated removals from LULUCF would amount to roughly 11.7 Gt CO_2eq from 2010 to 2050, which is way short of the needed removal of the 27 to 36 Gt CO_2eq which would be required if the EU aims to stay within a 100Gt budget and if it were to implement its 2030 targets of 40% and the 2050 aspiration of 80-95%. With the important exception of negative emissions from restoring degraded forests, the EU has no viable option to remove larger amounts of CO_2 from the atmosphere.

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1 Introduction

In 1850, the concentration of greenhouse gases (GHG) in the atmosphere was at about 280 parts per million (ppm). Since then, atmospheric GHG concentration has increased drastically, exceeding 400 ppm in 2016. In April 2017, GHG concentration reached a record-high 410 ppm. **400 ppm already marked the highest atmospheric GHG concentration that the world has seen in the last 800.000 years.**[1] Between 1850 and 1950, GHG concentrations increased only by 40 ppm, while the increase was a staggering 180 ppm between 1950 and 2016. Emissions from human activities are the main cause of this increase.[2]

Specific GHG concentrations entail certain **global warming potentials**. According to the IPCC's 5th Assessment Report of 2014, mitigation scenarios in which average global temperature remain below 1.5°C by 2100 with a 50% chance assume GHG concentrations of below 430 ppm CO_2eq in 2100, whereas scenarios in which temperature increase stay below 2°C with a 66% probability are characterised by concentrations of about 450 ppm CO_2eq.[3] There is universal agreement, most recently expressed in the Paris Agreement that the global average temperature should stay well below 2°C. That way, the worst effect of global warming on human societies can hopefully be avoided, which include increased sea level rise, increased frequency and intensity of droughts, floods and other extreme weather events, resulting in decreased food production, threatening the livelihoods of millions, and adding to already existing migratory pressures.

In other words, **GHG concentrations** can only increase by additional 30 ppm until 2100 to have a 50% likelihood of keeping temperatures below 1.5°C. GHG concentration can only grow by an additional 50 ppm to have a 66 % chance of staying below 2°C. GHG concentrations in excess of this value decrease the probability of keeping temperature increases well below 2°C. With higher concentrations, it is still possible that the temperature increase might remain below 2°C, but it becomes less and less likely. It should be stressed that these IPCC findings date from 2014: New research by the IPCC is under way and due to be published in late 2018.

With the entry into force of the **Paris Agreement** (PA), 195 countries obliged themselves to hold the increase of global average temperatures well below 2°C and to pursue efforts to hold it below 1.5°C.[4] These obligations are legally binding, but there is no political agreement whether the PA also commits Parties, collectively, to stay below a specific GHG concentration in the atmosphere, despite the fact that science helps to translate the temperature goals of the PA into GHG concentrations targets (of 430 or 450 ppm, respectively, for the 1.5° (50% chance) and 2°C targets (66% chance). The PA also obliges Parties to aim for peaking emissions as soon as possible and to pursue climate-neutrality in the second half of this century. With its entry into force

[1] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[2] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[3] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[4] As of May 2017, 147 countries have ratified, 195 countries have signed the Agreement, http://unfccc.int/paris_agreement/items/9444.php

on November 4th 2017, the PA obliges the EU – and all other Parties – to ensure that its policies and targets make an adequate contribution to achieving these objectives.

In **EU climate policy**, the single most important instruments to ensure that the EU meets its obligations are the EU Emission Trading Directive (ETS) and the successor of the Effort Sharing Decision (ESD). The EU is about to finalize reforms of these instruments. As an additional key instrument, the new Governance Regulation for the Energy Union (GR) has potentially far-reaching implications for the implementation of the PA. This regulation is currently being negotiated. In light of these reforms, but also against the background of the up-coming facilitative dialogue under the PA, the IPCC report on the implantation of the 1,5°C target under the PA, the adoption of Long Term Low Emission Strategies and up-dating of the EU's nationally determined contribution in 2020, it is necessary that the EU takes a fresh look at its policies. In light of these political processes, the EU has to answer the question whether its laws and policies are capable of making an adequate contribution to the implementation of the PA – or not.

Against this backdrop, **this paper discusses and quantifies the EU's remaining emission budget** for the remainder of the century. It defines the EU's emission budget as the EU's share of remaining global emissions; not as the quantity of emissions that the ETS and the ESD allow Member States to emit. The paper explores necessary EU reductions until 2030, 2050 and beyond – as the EU's meaningful contribution to global efforts to keep temperature increases well below 2°C. The paper also discusses the implications of the required EU reductions on its climate policies and laws and in particular for the EU ETS and the Climate Action Regulation (CAR)[5], the successor to the Effort Sharing Decision. The paper does not analyse technical details of specific EU climate instruments.

[5] In late December 2017, trilogue between Council, Parliemant and Commission agreed on the Regulation on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013.

2 Implementing the Paris Agreement – which long-term targets and emission budgets for the world?

High and rising concentrations of GHGs in the atmosphere lead to global warming.[6] These GHG concentrations are the result of the cumulative GHG emissions to the atmosphere. To protect the global climate and prevent dangerous and irreversible anthropogenic interference with it, cumulative emissions need to remain within safe limits. This effectively sets an **emission budget** that the world must not exceed.

To help identify the emission budget that is available for the EU for the rest of century and the corresponding reduction targets and trajectories, this section discusses:

- The remaining emission budgets for the world and the resulting global reduction targets and trajectories – associated with 2°C and 1.5°C.
- The potential of permanent removal of carbon from the atmosphere, i.e. whether it is possible to generate so-called negative emissions at a scale that would effectively allow increasing the carbon budget significantly.
- Implications of the size of the remaining budgets for global emissions until 2030.

Emission budgets, reduction targets and trajectories

The concentration of GHGs in the atmosphere is the direct result of the total, cumulative emissions over time. Emission budgets reflect this idea: they show the amount of GHG that can be emitted during the budget period without exceeding a certain GHG concentration. Compared to a reduction target for a given year, budgets have the advantage that they take account of total admissible emissions. Without a clearly defined trajectory, reductions targets can allow very different amounts of emissions, as shown in the following graphics:

In this (stylised) example, the cumulative emissions are measured by the integer, i.e. the shaded area. While all scenarios lead to the same reduction target at the end of the period, the cumulative emissions under the three scenarios differ markedly.

Regardless of this weakness, reduction targets and reduction trajectories must complement emission

[6] According to the IPCC today's unprecedented levels of GHG concentrations are "extremely likely to have been the dominant cause of the observed warming since the mid-20th century". IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

budgets:

- **Realistic reduction pathways crucial:** It is possible to reach a given target by emitting large amounts of GHG at the beginning of the budget period and to reduce sharply at the end of the period. Yet this approach makes it less likely that a given country will stay within its budget. Targets and trajectories give a realistic indication how to stay within a given budget.
- **Targets and trajectories part of EU law and policies:** Unlike explicit emission budgets for the EU and its Member States, targets and trajectories are already part of EU law and policies. The political discourse uses to this terminology and the actors are used to it.
- **When to go negative:** In real terms, targets and trajectories show when and to what extent countries have to start generating negative emissions – to stay within the budget.
- **Emission budget set by EU law[7]:** The ETS and the ESD set emission budgets for sectors covered and Member States. Both instruments are currently being reformed but are set to continue its budget approach. The emission budgets permitted by these instruments has to be compatible with the EU reduction target as well as the overall EU emission budget, defined by the EUs share on global emissions. In other words, the emission budget defined by EU law may not allow more emissions than determined by reduction targets and the EUs overall budget (see below, section 3.3.).

2.1 Global emission budgets and trajectories associated with 2°C and 1.5°C

The size of the world's remaining emission budget for the 21st century depends on a range of criteria. Depending on how criteria are chosen and combined, emission budgets vary considerably. Criteria include:

- **The maximum allowable temperature increase**, i.e. 2°C or 1.5°C, where a higher target corresponds to a larger emission budget;
- **The probability** of meeting the maximum temperature increase that is considered desirable or necessary. A higher probability reduces the remaining emission budget, while low probabilities increase it.
- The capacities to **generate negative emissions**, i.e. to remove CO_2 from the atmosphere and to store it safely and permanently.[8]

In its 2017 Emission Gap Report, United Nation Environment Programme (UNEP) presents the annual and total global carbon budgets that would deliver a 50 - 66% probability of staying below 1.5°C and a 66% prob-

[7] For the purpose of this paper, however, the EU's emission budget means the EU's share of remaining global emissions; not the quantity of emissions that the ETS and the ESD (and their successors) allow Member States to emit.

[8] To a large extent, the size of the remaining budget also depends on tolerating temporary overshooting of average temperatures and on the capacity of natural processes to absorb $C0_2$ from the atmosphere but these scientific questions are not part of this paper.

ability of limiting temperature increases below 2°C.[9] Accordingly, the remaining carbon budget for the period between 2011 and 2100 to stay below 1.5°C with a 50 - 66% chance is less than **600 Gt**, equivalent to around **16 years** of the current 36 Gt of global carbon emissions. For a 66% chance of keeping temperature increases below 2°C, the remaining carbon budget from 2011 to 2100 would add up to **1000 Gt**. This 1000 Gt equals roughly **28 years** at current annual emissions. With annual CO_2 emissions of about 36 Gt, these budgets shrank by 180 Gt between 2011 and 2016, leaving a carbon budget of **420 Gt (1.5°C with a 50 - 66% chance) and 820 Gt (2°C with a 66% chance) for the period 2017-2100**. With current CO_2 emissions, these budgets would be exhausted in 12 years time or 23 years time respectively. It is important to note that these figures represent a median; scenarios for remaining budgets vary significantly.[10] It is also noteworthy that the 2016 UNEP gap report estimated a much smaller carbon budget of 217 Gt (1,5°C with a 50% chance) and 553 Gt (2°C with a 66% chance) for the period 2015-2100.

Working with similar probabilities, the **IPCC sets out a range of different potential carbon budgets for the period between 1870 and 2100**.[11] For a 66% chance of keeping temperatures below 2°C, the world has a total emission budget of about 2900 Gt CO_2 (the figure circled in red). To have a 50 - 66% chance of staying below 1.5°C, total emissions should be no higher than 2250 Gt CO_2 (circled in green). In both cases, most of the budget has already been used up – for a 66% chance of staying below 1.5°C, for example, there is (as of 2011) only around 400 Gt CO_2 left (the figure circled in blue). For a 66 % chance of staying below 2°C, the remaining budget for the remainder of the century is only a median 1000 Gt (the figure circled in brown).[12]

Table 2.2 | Cumulative carbon dioxide (CO_2) emission consistent with limiting warming to less than stated temperature limits at different levels of probability, based on different lines of evidence. *{WGI 12.5.4, WGIII 6}*

Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Net anthropogenic warming [a]	<1.5°C			<2°C			<3°C		
Fraction of simulations meeting goal [b]	66%	50%	33%	66%	50%	33%	66%	50%	33%
Complex models, RCP scenarios only [c]	2250	2250	2550	2900	3000	3300	4200	4500	4850
Simple model, WGIII scenarios [d]	No data	2300 to 2350	2400 to 2950	2550 to 3150	2900 to 3200	2950 to 3800	n.a. [e]	4150 to 5750	5250 to 6000
Cumulative CO_2 emissions from 2011 in $GtCO_2$									
Complex models, RCP scenarios only [c]	400	550	850	1000	1300	1500	2400	2800	3250
Simple model, WGIII scenarios [d]	No data	550 to 600	600 to 1150	750 to 1400	1150 to 1400	1150 to 2050	n.a. [e]	2350 to 4000	3500 to 4250
Total fossil carbon available in 2011 [f]: 3670 to 7100 $GtCO_2$ (reserves) and 31300 to 50050 $GtCO_2$ (resources)									

[9] UNEP (2017): The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi

[10] According to Mercator Research Institute on Global Commons and Climate Change, for example, reaching the 2°C target with a high probability allows for total global CO2 emissions between 2017 and 2100 of a maximum of about 940 GT of CO2. Medium estimates allow for about 760 Gt, while lower scenarios permit for only about 390 Gt. According to another recent research paper, the remaining budget for a 66% probability of limiting warming to 1.5C in 2100 at 880 – 915bn tonnes of CO2 (from the start of 2015) - Richard Millar et al: Emission budgets and pathways consistent with limiting warming to 1.5 °C, Nature Geoscience (2017), and Richard Millar: Why the 1.5C warming limit is not yet a geophysical impossibility https://www.carbonbrief.org/guest-post-why-the-one-point-five-warming-limit-is-not-yet-a-geophysical-impossibility.

[11] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[12] Annex 1 contains required reductions in percentage points for 2050 and 2100 as estimated by IPCC AR 5.

The reports by UNEP and the IPCC reflect the 2°C target adopted at COP 16 in 2010 (Cancun). **They do not take account of the more ambitious targets of "well below 2°C" established by the PA in 2015.** To take account of the new framework of the PA, additional research by the IPCC is under way and due to be published in late 2018. But already today there is analysis of scenarios that that keep temperature increases well below 2°C or even below 1,5°C. According to **Anderson** et al. (2017) global carbon budgets compatible with the objectives of the PA range between 490 to 640 Gt CO_2eq for the period 2017 – 2100.[13] Other studies carried out by **Climate Analytics** work inter alia with a 90-100% probability, which is an important expansion of UNEP's and IPCC's report because these reports are based on considerably lower (or dangerous) probabilities of only 66% or a mere 50%. According to this analysis, a very likely chance of meeting the 2°C target would require that GHG emissions are net zero by 2065 and negative thereafter. For a very likely chance of meeting the 2°C target, global CO_2 emissions would need to be zero as early as 2045, and be negative thereafter.[14]

Climate Analytics use among other a so-called Paris Agreement 1.5°C Scenario and a so-called Cancun Agreements 2°C Scenario.[15] In the Paris Agreement 1.5°C Scenario, the global carbon budget for the period 2010-2100 is 450 GtCO_2. In the Cancun Agreements 2°C Scenario, it is 950 GtCO_2. With a CO_2 share of about 66% in overall GHG emissions, these carbon budgets result in **global GHG budgets of about 680 Gt for 1.5°C and 1440 Gt for 2°C**. We use these Paris Agreement 1.5°C Scenario and the Cancun Agreements 2°C Scenario as the basis for our calculations because they do not only focus on global budgets, but also provide numbers on EU least-cost emission budgets.

[13] Anderson et al. (2017): Natural gas and climate change http://www.foeeurope.org/sites/default/files/extractive_industries/2017/natural_gas_and_climate_change_anderson_broderick_october2017.pdf

[14] Niklas Höhne, Michel den Elzen, Annemiek Admiraal: Analysis beyond IPCC AR5: Net Phase Out of Global and Regional Greenhouse Gas Emissions and Reduction Implications for 2030 and 2050 http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-215-act-factsheet-net-phase-out-of-global-and-regional-ghg-emissions-and-reduction-implications-for-2030-and-2050.pdf

[15] Both scenarios were developed by the Institute of Applied Systems Analysis (IIASA), using their Integrated Assessment Model (IAM) MESSAGE. MESAGE, like other IAMs, provides scenarios consistent with limiting global warming below 2°C and 1.5°C by calculating the optimal emission pathway over time. For both scenarios, negative CO_2 emissions play a crucial role in the second half of the 21st century. For more information on the carbon budgets see: Climate Analytics (2016) What does the Paris Climate Agreement mean for Finland and the European Union? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf. For more information on the MESSAGE model see: Rogelj et al. (2015) Energy system transformations for limiting end-of-century warming to below 1.5°C , or http://www.iiasa.ac.at/web/home/research/modelsData/MESSAGE/MESSAGE.en.html

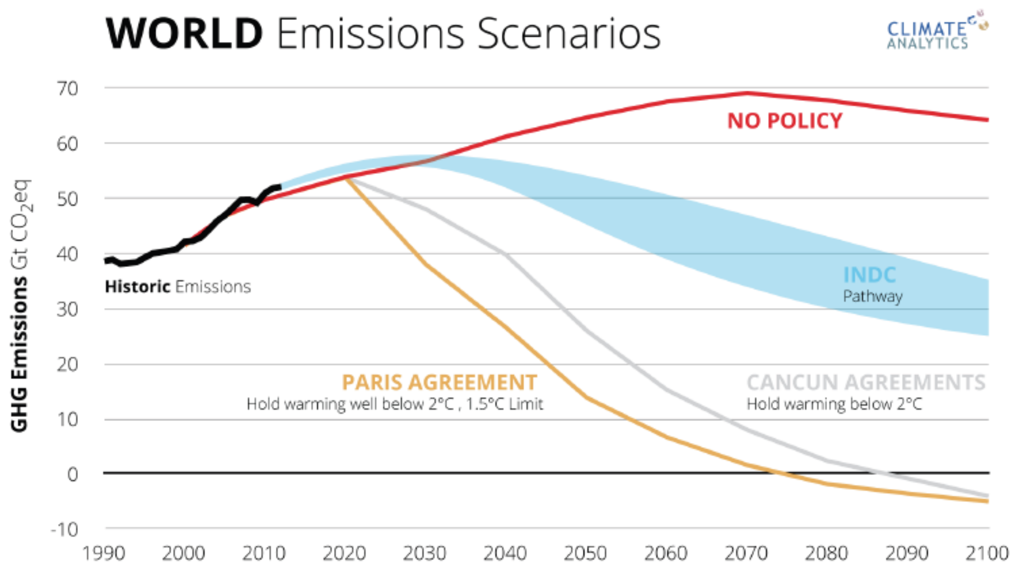

Figure 2: Global policy-relevant scenario cases assessed in this report compared to estimated global INDC pathway (Climate Action Tracker)

2.2 Negative emissions and overshooting

Most 2°C and all 1.5°C scenarios involve **negative emissions** in the second half of the century.[16] This means that these scenarios assume the active and permanent removal and storage of CO_2 from the atmosphere through Carbon Dioxide Removal technologies (CDR). Furthermore, mitigation scenarios reaching about 450 ppm CO_2eq in 2100 typically involve a temporary overshoot of atmospheric concentrations, as do many scenarios reaching about 500 ppm to about 550 ppm CO_2eq in 2100.[17]

There are a number of different CDR technologies, but all of them face a number of **significant challenges**. Technological innovation could help to address these in the future, but at this point in time no CDR technology is a realistic option to remove very large quantities of CO_2 from the atmosphere without significant environmental risks and at economically viable costs:

- **Volume of required removals:** Many 1.5°C or 2°C scenarios assume negative emissions as high as 1,020 Gt CO_2, while the median (2010-2100) removal is 810 GtCO_2.[18] For a sense of proportion: in 2015, the global annual crude oil production came to 4 Gt of oil equivalent. Just in terms of weight, 810 Gt of CO_2 would be as heavy as the oil that would be produced over the next more than 200 years (*ceteris paribus*). This gives a sense of the scale of infrastructure that would be necessary to handle – and to safely store such amounts of CO_2. Even more optimistic scenarios that are based on

[16] UNEP (2017): The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi

[17] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[18] UNEP (2017): The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi

lower negative emissions still require removals of about 480 Gt CO_2,[19] equivalent to over 13 years' worth of current annual emissions. Existing technologies and infrastructure are nowhere near capable of handling negative emission of this magnitude.

- **Limited storage capacities:** CDRs depend on accessible and economically affordable storage sites for permanent and safe storage of CO_2. Local communities have to accept storage sites. This limits storage capacity further.

More specifcally, **each CDR technology has to overcome its specific challgenges**:

- **Bioenergy with carbon capture and storage (BECCS):** BECCS technologies are CDR technologies that have gained some attention. These technologies burn biomass or biogas in stationary installations that can be equipped with CCS. Estimates show that by 2050, BECCS technologies could sequester 10 billion metric tons of industrial CO2 emissions annually worldwide.[20] But to achieve removals of this scale, BECCS would have to take up vast amounts of land. There is also considerable difference in cost estimates which vary from around 60 to 250 USD / tCO2.[21]
- **Direct Air Capture:** Direct Air Capture (DAC) is another option to remove CO_2 from the atmosphere, but currently this technology is expensive and energy intensive.[22] Estimates range from $400 to $1,000 per tonne of CO_2.[23] Capturing 12 billion tonnes of CO_2 equivalent per year or third of annual global emissions would require 156 exajoules of energy, which is more than a quarter of total annual global energy demand.[24] In short, DAC is still a premature technology but it is possible that innovation will make DAC an important tool to help keep temperature increases well below 2°C
- **Enhanced weathering:** Enhanced weathering, another CDR technology, uses the dissolution of natural or artificially created minerals to remove CO_2 from the atmosphere. According to estimates, enhanced weathering could sequester up to 3.7 Gt of CO_{2e}eq per year globally, but at very high costs.[25]

In light of the difficulties of today's CDR technologies, another option is gaining momentum: **restoring degraded forests**. According to some estimates, the restoration of degraded forests could remove up to 330 Gt

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[19] Sivan Kartha, Kate Dooley (2016): The risks of relying on tomorrow's 'negative emissions' to guide today's mitigation action, https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2016-08-Negative-emissions.pdf

[20] Sivan Kartha, Kate Dooley (2016): The risks of relying on tomorrow's 'negative emissions' to guide today's mitigation action, https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2016-08-Negative-emissions.pdf http://gcep.stanford.edu/pdfs/rfpp/Report%20from%20GCEP%20Workshop%20on%20Energy%20Supply%20with%20Negative%20Emissions.pdf and http://news.stanford.edu/pr/2013/pr-reducing-carbon-dioxide-021513.html

[21] IPCC (2014): Climate Change 2014: Mitigation of Climate Change

[22] Carbon Brief (2016): 10 ways negative emission could slow climate change: http://www.carbonbrief.org/explainer-10-ways-negative-emissions-could-slow-climate-change

[23] Simon, Evans (2016): Swiss company hoping to capture 1% of global CO2 emissions by 2025, https://www.carbonbrief.org/swiss-company-hoping-capture-1-global-co2-emissions-2025

[24] Smith, Pete et. al. (2016): Biophysical and economic limits to negative CO2 emissions, Nature Climate Change 6, 42–50

[25] Carbon Brief (2016): 10 ways negative emission could slow climate change: http://www.carbonbrief.org/explainer-10-ways-negative-emissions-could-slow-climate-change

from the atmosphere in the course of the century.[26] If done right, restoring forests would not only avoid the many problems that mar current CDR technologies, but it would also have important co-benefits for biodiversity, water quality and soil protection. With its theoretical removal capacity of up to 330 Gt, however, restoring degraded forests alone will probably not be able to keep GHG concentrations below 450 ppm over the course of the century.

2.3 Implication for global emissions until 2030

At current annual emission levels, the global CO_2 budget for limiting warming to below 2°C with at least 66% probability will be almost entirely depleted by 2030. The budgets that would preserve at least a 50 - 66% change of limiting warming to below 1.5°C would already be well exceeded by then.[27] In its 2017 Emissions Gap Report, UNEP analyzes the gap between 2030 emission levels and those consistent with least-cost pathways to the 2°C and 1.5°C goals respectively. The report highlights that even with full implementation of both unconditional and conditional NDCs for 2030; the gap to staying below an temperature increase of 2°C is 11 – 13.5 Gt CO_2eq. For the 1.5°C, it is 16 – 19 Gt CO_2eq. The global scenarios assessed by UNEP show further, that if least-cost trajectories are followed, greenhouse gas emissions should not exceed 42 Gt CO_2eq in 2030, if a chance of at least 66% is to be attained for reaching the 2°C target. Earlier UNEP reports argued that 2030 global emissions should not exceed 37 Gt CO_2eq - for a 50% chance of keeping temperature increases below 1.5°C. For securing a chance of at least 66% for keeping the global temperature rise below 1.5°C, new studies indicate that least-cost pathways starting from 2020 indicate a much lower 2030 level of around 24 Gt CO_2eq. This would imply significantly faster and deeper reductions than previously anticipated.[28]

These estimates show that even with the full implementation of the NDCs by 2030, the world would significantly exceed its CO_2 budget for keeping temperature increases below 1.5°, and it would almost have exhausted its all-time budget for staying below 2°C. In consequence, **emissions must decline far more steeply until 2030 than the level implied by the nationally determined contributions (NDC)**.[29]

In conclusion, the emission trajectories until 2030 determine whether it will even be possible, let alone economically feasible, to keep concentrations at 430 to about 450 ppm CO_2eq by 2100. Only immediate and more drastic emission reductions will maintain a realistic chance to hold average temperature increases well below 2°C. Slow emission reductions in the next decade drastically increase the need for emission removals, which is a risky bet on an uncertain development and deployment of new break-through CDR technologies (see above).

[26] Sivan Kartha, Kate Dooley (2016): The risks of relying on tomorrow's 'negative emissions' to guide today's mitigation action, https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2016-08-Negative-emissions.pdf

[27] UNEP (2016): The Emissions Gap Report 2016. United Nations Environment Programme (UNEP), Nairobi

[28] UNEP (2017): The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi

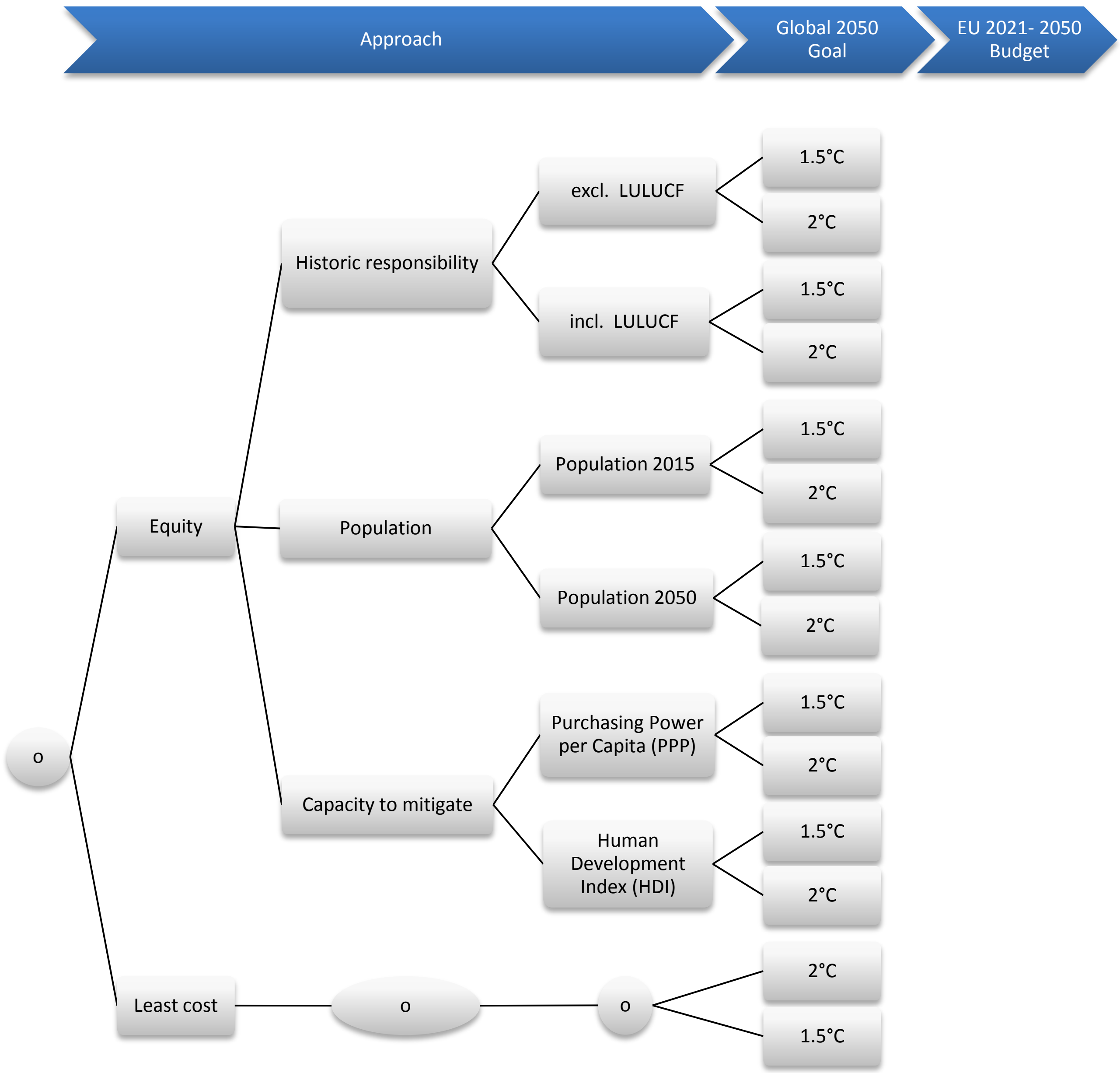
[29] IPCC AR 5 also shows that emissions until 2030 have strong implications for keeping concentrations to about 450 – 500 ppm CO_2eq by 2100 but note that these estimates refer to 450-500 ppm scenarios, not 430-450 ppm).

3 EU emission budgets, trajectories and long-term targets

The remaining global emission budgets and the required global reductions do not answer the **effort sharing question**: which countries have to reduce by which amount by when? How should the emission budgets be distributed among countries? What is the share for the EU? There are various criteria that help inform the distribution of the remaining emission budgets between the EU and the rest of the world. In particular, these include **cost-effectiveness (global mitigation costs) and equity considerations (historic emissions, national capacities, per capita emissions or GDP)**.

Depending on the choice of criteria, or their weighting and combination, emission budgets for countries differ considerably. Effort-sharing proposals largely based on equity considerations distribute the remaining emission budget completely different than proposals that are primarily based least cost considerations.[30] Emission budgets also differ drastically depending on whether they are intended to contribute to 1,5°C or 2°C scenarios. The following graphic provides an overview of possible criteria and their combination:

[30] For example, according to an exemplary calculation by Climate Analytics, Finland would have to reduce its emission by 130% in 2050 according to the least-cost models; required emission reductions in Finland would be even higher in line with equity models, where Finland would have to reduce emissions by 150% http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf



It is important to understand, however, that none of these criteria constitute an automatism which is intended or even able to determine in an objective manner the EU's emission budget for the time until 2050 and beyond. There are no scientific criteria or no one formula for the distribution of the required reductions among countries. Allocating of the world's remaining emission budget among countries – in any form – is a **political decision that must be informed by science and should be based on the criteria above.** This political decision has to weigh the specific advantages and disadvantages of these criteria and should take account of equity and least cost considerations.

3.1 What are the necessary reductions for the EU?

Since the budget distribution is an inherently political decision, it is not surprising that neither the IPCC nor UNEP identify an emission budget for the EU (or for any other country). Yet the IPCC does present a table for

emission reduction scenarios by OECD countries (and other country groups). Accordingly, GHG emissions from OECD countries would have to be reduced by 32% (between 23% and 40%) in 2030 in 430-550 ppm scenarios. Emissions would need to decline by 14% in 530-650 ppm scenarios.

		OECD-1990	ASIA	LAM	MAF	EIT
Peak year of emissions	430–530 ppm CO_2eq	2010 (2010/2010)	2020 (2015/2030)	2015 (2010/2020)	2020 (2010/2030)	2014 (2010/2015)
Peak year of emissions	530–650 ppm CO_2eq	2014 (2010/2015)	2030 (2030/2030)	2020 (2010/2030)	2034 (2020/2040)	2016 (2010/2020)
2030 Emission reductions w.r.t. 2010	430–530 ppm CO_2eq	32 % (23/40 %)	−1 % (−15/14 %)	35 % (16–59 %)	8 % (−7/18 %)	32 % (18/40 %)
2030 Emission reductions w.r.t. 2010	530–650 ppm CO_2eq	14 % (6/21 %)	−34 % (−43/−26 %)	9 % (−17/41 %)	−22 % (−41/−12 %)	8 % (−5/16 %)

Concerning required reductions by 2050, OECD countries would reduce their emissions by 90-100% in 2050 in 430 ppm scenarios and by 80-95% in 450 ppm scenarios:

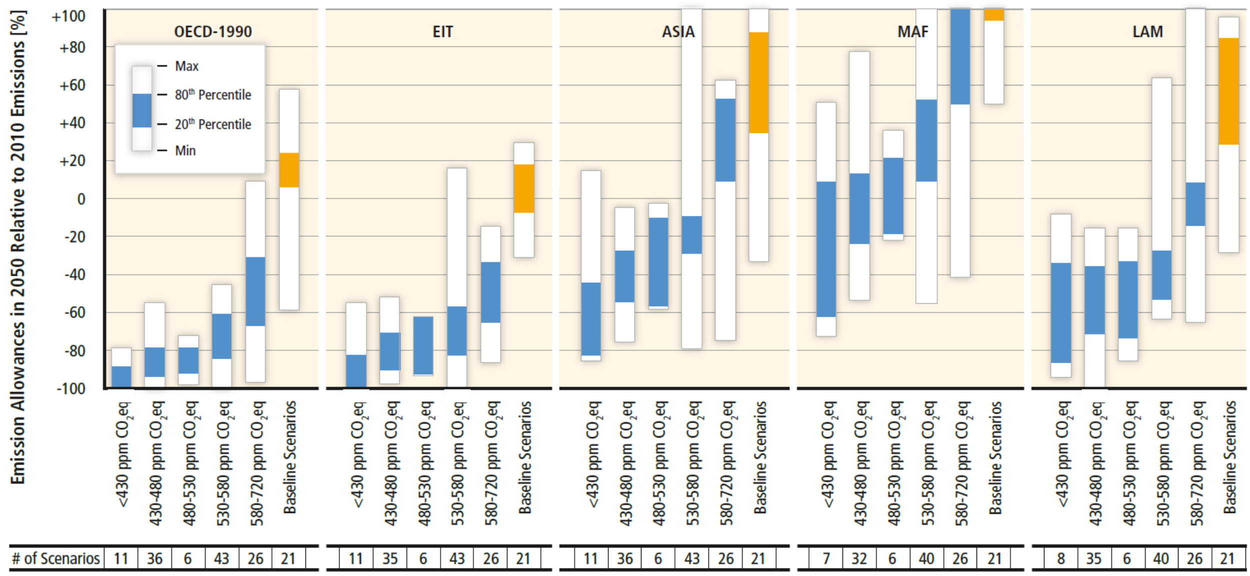


Figure 6.29 | Emission allowances in 2050 relative to 2010 emissions for different 2100 CO_2eq concentration ranges by all effort-sharing categories except 'equal marginal abatement costs'. For comparison in orange: baseline scenarios. Source: Adapted from Höhne et al. (2014). Studies were placed in the CO_2eq concentration ranges based on the level that the studies themselves indicate. The pathways of the studies were compared with the characteristics of the ranges, but concentration levels were not recalculated.

Unlike the IPCC, **other analysts calculated necessary EU reductions for 2030 and 2050 for the period 2010 to 2100**. Depending on the approaches, estimates yield very different results: According to estimates by the Öko Institut, the EU would have to reduce its emissions by 2050 between a staggering range of 70% (target based on grandfathering 2°C with overshooting and 66% probability) and 180% (target based on historic responsibility, 1.5 °C, no overshooting, and 50% probability).[31] According to Climate Analytics, the EU would need to reduce greenhouse gas emissions by about 90% until 2050 and 50% by 2030 – if least-cost approaches apply.[32] If equity approaches apply, the EU would have to reduce emissions by 75% by 2030 and by 160% for

[31] Jakob Graichen (2016): Targets for the non-ETS sectors in 2040 and 2050: https://www.oeko.de/fileadmin/oekodoc/Targets-for-the-non-ETS-sectors-in-2040-and-2050.pdf

[32] Climate analytics (2016): What does the Paris Agreement mean for Finland and the EU? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf

2050 (compared to 1990).[33] Importantly, these estimates have to be interpreted carefully because of large uncertainties, on-going research and great differences in models.[34] They give, however, a solid indication of the scale of required reductions.

3.2 What is the EU's remaining GHG budget for rest of the century?

In least-cost approaches, the median EU carbon budget between 2010 and 2100 would be 83 Gt in the 1.5°C scenario and 116 Gt in the 2°C scenario.[35] As CO_2 has a share of roughly 80% in EU overall GHG emissions, this carbon budget results in an EU GHG budget of about 100 Gt for 1.5°C and 140 Gt for 2°C. The EU emission budget would be drastically smaller if it were calculated on population shares in 2050 – one of the central equity considerations – leaving the EU only a meagre 56.9 Gt in the 2°C budget. The 1.5°C EU budget based on 2050 population shares would be 39.7 Gt.

Regardless of the method chosen to split up the global budget, the EU already used up 28 Gt CO_2eq between 2010 and 2015 – roughly one fourth of its emission budget for the entire century (1.5°C scenario and least-cost considerations). Emissions from 2015-2020 are projected to amount to 22 Gt CO_2eq if trends from 1990 to 2015 continue.[36] This means that by 2020 the EU will have emitted 50 Gt or consumed roughly 50% of its 1.5°C least-cost GHG budget. In other words – based on the EU GHG budget – only **50 Gt CO_2eq (in case of the 1.5°C scenario) would be available for the period 2020 to 2100. In case of a 2°C scenario, the EU would have used 36% of its remaining budget before 2020, allowing the EU to emit about 90 Gt for the rest of century.** The EU 1.5°C equity budget based on 2050 population shares would already be well depleted and in the 2°C equity budget based on 2050 population shares, less than 7 Gt CO_2eq would be left. These figures must be treated with care, but they give an indication of how small the quickly shrinking EU emission budget is.

Defining the EU emission budget is ultimately a political decision (as discussed above) but it is likely that the emission budget will be defined on the basis of a combination of least-cost and equity considerations. A pure least-cost approach is politically unviable because it unfairly favours the EU and other industrialised nations to the detriment of the rest of the world. It would give the EU 29.4% (Paris Agreement 1.5°C scenario) or 9.7% (Cancun Agreement 2°C scenario) of the global budget from 2021.

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[33] Climate analytics (2016): What does the Paris Agreement mean for Finland and the EU? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf

[34] There als also other approaches for determining the EU carbon budget. Anderson et al. for example determine the non-OECD countries' share of the global budget by aksing for the most ambitious peak date non-OECD nations could achieve and what they could subsequently deliver in terms of mitigation rates. By taking this approach, the non-OECD regions' cumulative emissions range from 502 GtCO2 to 620 GtCo2, leaving OECD countries with only 20 – 140 GtCO2 from 2017-2100. Depending on the subsequent approach of splitting up the OECD budget, the mid-value EU carbon budget ranges from 23 to 32 Gt.To stay within these budgets, the EU would have to mitigate at an annual rate of minimum of 12%.

[35] Climate analytics (2016): What does the Paris Agreement mean for Finland and the EU? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf; Climate Analytics did not estimate the EU carbon budgets based on equity considerations.

[36] The trend over the period 1990-2015 shows an average reduction of 51 Mt CO_2eq/yr.

3.3 Has the EU adopted the necessary reduction targets?

The EU has adopted a number of **decisions relevant for its emission budget and the related emissions reductions** until 2030, 2050 and / or the second half of the century:

- **Conclusions of the European Council of 2009:** In 2009, the European Council adopted the aspirational long-term target of 80-95% GHG emissions reduction by 2050 (compared to 1990 levels). The European Council adopted this aspirational target six years before the PA was ratified, i.e. at a time when the EU had not accepted the obligations to contribute to hold temperature increases well below 2°C and to pursue efforts to keep temperature increases below 1.5°C.
- **Conclusions of the European Council of 2014:** In October 2014, the European Council adopted a domestic GHG reduction target of at least 40% by 2030 compared to 1990 levels.[37] These conclusions did not address the period beyond 2030.

The table below compares these decisions with necessary reductions compared to the 1990 base year:

[37] European Council (2014): European Council Conclusions, 23/24 October 2014. EUCO 169/14, para. 2.1. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

	2030 target: at least -40% domestic[38]	**2050 aspiration: -** 80 to 95%[39]
Least-cost assumptions for a 2°C world: IPCC AR5[40]; 430-480ppm, OECD&EIT Knopf et al. 2013	-42% [24-44%] -47% [40–51%]	
Ökoinstitut, target based on grandfathering 2°C with overshooting and 66 % probability	-33%	63%
Ökoinstitut, target based on historic responsibility, 1,5 °C, no overshooting, 50 % probability	-40%	- 180 %
Climate Analytics, least-cost approach	-47 %	-88 %
Climate Analytics, equity approach	-75 %	-164 %

Accordingly, **the EU 2030 target and 2050 aspiration are not in all cases in line with the respective required emission reductions**. If the global emission budget was distributed on the basis of least-cost mitigation, the EU's aspiration for 2050 of reductions between 80-95% would be roughly in line with the necessary reductions (reductions of -88% in 2050). In all other approaches, however, the EU's targets are not sufficient. The gap between adopted targets and required reductions grows considerably if the remaining global emission budget is distributed based on equity considerations. In this case the EU would need to achieve negative emissions of up to 164% and 180% by 2050.

3.4 Are ETS and non ETS emission budgets compatible with EU targets and overall EU emission budgets?

Effectively, the ETS Directive sets a budget for the emissions that it covers, while the ESD and CAR introduce a budget for non-ETS emissions. In combination, both instruments establish an emission budget for the EU as a whole but only until 2030 – as the CAR will only cover the period until 2030. Neither instrument sets an overall EU emission budget that explicitly derives from the EU's fair share of global emissions.

[38] European Council (2014): European Council Conclusions, 23/24 October 2014. EUCO 169/14, para. 2.1. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

[39] European Council (2009): https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/110889.pdf

[40] IPCC AR5, Table 6.4. OECD and EIT regions: 32% (18/20% to 40%) emission reduction by 2030 compared to 2010 converts to a reduction of 42% compared to 1990 as the EU has reduced its emissions from 1990 to 2010 by 14% (EEA 2017).

3.4.1 ETS and non ETS emission budgets until 2030: Compatible with EU 2030 targets and overall EU emission budgets?

The **ETS** is set to reduce covered emissions by 43% in 2030 (compared to 2005). With emissions of 2338 Mt in 2005, the total ETS emission budget for the period between 2005 and 2030 is about 49.2 Gt.[41] This emission budget could be reduced to 47.7Gt if an estimated 1,5 billion allowances between 2021 and 2030 are cancelled as determined by the revised ETS.[42] The MSR and backloading regulate the timing when a specific amount of allowances becomes available but it does not have a direct impact on the overall ETS budget for the period until 2030.

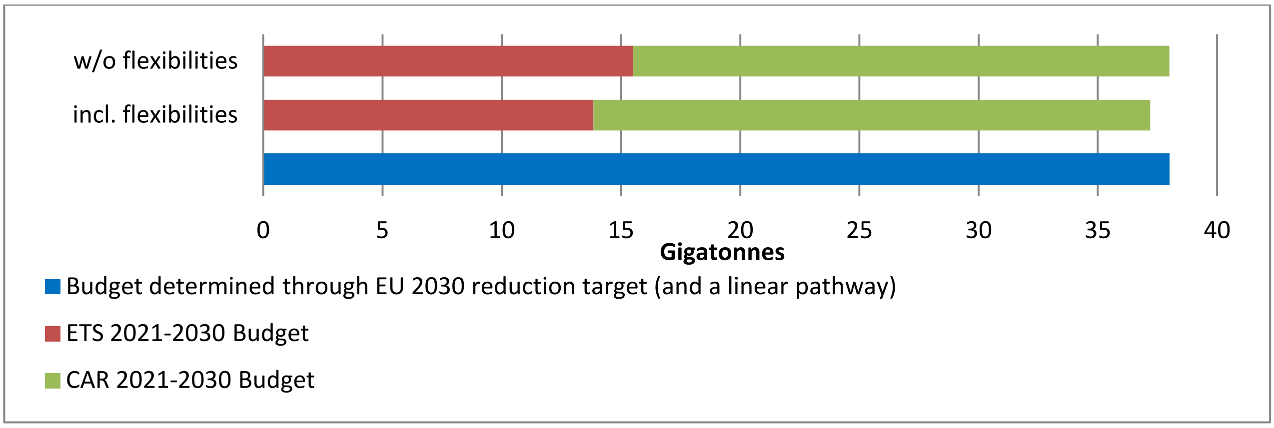
The **CAR** is supposed to reduce covered emissions by 30% in 2030 (compared to 2005). With emissions of 2848 Mt in 2005, this reduction target entails an overall budget of about 22.5Gt – provided Member States reduce their emissions along a linear reduction pathway as stipulated in the ESD (Article 3.2) and the CAR proposal (Article 4.2). According to our calculations, this emission budget could increase by up to 927 Mt to about 23.3 Gt because of a number of so-called flexibilities that the CAR is set to contain:

- **LULUCF:** up to 280 mio. through LULUCF (Article 7).
- **ETS:** up to 100 mio. through ETS exception (Article 6).
- **So-called safety reserve:** up to 105 mio. through bonuses for lower-income states (Article 10 a).
- **Starting year:** As proposed by the Commission, the CAR is set to use average 2016-2018 emissions as a starting point for calculations after 2020. This starting point leads to a carbon budget of 22Gt between 2021 and 2030, which is 442 Mt higher than the budget would be if estimated 2020 emissions were taken (estimated according to 2020 goals).

Accordingly, the ETS and the CAR provide in sum for a total EU emissions for the period 2021 to 2030 of about 38 Gt (15,5 Gt for the ETS and 22,5 Gt for the non ETS) if flexibilities are not included. With the cancellation of 1.5 billion allowances in the ETS and with the flexibilities in the CAR sector, the budget for the two sectors combined decreases to 37.4 Gt (14 Gt for the ETS and 23.4 Gt for the non ETS). **In theory, these budgets are compatible with the overall EU budget until 2050 of 50 Gt but this leaves the EU with meagre 12 Gt (12.6 Gt, respectively) for 2031-2050.** This means that far less than 1Gt per year would be available each year after 2030.

[41] 4784 Mt emissions in 2006-2007, a reduction of 6.5% in 2008-2012 (compared to 2005) and a linear reduction factor of 1.74% (between 2013 and 2020) and 2.2% (between 2021 and 2030)

[42] In 2019, a total of 1232Mt allowances go into the MSR. (400 of these come from backloading, 625 Mt are based on an estimation from https://ec.europa.eu/clima/policies/ets/reform_de and the remaining 207Mt. reflect 24% of the 2018 surplus allowances that exceed 833Mt). From 2019-2023, 24% of the surplus exceeding 833Mt of the previous year go into the MSR (current Council proposal). Allowances are cancelled from 2024 onwards if the amount of allowances in the MSR is higher than the amount of allowances distributed in the previous year (current Council proposal). This means that the amount auctioned in the previous year sets the limit for the MSR in the current year. For our calculations we assumed that after 2017, ETS participants in each year use exactly as many allowances as are distributed. This assumption is critical, because it determines the amount of allowances cancelled. Through the proposed functioning of MSR and cancellation, it is generally true that less allowances are cancelled if the ETS participants use more allowances and vice versa.

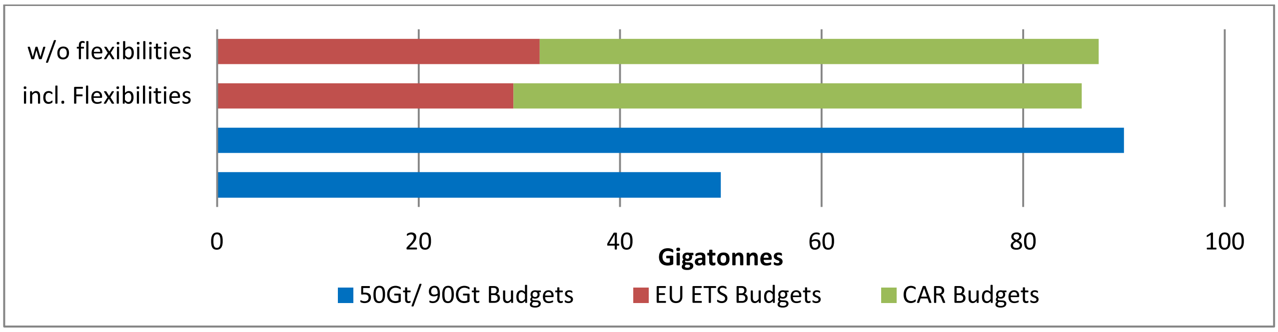


3.4.2 ETS and non ETS emission budgets until 2050: Compatible with EU 2050 aspiration and overall EU emission budgets?

The total **ETS emission budget** for the period between 2021 and 2050 would amount to 32 Gt, provided the ETS continues to reduce emissions at current rates, i.e. with a LRF 2.2%. Through the ETS reforms agreed in November 2017, this budget could be reduced by 2.2 billion allowances (1.5 billion allowances in 2021-2030 and 632 Mt in 2031-2050)[43] if the proposed rules for the MSR and cancellation continue after 2030.

The emissions between 2021 and 2050 under the **CAR** would amount to 55.5Gt (21.8Gt between 2021-2030 and 33.7Gt between 2031-2050) if current annual reductions of 33Mt continue. This equals to reductions of about 52% reduction in 2050 (compared to 2005). A decarbonisation of the CAR sector would – by continuing the current path - take until year 2092. In total, the sector would emit 83.3Gt (27.9Gt after 2050).

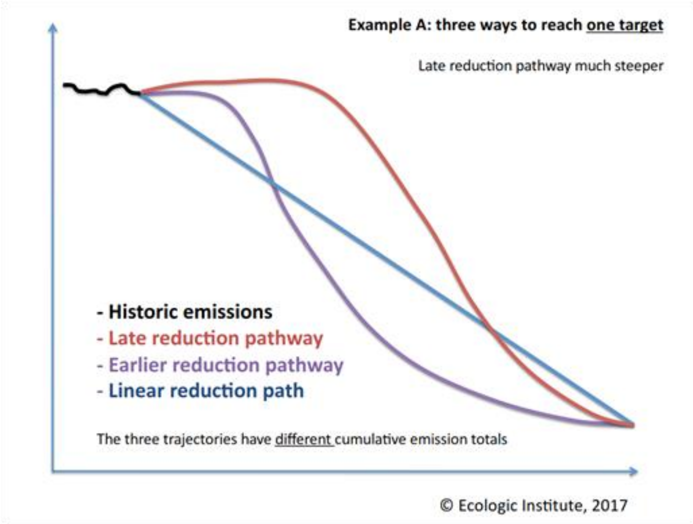
In sum, this would entail **total EU emissions for the period 2021 and 2050 of 87,5 Gt** (32+55.5=87.5Gt) if both sectors continue as they currently do and no flexibilities are taken into account. These levels of emissions exceed the EU's 50Gt budget by 37.5Gt. Including flexibilities leads to excess emissions of 36.1 Gt (which means that the estimated flexibilities in total reduce the emissions budget until 2050 by 1.4 Gt).



[43] This is true under two conditions: 1.) our assumption on the use of allowances for 2021-2030 is still true after 2030 and 2.) the proposed rules for the MSR and cancellation continue after 2030

3.5 How to close the gap: Which EU reduction targets, trajectories and budgets?

Reduction targets are essential – but depending on the emission trajectories between now and the target year, the same reductions target can result in very different emission amounts, as shown in the following graph:



For this reason, the design of trajectories and targets post-2020 result is crucial. It determines the total amount of permissible emissions over time. In other words, it is not (only) the target achievement that matters, but the emission trajectory leading to the target has to develop in such a way that the EU will not exceed its remaining emission budget in the process. The table below gives an overview of which targets and trajectories would allow the EU to stay within a given emission budget and which would exceed it. The graphic following the table visualises the table. **Bearing in mind that there is not one single objective budget, but that this ultimately remains a political decision, we use the 100 Gt (1.5°C) and 140 Gt (2°C) for period 2010 – 2100 (based on least cost assumptions, as discussed above).** In light of current technological capacities, we assume that this budget is effectively available only up to 2050. In other words, we assume that technological and political changes make zero emission after 2050 easier than linear reductions over the entire century. Overshooting emissions have to be compensated by negative emissions in the second half of the century.

Table 1: Staying within a 2010-2050 emission budget of 100 Gt (1.5°C) and 140 Gt (2°C) and least costs: Targets and pathways

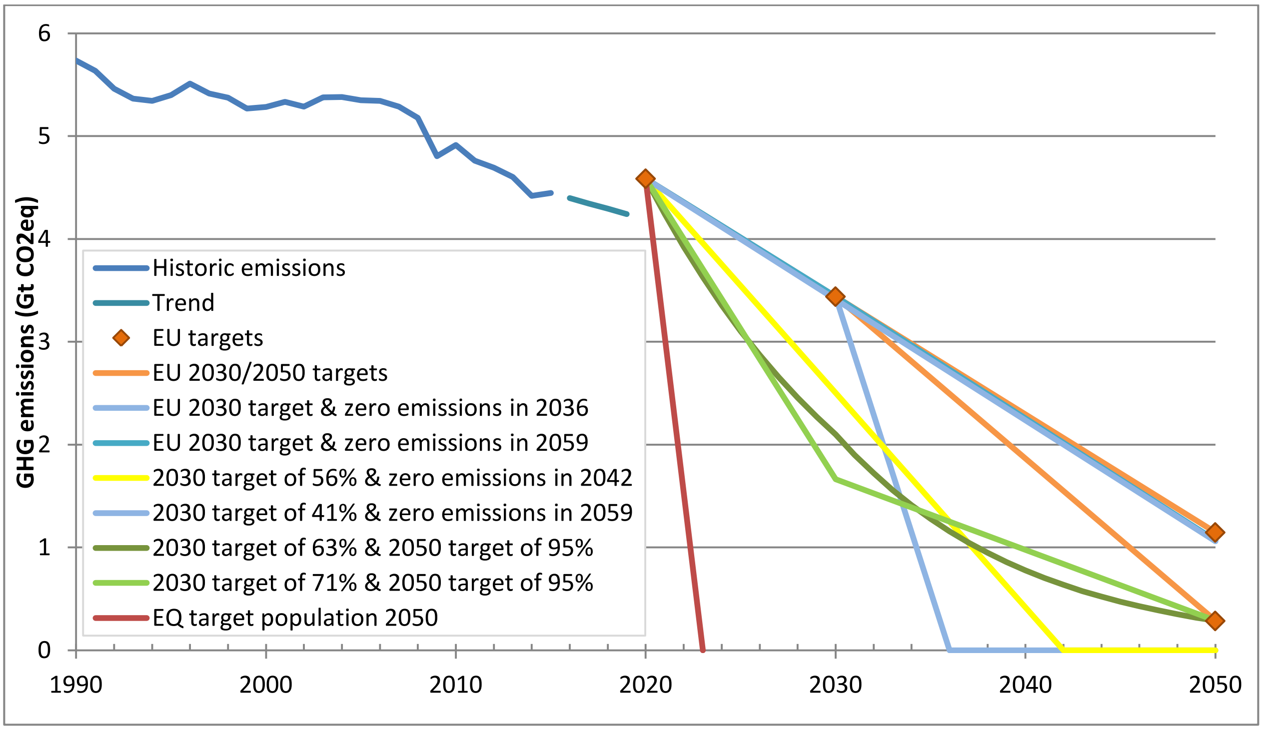
Pathway	Reduction path	Emissions 2021-2050 in Gt CO_2eq	Emissions 2011-2050 in Gt CO_2eq	Emissions above/below least cost GHG budget in Gt CO_2eq	
				1.5°C	2°C

Pathway	Reduction path	Emissions 2021-2050 in Gt CO_2eq	Emissions 2011-2050 in Gt CO_2eq	Emissions above/below least cost GHG budget in Gt CO_2eq	
EU 2030 target of 40% and 2050 target of 80-95%	Linear reduction [orange lines]	86 to 77	136 to 127	+27 to +36	-4 to -13
EU 2030 target of 40% and zero emissions in 2036 (1.5°C) or 2059 (2°C)	Linear reduction [light-blue line]	50 to 85	100 to 135	0 to +35	-40 to -5
2030 target of 56% and zero emissions in 2042 (1.5°C)	Linear reduction to zero emis-sions [yellow line]	50	100	0	-40
2030 target of 41% and zero emissions in 2059 (2°C)	Linear reduction to zero emis-sions [similar to light-blue line]	85	134	+34	-6
2030 target of 63% and 2050 target of 95%	Exponential [dark green line]	50	100	0	-40
2030 target of 71% and 2050 target of 95%	Piecewise-linear reduction [light green line]	50	100	0	-40
Equity target de-termined by share of population in 2050	Linear reduction to zero emis-sions [red line]	6.9	28.5	-43.1	-83.1

Please note that we assume that the EU 2020 target is the starting point for further calculations although the GHG trend is below of the target. The main reason is that the ETS delivers a fixed budget and banking into the next phase and non-ETS post-2020 target might be based on the 2020-target and not on real emissions. In other words, we assume that emission budgets are transferred into the next phase under the ETS and possibly also under the ESD. The ETS may even result in higher emissions shifted to next phase due to offset use and large reductions before of 2010 due to the financial crisis.

Figure 1 illustrates the associated pathways up to 2050 for the different targets.

Figure 1: Pathways



In **conclusion**, if the EU maintains its 2030 target of 40% and adopts a 2050 target of 80-95% – not an unlikely scenario – a linear trajectory would be in line with the EU 2°C GHG budget (least cost), but would exceed the EU 1.5°C GHG budget by 27-36 Gt CO_2eq depending on the 2050 target being 80% or 95% (orange lines). Moreover, these pathways would imply that the EU uses up 28.2% – 31% of the global 1.5°C GHG budget and 8.4% – 9.2% of the global 2°C GHG budget which will be left after 2017.

Part of the problem is the 2030 target of a 40% reduction: this target is incompatible with the available 1.5°C GHG budget. If the EU were to remain on a linear path to this target and wanted to stay within the 1.5°C GHG budget, it would have to reduce its emissions to zero by 2036 (see light blue line).

For this reason, scenarios that remain within the 1.5°C GHG budget require steeper emission reductions by 2030. For instance, the **EU would not exceed its 1.5°C GHG budget if it would reduce emissions by about 56% in 2030 along a linear trajectory**. In this case, the EU would be required to reach zero emissions by 2042. If the EU further emits GHG emissions by 2050 in the order of the **95% target, it would have to reduce its emissions by 63% – 71% by 2030** (see green lines).

4 2030 EU policy architecture – fit for 2050?

What are the policy implications of steeper emission reductions pathways – as discussed above – for the existing EU climate policy architecture? What are the consequences of the discussed reduction pathways for the EU ETS, the CAR and LULUCF Regulation?[44] **What are the emission reductions required by the sectors covered by the ETS and non-ETS sectors by 2030 and 2050?** There are a range of criteria that help answer these questions:

- **Cost effectiveness:** Cost-effectiveness is central to successful climate policy. It is also a central criterion for choosing and designing instruments. Compared to other instruments, such as taxation or performance standards, emission trading is often considered particularly cost-effective. However, the transaction costs of emission trading for defuse sources of emissions, such as cars or buildings, could make this instrument overly expensive for these emission sources. It should also be noted that estimates of mitigation costs and cost-effectiveness often focus on short term costs, neglecting long term cost developments, innovation and transformational policies.
- **Technological feasibility:** In principle, ETS sectors have a number of technological opportunities to reduce emissions to nearly zero at relatively low costs. The power sector can reduce its emissions to zero mainly through a shift to renewable electricity generation.[45] The industrial sector can significantly reduce its emissions by 2050 that mainly arise from process heating, but break-through technologies reducing emissions to near zero are not yet available at economic costs. Technologically it is more challenging for the non-ETS sectors to reduce emissions to zero at relatively low costs. The emissions from the building sector, for example, can be reduced to zero but long timeframes for renovation is a challenge. With today's technologies, zero emissions are particularly challenging in agriculture and aviation.

These criteria help inform the discussion about the distribution **of what the ETS and the non-ETS sectors have to contribute to the overall EU's reduction targets. But ultimately the distribution of sectors is a political decision,** as there is no formula that automatically defines the distribution.

In its 2011 **Low Carbon Economy Roadmap**, the European Commission based its calculation largely on cost effectiveness criteria. On this basis, the Commission estimated 2050 reductions of 88-92% for the ETS and of 66-71% for the non-ETS sectors compared to 2005.[46] For the period until 2030, estimated reductions are 43-

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[44] The required reductions are given in section 3 based on different considerations such as about the overall EU carbon budget and EU targets calculated based on least-cost or equity approaches.

[45] See e.g. COM (2011): Low Carbon Economy Roadmap; COM (2011): Energy Roadmap 2050; ISI (2014): Optimized pathways towards ambitious climate protection in the European electricity system (EU Long-term scenarios 2050 II)

[46] The Roadmap shows the contribution of sectors for achieving an 80% reduction in 2050. The sectoral contributions depend on the available technologies and processes to reduce GHG emissions and the related cost assumptions. As such, specific technologies and processes will be used only after 2030 as they still need development and/or are more expensive than other technologies and processes that are applied until 2030. These cost and availability assumptions are crucial to define which sectors should reduce how much and when.

48% in the ETS sectors and 24-36% in the non-ETS sectors, also based on 2005.[47] In line with the lower end of these estimates, the European Council decided that the ETS would have to reduce its emissions by 43% and the non-traded sectors by 30% (both compared to 2005) as their contribution to the overall reduction target of 40% (compared to 1990). To achieve these reductions in the ETS sectors, the European Commission proposed to increase the linear reduction factor (LRF) of the ETS from annually 1.74% to 2.2% from 2021 onwards. This proposal was agreed in November 2017. The proposal is also largely based on considerations of cost effectiveness.

Box 1: Sectoral split of ETS, non-ETS and other emissions

The overall GHG reduction targets for 2020 and 2030 are split into two different "sub-targets" due to the legal framework of the EU: it regulates emissions covered by the EU Emission Trading System (EU ETS) and the remaining non-ETS emissions under the Effort Sharing Decision (ESD). The EU ETS sets a cap and a price on GHG emissions coming from electricity and heat generation, from industry and from flights within the borders of the EU. The ESD sets national targets covering emissions from the residential and tertiary sector (heating and cooling in buildings), transport emissions and emissions from agricultural activities. International aviation is not covered by the EU ETS due to global negotiations within the International Civil Aviation Organisation (ICAO)[48] neither are international shipping and LULUCF covered by one of the two policy frameworks. Thus, these emissions are excluded in the following assessment.

It is possible to **continue the proportional split** between ETS and non-ETS for the period until 2050 that the Low Carbon Economy Roadmap and the European Council adopted. In other words, the ETS and non-ETS would contribute the same proportional reductions to the overall EU reductions as indicated by these documents but its contributions would increase proportionally to the higher EU targets. It is also possible to distribute emissions disproportionately, i.e. the proportional split applied by the Roadmap would discontinue. Because of its limited scope, this paper's estimates are based on the proportional split of the Roadmap and an equal distribution to ETS and non-ETS – although it would have been preferable if the distribution between the ETS and non ETS emission would be modelled with up-to-date data and information.[49]

[47] The split depends on a range of assumptions. The Impact Assessment (p.54) highlights the role of the relative oil and gas prices level as the higher reductions for the ETS sectors are mainly a result from fast and large emission reductions in the power sector.

[48] European Commission (2017): The EU tackles growing aviation emissions. http://europa.eu/rapid/press-release_IP-17-189_en.htm

[49] It should be noted that the Roadmap is from 2011, which means that its assumptions do not take account of the PA and recent technological developments. For this reason, the Roadmap's estimates are in line with the 2°C GHG budget, but not with the 1.5°C GHG budget (see Chapter 3.3).

4.1 EU Emissions Trading System: What are the necessary reductions until 2050?

The following table shows which emission reductions the ETS has to achieve by 2030 and 2050 to contribute to the existing EU targets (upper part of table). The table also presents the ETS reduction pathways that are in line with the EU's remaining **1.5°C GHG least cost budget** (lower part of table).[50]

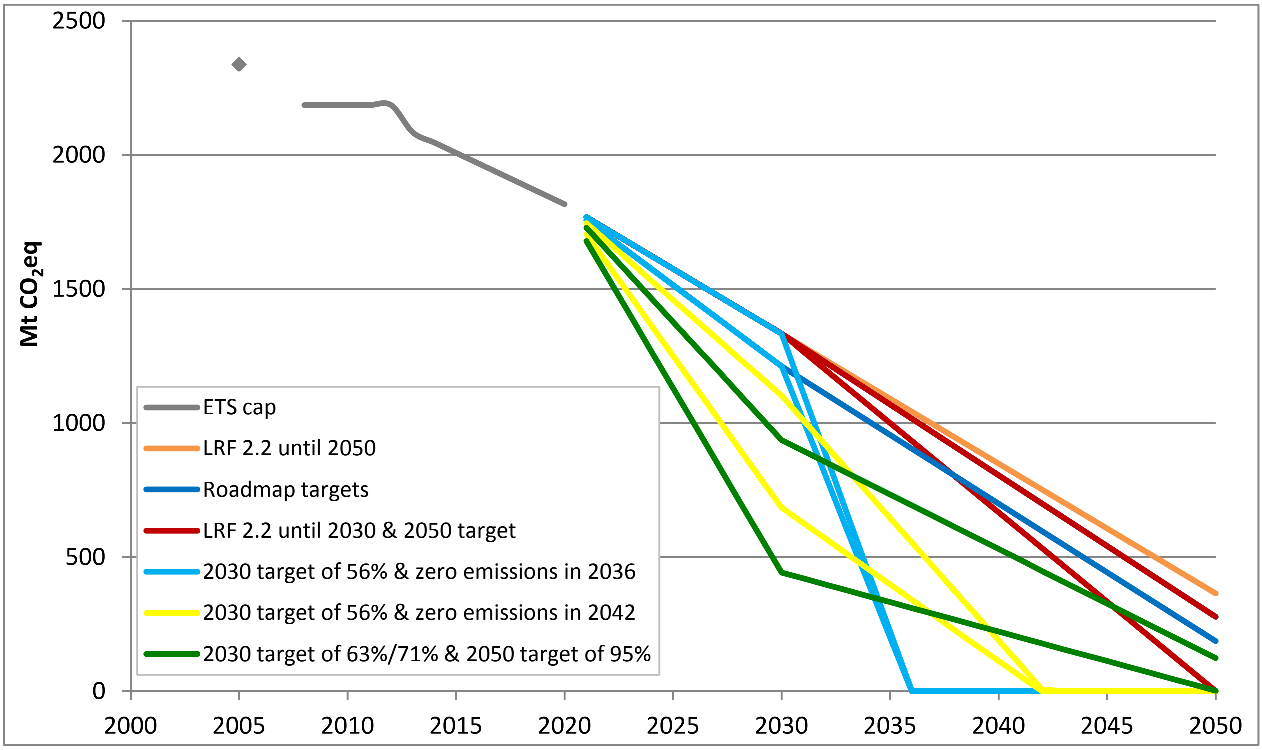
[50] There are various ways to calculate reduction pathways but steep early reductions have two advantages: they avoid to lock-in carbon intensive investments and they are safer because they increase the likelihood to stay within emission budgets. Climate Analytics (2016): What does the Paris Agreement mean for Finland and the European Union? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf.

Table 2: Total reductions and related ETS emission reductions based on 2005 for different 2030/2050 targets and pathways

Options	Overall reduction 2030/2050 [against 1990]	ETS emission reduction		LRF		ETS accumulated emissions
		2030	2050	2021-2030	2031-2050	2010-2050
Currently discussed EU targets and pathways						
LRF 2.2 until 2050 and beyond [orange line]	36% / 78-95% [40% / 80-95%]	43%	84%	2.2% until 2030 and possibly until 2050		53 Gt CO_2eq
LRF 2.2 until 2030, then 2050 target (80% -95%) based on equal split between ETS and non-ETS [red line]	36% / 78-95% [40% / 80-95%]	43%	88-100% ([1])	2.2%	2.4-3%	49-52 Gt CO_2eq
Roadmap targets [blue line]	22-36% / 78% [35-40% / 80%]	43-48%	88-92%	2.2-2.75%	2.4-2.3%	49-52 Gt CO_2eq
Pathways to stay in the GHG budget for 1.5°C (least costs)						
EU 2030 target and zero emissions in 2036 (1.5°C GHG budget) [light blue line]	36% / 100% [40% / 100%]	43-48% ([2])	100%	2.2-2.75%	10.1-9.2%	39-40 Gt CO_2eq
2030 target of 56% and zero emissions in 2042 [yellow line]	53% / 100% [56% / 100%]	53-71% ([3])	100%	3.25-5.15%	4.15-2.6%	37-41 Gt CO_2eq
2030 target of 63% and 2050 target of 95% [dark green line]	60% / 95% [63% / 95%]	60-81% ([3])	95-100% ([4])	4-6.25%	1.85-1%	36-45 Gt CO_2eq
2030 target of 71% and 2050 target of 95% [light green line]	71% / 95%	60-81% ([3])	95-100% ([4])	4-6.25%	1.85-1%	36-45 Gt CO_2eq

Light blue cells are calculated. ([1]): lower value as set by the Roadmap; upper value is calculated based on the proportional split given by the Roadmap for 2050 but not more than 100%. ([2]) lower value as set by the COM proposal; upper value is calculated based on the proportional split given by the Roadmap for 2030. ([3]) lower value is the same as overall target; upper value is calculated based on the proportional split given by the Roadmap for 2030. ([4]) lower value is the same as overall target; upper value is calculated based on the proportional split given by the Roadmap for 2050 but not more than 100%.

The following graphic visualises the pathways of the different reduction targets for the ETS as given in the table. Figure 2: Emission reduction pathways for the ETS



Summarizing these estimates the ETS sectors would have to reduce their emissions by roughly 81% by 2030 and 100% by 2050 compared to 2005 – **if the proportional distribution between ETS and non-ETS that the Low Carbon Economy Roadmap and the European Council adopted continues**. This would result – as one possible option – in a linear reduction factor of 5,15% or an annual reduction of 113 Mt CO_2eq from 2020 to 2030; from 2030 to 2050 the linear reduction factor would be 2,6% (annual reduction of 57 Mt CO_2eq). As another option, a linear reduction factor would amount to 6.25% or an annual reduction of 137 Mt CO_2eq from 2020 to 2030; from 2030 to 2050 the linear reduction factor would be only 1% (annual reduction of 22 Mt CO_2eq).

If **reduction efforts are equally distributed between the ETS and non-ETS sectors**, ETS sectors would have to reduce their emissions by at least 60% by 2030 and to 95% by 2050 compared to 2005 (dark green line). Reductions of this scale are compatible with the EU's remaining 1.5°C GHG budget for the ETS sectors, which is roughly 35-50 Gt. These 2030/2050 ETS reduction targets mean that the LRF has to be increased from the current proposed 2.2% to at least 4% for the period 2021 to 2030. From 2031 to 2050 it would then only amount to around 1%. Alternatively, the LRF could amount to 3.25% from 2021 to 2030 and 4.15% after 2030. Steeper early reductions between 2020 and 2030 are sensible because they help meet long term targets and avoid to lock-in carbon intensive investments.

The **2.2% LRF of the revised ETS** for the period until 2030 and beyond will only lead to reductions in the ETS sectors of 84 % in 2050. Reductions of this scale would exceed the ETS emission budget by 3-18 Gt.

4.2 Non-ETS sectors: What are the necessary emission reductions for 2050?

The following table shows the emission reductions by 2030 and 2050 for the non-ETS contribution to achieve the existing EU targets (upper part of table) and for the pathways that are in line with the EU's remaining emission budget, least costs and 1,5°C (lower part of table).

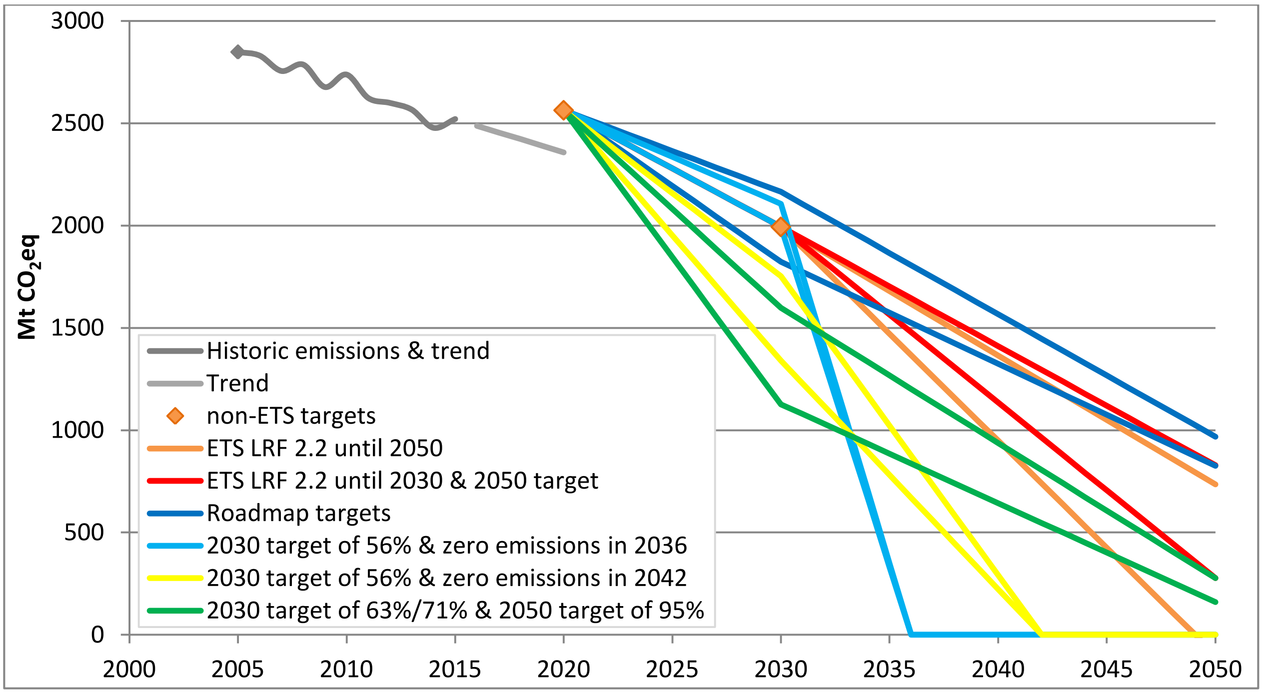
Table 3: Emission reductions of the ETS and non-ETS for different targets and pathways compared to 2005

Options [Fig. x line colour]	Overall reduction 2030/2050 [against 1990]	2030 emission reduction compared to 2005		2050 emission reduction compared to 2005		Average yearly reduction of the non-ETS		Non-ETS accumulated emissions
		ETS	Non-ETS	ETS	Non-ETS	2021-2030	2031-2050	2010-2050
Existing EU targets and pathways								
ETS LRF 2.2 until 2050 [orange line]	36% / 79-95% [40% / 80-95%]	43%	30%	84%	74-103%	57 Mt CO_2eq	63-105 Mt CO_2eq	70-78 Gt CO_2eq
ETS LRF 2.2 until 2030, then2050 target (80% - 95%) based on equal split between ETS and non-ETS[red line]	36% / 79-95% [40% / 80-95%]	43%	30%	88-100%	71-90%	57 Mt CO_2eq	58-86 Mt CO_2eq	73-79 Gt CO_2eq
Roadmap targets [blue line]	31-36% / 79% [35-40% / 80%]	43-48%	36-24%	88-92%	66-71%	74-39 Mt CO_2eq	60-50 Mt CO_2eq	76-83 Gt CO_2eq
Pathways to stay in the GHG budget for 1.5°C (least costs)								
EU 2030 target and zero emissions in 2036 (1.5°C GHG budget) [light blue line]	36% / 100% [40% / 100%]	43-48%	30-26%	100%	100%	57-46Mt CO_2eq	332-351 Mt CO_2eq	57-58 Gt CO_2eq
2030 target of 56% and zero emissions in 2042 [yellow line]	53% / 100% [56% / 100%]	53-71%	53-38%	100%	100%	122-81 Mt CO_2eq	112-146 Mt CO_2eq	55-60 Gt CO_2eq
2030 target of 63% / 71% and 2050 target of 95% ([1]) [green line]	60% / 95% [63% / 95%]	60-81%	60-44%	95-100%	90-95%	144-97 Mt CO_2eq	48-66 Mt CO_2eq	59-67 Gt CO_2eq

Light blue cells are calculated. ([1]).

The following graphic visualises the pathways of the different reduction targets for the ESD as given in the table.

Figure 3: Emission reduction pathways for the ESD



In summary, **the 1.5°C least costs EU budget requires emission reduction of the non-ETS sectors of at least 44% by 2030 and 90% by 2050** (see dark green lines). These targets result in a yearly reduction of non-ETS emissions in the order of 97 Mt CO_2eq and of 137 Mt CO_2eq for the ETS sectors (LRF of 6.25%) from 2020 to 2030. From 2030 to 2050 the yearly reduction of non-ETS emissions would amount to 66 Mt CO_2eq and to 22 Mt CO_2eq for the ETS (LRF of 1%). If the overall emission reduction is distributed equally to ETS and non-ETS, both would have to reduce emissions by 60% by 2030 and by 95% by 2050. This would result in an annual reduction of non-ETS emission of 144 Mt CO_2eq and of 88 Mt CO_2eq for the ETS (LRF of 4.4%) from 2020 to 2030; for 2030 to 2050 the annual reduction would amount to 48 Mt CO_2eq for the non-ETS and to 41 Mt CO_2eq for the ETS (LRF of 1.85%).

The current EU targets for the ETS and non-ETS for 2030 will lead to yearly reductions of roughly half of the required reductions to stay in the 1.5°C least costs GHG budget: the non-ETS would reduce 57 Mt CO_2eq per year from 2020 to 2030 and the ETS 48 Mt CO_2eq per year. A pathways with zero emissions before 2050 (light blue and yellow line) which are in line with the EU 1.5°C GHG budget result in emission reductions by 2030 of at least 26% to 53% for the non-ETS sectors. The range of emission reduction by 2030 depend on the overall 2030 target, respective year of zero emissions, and the expected emission reductions by the ETS.

4.3 Required negative emissions

With the implementation of the existing targets, the EU would exceed the remaining emission budget. The implementation of the 2030 targets of 40% and the 2050 aspiration of 80-95% would require **removals be-**

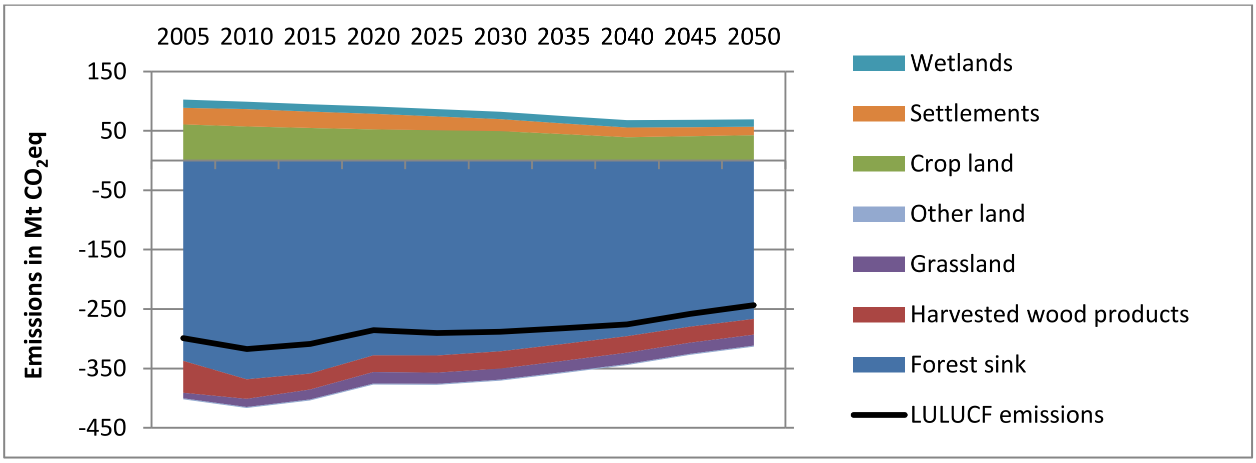
tween 44 to 53 Gt CO_2eq. Implementation of less stringent targets would increase the need of removals. Conversely, the implementation of more ambitious targets would reduce the amount of required removals. In principal, the EU has two options to generate negative emissions domestically:

- land carbon sequestration through restoration of degraded forests, afforestation, soil management and bio char (all considered under LULUCF),
- carbon capture with geological storage, in particular BECCS.[51]

4.3.1 LULUCF

It is expected that LULUCF will remain a net carbon sink until 2050. Considering a reference development, the sink will decline to -214 Mt CO_2 in 2030 and -196 Mt CO_2 in 2050.[52] The 2017 EEA emission trends and projections report assumes similar rates of decline. This report expects that the rate of accumulation of carbon will decline by 32 % until 2030, which is partly compensated by afforestation and a decreasing emissions from deforestation (extimated 20 Mt CO_2eq in 2030).[53] These declines are mainly the result of changes in forest harvesting which is only partly compensated by additional afforestation and less deforestation to some extent.

Figure 4: Development of LULUCF emissions in a reference case (2005-2050)



Source: European Commission (2016): EU Reference Scenario 2016: Energy, transport and GHG emissions, Trends to 2050

Under this reference assumption, the removals created through LULUCF would be 4% lower in 2030 and 23% lower in 2050 than in 2010. The potential cumulated compensation would amount to roughly **11.7 Gt CO_2eq** from 2010 to 2050. However, studies estimate that the net sink of LULUCF could be much smaller due to in-

[51] Direct air capture (DAC) is another option but given the very premature development state of DAC there are not reliable estimates for its potential in the EU (see above).

[52] European Commission (2016): EU reference Scenario 2016: Energy, transport and GHG emissions, Trends to 2050

[53] EEA (2017): Trends and projections in Europe 2017 - Tracking progress towards Europe's climate and energy targets

creased biomass use and land competition if the EU aims for higher shares of renewables for the decarbonisation of the energy system: The Low Carbon Economy Roadmap considers two different wood production levels (high and low). Both levels would result in a lower LULUCF sink when compared to the reference case. The negative emissions would be 56% or 26% lower in 2030 (instead of only 4%) and 38% or 50% lower (instead of 23%) in 2050 for the high wood production and low wood production scenarios, respectively. This means that the cumulated compensation would be up to almost a third smaller than under the reference case. **In either case, the LULUCF sectors are currently not expected to generate negative emissions nearly at a scale of 44 to 53 Gt CO_2eq, which would be required if the EU would implement its 2030 targets of 40% and the 2050 aspiration of 80-95%.**

4.3.2 Bioenergy-CCS

Bioenergy-CCS (BECCS) depends on accessible and affordable storage sites for permanent storage of CO_2. They also strongly depend on social acceptance (see above). From a purely technical perspective, a conservative estimate of the geological storage capacity in the EU results in 88 Gt CO_2eq, which would be sufficient for removing the excess emissions of 44 to 53 Gt CO_2eq in the EU target scenario.

However, the Energy Roadmap assumes that in 2050 roughly 460 TWh of electricity will be produced using biomass. If this electricity mainly comes from larger plants, this would roughly amount to carbon emissions that could be sequestrated of 450 Mt CO_2 in that year.[54] CO_2 emissions from biomass would amount to max. **8 Gt** available for sequestration when assuming an early start already around 2030. Consequentially, BECCS is very unlikely to contribute large amounts of negative emissions.

[54] Considering an electric efficiency of around 40% and emissions of 109.6 kg CO_2/GJ of biomass.

5 Annexes

5.1 Annex 1: Required reductions in percentage points for 2050 and 2100 (IPCC AR 5)

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a]. *{Table 3.1}*

<table>
<tr><th rowspan="2">CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f]

Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs [d]</th><th colspan="2">Change in CO_2-eq emissions compared to 2010 (in %) [c]</th><th colspan="4">Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]</th></tr>
<tr><th>2050</th><th>2100</th><th>1.5°C</th><th>2°C</th><th>3°C</th><th>4°C</th></tr>
<tr><td><430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]</td></tr>
<tr><td>450
(430 to 480)</td><td>Total range [a, g]</td><td>RCP2.6</td><td>–72 to –41</td><td>–118 to –78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500
(480 to 530)</td><td>No overshoot of 530 ppm CO_2-eq</td><td></td><td>–57 to –42</td><td>–107 to –73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2-eq</td><td></td><td>–55 to –25</td><td>–114 to –90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 to 580)</td><td>No overshoot of 580 ppm CO_2-eq</td><td></td><td>–47 to –19</td><td>–81 to –59</td><td rowspan="3">More unlikely than likely [i]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2-eq</td><td></td><td>–16 to 7</td><td>–183 to –86</td></tr>
<tr><td>(580 to 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>–38 to 24</td><td>–134 to –50</td></tr>
<tr><td>(650 to 720)</td><td>Total range</td><td>–11 to 17</td><td>–54 to –21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 to 1000) [b]</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>–7 to 72</td><td rowspan="2">Unlikely [h]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000 [b]</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely [h]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

5.2 Annex 2: Underlying calculations for Section 3.4:

5.2.1 Calculating emissions in the ETS sector

For the ETS sector, we calculated the amount of cancelled emissions based on the following assumptions. Assumptions on the 2013-2020 surplus development base on Jalard et al. (2015), p. 37 and on European Commission (2017). Furthermore, we assumed that from 2021 onwards, the annual useage of ETS allowances equals the number of certificates distributed in the respective year.

Year	Allowances distributed (w/o MSR)	Share of 2005 Allowances	Share of allow-ances auctioned (Council proposal)	Allow-ances auctioned w/o MSR (Council proposal)	Allowances auctioned minus what goes into MSR (Council proposal)	Surplus deve-lopment	MSR annual intake (from surplus only: 24% until 2023, then 12%)	MSR (backloading+unallocated allow-ances+24% until 2023, then 12%)	Cancellation
2013	2084	11%		1066*	1066	1750**			0
2014	2046			655*	655				0
2015	2008			744*	744				0
2016	1970			831*	831	1694**			0
2017	1931			1017*	1017				0
2018	1893			1003*	1003	1694***			0
2019	1855			988*	781	1487,36	206,64	1231,64	0
2020	1816			973*	816	1330,31	157,05	1688,69	0
2021	1768		57%	1008	888	1210,96	119,36	2008,04	0
2022	1720		57%	980	890	1120,25	90,71	2098,75	0
2023	1671		57%	953	884	1051,31	68,94	2167,69	0
2024	1623		57%	925	899	1025,11	26,20	2193,89	1310
2025	1575		57%	897	874	1002,06	23,05	906,76	8
2026	1526		57%	870	850	981,77	20,29	919,16	45
2027	1478		57%	842	824	963,92	17,85	892,29	43
2028	1429		57%	815	799	948,21	15,71	865,34	41
2029	1381		57%	787	773	934,38	13,83	838,31	39
2030	1333	43%	57%	760	747	922,22	12,17	811,22	38
Total 21'-'30	15504			8837	8429	10160	408	13701	1523
2031	1284		57%	732	721	911,51	10,71	785,53	38
2032	1236		57%	704	695	902,09	9,42	758,15	37
2033	1188		57%	677	669	893,80	8,29	730,75	36
2034	1139		57%	649	642	886,50	7,30	703,33	35
2035	1091		57%	622	615	880,08	6,42	675,89	34
2036	1042		57%	594	589	874,43	5,65	648,43	33
2037	994		57%	567	562	869,46	4,97	620,96	32
2038	946		57%	539	535	865,09	4,38	593,47	32
2039	897		57%	511	508	861,24	3,85	565,98	31
2040	849		57%	484	480	857,85	3,39	538,47	31
2041	800		57%	456	453	854,87	2,98	510,96	31
2042	752		57%	429	426	852,24	2,62	483,44	30
2043	704		57%	401	399	849,93	2,31	455,91	30
2044	655		57%	374	372	847,90	2,03	428,38	30
2045	607		57%	346	344	846,11	1,79	400,84	29
2046	559		57%	318	317	844,54	1,57	373,29	29
2047	510		57%	291	289	843,15	1,38	345,75	29
2048	462		57%	263	262	841,94	1,22	318,20	29
2049	413		57%	236	235	840,86	1,07	290,64	29
2050	365	84%	57%	208	207	839,92	0,94	263,09	29
Total '31-'50	16493			9401	9319	17264	82	10491	632
Total '21-'50	31997			18238	17748	27424	490	24193	2156

* estimate based on European Commission (2017): How many allowances will be auctioned in individual years up to 2030? https://ec.europa.eu/clima/policies/ets/auctioning_en#tab-0-2

**real number based on European Commission (2017): Publication of the total number of allowances in circulation https://ec.europa.eu/clima/sites/clima/files/ets/reform/docs/c_2017_3228_en.pdf

***estimate based on European Commission (2017): Publication of the total number of allowances in circulation and on the assumption that the surplus does not change between 2016 and 2018

5.2.2 Calculating the flexibility of different starting years in the non-ETS sector

For the non-ETS sector, we calculated the impact of the starting point by comparing the EC proposal (average 2016-2018 emissions) to the 2020 estimate (based on EU 2020 goals)

- 2016-2018 average: 2455 Mt
- 2020 estimate: 2357 Mt

Year	Emissions	Year	Emissions
Base	2455	**Base**	2357
2021	2409	2021	2320
2022	2363	2022	2284
2023	2317	2023	2248
2024	2271	2024	2212
2025	2224	2025	2175
2026	2178	2026	2139
2027	2132	2027	2103
2028	2086	2028	2066
2029	2040	2029	2030
2030	1993,6	2030	1993,6
Total 2021-2030	**22013**		**21570**

In total, the starting point proposed by the EC increases the budget by **442 Mt** compared to the 2020 estimate.

6 Literature

Climate analytics: What does the Paris Agreement mean for Finland and the EU? http://climateanalytics.org/files/ca_paris_agreement_finland_eu.pdf

European Commission (2011): Energy Roadmap 2050

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