Carbon budget and pathways to a fossil-free future in Järfälla Municipality

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SUMMARY OF MAIN RESULTS

In 2015, the global community committed to hold global average temperature increase to “well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C.”. While nations showed clear commitment to the Paris Agreement’s temperature goals, what would those pledges entail for cities desiring to make a fair contribution to addressing climate change?

This report is the result of research that the Centre for Sustainable Development (CEMUS) at Uppsala University and SLU conducted on behalf of Järfälla Municipality. The report describes the calculation of a carbon budget for Sweden, followed by a calculation of Järfälla Municipality's carbon budget. The report concludes with a chapter describing emissions reductions pathways (and possible corresponding measures) for Järfälla Municipality if they are to make their fair contribution to the Paris Agreement and pave the way for the transition to a fossil-free future.

The main results of the report are summarized below.

1) Our Paris commitment will be exceeded in less than 18 years with current emissions

In order to have a reasonable chance of meeting the Paris agreement's 2°C commitment, only 490-640 billion tonnes of carbon dioxide remain available that the energy sector can release globally. This carbon dioxide budget range requires, in addition to drastic emissions reductions in the energy sector, an immediate reduction of carbon dioxide emissions from global cement production, and a drastic reduction in emissions from deforestation. With current global carbon dioxide emissions from the energy sector, this entire carbon budget will be exceeded within 14-18 years. The 1.5°C objective of the Paris Agreement is unfortunately no longer a reasonable or achievable commitment.¹

2) Sweden and Järfälla Municipality need to aim for 15% mitigation per year, starting now, in order to fulfil their temperature commitments made in Paris

For Sweden, the Paris Agreement's 2°C commitment means a remaining global carbon budget of 300-600 million tonnes of carbon dioxide. With current annual emissions, this carbon budget will be used up in only 6-12 years.² Both Sweden and Järfälla Municipality need to begin an immediate programme of profound mitigation at a minimum annual rate of 10% in absolute terms - but quickly increase this rate up to 15 % per annum. Any delay in starting, or in pursuing a rate below 10% per annum, will either put a “likely” chance of 2°C beyond reach, or require even

¹ Only if ‘real’ mitigation guided by the carbon budgets for a “likely” chance of 2°C are pursued and highly speculative negative emissions prove to be successful at an early and unprecedented planetary scale, can 1.5°C be considered achievable – at least theoretically.

² This conclusion is based on a calculation that assumes a peak in emissions from poorer non-OECD countries occurring between 2022 and 2023, with a 10% annual emissions reduction by 2045 and over 95% reduction in emissions (cf. 2015) in the early 2060s. This is a far more ambitious agenda for these countries than was discussed in Paris.
more fundamental mitigation later. Note that other municipalities in Sweden also need to embrace an equally ambitious mitigation agenda in order not to exceed the Swedish carbon budget.

3) Järfälla Municipality and Sweden have a responsibility to support poorer countries in their transition

There are two principal reasons for the Municipality of Järfälla and Sweden to broaden their climate responsibility beyond geographical boundaries. First and foremost, a 2°C increase in global average temperature represents a real threat to human and ecosystem survival. This is an ethical issue but also a pragmatic one: what happens in other parts of the world will affect people in Sweden. Furthermore, Swedish citizens already have an impact abroad as they contribute to emissions in other countries through their consumption.

Secondly, Järfälla's carbon budget is estimated based on the assumption that poorer, non-OECD countries, reduce their emissions drastically - far more rapidly than anything discussed in Paris. The reductions in emissions from poorer, non-OECD, countries that this report assumes are far from fair, based on their historically very limited contribution to the causes of climate change. These countries will need support in their efforts to realise the required mitigation pathways. The authors of this report recommend that a further investigation is conducted which examines the different types of financial and technical support and cooperation a country such as Sweden and a municipality such as Järfälla could contribute with to address this unfair distribution of the climate burden. Such an investigation would need to relate to Swedish legislation on municipalities’ authority and the use of tax revenues ('town twinning' collaborations might be one way forward).

4) Järfälla Municipality can lead the way towards a rapid transition to a sustainable and fossil-free society

Järfälla Municipality's territorial emissions are low compared to many other municipalities, and originate primarily from the transportation and construction sector. Järfälla Municipality now has the chance to take leadership on climate change. This will require consistent measures within the municipality's own operations and within the municipality's borders. Immediate reductions in demand for energy would need to be combined with the expansion of a fossil-free energy system and complemented with policies that enable the required long-term and ambitious investments. Järfälla can lead the way, and enable other regions and municipalities in both Sweden and other countries to advance and accelerate rapid transitions towards fossil-free and sustainable futures.
1. INTRODUCTION

Purpose and goals of the report

The Järfälla Municipal board has been given the task from politicians in Järfälla to investigate the consequences of adjusting the municipality’s environmental plan to align with the temperature commitments enshrined in the Paris Agreement and the requirements resulting from the recent work of the Swedish All Party Committee on Environmental Objectives.

The commissioned investigation, which resulted in this report, aimed to answer the following questions:

1. Can Järfälla Municipality work towards the 1.5°C target? If not, why?

2. Are there illustrative examples of how a municipality can work with the 2°C target and make its fair contribution to delivering on the temperature commitments in the Paris Agreement (and where relevant, relate this to the Swedish All Party Committee on Environmental Objectives’ recent investigations and reports).

This report is designed to act as a background paper that informs the ongoing revision of the energy and climate plan for Järfälla Municipality. The energy and climate plan is a policy document based on the environmental plan for the municipality.

The Paris Agreement – A science based and equitable mitigation agenda

The Paris Agreement\(^3\) on climate change delivered an unprecedented covenant amongst world leaders to take action to hold “the increase in ... temperature to well below 2°C ... and to pursue efforts to limit the temperature increase to 1.5°C.” It also acknowledged the need “to undertake rapid reductions [in greenhouse gas emissions] in accordance with the best available science [...] and on the basis of equity”.

From global to local carbon budget - A short overview of this report’s methods

The carbon budgets provided by the Intergovernmental Panel on Climate Change Synthesis Report (AR5) is used as a basis for calculating the emission-space left at the global level to deliver on the temperature commitments enshrined in the Paris Agreement. The global carbon budget has then been disaggregated to provide Sweden with a national carbon budget range based on two different distribution principles.\(^4\)


\(^4\) The two principles of distribution are: the principle of sovereignty, based on historical emissions, and the egalitarian principle, based on population.
This budget range for Sweden has then been further disaggregated to the municipal level, taking principles of equity into consideration (such as population, size of economy, current and previous emissions, GDP per capita). The resulting regional carbon budget range for the municipality has then been translated into emissions reductions scenarios required if Järfälla wants to make its fair and science-based contribution to the fulfilment of the Paris Agreement.

The carbon budgets and emissions reductions scenarios that they result in include all activities in Järfälla Municipality that require energy (such as transport, construction, heating, production of goods etc.) yet only include the emissions produced within its geographic territory (so-called territorial emissions). The carbon budgets in this report do not include the emissions generated by the consumption of goods and services produced abroad (so-called consumption-based emissions), nor indirect emissions from agriculture and forestry.\(^5\)

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\(^5\) This delimitation was necessary because of the limited scope of the report. However, the emissions reductions calculated in this report can also be seen as an indicative minimum rate of reduction also for consumption-based emissions.
2. QUANTIFYING THE IMPlications OF THE PARIS AGREEMENT: A CARBON BUDGET FOR SWEDEN’S ENERGY SYSTEM

This section of the report translates the temperature and equity commitments enshrined in the Paris Agreement into a range of carbon budgets for Sweden from July 2017 until we reach a zero-emissions level globally. To appropriately understand and contextualise the conclusions of this section, it is important to be aware of the principal assumptions underpinning the analysis:

1) A very conservative reading of the Paris commitments; consequently, the conclusions should be understood as erring towards a highly optimistic range of carbon budgets and a minimum level of mitigation required.
2) All other major emitters make their respective contributions to reducing emissions in line with, as a minimum, a similar reading of the Paris commitments (i.e. there are no significant ‘free riders’).
3) No ‘negative emission technologies’ (NETs) are used to extend the carbon budget ranges (i.e. to make the mitigation challenge less onerous). See Appendix 1 for details.
4) No carbon-cycle feedbacks, outside those included in the model underpinning the IPCCs carbon budgets, are included. For example, the carbon budgets in this report are not affected by issues such as methane emissions from melting permafrost or additional soil metabolism as temperatures rise.6
5) Emissions of carbon dioxide from deforestation are, across the century, matched by carbon sequestration through progressive ‘land use’ and ‘land-use change and forestry’ (LULUCF).
6) Emissions from international aviation and shipping are included in Sweden’s carbon budgets through the emissions relation to the use of bunker fuels. If these emissions were to be considered separately7 then the corresponding cumulative emissions over the entire century would need to be removed from Sweden’s carbon budget.

IPCC carbon budgets

In November 2014, the Intergovernmental Panel on Climate Change (IPCC) published The Climate Change 2014 Synthesis report.8 Bringing together expertise from across the IPCC’s working groups, the Synthesis report provided a clear suite of “cumulative CO₂ emissions” (carbon budgets) for a range of different probabilities of “limiting warming” to below a rise of 1.5°C, 2°C and 3°C (relative to an 1861 to 1880 baseline).

6 For a detailed overview of this issue, see article in the journal Nature: Crowther, Todd-Brown et al. (2016) Quantifying global soil carbon losses in response to global warming.
7 e.g. the responsibility of the International Maritime Organisation (IMO) and the International Civil Aviation Authority (ICAO).
These budgets are and will remain the subject of ongoing and incremental study and refinement by climate science. However, until a new consensus is reached, the IPCC budgets remain the most authoritative source and should provide the foundation for any evidence-informed policies around energy issues related to climate change. The latest summary of the IPCC’s carbon budgets is found in Table 2.2 of the IPCC Synthesis Report. The table, copied below, has the block arrows marking the most relevant rows to this report.

![Table 2.2](image)

*Figure 1: likelihood of limiting the global increase of average temperature with different quantities of global cumulative emissions (carbon budgets). Taken from table 2.2 from IPCC synthesis report (2014).*

The carbon budgets for the temperature ranges of below 1.5°C and 2°C (<1.5°C & <2°C in the row with the white arrow) are the focus of this analysis. The row signalled with the grey arrow provides the probabilities of staying below that temperature (for a more precise explanation of these probabilities see Notes b to e accompanying the Table 2.2 in the full IPPC report). The headline carbon budgets for each of these probabilities for 1.5°C and 2°C are provided in the row signalled with the black arrow.

The carbon budgets are given in GtCO₂, i.e. billion (Giga) tonnes of carbon dioxide. It is important to note the budget is for the period of 2011-2100; this report adjusts the carbon budgets to allow for emissions between 2011 and July 2017, with values for the period 2016 to July 2017 extrapolated from near-term trends.

**Nota Bene:** In preparing this report, confidential conversations were had with a small selection of climate scientists as to the appropriateness or otherwise of continuing to use the IPCC AR5 carbon budgets as the basis for analysis. Whilst there was universal agreement that these would ultimately need amending to account for evolving scientific understanding, at this time the budgets in the IPCC’s Synthesis report remain apposite for the purpose of our analysis. An interesting facet of the discussions was an acknowledgement that the budgets were much less...

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9 The IPCC’s next synthesis report is due to come out in 2022.
susceptible to advances in scientific understanding than they were to potential changes in the assumptions about the emissions levels and timelines of the non-CO₂ greenhouse gases.

The Paris Agreement

In December 2015, all 195 member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the final text of the Paris Agreement. One of the principal aims of the agreement is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change”.

Another important commitment within the Paris Agreement and of particular relevance to this analysis is that “Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties”. This explicit distinction between industrial nations and poorer and industrialising nations is important in determining how to apportion the global carbon budget between different nations.

Converting qualitative obligations into quantitative objectives

The language of various international agreements on climate change is typically framed in qualitative terms in relation to quantitative temperatures. For example, the Copenhagen Accord formulation is “hold ... below 2°C”; the Camp David Declaration says to “limit... the increase ... below 2°C”; and now the Paris Agreement states to stay “well below 2°C” – and importantly to “pursue efforts to limit the temperature increase to 1.5°C”. In relation to all of these, it would be disingenuous to suggest anything other than they require mitigation in line with at least a likely chance of remaining below 2°C. With its additional reference to pursuing efforts for 1.5°C, the Paris Agreement clearly implies a still more stringent likelihood, so at least a very likely chance of 2°C.

Within the IPCC’s guidance notes to the authors of their latest report,¹⁰ they provided a taxonomy of likelihoods that facilitate a translation of qualitative chances into quantitative probabilities. Based on Figure 2 below (Table from the Guidance Notes) the language of international agreements on climate change, from Copenhagen onwards, clearly relate to a 66-100% probability of not exceeding 2°C. The Paris Agreement, with its reference to pursuing 1.5 °C as well as 2°C, suggests a still higher chance of the latter – more in line with a 90-100% probability of 2°C.

Consequently, the sequential logic of the Paris Agreement leads to a carbon budget from IPCC’s Synthesis report of somewhere between 850 and 1000 GtCO₂. The lower end of this range equates to an “unlikely” chance of staying below 1.5°C (i.e. a probability of 0 to 33% of <1.5 °C) with the upper end relating to a “likely” chance of staying below 2°C (i.e. a probability of 66-100% of <2°C).

Estimating the global energy-only CO₂ budget from July 2017

The 850 to 1000 GtCO₂ range is for all carbon emissions from all sectors from 2011 until we reach zero emissions globally. Therefore, in order to understand what emissions are available from July 2017, it is necessary to subtract emissions released between 2011 and up to and including June 2017. Based on CDIAC (Carbon Dioxide Information Analysis Centre)\(^\text{11}\) data, extrapolated to June 2017, at least 260GtCO₂ has been emitted since 2011 leaving a range of 590 to 740GtCO₂ for post-June 2017 until we reach zero emissions globally.

Making allowance for emissions from deforestation and cement manufacture (process-CO₂ only)

Given this analysis relates specifically to the energy sector, it is necessary to remove projected global deforestation and industrial process emissions for the period 2017 to 2100; the latter of which relates primarily to cement production. Based on research recently published in Nature

\(^{11}\) http://cdiac.ornl.gov/
Geoscience, an optimistic interpretation of deforestation and cement process emissions post-2015 are, respectively, in the region of 60GtCO₂ and 150GtCO₂ (for the period 2017-2100).

However, for this analysis, still more optimistic assumptions have been made for both sectors, broadly in accordance with the titanic mitigation efforts required of the energy sector. In terms of carbon dioxide from deforestation, and following on from the headline assumption #5, no reduction in the global carbon budget is made in this analysis. For this analysis, it has also been assumed that process emissions from cement production are 100 Gt CO₂ for the period after July 2017. Thus, the global range of carbon budgets from energy is between 490 and 640 Gt CO₂ (from July 2017), when emissions from deforestation and cement have been taken into account. For a detailed account of these calculations, see Appendix 2.

Apportioning the global budget among industrialised and industrialising nations

This is undoubtedly an area where different interpretations of fairness and equity can give potentially very different results in terms of national carbon budgets. For an account of the assumptions that support the analysis in this report, see Appendix 3. The approach adopted here builds on the pragmatic and open process of apportionment used in a number of analyses and high-level reports since 2011. Put simply, the approach recognises the highly-limited nature of the 2°C carbon budget and then asks, within such a constraint, what is the most ambitious peak date industrialising nations could achieve and what could they subsequently deliver in terms of mitigation rates. The wealthy OECD countries' emissions allowance will be the very limited share that remains in the carbon budget.

This approach is in line with the internationally established principle of Common but Differentiated Responsibilities (CBDR) on which the UNFCCC and, subsequently, the Paris Agreement are based upon. This principle recognizes the greater responsibility of wealthier industrialised countries, based on both their major contributions to climate change over time (historical responsibility) and their greater capacity to do something about it (higher incomes, existing infrastructure, institutions, etc.). The principle also recognizes the poorer countries' rights to development and the responsibility of richer countries to provide financial and technological support to enable poorer countries to decrease their emissions and to adapt to the impacts of climate change.

The Paris Agreement thus implies that a country such as Sweden, and in extension, a municipality like Järfälla must both ensure drastic emission reductions within its territory, in line with this report, while also contributing both to climate financing and technology transfer to allow emission reductions in other poorer countries as well as resources for adaptation measures. In short, this means that, in addition to their own ambitious emissions reductions,

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13 The total emission peak is the time when carbon dioxide emissions reach their highest value.
14 See, for example, Fair Shares: A Civil Society Review of INDCs Report, November 2015,
Järfälla Municipality should enable a transition in one or more municipalities / regions in other countries. This, however, falls outside the scope of this report.15

Scenarios and carbon budget for industrialising countries

For this report, a series of updated scenarios (see Box 2 in the Appendix) have been generated, building on earlier research16 and recognising the stipulation of the Paris Agreement that “developing” nations will take longer to make the transition away from fossil fuels than richer, more industrialised nations. For the analysis here, industrialising and developing nations are captured within the non-OECD classification; in relation to emissions, this is sufficiently close to the groupings used in international climate negotiations (non-Annex 1 and non-Annex B) to make no discernible difference.

The non-OECD scenarios developed for this report assume highly ambitious rates of mitigation beyond any thus far considered in other similar analyses. Nevertheless, the cumulative emissions from these mitigation scenarios have fundamental and challenging implications for both the Paris temperature commitments and the 2°C mitigation challenge of the OECD.

The post-2017 cumulative emissions for the non-OECD region range from:

**Scenario 1 - S1**: 2020 peak emission year; 10% p.a. mitigation by 2042; 95% CO\textsubscript{2} cut by 2060 = 502 GtCO\textsubscript{2}

**Scenario 6 - S6**: 2025 peak emission year; 10% p.a. mitigation by 2047; 95% CO\textsubscript{2} cut by 2065 = 620 GtCO\textsubscript{2}

What is immediately evident, is that even a highly ambitious mitigation programme by the non-OECD region would have cumulative emissions in excess of the fossil fuel carbon budget for an “unlikely” chance of staying below 1.5°C (i.e. 490 GtCO\textsubscript{2}). Consequently, from a carbon budget and mitigation perspective, 1.5°C is no-longer a viable temperature commitment.

Moreover, a mitigation agenda across the industrialising nations at a level of ambition far beyond anything discussed in Paris would also exceed the global (energy-only) carbon budget for a “very likely” chance of 2°C. That is to say, a strict reading of the political framing of the Paris ambition in terms of “well below 2°C” is also now not a viable goal. For the more conservative reading of Paris underpinning this report, the carbon budget accompanying a “likely” chance of 2°C remains viable - just. However, the enormous scale of ambition embedded in the non-OECD scenarios still


15 This report has not been able to analyse and quantify implications for Sweden or Järfälla regarding the necessary climate financing, technology transfer, and adaptation measures, but points out that this responsibility should be recognized and quantified in the future.


http://rsta.royalsocietypublishing.org/content/369/1934/20
delivers emissions that consume between 78% and 97% of the remaining fossil fuel global carbon budget for a probable chance of keeping the global temperature rise below 2°C.

A carbon budget for the OECD countries

As demonstrated above, the Paris requirement of nations “to pursue efforts to limit the temperature increase to 1.5°C” is no longer a viable mitigation commitment. Furthermore, a “very likely” chance of staying “well below 2°C” is also now beyond any conceivable mitigation programme. However, holding emissions within the carbon budget range for a “likely” chance of 2°C does, at least theoretically, remain achievable. It is this agenda that now provides the focus of the remaining analysis within this chapter of the report.

With a global energy-only CO₂ budget of 490 to 640 Gt CO₂ (from 2017), and with non-OECD cumulative emissions (according to scenarios S1 to S6) of 502 to 620 Gt CO₂, the remaining budget range for the OECD extends from a high of 140 Gt CO₂ to a low of just 20 Gt CO₂. Transposing these into theoretical mitigation rates, these equate to immediate and prolonged cuts in emissions of between 9% and 40% per annum (p.a).

A carbon budget for Sweden (for a fair contribution to a “likely” chance of 2°C)?

There are various regimes for apportioning the emissions budget from the industrialised nations grouping of the OECD to individual nations or regions. Such approaches cover the relatively simple population or sovereignty approaches (allocation on the basis of recent emissions) to more elaborate relationships founded on economic wherewithal, geographic and cultural capacity, etc. For this report, the two simple approaches are applied; the sovereignty principle, also known as ‘grandfathering’ (based on average emissions since 2010), and the so-called Egalitarian Principle (based on population). Overall, these both play in favour of Sweden, reducing the relative contribution it would otherwise need to deliver if its high income per capita (~18% above the OECD mean), its geography and climate (conducive to very large renewable energy development), and its highly-educated (and environmentally aware) electorate were to be taken into account. As such the carbon budgets developed here specifically for Sweden, are at the higher end of those that a more stringent equity criteria would otherwise yield. See Appendix 4 for a more detailed review of different apportionment regimes.

Based on data about Sweden and OECD from 2010 up to and including 2015, the two apportionment regimes adopted for this project allocate to Sweden 0.361% (Grandfathering) and 0.767% (Population) of the OECD’s post-2017 energy-only CO₂ budget range (140 to 20 Gt CO₂). Building on this, Sweden’s post-2017 budget range is outlined in Table 1, with the final (red) columns providing numbers associated with the central budget range for this report.
Apportionment regime | Based on 140GtCO₂ | Based on 20GtCO₂ | Sweden’s mid-value CO₂ budget | Sweden’s minimum mitigation rate  
--- | --- | --- | --- | ---  
Grandfathering (0.361%) | 505MtCO₂ | 72MtCO₂ | 289MtCO₂ | 15% p.a.  
Population (0.767%) | 1074MtCO₂ | 153MtCO₂ | 614MtCO₂ | (7% p.a.)

Table 1: Sweden’s “likely” 2°C post-2017 energy-only CO₂ budget (MtCO₂)

a: assumes a peak in non-OECD emissions by 2020  
b: assumes a peak in non-OECD emissions by 2025  
c: assumes a peak in non-OECD emissions between 2022 and 2023 (to remove any spurious precision, this is rounded to between 300 and 600MtCO₂ in the “Key Messages” section).  
d: this rate needs to be raised to at least, 10% p.a. starting immediately, for a variety of reasons, but mainly because of the highly ambitious and comprehensive emission scenarios for poorer (non-OECD) countries in which the analysis in this report is based. See the following section for a more detailed account.

What is immediately obvious from the table (see table notes a to c) is how highly sensitive Sweden’s carbon budget is to the precise date by when the non-OECD nations reach a collective peak in emissions. The choice of apportionment regime, though important, has a relatively small impact on the size of Sweden’s carbon budget.

Mitigation rates for Sweden to meet its 2°C commitments

It has already been established that it is no longer possible for the global community to mitigate energy emissions in line with the carbon budget range for even an “unlikely” chance of 1.5°C. In relation to the budgets for a “likely” chance of 2°C, a small but rapidly dwindling prospect remains, with Sweden’s respective carbon budgets outlined in Table 1. Translating these budgets into simple mitigation pathways, and hence rates, provides a quantitative framework against which policies can be examined to judge whether they are or are not commensurate with Paris.

The final column of Table 1 transposes the budgets into stylised mitigation pathways for Sweden. These pathways assume a set mitigation rate, beginning in July 2017 and reducing emissions at a sufficient rate to maintain total emissions within the given budgets. This rate is lower than what would be required in reality since it does not take into account the transition period from Sweden’s current very gradual and low reductions to the high and sustained emission reductions that would allow Sweden to stay within its carbon budget.

An immediate issue with the 7 to 15% p.a. mitigation rates described in Table 1, is the inequitable position that arises when Sweden’s mitigation agenda depends on highly ambitious and all-encompassing scenarios for non-OECD nations (S1-S6). Under such circumstances, Sweden’s 7% p.a. mitigation rate is lower than that ultimately demanded of the non-OECD nations (10% p.a.).
Given the substantial (and growing) asymmetry for existing anthropogenic climate change between wealthier nations and poorer, industrialising nations, it would be difficult, if not impossible, to justify lower mitigation rates for Sweden than those ultimately required by non-OECD nations — even though there is an important time differential between the two. For this reason, the main recommendation of this report, in relation to Sweden, is that its immediate mitigation rate be at a minimum level of 10% p.a. and ideally at 15% p.a. Any delay in delivering on such mitigation will see either the mitigation rate increase still further, or Sweden’s relative inaction jeopardising global delivery of the Paris 2°C commitment. Figure 3 shows how the scenarios of Swedish territorial emissions look over time at 10% and 15% annual emissions reductions.

Figure 3: Two emissions scenarios for Sweden based on annual territorial carbon emission reduction at 10% and 15% respectively from July 2017. Historical emissions based on data provided by Statistics Sweden (Statiska Centralbyrån) in their Systems of Environmental and Economic Accounts.

A first step in realizing these challenging emissions reductions, is to understand which activities and sectors are producing the emissions. Figure 4 below shows the distribution of Swedish territorial CO₂ emissions by sector. As seen in this figure, transport and industry accounted for a majority of emissions in 2015. Their emissions have also been more or less constant over the period 1990-2015. There are major challenges and opportunities for Sweden and its regions and municipalities to pursue active policy instruments that drastically and immediately reduce emissions from these sources.
An illustration of this can be observed in Figure 5 (below) which illustrate the historical emissions from two different sectors that have had opposite trend in recent decades. The phasing out of fossil fuels in the heating of houses may be seen as an illustrative example to draw lessons from in the implementation of policies that reduce emissions in other sectors. Parallely, international transportation (Maritime and Aviation)\textsuperscript{17} has, however, seen a considerable increase in its emissions. The phasing out of fossil fuels may be more difficult here, as alternatives to fossil fuels are very limited in these sectors today and will remain so within the time frame to deliver on the Paris Agreement goals. Appropriate and effective instruments are required to ensure that these emissions trends are immediately reversed and begin to decline drastically. Most likely, this will apply to all the major sectors responsible for Sweden’s carbon emissions, as presented in Figure 4.

\textsuperscript{17} Applies to both transport of people and goods.
The Swedish All Party Committee on Environmental Objectives and its proposed climate policy framework

In 2016, the All Party Committee on Environmental Objectives presented two reports\(^\text{18}\) as the basis for the preparation of a Swedish climate policy framework in the form of a proposal referred to the council of legislation in March 2017.\(^\text{19}\) In very short terms, it was proposed that Sweden’s commitment should be to achieve net zero emissions in 2045. The reports of the All Party Committee and the proposal to the council of legislation are a step in the right direction and could play a significant role in forming a framework to articulate Sweden’s climate commitments.

Unfortunately, the climate policy framework, now adopted as a ‘Swedish climate law’, (in contrast to, for example, the British equivalent) currently lacks a scientific basis, and also a

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\(^{18}\) A climate policy framework for Sweden - A partial report from the Cross-Party Committee on Environmental Objectives [2016-03]: http://www.regeringen.se/rattsdokument/statens-offentliga-utredningar/2016/03/sou-201621/

\(^{19}\) Proposal to the council of legislation on a climate policy framework for Sweden [2017-02-02]: http://www.regeringen.se/rattsdokument/lagradsremiss/2017/02/ett-klimatpolitiskt-ramverk-for- sverige/
coherent account of how the Swedish climate policy framework ensures that Sweden makes its fair contribution to the fulfilment of the Paris Agreement. The adopted climate policy framework is not based on the most up-to-date and relevant climate research in that it does not build its analysis on cumulative emissions budgets but rather on long-term, politically determined goals.

It further sets out insufficient sub-goals in that they have little to do with the actual Swedish climate impact or fulfilment of commitments in the Paris Agreement and therefore does not offer a contribution based on the basis of equity. Furthermore, the goals in the climate policy framework are quite general and largely not applicable at the municipal-level, wherein a more in-depth analysis of the goals is not part of this report.

Assuming that the climate policy framework in its current form is followed, a preliminary estimate shows that it could result in cumulative carbon dioxide emissions that are more than 3 times higher (already in 2045) than the carbon budget Sweden must adhere to, according to the estimates of this report, in order to reach the 2°C commitment. If Sweden is to live up to its stated ambition to be a leading country in the climate change transition, a far more ambitious agenda than that arising from the current climate policy framework must be initiated and without delay.
3. QUANTIFICATION OF THE PARIS AGREEMENT’S IMPLICATIONS: A CARBON BUDGET FOR JÄRFÅLLA MUNICIPALITY

This section of the report describes how the carbon budget set out for Sweden can be allocated to the level of a municipality and aims to outline the possible distribution principles that can be used, before calculating a carbon budget and associated emissions reductions for Järfälla Municipality. In order to allocate the Swedish carbon budget between municipalities, a transparent, fair, and agreed-upon distribution model at the national level is required to ensure that total emissions from Sweden do not exceed the country’s carbon budget. In the absence of such an agreed-upon national distribution model, this report has produced a preliminary carbon budget for Järfälla Municipality based on the line of reasoning below.

Allocation of Sweden’s carbon budget at the municipal level

Analogously with distribution principles at the international level, principles at the national level were identified for Sweden’s carbon budget to be divided fairly and efficiently between Sweden’s municipalities and sectors.

The operationalisation of equity and fair shares within the logic of global carbon budgets and applied locally, in the case of the Järfälla Kommun, was based on a set distribution principles outlined below. There are a number of different principles that can be used to allocate the remaining emission space of a carbon budget between, for example, municipalities, regions, or sectors in society. The four considered in the preparation of this report are based on environmental and ethical research on the sharing of the climate burden, and are presented in more detail in Appendix 4. The four principles for calculating carbon budgets are, in brief, based on:

1. Population - the so-called egalitarian principle
2. Earlier emissions determine future emissions - the so-called sovereignty principle or ‘grandfathering’
3. Ability to pay for emission reductions – a payability principle
4. Higher emissions give higher emissions reduction requirements - 'polluter pays' principle

A significant difference when it comes to choosing a distribution principle within Sweden (as compared to the calculation of Sweden’s carbon budget) is that a municipality is much more economically, politically, and geographically bound and dependent on Sweden and other Swedish municipalities than a country like Sweden is within the OECD. The economic structures also vary considerably between Sweden’s municipalities, which is reflected in their different territorial emissions. Municipalities with heavy industry such as Lysekil and Oxelösund have, for example,

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emissions per capita up to 100 times as large as, for example, most Stockholm municipalities such as Danderyd, Sundbyberg, and Solna, and up to 60 times larger than Järfälla Municipality.

In this report, we have based the calculation of carbon budgets on territorial emissions\textsuperscript{21}. Due to the large variation between municipal territorial emissions and the high degree of interdependence between municipalities and regions (to meet basic societal functions), the 'polluter pays' principle and the egalitarian principle are considered inappropriate to calculate municipal carbon budgets. For the purposes of this report and within the context of Sweden we found the sovereignty principle (grandfathering) to be the most appropriate and fair principle. For future reference, adjustments to this principle might be appropriate, e.g. considering municipalities' ability to pay (Gross Regional Product) and economic demography (average income of population) and the degree that a municipality's activities contribute to societal functions that benefit other municipalities.

A carbon budget for Järfälla Municipality

Territorial emissions from Sweden's municipalities can be calculated in two different ways:

1. The environmental accounts from Statistics Sweden (SCB) provide regional and local statistics, which are then used for reporting to the climate convention.\textsuperscript{22} Emissions from registered individuals and registered activities with headquarters in the municipality are included in these estimates of territorial emissions (no matter where the individuals or activities release them).\textsuperscript{23}

2. RUS (Regional Utveckling & Samverkan i Miljömålssystemet) provides an emissions database\textsuperscript{24} based on statistics submitted for reporting to the climate convention, but distributing emissions across Sweden with a strict geographic method where only actual emissions within a municipality's limits are taken into account (from both point sources and more diffuse sources). However, RUS statistics do not include emissions from international transport (air and shipping).

As far as the RUS statistics are concerned, the Swedish emissions from international transport should therefore be removed from the calculated carbon budget for Sweden at 614-289 Mt CO\textsubscript{2}. Emissions from international transport (2010-2015) were on average 14.88% of Sweden's total

\hspace{1cm}

\textsuperscript{21} For a country like Sweden, as well as many Swedish municipalities, a calculation of carbon budgets based on consumption would result in more challenging requirements for annual emissions reductions than those resulting from territorial carbon budgets. Statistics on consumption-based emissions as well as other demographic indicators such as per capita average income could also be included in a more detailed allocation principle of the Swedish carbon budget.

\textsuperscript{22} \url{http://www.scb.se/hitta-statistik/statistik-efter-amne/miljo/miljoekonomi-och-hallbar-utveckling/miljorakenskaper/}

\textsuperscript{23} Personal communication with Maria Lidén, responsible for environmental accounts at Statistics Sweden, 2017-05-02

\textsuperscript{24} \url{http://extra.lansstyrelsen.se/rus/Sv/statistik-och-data/nationell-emissionsdatabas/Pages/default.aspx}
emissions. Based on this, the Swedish carbon budget in relation to the RUS statistics is 85.12% lower than for Statistics Sweden, i.e. 523 Mt CO₂ to 246 Mt CO₂.²⁵

When the allocation principle of 'grandfathering' is applied to statistics on Sweden’s and Järfälla’s emissions (2010-2014), Järfälla receives an allocation of 0.172% (RUS) and 0.214% (SCB) of the respective Swedish carbon budget for energy (from July 2017 and beyond). Based on this, Järfälla's carbon budget range is presented in Table 2 below, where the final (red) columns present the necessary annual emission reduction rates from July 2017 onwards.

<table>
<thead>
<tr>
<th>Distribution Based on source</th>
<th>Based on the Swedish max. budget range</th>
<th>Corresponding annual emission reductions</th>
<th>Based on the Swedish min. budget range</th>
<th>Corresponding annual emission reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCB a (0.214%)</td>
<td>1314 KtCO₂</td>
<td>(≥8%)c</td>
<td>618 KtCO₂</td>
<td>16%</td>
</tr>
<tr>
<td>RUS b (0.172%)</td>
<td>900 KtCO₂</td>
<td>(≥7.5%)c</td>
<td>423 KtCO₂</td>
<td>15%</td>
</tr>
</tbody>
</table>

Table 2: Järfälla’s Carbon Budget (KT CO₂) for energy from July 2017 for a “likely” chance to reach the 2°C commitment.

a: Calculations are based on a Swedish carbon budget range of 614 to 289 Mt CO₂ for energy (July 2017)
b: Calculations are based on a Swedish carbon budget of 523 to 246 Mt CO₂ for energy (July 2017)
c: These rates should be increased to at least 10% per year with immediate effect, see below.

For the same reasons as stated earlier with regards to Sweden’s emission reductions (in Part 2 of this report), the lowest emission reductions for Järfälla should be raised to at least 10% per year with immediate effect. It is worth recalling that the budget for Sweden that this analysis is based on presupposes a peaking of emissions from the non-OECD region already in 2022-2023 which, as already mentioned, is a much more ambitious target than discussed in at international climate negotiations.

The emission profile of the municipality heavily influences its budget. Indeed, the municipality of Järfälla does not have any particular extensive activity that is both emissions-intensive and which

²⁵ Even with this adjustment, the aggregated sum of total annual CO₂ emissions from the RUS database differs from the corresponding statistics from SCB’s environmental accounts by approximately 4%. The reason has not been able to be investigated within the scope of this report, but the difference is small enough in relation to other assumptions in order not to make a noticeable difference.
benefits other regions. It also offers a quality of life for the municipality's inhabitants which is partially upheld by the emissions of other municipalities and regions. Therefore, the necessary emissions reductions of Järfälla Municipality should not be adjusted downwards for this reason (rather the opposite). Järfälla's Gross Regional Product per capita is 73.5% of gross domestic product per capita in Sweden, which is largely due to the relatively low level of industries and production in the municipality. If we look at the median income per inhabitant in Järfälla, it was 8% higher than the Swedish median income in 2015.26

In conclusion, if any adjustment of the carbon budget for Järfälla Municipality (and the associated necessary emission reductions) would be carried out based on economic factors, it would result in even more challenging emissions reductions for the municipality.

The calculation of the carbon budget and emissions reductions found in Table 2 above provides an indication of what Järfälla Municipality needs to aim for: 15% annual emissions reductions, with 10% as an initial minimum, with immediate effect, if a fair contribution is to be made to a "likely" chance of achieving the 2°C commitment.

This section of the report presents scenarios for the emissions reductions resulting from the calculated carbon budgets for Järfälla Municipality. Through a closer look at the municipality of Järfälla and with a number of illustrative examples, possible measures are also proposed to enable the transition to a fossil-free future in Järfälla Municipality, in Sweden, and in the world.

Emissions reductions in Järfälla to reach the 2°C commitment

As stated in Section 3 above, the calculated carbon budget (based on two different databases) calls for territorial emissions reductions in Järfälla Municipality of 10%-16% per annum. Based on the emissions database (RUS) of territorial CO₂ emissions from municipalities, two emissions scenarios for Järfälla Municipality are presented in Figure 6, based on the headline 10% and 15% annual reductions in territorial emissions.

![Figure 6: Two emissions scenarios for Järfälla based on territorial emissions reductions of CO₂ at 10% and 15% from July 2017. Historical emissions based on statistics from the Emissions database of RUS.](image-url)
The territorial emissions in 2015 for Järfälla Municipality were 72,540 kt CO₂ according to RUS emissions database. Based on the environmental accounts of SCB, emissions were 117,000 kt CO₂ in the same year, or 61% higher than emissions based on the RUS statistics. As mentioned earlier, Järfälla should aim for a 15% reduction in emissions per year, rather than the minimum annual rate of decline of 10%. This applies not least if the strict territorial emissions statistics from RUS are used, since this statistic takes less account of Järfälla’s overall climate impact and responsibility in comparison with SCB’s environmental accounts.

Järfälla’s emissions – a brief analysis

As can be seen in Figure 7, a majority of Järfälla’s territorial emissions come from transport. In 2014, transport accounted for 71% of total CO₂ emissions. Of these transport emissions, passenger cars accounted for 64% and trucks for 28%. With regards to energy supply, we can see that emissions have fallen sharply over the period of 2005-2014 from nearly 20,000 to only 6,000 KtCO₂. This reduction has been largely achieved by reducing emissions produced by energy supply from electric and thermal power plants, but emissions from district heating infrastructure have also decreased significantly percentage wise. Of the 6,000 annual KtCO₂ from energy supply that were measured in 2014, the majority (62%) derived from combustion from industry for energy purposes. Looking at Järfälla’s total emissions, energy supply is only a small part (8% in 2014). Product use (mainly from lubricants) also accounts for a relatively small proportion (just under 5% in 2014) of total emissions. Emissions from industrial processes are small and could be considered negligible. Emissions from fuel-driven machinery (for construction and more), on the other hand, are significant and have also been relatively constant over the period 2005-2014. In 2014, they were 16% of total emissions, and to a large extent consisted of emissions from companies’ machinery. It is not clear what these exact activities are by analysing the statistics, but they are likely to relate to building and construction.

Figure 7: Territorial emissions of carbon dioxide in Järfälla Municipality according to emission source. Statistics from emissions database (source: RUS).
As mentioned earlier, Järfälla Municipality's territorial emissions (whether based on RUS or SCB) are low in comparison with other municipalities or regions in Sweden. The special conditions that exist for the municipality of Järfälla probably have largely enabled this, including the absence of heavy industries as well as other significant sources of emissions within the municipality's borders that contribute to welfare functions in their own or other municipalities. This is also reflected in Figure 7 where transport (and partly the construction sector) accounts for the vast majority of emissions.

A framework for Järfälla’s energy and climate plan

Demonstrating comprehensive and coherent leadership on climate change in a municipality like Järfälla entails expanding its responsibility beyond the geographic boundaries of the region (see Figure 8). It includes actions within the municipality's own organisation, actions that occur within the municipality's borders, and pushing for higher ambitions regionally as well as nationally. For Sweden and its municipalities, this type of leadership also includes supporting and enabling countries and other municipalities in poorer countries to advance and accelerate their transformation towards a fossil-free future, at least in line with the assumptions made in this report for non-OECD countries' collective peaking of emissions in the years of 2022/2023.

In order to enable these highly ambitious transformations in developing countries while also building infrastructure and welfare systems, financing and technology transfer are required to an extent that likely corresponds to several times that of the existing budget for foreign development cooperation. In order to fulfil the Paris Agreement, municipalities need to contribute their fair share - partly in terms of the contributions of its residents and companies to national-level taxes for new, increased climate financing, and partly in the form of direct actions and transfers from municipalities in Sweden to municipalities in other countries. By building on the "sister cities" model, municipalities could find ways to collaborate across national borders to work with the shared challenge of climate change. Järfälla Municipality can also reduce its own climate impact by, for example, placing higher demands in its procurements and purchases, especially in those sectors where emissions continue to be high.
Figure 8: Climate responsibility and climate leadership from Järfälla Municipality.

An inventory of opportunities and analysis of how Järfälla Municipality can assume responsibility for the different geographical areas presented in Figure 8 is beyond the scope of this report, but it is recommended that Järfälla further investigates this if a fair and real contribution is to be made to keeping the average temperature rise on Earth below 2°C.

An analysis of the emissions from the municipality's own activities (Järfälla Municipality in Figure 8) vis-à-vis those for the entire municipal territory (Local (Järfälla) in Figure 8), has not been possible with the statistics that were available. However, the following section contains a preliminary outline of how Järfälla could initiate and start to work towards a fossil-free future.

Pathways to a fossil-free future for Järfälla Municipality

There are around 74,000 people living in Järfälla. The night population is about 34% higher than the day population (which indicates that is is, in part, a commuter municipality). In recent years, there has been a significant increase in the number of homes being built. A goal of the municipality is to build 1000 new apartments per year with an expected population of 100,000 in the year 2030.27

These goals create both challenges and opportunities from an energy and climate perspective. The results of this report need to be set in relation to these ambitions and goals if Järfälla Municipality wants to make their fair contribution to a "likely" chance of achieving the 2°C

27 This paragraph is based on personal communication with Megha Huber, Järfälla Municipality and ‘Kommunfakta’ for 2016 from SCB.
commitment. The obvious impact that the municipality can have is to ensure that all new construction is as CO₂-neutral as possible and that the emissions from the transport sector (from both public and private activities) are rapidly reduced. Below are some preliminary proposals and policy instruments that could deliver real and significant emission reductions from the energy sector at municipal, regional, and/or national level. They are divided into three headings in relation to their focus: demand for energy, access to renewable energy, and other policy measures.

**Demand for energy**

- Ensure that all new buildings are of passive house standard
- Retrofitting existing buildings
- Max CO₂ standard on all new cars / trucks combined with electrification of the transport system (e.g. Max 100g CO₂ / km and decrease by 8% per year)
- Policies that drive behavioural change by high-energy users. (e.g. progressive metering tariffs, frequent flyer levy, personal carbon allowances)

In a Swedish context according to preliminary estimates, these measures could, if combined, reduce energy demand between 40-70% in just 10-15 years.

**Access to renewable energy**

- A major electrification program (heating, transport, etc.)
- More efficient and much higher rated interconnectors (mainly relevant for the national level)
- Support the expansion of smart grids, intelligent metering, and renewable, community energy production
- Sustainable expansion of renewable energy sources and very low CO₂ energy
- Develop indigenous biomass, biogas, and P2G for intermittency/base load

**Other policy measures**

- Immediate divestment and rapid retirement of all hydrocarbon assets
- Investments in carbon capture and storage of emissions from cement and steel production
- A moratorium on airport development (mainly relevant to the national level and municipalities where airports exist or are intended)
- Major programme and investment in public transport, such as modern and efficient high-speed trains (including night train in Sweden and to Europe), subways, tramways, etc.
- Enable long-term investment environments and investment cycles (low interest rates, climate and environmental accounting, etc.)
This is of course a very preliminary, incomplete, and relatively general list of possible measures. Some of these proposals are probably possible and appropriate to implement within the municipality, while other proposals may require coordination or cooperation at the regional level as well as leadership at the national level. Given the territorial emission profile of Järfälla Municipality, the proposals focusing on the transport and construction sector may be most relevant in terms of emissions within the municipality's borders. However, other proposals can still have a significant and central role to play in dealing with emissions outside the municipality's borders and further measures should be taken to reduce consumption-based emissions.

Järfälla and the global climate transition

One should recognize that the challenge presented in this report is so comprehensive that it is difficult to find contemporary examples where this kind of rapid social change and emissions reductions have been carried out within a municipality, region, or country. However, there are plenty of historical examples where societies quickly transitioned their societies, and they are often associated with crises, conflicts, wars, or subsequent reconstruction.

The option, however, of not assuming this challenge is that current and future generations will have to live with the radical changes that escalating climate change will entail. If this transition can take place within Järfälla Municipality, in other Swedish municipalities, in Sweden, and in other parts of the world, bold visions and leadership are needed. It is gratifying to see that, for example, Oslo Municipality also has calculated its carbon budget and set a clear objective of reducing its emissions by 50% by 2020 and by 95% by 2030 (relative to the reference year 1990).28 Also in the business sector there are networks such as ‘Hagainitiativet’ where a number of large companies have committed to emissions reductions that are more ambitious and drastic than those proposed by the Swedish All party committee on environmental objectives.

About 40 megacities around the world have collaborated since 2005 to reduce their emissions and climate impacts within the C40 network.29 The Uppsala Climate Protocol is an example of a local initiative that enables and encourages cooperation between public authorities, companies, and civil society in the region.30 Transition Towns and The Transition Network31 is another interesting initiative with roots in the English countryside, but now growing into a popular movement all over the world. Swedish networks of municipalities such as ‘Sverige Ekokommuner’32 and ‘klimatkommunerna’33 are other interesting examples which could also

29 http://www.c40.org/
30 https://www.uppsala.se/klimatprotokollet
31 https://transitionnetwork.org/
32 http://www.sekom.se/
33 http://www.klimatkommunerna.se/
potentially play an important role in catalysing and supporting cooperation between municipalities that wish to make their fair contribution to the fulfilment of the Paris agreement.

We hope that this report can be an important and useful document for Järfälla Municipality to reflect on and use as a basis when further developing its energy and climate plan, and consequently have an impact on the municipality's environmental and financial plans for the years to come. We also hope that the municipality of Järfälla will take responsibility and show true leadership in the climate issue by unlocking pathways to a fossil-free and sustainable future in Sweden and in the world - we and future generations will thank you.
Appendix 1 – Negative Emissions Technologies and 2°C

Virtually all of the 2°C scenarios within the IPCC’s database include negative emissions technologies removing several hundred billion tonnes of carbon dioxide directly from the atmosphere across, and beyond, the century. However, there is wide recognition that the efficacy and global rollout of such technologies are highly speculative, with a non-trivial risk of failing to deliver at, or even approaching, the scales typically assumed in the models.

Whilst the authors of this report are supportive of funding further research, development and, potentially, deployment of NETs, the assumption that they will significantly extend the carbon budgets is a serious moral hazard. Ultimately, if there is genuine action to mitigate emissions in line with a “likely” chance of staying below 2°C, and then NETs do prove to be a viable and scalable option, then, in theory at least, an opportunity arises for holding the temperature rise to 1.5°C. By contrast, if action to mitigate for 2°C is undermined by the prospect of NETs, and such technologies subsequently prove not to be scalable, then we will have bequeathed a 3, 4°C or higher legacy. As is clear from the 2°C scenarios submitted to the IPCC, the inclusion of carbon capture and storage (CCS) and biomass with carbon capture and storage (BECCS) include considerably more fossil fuel combustion than those without them. It is evident, that mitigation advice to government is already being influenced by assumptions about NETs, and indeed the rapid uptake of CCS, neither of which shows any sign of approaching the scales of rollout in the models.

These figures, provided by Glen Peters (Cicero) and based on the IPCC scenarios for a 66-100% chance of staying below 2°C, demonstrate how the inclusion of CCS (and by definition BECCS) result in much more fossil fuel use (i.e. much less actual mitigation).

Appendix 2 – Emissions from deforestation and cement production

Making allowance for emissions from deforestation and cement manufacture (process-CO₂ only)

Given this analysis relates specifically to the energy sector, it is necessary to remove projected global deforestation and industrial process emissions for the period 2017 to 2100; the latter of which relates primarily to cement production. It could be argued that these should both be considered at a national level, however, given the very clear equity steers within all agreements since the Copenhagen Accord, such emissions are more rightly considered as a global overhead. Wealthy industrial nations already have highly developed and cement-rich infrastructures – from the domestic and commercial built environments, to transport and energy networks, power stations and industrial facilities. Poorer and less-industrialised nations still have to construct their modern societies. Penalising them for their later development is inconsistent with the equity dimension of the various agreements. Similar arguments prevail for deforestation emissions, where most industrial nations have already benefitted from the land released through deforestation. Considering these emissions as a global overhead does not absolve those nations using cement and deforesting from responsibility. It does however reduce the burden and provide an incentive for all nations to encourage a global reduction in deforestation and the development of low-carbon cements (or alternatives).

Based on research recently published in Nature Geoscience, an optimistic interpretation of deforestation and cement process emissions post 2015 are, respectively, in the region of 60GtCO₂ and 150GtCO₂. However, for this analysis, still more optimistic assumptions have been made for both sectors, broadly in accordance with the titanic mitigation efforts required of the energy sector.

In terms of carbon dioxide from deforestation, and following on from the headline assumption #5, no reduction in the global carbon budget is made in this analysis. Given the high correlation between cumulative emissions across the century and temperature rise towards the end of the century, it is assumed here that enormous efforts are put into rapidly eliminating deforestation, with all related emissions more than compensated by a programme of afforestation and progressive changes in land-use. Under such an ambitious framework, the emissions from deforestation will occur earlier than sequestration from afforestation etc., consequently it is important that any planned programme of the latter is notably larger than the emissions of former. This is necessary to help reduce the very real risk that sequestration in the longer-term will not match emissions from deforestation in the nearer term.

For this analysis two new cement scenarios have been developed using the most recent emissions data and with still more optimistic assumptions about the role of cement, and therefore process emissions, between now and the middle of the century. These scenarios are summarised in Box 1 below and for the purpose of this report, the highly optimistic estimate of process emissions from cement is assumed to be 100GtCO₂ for the period post 2017.

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Consequently, once allowance has been made for emissions from deforestation and cement, the global carbon budget range for energy-only emissions associated with the temperature commitments of the Paris Agreement reduces to between 490 and 640 GtCO₂ (from July 2017).

**BOX 1: Global Cement Scenarios of Process Emissions (C1 & C2)**

According to the Global Carbon Project’s emission database (private communication with Glen Peters and Robbie Andrews at Cicero) cement process emissions grew at 5.5% per annum between 1950 and 2015. Since 2000, the five-year annual average growth has been over 6% per annum, with the latest data for 2015-16 notably lower at just 2.4%.

There are almost no long-term forecasts or explicit scenarios of cement growth and emissions. However, the 2009 IEA Cement Road Map does provide two scenarios for cement growth from 2009 to 2050. That said the growth rates are far lower than those witnessed since 2009 or are evident over any period during the past six decades.

The two scenarios developed here (C1 and C2) both adopt the optimistic carbon intensity assumptions within the IEA report in relation to reducing the CO₂ emitted per tonne of cement produced. The IEA ratio of 60:40 for process relative to energy emissions is also maintained, but with CCS introduced to the industry by 2030 and increasing at different rates in C1 and C2 to complete (or very high) levels of penetration, and with complete or very high levels of capture, later in the century.

There is an evident anomaly between the (calculated) IEA and (published) GCP process emissions estimates for cement. Given this analysis relies on data from GCP (and CDIAC), a relatively small uplift factor is applied to the calculated IEA process emissions to bring the values into line with those from the GCP.

Both scenarios, C1 and C2, adopt growth rates that represent a step change from long-term historical trends, have growth rates that are maintained low through to 2030 after which they gradually decline still further. Of the two scenarios, C1 pushes the technology and growth reductions to levels that may have theoretical merit but are more difficult to justify as viable. In effect C1 risks implying that infrastructural development in poorer and industrialising nations is either significantly constrained or unknown alternatives to cement are discovered and penetrate the market from 2030 onwards. C2 is also highly optimistic, but with growth and technology not pushed to the limits assumed in C1. It is the C2 scenario that is adopted as appropriate for this analysis, demonstrating deep and profound mitigation, but with technologies just held back from their theoretical optimum.

**C1:** low cement growth: growth a less than half that of historical trends, through to 2030, then reduces to growth of 1% p.a. by 2044 and no growth by 2054; CCS starts 2030 penetrating sector in 2030 (with CCS plants at 100% capture rate from the start). Complete penetration by 2055 - after which there are no emissions from cement production. Total post-2017 CO₂ of 69GtCO₂

**C2:** medium cement growth (still well below historical and recent rates), sees a gradual rise above from the latest (and anomalous) 2016 growth rate towards 60% of historical trend values – maintained till 2030 after which it fall to just 1% p.a. in 2055 and no growth from 2065; CCS starts in 2030, initially with 80% capture rate on the plants with CCS installed. This rate increases at 0.5 % p.a. to a maximum of 98% capture by 2066 after which it continues at that rate to 2100. Almost complete CCS penetration (i.e. 98% capture) occurs in 2061. **Total post-2017 CO₂ of 100GtCO₂**
Appendix 3 – Distribution of the global carbon budget to industrialized countries

Apportioning the global budget to Industrial nations

This is undoubtedly an area where different interpretations of fairness and equity can give potentially very different results in terms of national carbon budgets. However, the Paris Agreement (and its international forebears) all draw attention to the importance of issues of equity and how poorer and less industrialised nations (hereafter referred to as industrialising nations) will need some significant period of grace in terms of decarbonising their energy systems. Specifically, they acknowledge that the peak in emissions from these poorer nations will be later than that within the wealthier industrial nations (hereafter referred to as industrial nations). Combine this equity criterion with the small and rapidly dwindling global carbon budget for 2°C (i.e. 490 to 640GtCO₂) and the range of potential national budgets is very significantly constrained.

The approach adopted here builds on the pragmatic and open process of apportionment used in a range of analyses and high-level reports since 2011. Put simply, the approach recognises the highly constrained nature of the 2°C carbon budget and then asks, within such a constraint, what is the most ambitious peak date industrialising nations could achieve and what could they subsequently deliver in terms of mitigation rates. This permits a mitigation pathway to be plotted for these nations. It is worth noting here, that the emission profile of China dominates those of the industrialising nations. Furthermore, even at a per-capita level, China is undoubtedly wealthier than many of the so-called ‘developing’ nations. Consequently, an emission profile for industrialising nations will mask the fact that many poorer nations will have a peak in their emissions up to a decade after that of China.

For this report, a series of updated scenarios (see Box 2 below) have been generated, building on earlier research and recognising the stipulation of the Paris Agreement that “developing” nations will take longer to make the transition away from fossil fuels than richer more industrialised nations. For the analysis here, less industrialised and less developed nations are captured within the non-OECD classification; in relation to emissions, this is sufficiently close to both non-Annex 1 and non-Annex B groupings to make no discernable difference.

The non-OECD scenarios developed for this report assume highly ambitious rates of mitigation beyond any thus far considered in other similar analysis. Nevertheless, the cumulative emissions for even these early and deep mitigation scenarios have fundamental implications for both the Paris temperature commitments and the 2°C mitigation challenge of the OECD.

The post-2017 cumulative emissions for the non-OECD region range from:

S1: 2020 peak emission year; 10%p.a. mitigation by 2042; 95% CO2 cut by 2060 = 502GtCO₂

S6: 2025 peak emission year; 10%p.a. mitigation by 2047; 95% CO2 cut by 2065 = 620GtCO₂

What is immediately evident, is that even a highly ambitious mitigation programme by the non-OECD region would have cumulative emissions in excess of the fossil-fuel carbon budget for an “unlikely” chance of staying below 1.5°C (i.e. 490GtCO₂). Consequently, from a carbon budget and mitigation perspective, 1.5°C is no-longer a viable temperature commitment.

Moreover, a mitigation agenda across the industrialising nations at a level of ambition far beyond anything discussed in Paris would also exceed the global (energy-only) carbon budget for a “very likely” chance of 2°C. That is to say, a strict reading of the political framing of the Paris ambition in terms of “well below 2°C” is also now not a viable goal. For the more conservative reading of Paris underpinning this report, the carbon budget accompanying a “likely” chance of 2°C remains viable - just. However, the enormous scale of ambition embedded in the non-OECD scenarios still delivers emissions that consume between 78% and 97% of the remaining fossil fuel global carbon budget.
BOX 2: non-OECD emission scenarios

The six non-OECD scenarios (S1 to S6) generated for this report are all for fossil fuels only, are highly ambitious and beyond anything thus far countenanced in international negotiations or in existing scenario sets. Process and deforestation (LULUCF) CO2 have been subtracted from the GCP database using estimates provided through private communication with the GCP team who compile the data. The scenarios include emissions data of the respective bunker fuel emissions from international aviation and shipping. These values are based on the difference between GCP global emissions and the sum of OECD and non-OECD emissions (a difference of approximately 4%). According to private communication with the GCP team this difference accounts for emissions from bunker fuels. For the analysis here, bunker fuel emissions are split between non-OECD and OECD on the basis of the regions’ relative proportion of global emissions (excluding bunkers). Following this approach (i.e. excluding CO2 from industrial processes & LULUCF, but including bunkers), the non-OECD and OECD emissions in 2015 were, respectively, 21.3GtCO2 and 13.0GtCO2.

Beginning from the 2015 emissions level, all scenarios initially grow at the same non-OECD rate as occurred in the years for which the latest data is available, i.e. 2014-15, where growth was 0.4%. This rate is far lower than historical rates for the region, but is considered appropriate here as this analysis is premised on immediate and unprecedented global effort to mitigate emissions inline with the Paris temperature commitments and the associated IPCC’s AR5 carbon budgets. [The authors acknowledge that action at this scale is highly unlikely in the near-term and that, as yet, there is no suggestion that such mitigation will be forthcoming in the medium-term].

The year where emissions peak (the ‘peak year’) varies across the six scenarios, from 2020 for S1 through to 2025 for S6. Once at peak emissions, all scenarios roll over to begin mitigation at 0.1% in the first post-peak year rising to a 1% reduction four years later before increasing at 0.5% each year to a maximum of 10% p.a.; this occurs 22 years after the peak year. Mitigation efforts thereafter deliver 10% reductions in absolute emissions each year for the remainder of the century. All the scenarios deliver an absolute reduction in emissions of approximately 95% (C.f. 2015) by 2060 to 2065 respectively. The total post-2017 cumulative emissions for the scenarios range from a low of 502GtCO2 for a non-OECD peak in 2020, through to 620GtCO2 for a peak in 2025.
Appendix 4 – Allocation principles for carbon dioxide budgets

The aim of this appendix is to rationalize and formulate how different considerations of equity can be articulated when apportioning a carbon budget between nations or between different municipalities or sectors within a nation. As such, it details different ways to calculate Sweden’s fair share of the OECD-carbon budget and how it also could be subsequently broken down to the municipal level. While there are a wide range of possible equity principles to apportion carbon budgets, Rose et al. (1998)\textsuperscript{36} outline four that have been considered for the purpose of this report: Egalitarian, Sovereignty, Polluter-pays and Ability-to-pay.

With an \textit{Egalitarian approach}, the remaining carbon budget is divided on a per-capita basis between inhabitants. The mitigation burden is consistent with the assumption that all individuals have an equal right to pollute or to be safe from pollution. The parameter used here is the ratio between the population of a subregion\textsuperscript{37} in relation to the larger region. Conversely, an apportionment based on a \textit{principle of Sovereignty}, holds that, within a region, all subregions (or sectors) have an equal right to pollute or to be safe from pollution and that such apportionment should then consider current CO\textsubscript{2} emissions as a right per-se. The parameter used for such calculation would then focus on subregional/sectoral CO\textsubscript{2} emissions in relation to the total emissions of the larger region. Thirdly, the tenets of a \textit{Polluter Pays} principle seek to divide and share the responsibility of mitigation based on the principle of guilt. Here, the burden to mitigate is proportional to emissions, using the inverse of per capita emissions as allocation parameter. Finally, dividing the remaining carbon budget based on a subregion’s/sectors \textit{Ability to Pay} seeks to base the burden for mitigation on the capacity to pay for the transition to an infrastructure and development path consistent, in this case, with the 2-degree target enshrined in the Paris Agreement. The parameter used here relates to the capacity of a subregion for consumption and is proportional to the gross income of the subregion. The four equity principles outlined above with their particular allocation parameters are summarized in the table below:


\textsuperscript{37} The term subregion as used here refers to e.g. Sweden as a subregion of the OECD, or Järfälla Kommun as a subregion of Sweden.
### Equity Principles, their details and associated parameters used for the allocation of shares of a carbon budget.

<table>
<thead>
<tr>
<th>Equity Principle</th>
<th>Equity Criteria</th>
<th>Associated Parameters used in calculations</th>
<th>Notes for Sweden and Järfälla</th>
</tr>
</thead>
</table>
| Egalitarian principle of per-capita allocation based on population. | Burden of mitigation efforts are assumed to be equally shared among individuals | Population in a particular year           | Sweden comprises 0.767% of the OECD population.  
Järfälla comprises 0.755% of the Swedish population. |
| Sovereignty principle of ‘grandfathering’ | Based on subregional CO₂ emissions and compared to total emissions | Subregional average CO₂ emissions compared to the total average emissions in a given time period | Between 2010 and 2015 Sweden on average emitted 0.361% of the total OECD emissions.  
Between 2010 and 2014, Järfälla Kommun on average emitted 0.172% (based on RUS) or 0.214% (based on SCB) of Total National Emissions |
| Ability-to-pay principle                | Relates to the capacity of the subregion for consumption and is proportional to Gross Regional Product. | Inverse of Gross Regional/Domestic Product | In relation to other municipalities, Järfälla’s Gross Regional Product represents 0.526% of GDP of Sweden.  
Between 2012 and 2014, Järfalla had a GRP per capita equivalent to 73.5% of Sweden’s GDP per capita. |
| Polluter pay principle                  | The economic burden is proportional to per capita carbon emissions            | The inverse of per-capita annual CO₂ emissions | Per-capita CO₂ emissions, for Järfälla kommun represent 26% of the national average (between 2008 and 2014). |
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