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A GUIDE FOR A FAIR IMPLEMENTATION OF THE PARIS AGREEMENT WITHIN SWEDISH MUNICIPALITIES AND REGIONAL GOVERNMENTS

Part II of the Carbon Budget Reports Submitted to Swedish Local Governing Bodies in the 2018 Project "Koldioxidbudgetar 2020-2040"

A report from the Climate Change Leadership node at Uppsala University

A Guide for a Fair Implementation of the Paris Agreement within Swedish Municipalities and Regional Governments:

Part II of the Carbon Budget Reports Submitted to Swedish Local Governing Bodies in the 2018 Project "Koldioxidbudgetar 2020-2040"

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About the Project "Koldioxidbudgetar 2020-2040"

Since 2015, Uppsala University has hosted the Zennström Visiting Professorship in Climate Change Leadership, part of a 10-year series of visiting professorships (2015-2025) funded by Zennström Philanthropies. The ambition of the initiative is to tackle some of the largest challenges climate change poses to humanity, by developing new solutions and enabling transformational change at the intersection of science, politics and innovation. Kevin Anderson, Professor of Energy and Climate Change at the University of Manchester and Deputy Director at the Tyndall Centre for Climate Change Research was the second holder of this professorship, taking up the position in August 2016. He has pioneered research on carbon budgets and pathways to acceptable mitigation levels with a focus on Sweden and the UK (see Anderson et al., 2017 and Kuriakose et al., 2018).

In 2017, Järfälla municipality contacted the Climate Change Leadership (CCL) Node at Uppsala University seeking a carbon budget for their municipality which was published later that year (Anderson et al., 2017). When this report was completed, more municipalities contacted CCL to request similar carbon budget calculations. The great interest resulted in the project, "Koldioxidbudgetar 2020-2040" (Carbon budgets 2020-2040) starting in 2018 in collaboration with Ramboll. This ongoing project is characterised by a high level of collaboration and knowledge sharing between municipalities (kommuner), regional governments (län) and the Climate Change Leadership Node in order to produce reports that meet the needs and expectations of participating governing bodies. This report is part II of the project. Part I consists of individual carbon budget reports submitted to participating Swedish municipalities and regional governments.

A full list of all municipalities and regional governments that have been involved in the project as well as additional information about the Climate Change Leadership Node at Uppsala University and any potential updates to this report can be found at http://climatechangeleadership.se.

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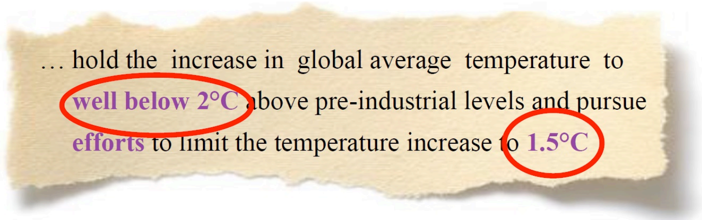
Contents

SECTION I - THE PARIS AGREEMENT: FAIR EMISSION REDUCTIONS GROUNDED IN SCIENCE

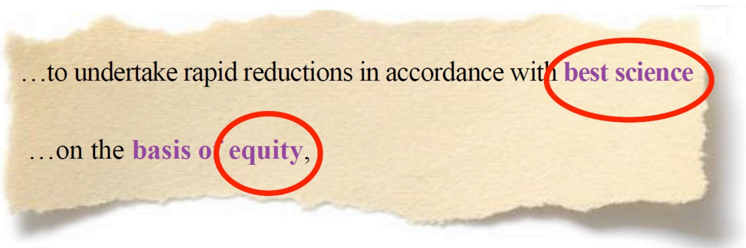
The Paris Agreement as the Political Basis for Action

In December 2015, all 195 member states of the United Nations Framework Convention on Climate Change (UNFCC) adopted the final text of the Paris Agreement. One of the main objectives of the agreement is to limit the global average temperature rise to well below 2°C,



"recognizing that this would significantly reduce the risks and impacts of climate change" (Paris Agreement 2015).

Another important commitment in the Paris Agreement and of particular relevance to the analysis in this report are the different capabilities that countries have to reduce their emissions: "Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognising that peaking will take longer for developing country parties". The agreement further defines this through recognising "common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (Paris Agreement 2015). This particular distinction between industrialised and industrialising countries is important in relation to the decision on how to allocate the remaining global carbon budget between countries. Furthermore, the agreement stipulates that these reductions must take place in accordance with "best science". These two principles have formed the basis for this report.



An Overview to the Carbon Budget Framework

This report employs a carbon budget framework based upon energy-related carbon dioxide emissions in order to establish a guide for a fair implementation of the Paris agreement within Swedish municipalities (kommuner) and regional governments (län). This is grounded in the IPCC's Climate Change 2014 Synthesis Report which states that, "*Cumulative* emissions of *CO_2* largely determine global mean surface warming by the late 21st century and beyond" (IPCC 2014, our italics). Carbon dioxide emissions account for over three-quarters of global greenhouse gas emissions (see *figure 1a*). The vast majority (over 70%) of these emissions arise from energy use (see *figure 1b*). Carbon dioxide emissions associated with other sources, such as agriculture, industrial processes and land use, land use change and forestry (LULUCF) are relatively much more difficult to mitigate due to a current lack of alternatives associated with these economic activities. Hence, energy-related carbon dioxide emissions account for both a majority of all greenhouse gas emissions (almost two thirds, Janssens-Maenhout et al., 2017) and present the best opportunities for immediate and significant mitigation strategies in order to comply with the Paris Agreement. Whilst these other emissions are taken into account when calculating the total available global carbon budget, it is energy-related carbon dioxide emissions that form the basis of the emissions reductions rates in this report.

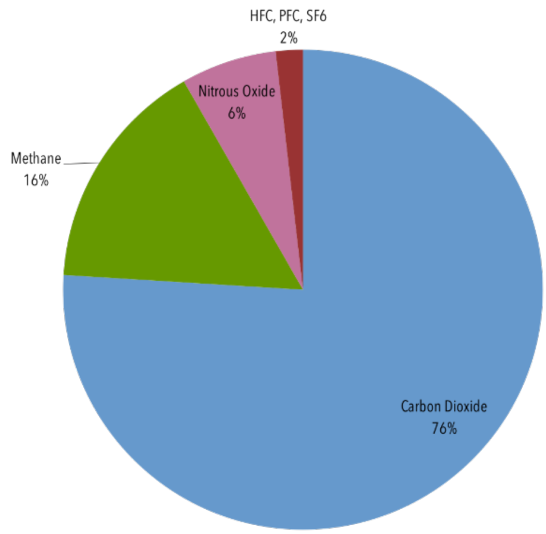


Figure 1a. Carbon dioxide emissions as a proportion of global anthropogenic greenhouse gas emissions. Source: Center for Climate and Energy Solutions[1].

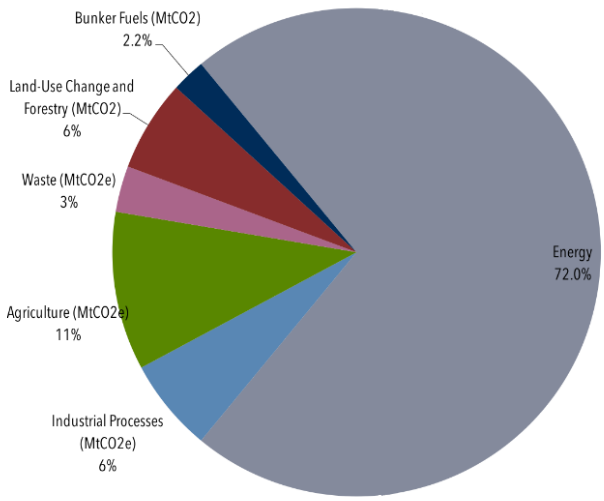


Figure 1b. Energy-related carbon dioxide emissions as a proportion of global anthropogenic carbon dioxide emissions. Source: Center for Climate and Energy Solutions[2].

[1] www.c2es.org/content/international-emissions
[2] ibid

Building on the science of climate change, the focus in this report is on *cumulative* emissions and associated carbon budgets as being the driver of temperature change, rather than long-term mitigation targets. The report starts with the Paris 2°C framing of climate change and then determines an accompanying carbon budget range and quantifies the required emissions reductions pathways to comply with the agreement. It is itself a continuation on the work begun by Anderson et al. (2017) in *Carbon Budgets and Pathways to a Fossil Free Future for Järfälla Municipality* (hereafter the "Järfälla Report")[3].

Carbon budgets relate to a fixed quantity (area under the curve of *figure 2a*) of carbon dioxide that can be released into the atmosphere, over a specific period of time, if we are to remain within a certain temperature threshold. If mitigation is delayed (represented by a delayed peaking in *figure 2b*), an additional quantity of carbon dioxide is emitted (area A). This means that even more stringent measures must be taken later in the century to compensate for this additional emission of carbon dioxide (represented by area B in *figure 2b*). This results in a steeper reduction curve (already from a higher starting point due to continued emissions increase); alternatively, failure to mitigate now risks putting the Paris temperature commitments beyond reach. It is hence critical that significant mitigation start immediately so as to avoid dramatic (or impossible) future mitigation rates.

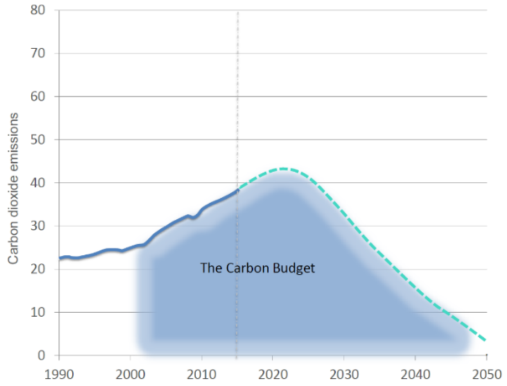


Figure 2a. Carbon budgets and associated emissions reductions curves.

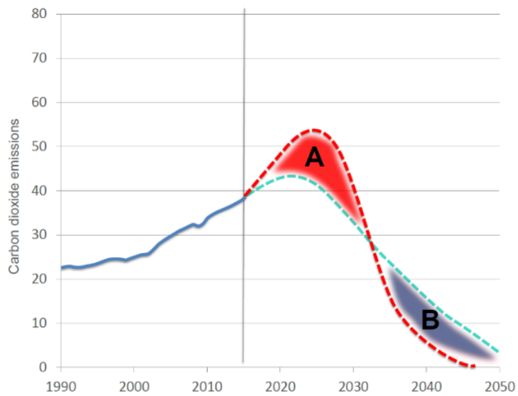


Figure 2b. Steeper emissions reductions curves due to delayed mitigation. Lower future emissions (area B) are needed to compensate for the additional emissions associated with delayed action (area A).

[3] Available at www.web.cemus.se/oct-17-the-path-to-a-fossilfree-society-the-case-of-jarfalla-kommun

Box 1. Territorial vs Consumption Emissions

This report uses global data on carbon emissions from the Global Carbon Project (2018) in combination with national and regional data from RUS (2018, *regional utveckling och samverkan i miljömålssystemet*). Both of these carbon emissions datasets are based upon a territorial allocation and inventory of emissions. This approach assigns emissions to the geographic area where they are produced. While other inventory methods exist (consumption-based, or production-based approaches, see Naturvårdsverket 2018) this method was deemed most relevant for this report due to the consistency, availability and accuracy that characterises territorial emission datasets.

Though territorial inventories are a prerequisite of reasoned national mitigation strategies, climate action needs to be informed by an approach that also includes the emissions occurring outside of national boundaries but linked to the activities and consumption occurring within them. This is especially the case for local and regional tiers of governance who have legislative power over relatively small areas and whose activities are inextricably linked to infrastructure and production processes available outside of its boundaries (nationally and internationally). An approach that has received increased attention in recent years is the consumption-based accounting method which classifies emissions caused by all forms of final demand for goods and services — by individuals or households, business or government.

Assigning emissions to the end consumer can support local governments in their climate strategies as it allows them to address the emissions linked not only to their own operations, but also those happening within their constituency. There are several reasons as to why consumption based accounting should be considered in outlining a municipality or region's climate targets.

First, using consumption based accounting will enlarge a municipality's emissions coverage. By including the emissions associated to the goods and services produced outside, but consumed within specific boundaries, a municipality or region will broaden its scope of emissions. For the majority of OECD countries, this means bringing the export and international trade sector into consideration for local climate strategies. This is especially the case in Sweden where some estimates of consumption emissions per capita are roughly 70% higher than territorial emissions Global Carbon Project (2018).

Second, considering consumption emissions will allow municipalities to switch the focus of their climate strategy from production process to consumption practices. This way of looking at emissions would be a potential driver for cleaner production abroad, but also would highlight the individual and collective practices that are linked to high emissions locally. In order to classify these emissions, the UN's COICOP (classification of individual consumption by to purpose) is often used which regroups consumption expenditures into more than 30 categories such as clothing, housing, communication, food and health amongst others. Through this lens, creating effective climate strategies involves identifying cost-effective emissions reductions via a focus on specific behaviours and practices occurring within municipal boundaries.

Finally, considering consumption emissions in framing local climate action has a strong equity dimension as it takes into account the emissions linked to the lifestyles of people living here in Sweden but currently allocated to the developing parts of the world. As demand for goods and services is driving production and associated emissions abroad, the responsibility for causing these emissions should fall, at least in part, on the consumers themselves. This is especially the case when considering the historical responsibility that developed regions of the world have for climate change. A study by Wei et al. (2012) estimated that developed economies have been responsible for 60-80% of the global average temperature rise since the preindustrial era, consigning a strong responsibility in regards to those regions in carrying the mitigation burden.

In sum, it is important to reflect upon the responsibility that Sweden has over the emissions that it creates in other countries through its demand of imported goods and services. Despite some uncertainties related with consumption-based accounting methodologies, their result should be used to inform a climate strategy based on a territorial approach to carbon accounting (such as this report). In the Swedish context, a carbon budget calculated on the basis of consumption emissions would result in more challenging annual emissions reductions than those resulting from territorial carbon budgets.

See also:

Afionis S Sakai M Scott K Barrett J Gouldson A. 2016. "Consumption-based carbon accounting: does it have a future?" *WIREs Climate Change* **8**(438).

Larsen, H. & Hertwich, E. 2009. "The case for consumption-based accounting of greenhouse gas emissions to promote local climate action." *Environmental Science & Policy* **12**(7), pp. 791-798.

UN (2003. *Classifications of Expenditure According to Purpose*. Department of economic and social affairs, Statistics division.

WWF 2017. *Chewing over consumption-based carbon emissions accounting. Futures food for thought.* WWF Paper.

Using the science of carbon budgets outlined above, we have translated the temperature and equity commitments enshrined in the Paris agreement into a methodological framework which underpins the following sections of this report. It establishes a global and Swedish carbon budget and outlines how a national carbon budget can be disaggregated to municipal and regional governments. The methodology of this report is a continuation of that used in the Järfälla Report, and based upon other works including Kuriakose et al. (2018) and Anderson and Bows (2011). It here considers territorial emissions as the basis for carbon budgets (see Box 1). The calculation of these budgets is based on various assumptions (see below), which inform the methodology as outlined across the six sections of this report.

Assumptions of this Report

The following six points make up the major assumptions upon which subsequent analysis rests:

1. A very conservative reading of commitments in the Paris Agreement. Consequently, the conclusions should be understood as a very optimistic spectrum of carbon dioxide budgets and a minimal level of emission reductions.
2. All other major emitters are expected to make their respective contributions to reduce their emissions (as a minimum) in line with a similar analysis of the Paris agreement (in other words, there are no significant free-riders in the analysis).
3. No negative emission technologies (NETs) are assumed to be used to increase carbon dioxide budgets (in other words, to reduce emission reduction requirements). See Box 2 for details about this.
4. No carbon cycle feedbacks have been counted, except those included in the models that support the IPCC's carbon dioxide budgets. For example, the carbon dioxide budgets in this report have not been limited to allow for methane emissions from melting permafrost or increased soil metabolism as ground temperatures increase[4].
5. Emissions and uptakes from land use, land use change and forestry (LULUCF) are assumed to compensate one another (i.e. net zero emissions) from July 2017 until the end of the century[5].
6. Emissions from international transport (aviation, shipping and military operations) based on bunker statistics (SCB and Kamb et al., 2016) have been included in the calculation of Sweden's carbon budgets (see section V). If these emissions were to be considered separately[6], the corresponding cumulative emissions (throughout the century) would have to be removed from Sweden's carbon budget.

[4] For a detailed overview of this issue, see Crowther et al. (2016)
[5] That is, none of the global carbon budget is allocated to deforestation (see section II). This will require significant global effort to reduce deforestation and increase reforestation and afforestation. July 2017 is consistent with the same start date used in the Järfälla report.
[6] For example as the responsibility of organisations such as the International Maritime Organisation (IMO) and International Civil Aviation Authority (ICAO).

How this Report is Structured

Building on the clear equity steer of the Paris Agreement, and based on the assumptions outlined above, this report outlines how municipal and regional government carbon budgets have been allocated in line with the temperature commitments agreed in Paris. The individual results pertaining to each municipality or regional government have been published separately in *Part I of the Carbon Budget Reports Submitted to Swedish Local Governing Bodies in the 2018 Project "Koldioxidbudgetar 2020-2040"* and on the basis of commissioned research.

In section II of this report, carbon budgets from the Intergovernmental Panel on Climate Change (IPCC) Synthesis Report (AR5) have been used as the basis for calculating the global carbon budget. Emissions from 2011 have been calculated using data from the Global Carbon Project. Here we also make a global overhead deduction from the global budget for the *process* emissions resulting from cement production (on the assumption that cement is a necessary and major component of continued development within industrialising nations).

In section III, emissions trajectories, including a peaking of emissions in industrialising countries, have been used to divide the global budget between industrialised (taken to mean OECD) countries and industrialising countries (non-OECD countries). This approach is perceived as a translation of the equity dimension enshrined in the Paris Agreement and outlined as the necessary 'common but differentiated responsibilities and respective capabilities' in burden sharing.

Section IV then apportions a share of the OECD budget to Sweden. This national carbon budget for Sweden is based on a combination of the egalitarian and grandfathering approach.

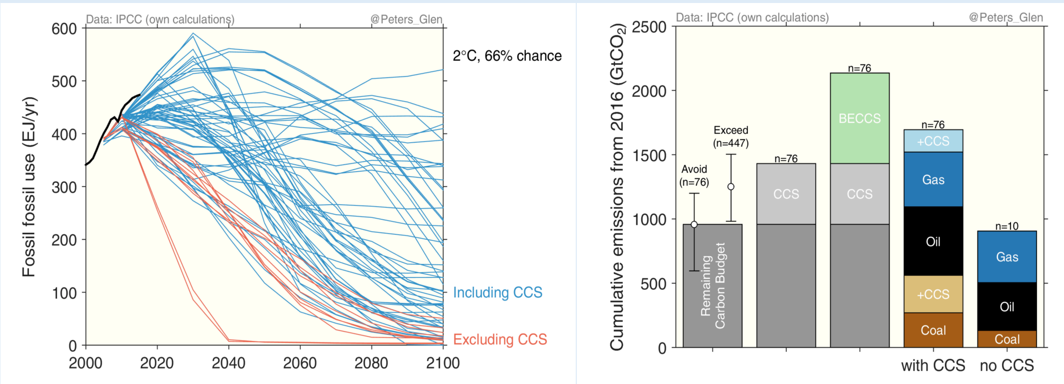
In section V, Sweden's national budget is further distributed to the municipal level, based upon a grandfathering of existing emissions.

Lastly, in section VI, we outline the consequences of this report for climate leadership and how local tiers of government can work towards a sustainable and equitable future.

Box 2. Negative Emissions Technologies

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 (Anderson and Peters 2016). 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 governments 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).

SECTION II - CALCULATING A GLOBAL CARBON BUDGET

From Qualitative Obligations to Quantitative Objectives

The language of international agreements on climate change is often framed in qualitative terms in relation to quantitative temperatures. The Copenhagen Climate Convention includes, for example, formulations "hold ... below 2°C"; the Camp David declaration; "limit ... the increase ... below 2°C"; and now the Paris agreement's "well below 2°C" and "pursue efforts to limit the temperature increase to 1.5°C". With these formulations, it would be unfair to propose something other than to bind us to emission reductions in line with at least one probable chance of not exceeding 2°C. Given that the Paris agreement strives for maximum 1.5°C warning, this agreement clearly indicates an even stronger likelihood, i.e. at least a very likely chance, of not exceeding 2°C.

In a guiding document to the authors of the latest IPCC Assessment Report (Mastrandrea et al., 2010), there is a taxonomy of probabilities that enables a translation of qualitative commitments to quantitative objectives. This taxonomy is shown in Table 1 below, where we see that the language of the international climate change agreements, from Copenhagen meeting onwards, clearly relates to a 66%–100% probability of not exceeding 2°C. The Paris Agreement's ambition to pursue 1.5°C in addition to 2°C suggests an even higher chance of achieving the latter goal - more in line with a 90–100% probability of 2°C.

In this report, we have translated the Paris Agreement's qualitative commitments and sequential logic to a range between the following (see also table 1):

- Lower range: an “unlikely” chance of limiting the heating to below 1.5°C,
  i.e. a probability of 0 to 33% of <1.5°C
- Upper range: a "likely" chance of limiting warming to below 2°C,
  i.e. a probability of 66–100% of <2°C

Table 1. Likelihood scale for consistent treatment of uncertainties (Adapted from Mastrandrea et al., 2010)

	Term	Outcome Likelihood
	Virtually certain	99–100%
	Very likely	90–100%
”Well below 2 °C →	Likely	66–100%
	About as likely as not	33 to 66%
”Pursue 1.5°C” →	Unlikely	0–33%
	Very unlikely	0–10%
	Exceptionally unlikely	0–1% probability

Emissions until 2011 – A Preliminary Carbon Budget

In November 2014, the IPCC (The Intergovernmental Panel on Climate Change) published the Climate Change 2014 Synthesis Report (IPCC 2014). This report brings together expertise from the various working groups of the IPCC and presents a clear set of cumulative carbon dioxide emissions (carbon budgets) for a variety of probabilities of limiting heating to less than 1.5°C, 2°C and 3°C (relative to a reference level between 1861 and 1880).

These budgets will continue to be researched and refined by climate science. However, in anticipation of a new consensus[7], IPCC's budgets are the most reliable estimates and should provide a basis for current evidence-based policy on energy issues related to climate change. Table 2.2 from the IPCC Synthesis Report, is included below (*figure 2*) with arrows that identify the most relevant lines for this report.

Figure 2: Likelihood of avoiding global average temperature increases according to different quantities of global cumulative emissions, ie. carbon budgets. Source: IPCC (2014) [own annotations].

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)									

The carbon budgets listed under the temperature ranges "<1.5°C" and "<2°C" (on the line marked with the white arrow) are our focus in this report. The row marked with the grey arrow contains the probabilities of limiting global average temperature increase to this extent. For a more accurate description of these probabilities, see the description of this table in the IPCC original report. The corresponding carbon budgets for each of these probabilities can be read in the row marked with the black arrow and encircled in red.

This corresponds to a remaining carbon budget of 850–1000 Gt in the year 2011 (see *figure 2*). The range of global carbon dioxide budgets from 850 to 1000 $GtCO_2$ applies to carbon emissions from all sectors for the period 2011 until we reach zero emissions globally. In order to calculate the remaining emission space from January 2020, emissions between January 2011 and December 2019 (inclusive) need to be deducted from the above carbon budget.

Emissions 2011 – 2019

Given that the report's emissions reductions trajectories begin in 2020 we need to calculate a global carbon budget from that year onward. Global emissions from 2011–2016 (inclusive) are reported by the Global Carbon Project (2018). We have assumed a continued increase in fossil fuels, cement and bunker fuels by 0.9% p.a.[8] to calculate emissions 2017–2019 (inclusive). In

[7] E.g. IPCCs next Assessment Report, AR6, will be published in 2022 https://unfccc.int/topics/science/workstreams/cooperation-with-the-ipcc/the-fifth-assessment-report-of-the-ipcc

[8] Based on average yearly global growth of emissions from 2012 to 2015

line with assumption #5 in this report, we assume net zero emissions from LULUCF from July 2017 onwards[9]. This corresponds to 370 $GtCO_2$ released between 2011 and end of 2019, i.e. this quantity will have to be subtracted from the carbon budget of 850–1000 $GtCO_2$. However, in order to quantify the effect this has on the remaining global energy carbon budget we must first consider several assumptions made about future emissions.

Assumptions on Post-2020 Emissions from Deforestation and Cement Production

Given this analysis relates specifically to the energy sector, it is necessary to remove projected global deforestation (LULUCF) and industrial process emissions (primarily cement production) for the period 2017 to 2100. It could be argued that both of these should be considered at the national level, however, given the very clear equity component within all agreements since the Copenhagen Accord, such emissions are more justly considered as a global overhead. Industrialised nations already have highly developed and cement-rich infrastructures, from domestic and commercial built environments, to transport and energy networks, power stations and industrial facilities. Industrialising 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 undertaking deforestation from their responsibilities. 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 published in Nature Geoscience (Anderson 2015), an optimistic interpretation of deforestation and cement process emissions post 2015 are, respectively, in the region of 60 $GtCO_2$ and 150 $GtCO_2$. However, for this analysis, still more optimistic assumptions have been made for both sectors, broadly in accordance with the large mitigation efforts required of the energy sector.

Regarding carbon emissions from deforestation, and consistent with 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 the former. This is necessary to help reduce the very real risk that sequestration in the long term will not match emissions from deforestation in the short term.

For the Järfälla report, two new cement scenarios were developed using the most recent emissions data and with still more optimistic assumptions about the role of cement, and therefore process emissions, between July 2017 and the middle of the century. These

[9] Emissions for the first half of 2017 are based on the average annual % change 2011-2016

scenarios are summarised in box 3 below. For the purpose of this report, the highly optimistic estimate of process emissions from cement is assumed to be 100 $GtCO_2$ for the period post 2017. Translating that analysis into this reports means that process emissions from cement production are 95 $GtCO_2$ for the period from 2020 onwards.

Thus, the global range of carbon dioxide budgets from energy is between 398 and 548 $GtCO_2$ (from 2020) when emissions from deforestation and cement have been taken into account (see table 2).

Table 2: Global emissions space left in 2020 according to the assumptions of this report

	33% chance of 1.5 degrees C	66% chance of 2.0 degrees C
Global emissions space left in 2020	398 GtCO2	548 GtCO2
Years left until budget exceeded at current emissions	9.5 years	13.3 years

Box 3. 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 recent 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 as 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 CO_2 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.

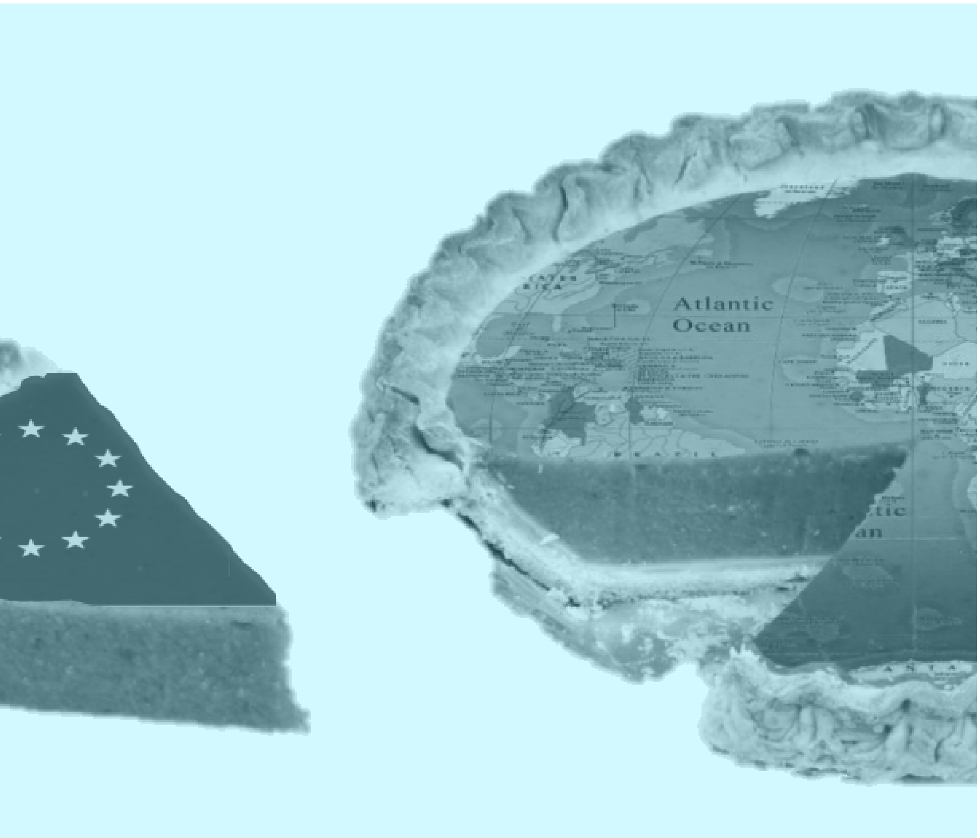
There is an evident anomaly between the (calculated) IEA and (published) GCP process emissions estimates for cement. Given this analysis relies on data from GCP (and CDIAC), a relatively small uplift factor is applied to the calculated IEA process emissions to bring the values into line with those from 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 at 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 CO_2 of 69 $GtCO_2$

C2: medium cement growth (still well below historical and recent rates), which 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 falls 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 CO_2 of 100 $GtCO_2$**

SECTION III – DISTRIBUTING THE GLOBAL CARBON BUDGET BETWEEN INDUSTRIALISING AND INDUSTRIALISED COUNTRIES



Emissions Space and Equity

When distributing the global carbon budget, different interpretations of equity in relation to national carbon budgets can yield potentially very different results. The approach we chose for this report is based on a pragmatic and open allocation process that has been used in a number of international reports and reports since 2011. In summary, this approach is based on the very limited emissions space from carbon budgets at 2°C, and then asks when the most ambitious total emission peak[10] could occur for industrialising countries, as well as the amount of annual emissions reductions that could then be implemented. The industrialised countries' emissions space will then be the very limited space that remains in the carbon budget.

This approach is in line with the internationally established principle of Common but Differentiated Responsibilities which serves as the foundation for the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. This principle recognizes the greater responsibility of 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.). This principle also recognises the industrialising countries' right to development and the responsibility of the industrialised countries to enable them to both reduce emissions through financial and technological support and to adapt to the effects of climate change.

The Paris Agreement thus means that a country like Sweden (along with its municipalities and regional governments) must ensure rapid and deep emissions reductions *within its territory*, whilst s*imultaneously* contributing both to climate financing and technology transfer to allow emissions reductions in industrialising countries as well as resources for adaptation measures[11]. In short and in addition to their own ambitious emissions reductions, each municipality or regional government in Sweden would have to enable transitions in one or more municipalities/regions in other countries. Whilst the importance of such international engagement must not be underplayed, within this report the focus is on territorial emissions only[12].

Scenarios and Carbon Budgets for Industrialising Nations

For this report, a series of updated scenarios have been generated (see Box 3). These are based on previous research (see Anderson and Bows 2011, Anderson et al. 2017) and further acknowledge the stipulated condition of the Paris Agreement that industrialising countries need more time to phase out fossil fuels and transform their energy systems than industrialised countries. Industrialising countries are considered in this report as belonging to the non-OECD grouping. In relation to carbon dioxide emissions, this is sufficiently close to groupings of

[10] The total emission peak is the time when carbon dioxide emissions reach their highest value.
[11] See for example *Fair Shares: A Civil Society Review of INDCs Report*, November 2015, http://civilsocietyreview.org/wp-content/uploads/2015/11/CSO_FullReport.pdf
[12] This report has not been able to analyse and quantify implications for Sweden (and Sweden's municipalities) of the necessary climate financing, technology transfer and adaptation measures, but points out that this responsibility should be recognised and quantified in the future.

countries used in the international climate negotiations (Non-Annex 1 and Non-Annex B), so as not to risk any appreciable difference in the conclusions of the analysis.

The scenarios for non-OECD countries developed here assume a very ambitious rate of emission reductions - more ambitious than previously considered in similar analyses. Nevertheless, the total emissions from these non-OECD scenarios are still such that they impose profound mitigation challenges on the OECD.

The cumulative carbon dioxide emissions for the non-OECD region (from January 2020) have been allocated in this report a range between (see Box 4):

Scenario 1 - S1: Peak by 2020; 10% annual emission reduction by year 2042; 95% reduction of CO_2 to 2060 = **437 $GtCO_2$**

Scenario 6 - S6: Peak by 2025; 10% annual emission reduction by year 2047; 95% reduction of CO_2 to 2065 = **555 $GtCO_2$**[13]

The conclusion that can be drawn from this is that even a very ambitious emission reduction agenda for the non-OECD region results in cumulative carbon dioxide emissions that do not achieve the "unlikely" chance of achieving the 1.5°C commitment (in other words 403 $GtCO_2$). Consequently, from a carbon budget and emission reduction perspective, limiting warming to 1.5°C as interpreted from the Paris Agreement is no longer a feasible temperature commitment (given the starting assumption on 'negative emission technologies').

In addition, even with this emissions reduction agenda for non-OECD countries, which is much more ambitious than discussed in Paris, the carbon budget (energy only) for a "very likely" chance of achieving the 2°C commitment would be exceeded. In other words, a strict reading of the Paris Agreement's "well below 2°C" is also not a viable goal. However, a more conservative reading of the agreement (that underpins this report, i.e. the carbon budget for a "likely" chance of achieving 2°C) is still feasible. However, even with the extremely high level of ambition in the non-OECD scenarios, this region alone still accounts for between 79% and >100% of the remaining global carbon budget for a "likely" chance of keeping global temperature rise below 2°C.

A Carbon Budget for the OECD Countries

The above reasoning shows both an "unlikely" chance of 1.5°C and "very likely" chance of 2°C are **no longer viable temperature commitments**. However, limiting carbon dioxide budget emissions for a "likely" chance to fall below 2°C is still a possible goal, at least in theory. Hence, our subsequent calculations are based on the global budget of 548 $GtCO_2$ (66% chance of 2°C) and not the budget of 398 $GtCO_2$ (33% chance of 1.5°C).

With a global carbon budget (energy only) of 548 $GtCO_2$ (after 2018), and with cumulative emissions from non-OECD countries (according to scenarios S1 and S6) of 437 to 555 $GtCO_2$,

[13] Whilst usually not accounted for at the national, we have included international bunkers' share of emissions to both OECD and non-OECD countries respectively.

the remaining post-2020 budget range for the OECD extends from a high of 111 $GtCO_2$ to a low of 0 Gt (in fact the OECD nations are indebted 7 $GtCO_2$ to the non-OCED nations) as summarised in table 3.

Table 3 OECD and Non-OECD budget ranges for 2020–2100 according to Non-OECD peak year. Based on a global carbon budget in 2020 of 553 GtCO2 (66% chance of limiting warming to 2.0 degrees C).

	Non-OECD Peak Emissions in 2020	Non-OECD Peak Emissions in 2025
Non-OECD Budget Range	437 GtCO2	555 GtCO2
OECD Budget Range	111 GtCO2	-7 GtCO2*

*this negative value implies that Sweden, as a part of all OECD nations, has a carbon debt to non-OECD nations if peaking occurs in 2025, i.e. it is not possible to satisfy both (1) a fair sharing of global the carbon budget between OECD and non-OECD nations; and (2) maintain a "likely" chance of reading the 2°C commitment if peaking of non-OECD emissions occurs as late as 2025

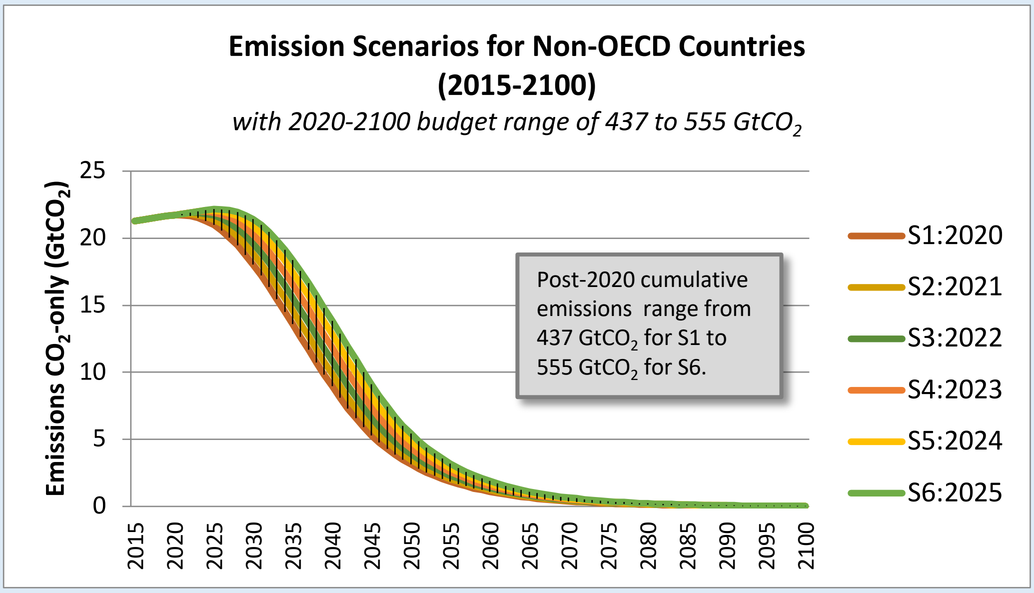
Box 4. Non-OECD Emission Scenarios

The six non-OECD scenarios (S1 to S6) generated for this report are all for fossil fuels only and based on data from the Global Carbon Project's (GCP) Global Carbon Atlas (http://www.globalcarbonatlas.org/en/CO2-emissions). They are highly ambitious and beyond anything thus far countenanced in international negotiations or in existing scenario sets. Process and deforestation (LULUCF) CO_2 have been subtracted from the GCP database using estimates provided through private communication with the GCP team who compile the data.

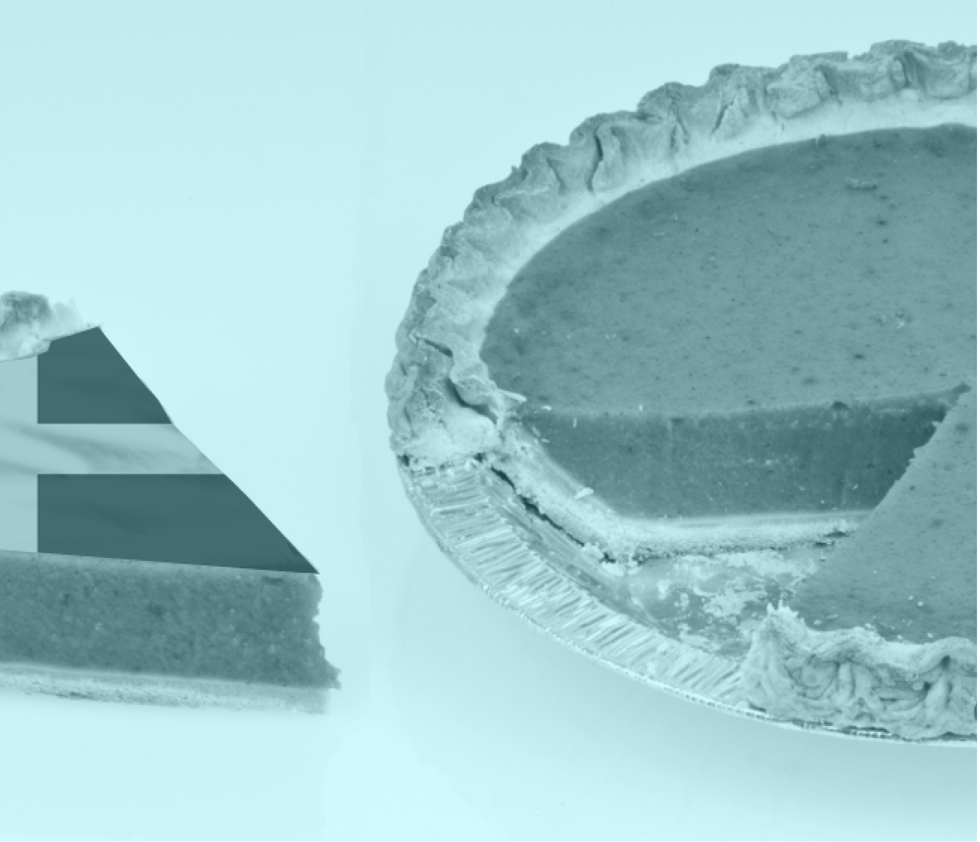
The scenarios include emissions data of the respective bunker fuel emissions from international aviation and shipping. These values are based on the difference between GCP *global* emissions and the sum of OECD and non-OECD emissions (a difference of approximately 4%). According to private communication 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 CO_2 from industrial processes & LULUCF, but including bunkers), the non-OECD and OECD emissions in 2015 were, respectively, 21.3 $GtCO_2$ and 13.0 $GtCO_2$.

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. 2014-2015, 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 in line 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-2020 cumulative emissions for the scenarios range from a low of 437 $GtCO_2$ for a non-OECD peak in 2020, through to 555 $GtCO_2$ for a peak in 2025.



SECTION IV - SWEDEN'S CARBON BUDGET - FOR A FAIR CONTRIBUTION TO A LIKELY CHANCE OF ACHIEVING THE 2°C COMMITMENT



Allocation Principles Considered for this Report

There are a number of different allocation principles that can be used to allocate the remaining OECD carbon budget to specific countries or regions. These are generally based on some idea of fairness and equity. Such methods can be relatively simple, such as an allocation based on population or grandfathering, or more detailed, such as an allocation based on economic resources, geographical and social capacity, etc.

For this study, we considered five different allocation principles based on environmental and ethical research and the associated methodologies used to calculate a subregion's fair portion of larger region's carbon budget. These principles are based on notions of grandfathering, equity (egalitarian approach), ability to pay, polluter pay and a blended sharing approach. A short summary of each of these principles follows. For more information, see Raupach et al. (2014), C40 and Arup (2017), Anderson et al. 2017), Rose et al. (1998) and table 4 below.

The principle of **grandfathering** (or inertia) states that the size of a nation's budget should be calculated based on the nation's current share of global emissions. This tenet takes into consideration current realities as it recognizes that high-emitting infrastructure and/or industries need to be accounted for when drafting climate strategies. This principle is also relevant for apportioning carbon budgets from a national to subnational level at is takes into consideration (to a certain extent) current import/export dynamics among municipalities and/or regions.

An **egalitarian** (equity-based) approach assumes that the burden of mitigation efforts is to be equally shared among individuals, assuming universal equal rights. This means that the carbon budget for a nation is commensurate to the size of its population in relation to global population. This principle, however, does not account for any past emissions, locked-in infrastructure, industry locations, etc.

Apportioning a carbon budget following a nation's **ability to pay** assumes that the size of its budget should be linked to its economic ability to finance a transition to a low-carbon society. This satisfies the principle of capability in that wealthier nations have a higher economic capacity for reducing emissions than low–income ones. The indicator often used is the region's Gross Domestic Product. This principle arguably offers a simple way of financing a reduction in emissions as often, but not in all cases, income levels correlates closely with emission levels.

The **polluter-pay** principle states that the size of a nation's carbon budget is inversely proportional to its carbon emissions, with the idea that the higher its emissions, the smaller its budget. I.e., the burden to mitigate is proportional to emissions, using the inverse of per capita emissions as the allocation parameter. This assumes that the mitigation burden is proportionate to a nation's current and past emissions and that high emissions means steeper reduction rates. While relevant when allocating a global carbon budget to individual countries, this might not be as relevant for an allocation of carbon budgets within Sweden, where high emitting industries have been relatively free to set their businesses anywhere within the country, and whose economic activities have brought benefits outside of its municipality or region's borders.

The approach termed **blended sharing** allows the amalgamation of two principles and the blending of their effects through the introduction of a 'sharing index', with values between 0 and 1. This method, developed by Raupach et al. (2014) creates a sharing principles that accommodates two differing viewpoints. The equation used for this approach is as follows, using population and emissions as example:

$$C_i = (1 - w)\ E_i/E_w + w\ P_i/P_w$$

Where w is the sharing index, C_i is the carbon budget of region i, E_i and P_i are its emissions and population respectively and E_w and P_w are the emissions and population of the country as a whole.

In this specific case, this approach offers a compromise between a transition to equal emissions per capita with a trajectory that recognises the emissions reduction challenge posed by the current state of the socio-economic and technical system. Such an approach can of course also blend other allocation principles.

Table 4: An overview of allocation principles and associated parameters used for calculating carbon budgets.

Allocation Principle	Description	Associated parameters used in calculations
Egalitarian	Burden of mitigation efforts are assumed to be equally shared among individuals	Population in a particular year
Grandfathering	Based on subregional CO_2 emissions and compared to total emissions	Subregional average CO_2 emissions compared to the total average emissions in a given time period
Ability-to-Pay	Relates to the capacity of the subregion for finance a transition to a low-carbon society	Inverse of Gross Regional/Domestic Product
Polluter Pay	The economic burden is proportional to per capita carbon emissions	The inverse of per capita annual CO2 emissions

Apportioning the OECD Budget to Sweden

From the above selection, the grandfathering (based on average emissions 2011–2016) and egalitarian (based on population) principles were selected as allocation approaches. We consider these two factors to balance the "fair" aspect of the Paris Agreement with the practicalities of current emissions profiles and the inertia of associated reductions. Overall, these two allocation principles are beneficial for Sweden by reducing the relative contribution that Sweden would otherwise have to deliver if its high per capita income (~18% above the OECD average), its geography and climate (suitable for large scale renewable energy development) and its highly educated (and environmentally conscious) citizenry should be taken into account. Thus, the carbon budget calculated here for Sweden is at the higher end of the range of possible budgets that could be calculated compared to if stricter justice principles had been used.

When the two allocation principles used in this analysis are applied to Sweden and OECD statistics[14], Sweden receives an allocation of 0.468% (grandfathering) and 0.767% (population) of the OECD post-2020 carbon budget for energy (111 to -7 $GtCO_2$). Based on this, Sweden's carbon dioxide budget is presented in table 5 below, where the final two columns present the carbon budget and minimum mitigation rate that underpin this report.

Table 5: Sweden's Carbon Budget for energy 2020–2100 for a "likely" chance of reading the 2°C commitment.

Allocation Principle	Based on OECD max budget[a]	Based on OECD min budget[b]	Based on OECD Mid budget[c]	Sweden Budget Midrange Value	Minimum Mitigation Rate
Grandfathering (0,468% of OECD Budget)	519 MtCO2	-33 $MtCO_2$*	243 $MtCO_2$	**321 $MtCO_2$**	**16,4 % p.a.[d]**
Population (0,767% of OECD Budget)	851 $MtCO_2$	-54 $MtCO_2$*	398 $MtCO_2$		

a) assumes a peaking of non-OECD emissions by 2020, i.e. *111 $GtCO_2$.*
b) assumes a peaking of non-OECD emissions by 2025 i.e. *-7 $GtCO_2$.*
c) assumes a peaking of non-OECD emissions by between 2022 and 2023.
d) based on the Sweden Budget Midrange Value (321 MtCO2) and then applied to Sweden's total emissions calculated using data from RUS (SCB and Kamb et al. 2016 for international transport) instead of GCP. This is to ensure a consistent reduction rate across municipalities and regional governments when RUS data is used at the next stage of allocation. Note that a national mitigation rate derived from GCP data is roughly 1% higher.
*these negatives values imply that Sweden, as a part of all OECD nations, has a carbon debt to non-OECD nations if peaking occurs in 2025.

As can be seen in table 5 (see also comments a to c), the carbon budget for Sweden is very sensitive to the exact date that non-OECD countries reach peak emissions. The choice of allocation principle is also important, but still has a relatively smaller impact on the size of Sweden's carbon budget.

[14]Grandfathering sourced from Global Carbon Project (data average over 2011-2016 period) www.globalcarbonproject.org/carbonbudget/17/data.htm
Population source from World Bank Data 2016 https://data.worldbank.org/indicator/SP.POP.TOTL?locations=OE)

Swedish Emissions Reductions Rates to Reach the 2°C Commitment

The last column in table 5 translates the carbon budget for Sweden into a minimum emissions reduction rate. This scenario assumes a constant rate of mitigation, starting in January 2020, leading to emissions that do not exceed the estimated carbon dioxide budgets. The resultant future emissions reduction curve is outlined in *figure 3. Figure 4* presents a cumulative emissions perspective of the same emissions reductions curve.

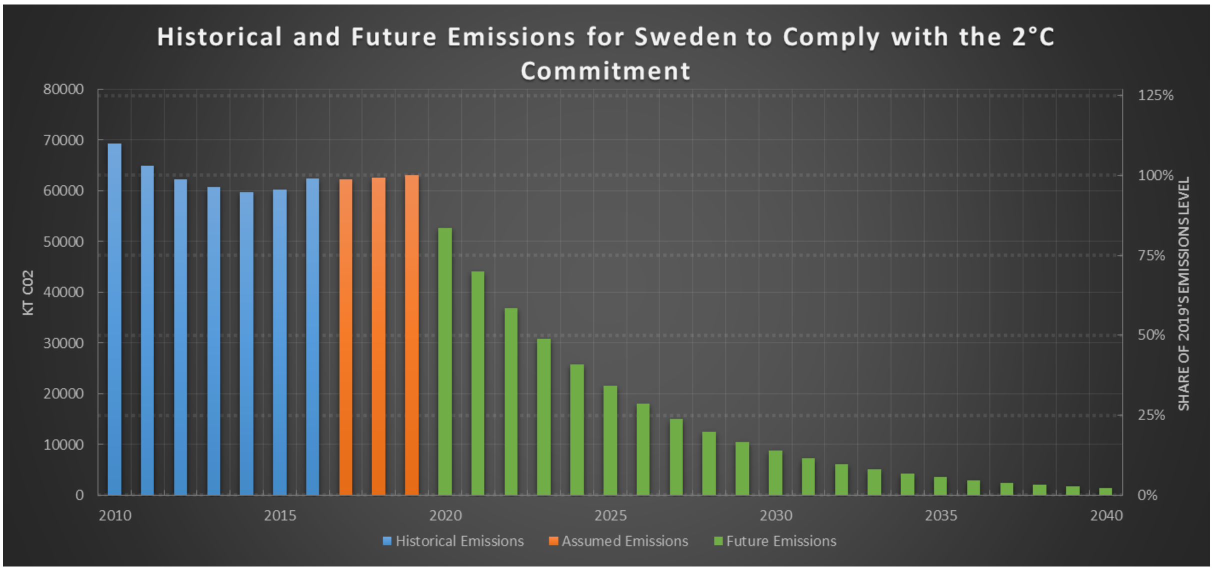


Figure 3. Historical and future emissions for Sweden to comply with the 2°C commitment. Historical emissions drawn from RUS, SCB and Kamb et al. (2016). Assumed emissions extrapolate from current trends. Emissions reduction curve and consequent budgeted emissions are based on an annual reduction rate of 16.4% beginning in 2020.

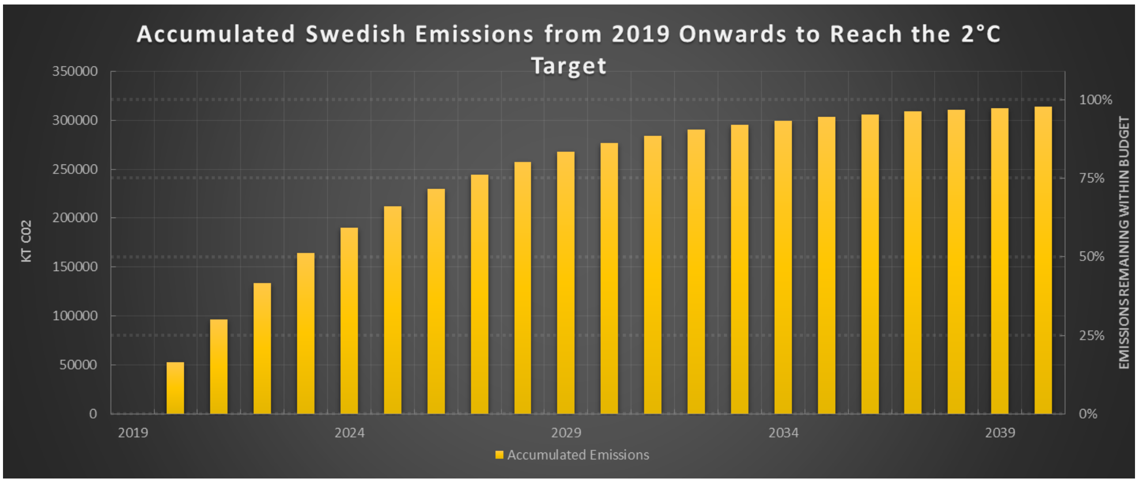


Figure 4. A cumulative emissions view of Sweden's emissions reduction pathway.

Current Carbon Emissions and Trends in Sweden

Figure 5 below shows the distribution of Swedish territorial CO_2 emissions by sector. As seen in this figure, international transport, national transport and industry together accounted for a majority of emissions in 2016. The emissions for the latter two have also been more or less constant over the period 1990–2016. Here there are major challenges and opportunities for Sweden to pursue an active policy of instruments that drastically and immediately reduce emissions from these sources.

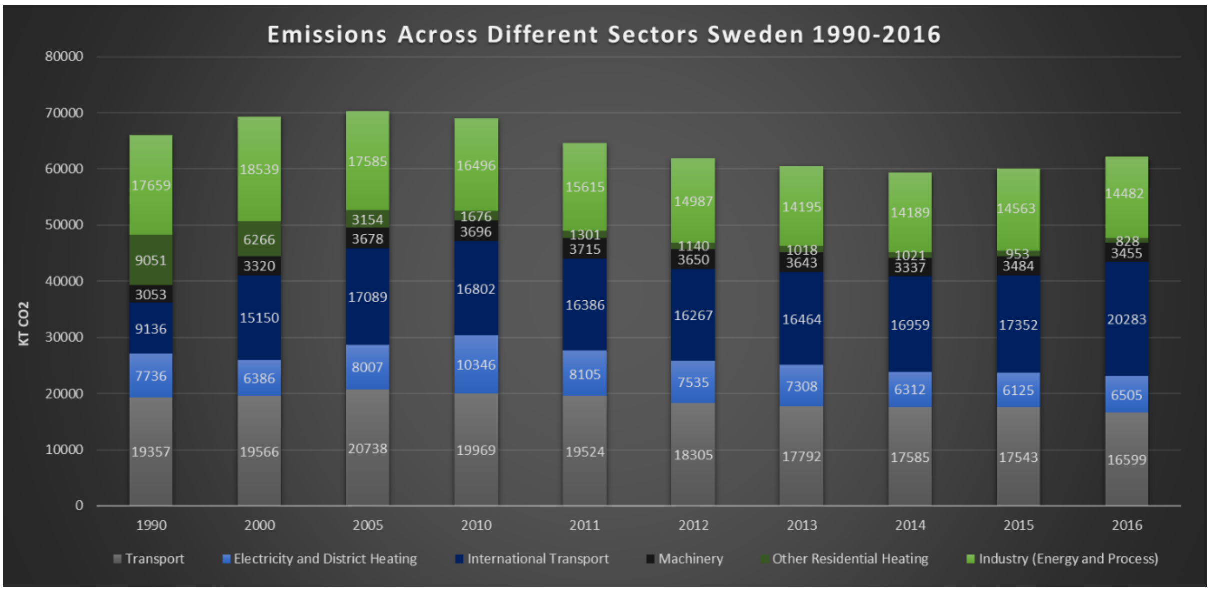


Figure 5. Territorial carbon emissions in Sweden 1990–2016 according to sector. Based on RUS (international transport data from SCB and Kamb et al. 2016)[15].

Figure 6 shows the historical emissions from two different sectors that have had the opposite trend in recent decades. The phasing out of fossil fuels in the residential heating may be seen as an illustrative example of drawing lessons from work and implementing policies that reduce emissions in other sectors. However, for the second source of emissions in *figure 6*, international transport (maritime and aviation)[16] it may be difficult, since alternatives to fossil fuels today are very limited in these sectors and will remain so within the time frame that is crucial for delivering upon the Paris Agreement. Effective instruments are needed to ensure that these emission trends are immediately reversed and drastically begin to decline. This likely applies to all the major sectors that represent Sweden's carbon dioxide emissions, as shown in *figure 5*.

[15] Due to their smaller relative size we have not included in this graph emissions from product use (413kT CO_2 in 2016), agriculture (125kT CO_2 in 2016) and waste management 55kT CO_2 in 2016)
[16] Includes both transport of people and goods.

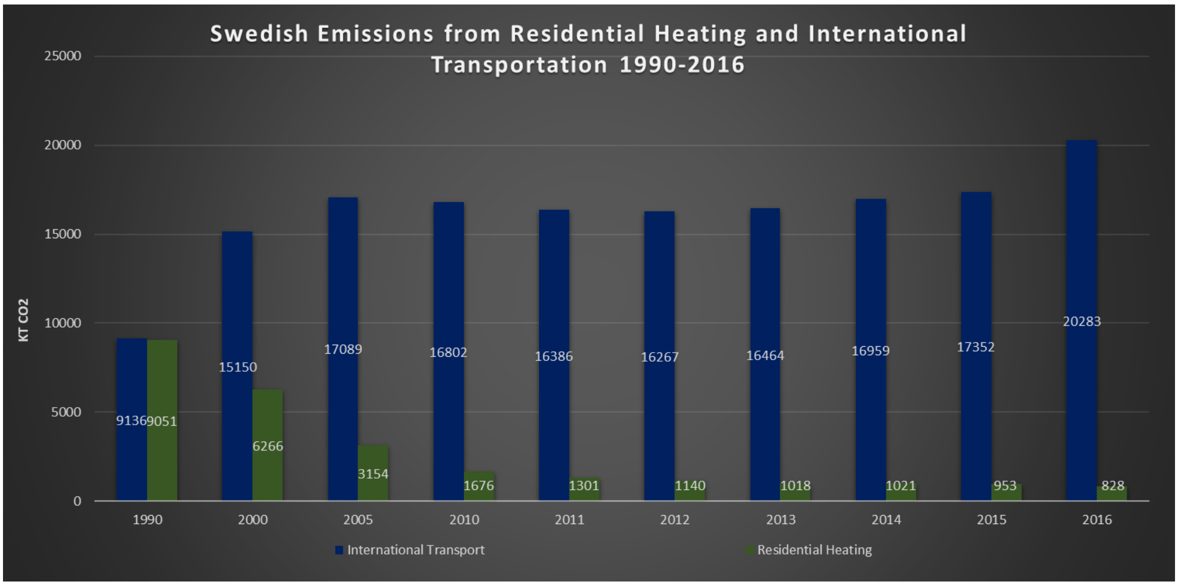


Figure 6. Comparison between Swedish emissions from residential heating and international transport 1990–2016. The former having reduce by over 90% in 25 years and the latter more than doubling during the same period.

SECTION V – DIVIDING SWEDEN'S CARBON BUDGET BETWEEN MUNICIPALITIES AND REGIONAL GOVERNMENTS (KOMMUNER AND LÄN)

Choosing an Allocation Principle for Diving Sweden's Budget

In accordance with the selection of distribution principles at the international level, appropriate allocation principles at the national level need to be identified in order for Sweden's carbon budget to be divided fairly and efficiently between Swedish municipalities and regional governments. A significant difference in choosing a sub-national distribution principle (as compared to the calculation of Sweden's carbon budget) is of course that a municipality is much more economically, politically and geographically bound and dependent on Sweden and other Swedish municipalities than what a nation-state is to the OECD. Wherever inequality does occur, there is also a clearer political framework for maintaining equality between these governing bodies (through taxation and redistribution e.g. *kommunalekonomisk utjämning*). The economic profile also varies considerably between Sweden's municipalities, which is also reflected in their different territorial emissions. Municipalities with heavy industry such as Lysekil and Oxelösund have, for example, emissions per capita up to 100 times as large as, for example, most Stockholm municipalities such as Danderyd, Sundbyberg and Solna. Due to these factors the 'polluter pays' principles and egalitarian principle are considered inappropriate to calculate municipal carbon dioxide budgets.

Hence, the most appropriate and fair principle we consider in this context is grandfathering, possibly with some adjustments for municipalities' ability to pay (GDP) and economic demography (average income of population) and the degree that a municipality's business contributes to social functions that benefit other municipalities.

Statistics for Calculating Grandfathered Emissions

Given that grandfathering forms the basis of our allocation at the regional level, the municipality's or regional government's emissions as a proportion of total Swedish emissions need to be calculated. Preliminary figures for Sweden's total emissions are drawn from RUS (2018) who manage an emissions database built on the statistics presented for reporting to the UNFCCC. In RUS emissions are allocated across Sweden through a strict geographic method where only actual emissions within a municipality's boundaries are taken into account (from both point sources and more diffuse sources).

An alternate emissions database is compiled by Statistics Sweden's (Statistiska Centralbyrån, SCB 2018) System of Environmental and Economic Accounts (Miljöräkenskaperna), who provide regional and local statistics that are used for reporting to the UNFCCC. However, emissions from registered individuals and registered activities with headquarters in the municipality are included in these estimates of territorial emissions regardless of where individuals or activities release them (personal communication with Maria Lidén, responsible for environmental accounts at SCB, 02/05/2017). For this reason, we have based our allocation on the statistics provided by RUS[17].

[17] For the years 2016-2019, we have assumed an emissions reduction rate of 2% based on a prediction of continued emissions trends.

Incorporating International Transport Emissions

RUS statistics only include emissions from domestic transportation (including domestic flights) and not emissions from international transport (aviation and shipping). When calculating carbon budgets this means that a large proportion of Sweden's emissions are overlooked. Much of these emissions relating to international transport occur outside of Sweden's territorial boundaries (and are hence not strictly territorial emissions), but considering that they both make up such a large proportion of national emissions (see table 6) and that the Paris Agreement did not account for them on any international platform, we judge it appropriate to incorporate them at the national level[18].

In order to account for emissions relating to aviation we have used two different statistical sources. SCB accounts for international transport divided into aviation, shipping and military operations overseas. However, the emissions associated in this dataset only represent the fuels bought in Sweden for outbound transport, so called bunkers. Regarding aviation, this would apportion a large percentage of aviation emissions to airport hubs, such as Schiphol, Frankfurt, Heathrow, Dubai etc. In contrast, Kamb et al. (2016) have calculated the total aviation emissions resulting from Swedish international flights including emissions associated with the total journey, which we have hence decided to use instead of SCB's aviation data. Kamb et al. (2016) use an uplift factor of 1.9 to account for warming effects of gases at high altitude, but we have instead used an updated calculation resulting in a factor of 2.0 (Jungbluth 2018). These aviation emissions were subsequently added to SCB's emissions statistics from shipping and military operations overseas[19] so as to generate a more accurate inventory of Sweden's total international transport emissions[20].

Using this methodology allows to produce an estimate of international transport emissions at the level of the entire nation, but does not disaggregate per municipality or regional government. To address this, we have apportioned national international transport emissions to local governing bodies based on their share of the national population using SCB's population statistics[21]. By assigning emissions equally across the Swedish population, this approach overlooks the fact that international travelling is not undertaken homogenously across income groups[22].

[18] In this report we included carbon dioxide emissions from international transportation, coupled with a high altitude effect of 2.0 (Jungbluth 2018), to Swedish total territorial emissions. We are conscious that this approach leads to a slight double accounting of CO_2 emissions in that it also accounts for emissions in other countries through bunker statistics in addition to the inclusion of the effect of non-CO_2 gases. As Sweden's share of total global air travel is small, the numerical difference of the double accounting makes this methodological flaw negligible.

[19] For shipping and military transport we continue to use SCB's data given a lack of alternative datasets.

[20] We have extrapolated emissions trends to calculate the emissions for the period 2016-2019 from Kamb et al. (2016) and 2017-2020 for SCB.

[21] www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/

[22] Despite this, we further justify this simplification on the basis of equity. Given the expenses associated with international travel, we assume that municipalities and regional governments with more wealthy inhabitants will likely also have higher associated international travel emissions. As this calculation apportions higher income earning municipalities and regional governments a carbon budget based on average travel statistics, they will experience a relative shortfall of emissions space (when clearer measures to apportion national-level international

Table 6. Swedish International Transport Emissions as a Proportion of Total Swedish Emissions (2016).

	Emissions (in 2016)
Total Swedish International Transport Emissions	13.5 $MtCO_2$
Total Swedish Emissions (RUS + International Transport)	55.6 $MtCO_2$
Proportion (International Transport / Total)	24%

Allocating amongst Municipalities and Regional Governments

With these figures finalised, each municipality and regional government has been grandfathered a proportion of the Swedish Carbon Budget for 2020 onwards according to its estimated share of nations emissions in 2019. This share of the Swedish carbon budget represents that municipality's or regional government's carbon budget for 2020 onwards.

In the individual reports calculated for municipalities and regional governments (Part I of the "Koldioxidbudgetar 2020-2040" project) published alongside this report, annual total emissions and associated accumulated emissions trajectories (for 2°C) of each municipality and regional government from 2020 onwards are estimated[23]. These are calculated on the basis of the 16.4% annual reduction rate with which all governing bodies (and associated regional actors) in Sweden are assumed to comply in order make their fair contribution to limiting warming to 2°C.

Other Factors to Consider

Applying general rules and principles to complex situations will always generate some inequalities and inconsistencies. Various other factors have been considered in writing this report and in calculating municipal and regional government carbon budgets, such as the economic situation of the municipality or regional government, whether operations within their geographical boundaries contribute to wellbeing of others beyond these borders (or vice versa), and the control that municipalities and regional governments have over all territorial emissions.

However, we have decided not to make additional adjustments to the grandfathered emissions allocations (aside from that arising from our calculation of international travel emissions). This is because we believe that making adjustments to this framework according to local circumstances can only fairly occur through a prolonged, democratic negotiation process if this framework were to one day become national policy. Furthermore, we note that where any

travel emissions become available). Hence, these municipalities would have to make more stringent reductions. The reverse is true for lower income earning municipalities.

[23] Alongside other individual analysis regarding e.g. emissions profiles

difficulties may arise on account of local circumstances, there is a role for the national government to provide financial and infrastructural assistance, and to undertake other measures to rectify this and support a more just transition to a zero-carbon future.

SECTION VI – CLIMATE LEADERSHIP NOW AND INTO THE FUTURE

A Framework for Municipal and Local Government Energy and Climate Strategies

A consequence of outlining local climate strategies from global budgets is that *climate leadership* within municipalities and local governments is associated with responsibilities lying beyond its territorial borders (see *figure 7*). This includes a consideration of measures within its own operations and activities within its borders, but also implies a need to challenge and exert pressure for higher ambitions regionally and nationally. For Sweden and its local governing bodies this also includes supporting and enabling countries and municipalities in industrialising countries to accelerate their transformation into a fossil-free future, at least in line with the assumptions made in this report on non-OECD countries' common emission cuts.

In order to enable these highly ambitious transformations in developing countries while they simultaneously build infrastructure and create welfare systems, finance and technology transfers are required to an extent that probably corresponds to several times existing aid. In order to achieve the Paris Agreement, municipalities need to contribute to this — partly in terms of the taxes paid by its residents and companies at the national level for new and 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, local governing bodies could find ways to collaborate across national borders in addressing on our common climate challenge.

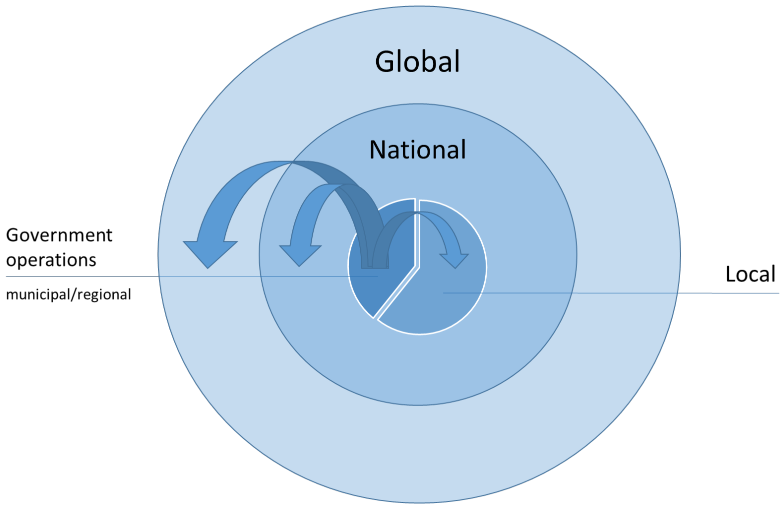


Figure 7. Local Climate Responsibility and Climate Leadership.

An inventory of opportunities and analysis of how local governing bodies can assume responsibility for the different geographical areas represented in *figure 7* is beyond the scope of this report, but we recommend that all such bodies further investigate this if a just and authentic contribution is to be made to keeping global temperature increase below 2°C.

Calculating the division of emissions between governing bodies' own activities and those of the entire municipality ("local" in *figure 7*), is beyond the scope of this report. Some useful insights can be given through consulting the Swedish Environmental Protection Agency's Emissions Register (https://utslappisiffror.naturvardsverket.se) which outlines the emissions from sectors and even individual factories within local government boundaries.

Pathways to Fossil Free Futures

Whilst detailed emissions reductions strategies fall beyond the scope of this report, and regardless must be adapted to each local entity, some general comments can be made. Below are some preliminary proposals and instruments that could help 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 and produced with low-emissions materials as well as efficient and low-carbon machinery
- Rebuilding (retrofitting) of existing buildings
- Max CO_2 standard on all new cars and trucks combined with automotive fleet electrification (e.g. 100 gCO_2/km and decrease by 8% per year)
- Controls and policies that drive behavioural change in high energy users. (e.g. progressively rising energy tariffs, fees for frequent flying, personal carbon dioxide allocations)

In a Swedish context, the above proposal, according to preliminary estimates, could jointly reduce energy demand between 40–70% in just 10–15 years.

Access to renewable energy

- An extensive electrification program (power grid, transport, etc.)
- More efficient and better DC links and transmission links (mainly relevant to the national level)
- Support the expansion of smart grids, meters and local renewable energy production
- Sustainable expansion of renewable energy sources + very low CO_2 energy
- Develop local biomass, biogas and P2G for periodic intermittency/basic load

Other policy measures

- Immediate divestment and rapid decommissioning of fossil-based assets
- Investments in carbon dioxide storage of emissions from cement and steel production
- A moratorium on airport development (mainly relevant to the national level and municipalities where airports are or are intended)
- Extensive expansion and investment in public transport, such as modern and efficient highways (including night trains in Sweden and Europe), subways, tramways, etc.
- Enable long-term investment environments and investment cycles (using low interest rates, etc.)

This is of course a very preliminary, incomplete and rather general list of possible measures. Some of these proposals are likely possible and appropriate to implement within the municipality, while other proposals may require co-ordination and cooperation at the regional level as well as leadership at the national level. Some quantified suggestions for emissions reductions strategies can be found at Drawdown[24].

It should also be noted that electrification of e.g. the transport sector, without increasing low emissions electricity production or reducing electricity consumption in other sectors, will at first reduce Sweden's export of low emissions electricity and subsequently turn annual export into import. Any negative change in this balance will in the short terms increase electricity production in other European countries from existing, mainly high emitting (coal fired) power plants. From a climate perspective, Sweden's electrification strategies need to take into account what measures are taken in the rest of Europe, e.g. the rest of the connected grid, to calculate the real climate impact of those measures. This impact is not seen if only Swedish territorial emissions accounting is used.

Local Governments and the Global Climate Conversation

We recognise that the challenge presented in this report is so far-reaching that it is very difficult to find contemporary examples where this scale 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 have quickly transformed themselves, for example in response to crises, conflicts, war or subsequent reconstruction. This could e.g. be drawn upon in an extension of this project.

Most importantly, we need to be reminded that the option of not accepting this challenge is that we, and our children, will live with the transformative changes that escalating climate change will entail. If this change is to take place within municipalities, regional governments, at the national level and in other parts of the world, both vision and leadership are needed. It is pleasing to see that, for example, Oslo municipality also calculated its own carbon budget and set a clear goal of reducing its emissions by 50% by 2020 and by 95% by 2030 (in relation to the 1990 reference year)[25]. Businesses also have networks such as *the Haga initiative* (*Hagainitiativet*), where a number of large companies are committed to emissions reductions that are larger and more drastic than those proposed by the Preparation for the Environmental Goals (*Miljömålsberedningen)*.

About 40 megacities around the world have collaborated since 2005 to reduce their emissions and climate impacts within the *C40 network*[26]. *Uppsala Climate Protocol* is an example of a local initiative that enables and encourages cooperation between public organisations, companies and associations in the region[27]. *Transition Towns* as part of the *The Transition Network*[28] is another interesting initiative with roots in the English countryside, but now growing into a kind of popular movement all over the world. Sweden's eco-municipalities (*Ekokommuner*) and climate municipalities (*Klimatkommuner*) are other examples. These initiatives will probably

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[24] www.drawdown.org/solutions

[25] www.oslo.kommune.no/politikk-og-administrasjon/politikk/budsjett-regnskap-og-rapportering/byradets-budsjettforslag-2017-og-okonomiplan-2017-2020/?del=2-2

[26] www.c40.org/

[27] www.uppsala.se/klimatprotokollet

[28] https://transitionnetwork.org/

play a significant role in catalysing and supporting cooperation between municipalities that want to make their just contribution to the fulfilment of the Paris agreement since no entity by itself has the ability or power to make this.

We hope that this report can be an important and useful basis for Swedish municipalities and regional governments (alongside other readers both in Sweden and abroad) to reflect on and inform the development of their energy and climate strategies. We specifically hope that this can have an impact on municipalities' and regional governments' environmental strategies (miljöplaner) and budgets (ekonomiska flerårsplaner). We also hope that the report provides guidance to governing bodies wishing to demonstrate climate leadership both in Sweden and internationally.

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Local Climate Leadership.

This report is part of the project “Koldioxidbudgetar 2020-2040” (Carbon budgets 2020-2040), initiated by the Climate Change Leadership Node at Uppsala University and in collaboration with the consultancy Ramboll.

The global carbon budget is the total amount of carbon dioxide that can be released to the atmosphere in order to achieve a certain temperature target. This budget can be distributed, in time and space, and expressed as local annual carbon budgets. This work has been done here for a set of Swedish municipalities and counties for the period 2020-2040.

This report is part II of the project and outlines the methodology behind the allocation of carbon budgets and associated emission reduction pathways for a set of municipalities and regional governments in Sweden.

The intention of this report is to contribute to the debate on the need for rapid and deep reduction in emissions in line with the commitments made in Paris in 2015. Through publishing this report, the Climate Change Leadership Node aims to supports municipalities and regional tiers of government in this transformation.

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