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Paris-compliant carbon budgets for Sweden's counties

Isak Stoddard[1,2] and Kevin Anderson[1,2,3]

[1]Natural Resources and Sustainable Development, Department of Earth Sciences, Uppsala University, Uppsala, Sweden.

[2]Centre for Environment and Development Studies (CEMUS), Uppsala University, Uppsala, Sweden.

[3]Tyndall Centre for Climate Change Research, School of Engineering, University of Manchester, Manchester, UK.

Preface

The research and analysis behind this report were made possible through generous funding from the Swedish Energy Agency for the project Regional carbon budgets and rapid transition to a fossil-free energy system (project number 46532-1), which ran from 2019-10-01 until 2023-09-30. The interest in carbon budgets and their use in national to local climate and energy governance has grown significantly over this time. The project members have thus been fortunate to have an increasing set of actors and people contact us and are grateful for the interest shown in the research produced within the project. All those that in some way have contributed to our thinking and engaged with our research over this time are too many to mention by name here, so instead we extend a heartfelt thanks to all of you that we've crossed paths with over these past four years. A special thanks however, must go out to our friends and colleagues at Klimatsekretariatet who have been an invaluable partner in helping to build bridges between our research and the Swedish public sector at the local and regional level. A big thank you also to members of Klimatriksdagen and broader civil society in Sweden for your interest and informed engagement with our research. And finally, to the civil servants from across Sweden as well as research colleagues from around the world to the corridors of CEMUS, NRHU and Uppsala University, we extend our deepest appreciation for your contributions and time.

Executive Summary

Sweden needs a fundamental and rapid transformation of its energy system to meet the "well below 2°C" and equity commitments enshrined in the Paris Agreement. In contrast to the comfy political rhetoric of Sweden's mitigation successes, the numbers tell a very different story. Include carbon dioxide emissions from imports and exports, and those from aviation and shipping, then since 1990 Sweden has cut its energy-related emissions by much less than 1% each year (based on Global Carbon Project data). To put this in context (based on IPCC data), for a flip of a coin chance of not exceeding 1.5°C of warming, global emissions must reduce at 11% each year, from now. For a good chance of "well below 2°C", the reduction rate globally is 5% per annum.

This report presents a clear and sequential logic to downscale global climate commitments, in the form of what are termed carbon budgets, to Sweden and then down to regions. Carbon budgets are a scientifically informed metric for understanding how fast emissions need to be cut, and how rapidly we need to cease using fossil fuels, to limit global warming to a particular temperature rise. The research underpinning this report was conducted in dialogue with a range of local civil servants and wider groups of citizens, as well as other academics and researchers. With their input we have developed a pragmatic approach to fairly divide Sweden's national carbon budget (for 2°C) between the regions. The budgets are presented in this report provide a quantitative basis from which to consider scenarios of emission reductions, with consideration for local circumstances.

The changes now required impact all elements of society, from housing to transport, industry to services, energy to commerce. This is a direct outcome of the commitments made in Paris and the long-term failure of the international community and national governments to seriously address the climate challenge. A third of a century since the first major international report on climate change, we face a dilemma. To continue with more fine speeches but very little meaningful action, and witness increasing levels of climate change. Or to address the challenge head on, with honesty, clarity and informed by detailed and thoughtful research. We hope our work will contribute to the latter.

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1. Introduction

Sweden is a signatory to the UN Framework Convention on Climate Change, UNFCCC (United Nations 1992). As such, it has agreed to make its fair contribution to "avoiding dangerous anthropogenic interference with the climate system". Two decades on from the UNFCCC, the Paris Agreement established a strong international consensus quantifying what constitutes "dangerous". It was agreed that signatory nations would reduce emissions sufficient to hold the rise in global average temperature to "well below 2°C", and ideally no more than "1.5°C" (UNFCCC 2015). Following Paris, scientific and empirical evidence on climate impacts has seen 1.5°C increasingly represent the appropriate threshold between 'acceptable' and 'dangerous' levels of climate change, sufficiently so for it to provide the headline framing of the Glasgow Climate Pact (UK COP26 2021).

Another key feature enshrined in the 1992 UNFCCC and all subsequent Conference of the Parties (COPs), is the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR–RC). Signatories to this principle acknowledge the necessity of many developing countries continuing to increase their emissions in the short term so as to provide for basic food and energy needs of their populations and bring their citizens' quality of life closer to the global average. Consequently, wealthier nations (variously referred to as "Annex 1" or "developed country parties") need to lead in cutting emissions, with less wealthy and poorer nations (non-Annex 1 and "developing country parties") offered some leeway in driving the necessary decarbonisation rates. In short, Sweden, as a designated Annex 1 member, is obliged to cut emissions at a faster rate and deliver full decarbonisation ahead of non-Annex 1 nations. Whilst, CBDR-RC has become an increasingly contentious principle, particularly amongst wealthier nations, it nevertheless remains deeply embedded in the text of the Paris Agreement, the 2021 Glasgow Climate Pact, and COP27 in Sharm el-Sheikh. The analysis and succeeding conclusions presented in this report take the Swedish Government's signatory to the UNFCCC, the Paris Agreement and subsequent COP protocols at face value. As such the report frames a Swedish decarbonisation agenda commensurate with the Paris temperature and equity commitments.[1]

The key to curbing global temperature rise is limiting the total cumulative amount of CO_2 released into the atmosphere, often referred to as the 'carbon budget'. The Intergovernmental panel on climate change (IPCC) has, over the past 10 years,

[1] The precise interpretation of Paris underpinning this analysis is described in section 2 of this report.

provided three different estimates of the remaining global carbon budgets for a range of probabilities to remain below certain temperature thresholds (IPCC 2014, 2018, 2021). In our previous analysis a set of downscaled Paris-compliant carbon budgets for Sweden were produced that included territorial emissions from all energy-related processes as well as emissions associated with international aviation and shipping (Anderson, Broderick & Stoddard 2020). To be in line with the temperature and equity commitments of the Paris Agreement (simplified then to a 50% chance of not exceeding 1.7°C), Sweden would need to limit their cumulative carbon dioxide emissions over the 21st century to no more than 280-370 $MtCO_2$[2], starting in January 2020. By January 2024, a further 4 years will have passed and Sweden will have emitted another 180$MtCO_2$ into the atmosphere, reducing this budget range to 100-190$MtCO_2$, or just 2 to 4 years of current emission levels.

The calculations in Anderson et al. (2020) were based on the most recent IPCC global carbon budgets then available (IPCC 2018). In Section 2, this report first sets out to revise these estimates of a Swedish Paris-compliant carbon budget range, based on the updated estimates of global carbon budgets in the IPCCs Sixth Assessment Report, AR6 (IPCC 2021). In Section 3, a set of provisional Paris-compliant carbon budgets for all 21 counties of Sweden are presented. The section also summarises the challenges and choices to consider when attempting to downscale a national carbon budget to the subnational level. Section 4 compares Paris-compliant pathways for Sweden with current plans and projections, illunating the big gap in ambition. Possibilities for delivering the very onerous mitigation requirements coming out of the Paris-compliant carbon budgets is briefly touched upon briefly in sections 5, and further developed in the report "Paris-compliant emission reductions for Sweden: heuristic narratives for guiding energy policy" (Andersson and Stoddard 2023). To conclude the report section 6 lists a few sources for further information and ways to engage.

2. Downscaling Paris-compliant global carbon budgets to Sweden

The IPCC's latest Assessment Report, AR6, sets out the scientific community's most recent estimates of carbon budgets for a suite of different probabilities of not exceeding a range of temperature increases. For 1.5°C, the IPCC provides global budgets of between 300 and 900$GtCO_2$, but this is from the start of 2020. Fast forward to the start

[2] The smaller carbon budget is a result of following the current UN classification of countries as either "developed" (Annex 1) or "developing" (Non-Annex 1) while the larger of the two carbon budgets is dependent on a reclassification of a handful of high-emitting, relatively wealthy "developing" countries" as "developed". See Anderson, Broderick & Stoddard (2020) for details.

of 2024, and these values are set to reduce to 140 and 740$GtCO_2$, respectively; equivalent to less than 4 to 19 years of current global emissions. The smallest budget (140$GtCO_2$) is associated with an *"83% or more"* chance of staying below 1.5°C and the more generous budget (740$GtCO_2$) a much lower chance of just *"17% or less"*.

The Paris commitments of curbing emissions sufficient to stay "well below 2°C" and "pursuing .. 1.5°C", can reasonably be associated with budgets within this range. Fortuitously, the IPCC budget for a 17% chance of staying below 1.5°C (i.e. 740$GtCO_2$ from January 2024), is the same as the budget for an 83% chance of staying below 2°C. Unfortunately, in all but a very abstract and theoretical framing of climate change, the carbon budgets associated with a high chance of staying below 1.5°C are now too small to be of practical use. Even if an immediate global agreement to radically cut emissions was forthcoming, the world would still need to be fully decarbonised (i.e. zero emissions of CO_2) by the end of 2030. For this reason, the level of highest ambition assumed in this report correlates with a 50% of not exceeding 1.5°C, i.e. a carbon budget of 340 $GtCO_2$ form January 2024. It is this value we take to represent the *"pursuing .. 1.5°C"* framing of the Paris Agreement. The lowest level of ambition is taken as the carbon budget for a good chance (83%, or 5 out of 6) of staying *"well below 2°C"*, which is the same budget as an outside chance (1 in 6) of staying below 1.5°C (i.e. 740$GtCO_2$ from January 2024). Global Carbon Budget values from 2020 (and what they have been reduced to in 2024), as well as their implications in terms of annual global reduction rates (for exponentially declining pathways) and zero-emission dates (for linearly declining pathways) are presented in Table 1.

Table 1: Paris-compliant global carbon budgets

Starting January 2020 → what these values are in 2024	**50% chance of not exceeding 1.5°C**	**83% chance of not exceeding 2°C (*)**
1. Remaining global budget in $GtCO_2$	500 → 340	900 → 740
2. Years of current CO_2 emissions in remaining budget	12.0 → 8.3	21.6 → 18.1
3. Exponential decline pathway: global % annual reduction rate	7.7 → 10.7	4.3 → 5.1
4. Linear / straight line reductions pathway: real zero year	2044 → 2040	2063 → 2060
5. % budget being used per month	0.7 → 1.0	0.4 → 0.5

*This budget also carries a 17% chance of not exceeding 1.5°C

Remaining global carbon budgets and implications for global mitigation pathways, highlighting the difference in the required pace when comparing values in January 2020 with current ones (January 2024). The table is based on IPCC AR6 carbon budgets (IPCC, 2021) with emissions data from the Global Carbon Atlas (2023).

The data in Table 1 is represented graphically in Figure 1, taken from Anderson and Caverley (2022), and illustrates how different pathways give different zero-emission

years. What is key to understand here, is just how critical early action is. As it stands, the collective global pledges of mitigation (national determined contributions) sum to a level that gives no reduction in total CO_2 emissions by 2030. In all but a very abstract sense, this reduces the available post-2030 carbon budgets to such low levels as to put both the 1.5 and 2°C framing of the Paris Agreement beyond reach. Consequently, there is an urgent need to significantly improve the NDCs and, importantly, deliver on these updated contributions, if the Paris commitments are to be met.

Figure 1: Paris-compliant global mitigation pathways

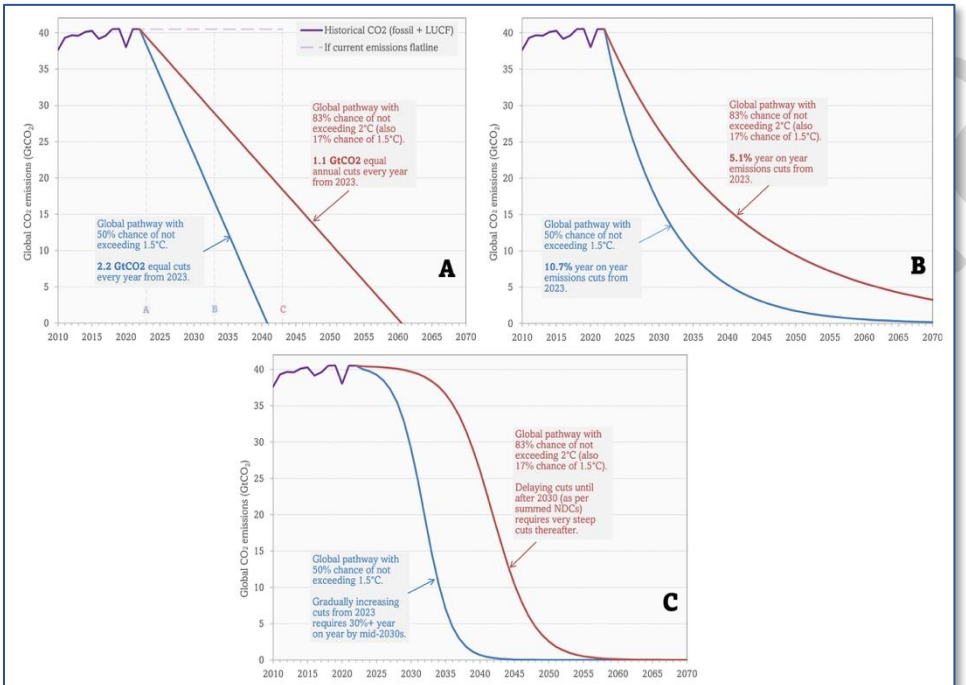


Figure 1. **Panels A to C** show three alternative hypothetical emissions reduction pathways compliant with the remaining carbon budgets for a 50% chance of not exceeding 1.5°C (blue lines) and an 83% chance of not exceeding 2°C (red lines; note that this budget also carries a 17% chance of not exceeding 1.5°C). **Panel A** also shows emissions staying constant at their current level, and indicates when the budgets for 1.5°C and 2°C would be completely exhausted (dashed vertical lines B and C). Note that the area under the blue curves (representing the emissions budget) is identical in each panel, likewise the area under the red curves (truncated in Panel B). All three 50% 1.5°C pathways (blue lines) indicate rates of decarbonisation widely regarded as infeasible (too steep). The red line in **Panel C** reflects current NDCs (negligible change in emissions by 2030, shown here at -2% against 2021 levels), with the subsequent rates of reduction required to comply with a budget for 83% chance of 2°C approaching the levels already deemed infeasible for 50% 1.5°C today.

Apportioning the Global budget to "developing" and "developed" regions

The Paris Agreement redefines the division adopted in previous agreements between industrialised (Annex 1) and industrialising (non-Annex 1) nations; the new classifications being "develop**ing** country parties" and "develop**ed** country parties". An approach for dividing the finite global budget values between these two categories

was developed by Anderson, Broderick and Stoddard (2020), which also provides the basis for the updated calculations in this report.

There are certainly different approaches to divide the global carbon budget between the "developing" and "developed" country parties. However, as we proceed through 2023, the mitigation framing of "pursuing .. 1.5°C" and staying "well below 2°C" sees the Paris-compliant carbon budgets shrink to such small levels that the degree of flexibility is severely constrained. In this light the framing of the division between "developing" and "developed country parities" proposed by Anderson, Broderick & Stoddard (2020), provides a sufficiently robust basis for this report[3]. The same proportional division that was used to divide a post-2019 global carbon budget for a 50% chance of 1.7°C (656$GtCO_2$) to developed (136$GtCO_2$) and developing country parties (520$GtCO_2$) is in this report applied to remaining budgets for 83% chance of 2°C and 50% chance of 1.5°C (also from January 1, 2020 onward).[4] The budgets developed are energy-only; that is to say, an allowance has been made for cement-based process emissions and those associated with land-use[5]. For reasons of equity, these allowances are made at the global level. For the detailed reasoning behind this, please refer to Section 3.1 of Anderson, Broderick and Stoddard (2020).

Apportioning the carbon budget of "Developed country parties" to nation states

There are a range of regimes for apportioning carbon budgets to the nations within the developed and developing groups. These extend from population to economic indicators and historical emissions to broader welfare indices (such as Human Development Index). Each method has its advantages and disadvantages. In our current work, with its focus on "developed" nations, we apply ''grandfathering'. The merits of this approach arise from it being simple and well understood, and able to capture a breadth of national circumstances, from structural lock-in of existing

[3] At the time of writing, Stoddard, Anderson and colleagues are developing a more refined method of division that does not rely on the overly simplistic "developing" and "developed" country split embedded in the Paris Agreement.

[4] Certainly, the similarity in size between the global carbon budgets for 83% chance of 2C and a 50% chance of 1.7C in IPCCs AR6 (2C budget only ~6% larger) lends validity to this approach. When it comes to the application on 50% of 1.5C, more caution around the results is warranted, but the global numbers are here so small that whatever division is chosen, it will inevitably lead to inequitable as well as infeasible mitigation rates for a number of countries.

[5] The optimistic assumption is made that net land-use emissions will be zero across the century. Cement process emissions (2020-2100) are in this report assumed to be 42 GtCO2 (in the 1.5C budget) and 75 GtCO2 (for 2C), which equates to the same proportion of the remaining global carbon budget as in our previous analysis (60 GtC02 for a 50% of 1.7C).

infrastructure through to the economic wherewithal to make rapid changes. Such an approach, whilst appropriate for considering nations with sufficiently similar criteria to be included in the "developed" country group, would be unsuitable for considering nations with very different levels of socio-economic wellbeing. Moreover, as some nations begin to take seriously their climate commitments, whilst others do not, so Grandfathering becomes increasingly partisan, favouring those nations failing to shoulder their proportionate burden of earlier transitions; in essence freeloading on those nations who are making meaningful efforts.

A new set of Paris-compliant carbon budgets for Sweden

The additional emission space following on from the larger global carbon budgets in AR6 (in comparison to SR1.5) could be allocated in different ways between the countries of the world. Certainly, the argument could be made that all of this increased allowance should be given to poorer, developing countries following the principle of CBDR-RC, but in our analysis we increase all carbon budgets calculated in Anderson, Broderick and Stoddard (2020) with the same amount. For Sweden, this means that the previously calculated Paris-compliant carbon budget of 370$MtCO_2$[6], increases to 444$MtCO_2$ (for a 50% chance of 1.7°C), 464$MtCO_2$ (for a 83% chance of 2°C) and decreases to 258 $MtCO_2$ (for the much tighter 50% chance of 1.5°C), all starting in January 2020.[7] Removing emissions between 2020-2023 (~180$MtCO_2$) results in the Swedish Paris-compliant carbon budgets as presented in Table 2. These are territorial budgets for CO_2-only, and so do not make any allowance for imports and exports (i.e. consumption-based accounting), but do include bunker fuel emissions for international aviation and shipping.

[6] This is the larger of two carbon budgets calculated and is dependent on a reclassification of a handful of high-emitting, relatively wealthy "developing" countries" as "developed". The smaller budget based on the current UN classification of countries was 280 MtCO2. See Anderson, Broderick & Stoddard (2020) for details.

[7] These updates assume that the same proportion of a finite global carbon budget is apportioned between developing country and developed country parties as in the analysis of Anderson et al. (2020) for 50% of 1.7C.

Table 2: Paris-compliant carbon budgets for Sweden

Starting January 2020 → updated values for January 2024	**50% chance of not exceeding 1.5°C**	**83% chance of not exceeding 2°C (*)**
1. Carbon budget for Sweden in MtCO2	~ 260 → 80	~ 465 → 285
2. Years of current CO_2 emissions in remaining budget	5.2 → 1.8	9.4 → 6.4
3. Exponential decline pathway: national % annual reduction rate	16.0 → 35.7	9.6 → 13.5
4. Linear / straight line reductions pathway: real zero year	~ 2030 → 2027	~ 2038 → 2036
5. % budget being used per month	1.4 → 4.7	0.8 → 1.3

The budget for a 50% chance of ≤ 1.5°C remains in line with what we have previously estimated for Sweden. The value for an 83% chance of ≤ 2°C is slightly higher than the earlier value provided for a 50% chance of ≤ 1.7°C. The main reason for this is that the IPCC's carbon budget for the former (2°C) is ~6% larger than for the latter (1.7°C). The estimated size of the remaining carbon budgets from January 2024 rests on the assumption that the estimated annual CO_2 emissions in 2022 (~45 $MtCO_2$) remain the same during 2023.

How confident are we in our findings?

The calculation and downscaling of global carbon budgets to the national level is a process with many uncertainties and assumptions that have to be made along the way. In the political and practical processes of trying to deliver on the mitigation commitments of the Paris Agreement, science plays a key informative role, but only as long as the analysis and the assumptions it relies on are presented in clear and transparent ways (and revised when needed). The bullet points below summarise the key issues that a discerning reader of this report needs to consider when drawing their own conclusion from the analysis presented.

- When it comes to the size of the remaining global carbon budgets, our analysis in relies on the budget values presented in AR6 (IPCC 2021). A recent study by Lamboll et al. (2023) reviews these budgets by including more recent data and refined calculations (not least on the contribution of non-CO_2 emissions). They conclude that the AR6 numbers (presented in Table 1 above) may be as much as 125 to 130$GtCO_2$ too large (for the 2 and 1.5°C budgets respectively), leading to even more onerous mitigation rates. Lamboll and colleagues challenging conclusions are not in isolation; increasingly others in the scientific community are highlighting how the IPCC's latest carbon budgets likely are very optimistic[8].

- The inclusion of more uncertain earth systems feedbacks (ESF) (and consideration of possible tipping points) could decrease the size of the budgets even further (Lowe

[8] See e.g. Forster et al. (2022) on the size of remaining carbon budgets, Hansen et al. (2023) on climate sensitivity and Rockström (2023), in conversation with Anderson, on the Earth System Feedbacks not accounted for in the IPCCs carbon budgets.

& Bernie 2018). Prompted by rapidly depleting carbon budgets and improved understanding of the severity of likely impacts at 1.5 and 2°C, mitigation scenario modellers have begun to assume increasing levels of future carbon dioxide removal (CDR). This takes the form of negative emissions technologies (NETs) and nature-based solutions (NbS), to the point that future planetary scale CDR has become ubiquitous across high level emission scenarios (such as those in IPPCs WGIII reports) (Caverley & Anderson 2022; Anderson et al. 2023). Set within the context of high levels of uncertainty associated with such levels and rapid rollout of CDR, this report adopts a conservative approach. As such, it uses the AR6 headline budgets, not increasing them through the inclusion of CDR nor reducing them through additional ESFs.

- As our focus in this analysis is on energy-related emissions only, key determinants to establishing the size of the remaining energy-only global carbon budgets are the prospective cumulative emissions from non-energy sources of CO_2 (dominated by cement process emissions and ongoing deforestation). As in Anderson, Broderick & Stoddard (2020) we make the highly optimistic assumption that CO_2 emissions from land-use, land use change and forestry (LULUCF) will rapidly be decreased, eliminated and followed by a net carbon sequestration across global forests, leading to no net accumulation of biogenic CO_2 emissions across the century. Highly optimistic assumptions are also applied to future process emissions from cement production (42-75GtCO_2 over the century for the 1.5 and 2°C budgets respectively).

- Another set of key assumptions need to be made when allocating a finite global carbon budget to all the nations of the world. This report starts from the high-level Paris-based division between "developed" and "developing country parties". However, which countries belong to which of these two groups has significant impact for the final budget numbers of Sweden. If we would simply follow the somewhat outdated classification previously adopted by the, UN, rather than reclassification proposed by Anderson, Broderick & Stoddard (2020), the budget for Sweden from January 2024 would be as small as 170MtCO_2 for a 83% chance of 2°C and virtually gone for a 50% of 1.5°C. On the other hand, and within this report's approach of using grandfathering as an allocation principle between "developed countries", if the reference year for making the allocation would be 2024 instead of 2020, the budget for Sweden may be as big as 370MtCO_2 (for 83% of 2°C) and 165MtCO_2 (for 50% of 1.5°C). But given that 2020 is already 5 years after the

commitments made in Paris, we have here chosen to stick with the values as presented in table 2.

- Recent years have seen other reports (Morfeldt et al. 2022; Hahn, et al. 2022) attempting to estimate Sweden's "fair" contribution to the Paris Agreement. We certainly welcome their questioning of the use of grandfathering as an allocation principle between developed countries, and their proposing alternatives. However, their preferred approaches are unfortunately not complemented with any form of analysis assessing the feasibility for other countries (and the global level) to deliver the required mitigation rates within their chosen (very tight) global carbon budgets and allocation principles. Consequently, whilst their proposals make for interesting reading, their abstract characterisation of the mitigation challenge fails to consider real-world feasibility. A further concern with these notional approaches is that they both rely on planetary scale levels of CDR. Morfeldt et al. (2022) are guided by the IPCC's IMP-Ren scenario (IPCC 2022) whilst Hahn et al. (2022) make no specific quantitative reference but their preference for a very small global carbon budget (67% chance of 1.5°C) implies the need for very high levels of CDR. Their analysis is therefore, in its current form, not directly comparable to the results presented in this report. More useful as a complement in determining the full extent of what a fair contribution to the Paris Agreement may entail (including financial transfers required on top of, and not instead of, delivering on the Paris-compliant budgets as presented in this report) is the work of the Climate Equity Reference Project[9] (Holz et al. 2019).

In conclusion, it is certainly possible to 'fine tune' some of the assumptions that underpin the downscaling of the IPCC's global carbon budget to Sweden. However, within the tight IPCC carbon budgets for 1.5–2°C, and with serious attention paid to the UN framing of equity, the budget values developed here provide a sufficiently robust and quantitative guide to the upper end of Sweden's Paris-compliant mitigation rates. In this report we have chosen a national budget of 285MtCO_2 for Sweden from Jan 2024 and related to the "well below 2°C" framing of the Paris Agreement, (interpreted as an 83% chance of not exceeding 2°C). It is this budget that we now downscale to regions. To reiterate, we caution any reader of the report to recognise that the adopted Swedish national carbon budget and all subsequent budgets downscaled to regions, are premised on: 1) the least ambitious framing of the Paris Agreement; 2) a highly optimistic estimate of the remaining global carbon budget; and

[9] Read more at: https://climateequityreference.org/

3) a relatively weak interpretation of equity and the principle of CBDR-RC. Ultimately, and regardless of any spurious level of precision, the key message is clear. The scale of change now required by Sweden (and all other wealthy, industrialised nations) demands a fundamental departure from earlier commitments (net-zero by 2045), the current government's climate plans, and, more profoundly, many of the core economic-growth tenets of contemporary society. In so many respects, this deeply uncomfortable conclusion is a product of the long-term failure of global and national leadership to deliver on the UNFCCC's original obligations to which nations committed in 1992 (Stoddard et al. 2021).

3. Regional carbon budgets for Sweden's 21 counties

Having downscaled the global carbon budget to Sweden, the obvious question arises, should the budget be further downscaled to a local or regional level of governance. The decision of whether or not to do so, is much more nuanced than downscaling from the global to the national scale. In some nations there are well established regional government structures, with considerable powers, autonomy and financial capacity. In other nations such devolved responsibilities are far less developed. Within Sweden the levels of devolved powers are sufficient to justify some levels of viable downscaling. Clearly, localised policy makers are more au fait with regional and local circumstances, be they socio-economic, cultural, or geographical. Moreover, such regional familiarity tends to inculcate greater levels of trust and acceptance than when decisions are made by officials located far away from where the impacts are going to play out. However, there are clearly major areas of governance that do not neatly reduce to a geographical scale, these range from cross-border infrastructure networks (e.g. road and rail), to large point source activities (e.g. cement and steel production) and on to geographically centred facilities that serve wider society (e.g. aviation and shipping).

In this section of the report we provide a set of provisional carbon budgets for Sweden's 21 counties by downscaling the national Paris-compliant carbon budget as estimated above, and compare these results to a selection of current mitigation plans. But before we do so, we first provide some further level of detail as to the activities that generate the emissions that are included in the national carbon budget, as well as a few comments and assumptions about those emissions that are not included.

Emissions that are included in the Swedish carbon budget

The carbon budget for Sweden includes territorial emissions of fossil CO_2, and CO_2 emissions from (fossil) bunker fuels used for international aviation and shipping. More specifically, these emissions are generated from the following sectors and activities (with the percentages indicating how much of the sector's total emissions arise from that activity calculated as an average over the years 2017-2021)[10]:

- Domestic transport: Comprised of CO_2 emissions from passenger cars (62%), heavy trucks (19%), light trucks (9%), civil seafaring (4%), aviation (2%), buses (1%), military transport (1%) and railroad, mopeds and motorbikes (all >1% respectively).

- Industry: Comprised of CO_2 emissions from industrial production in Sweden. The main industries being iron, steel, other metals, refineries and distribution of oil and gas, cement, limestone and chemical products. All fossil CO_2 emissions but cement process emissions are included here[11]. For reasons of confidentiality, industrial emissions are not divided into subcategories in the emissions database (SMED 2022), but from statistics used for reporting point-source emissions under the EU-ETS, the main industrial fossil emissions in 2021 can be seen to come from iron and steel (39%), refineries and distribution of oil and gas (19%), mineral industry, which is dominated by cement and limestone (18%) and chemical industry (9%) (Naturvårdsverket 2023a).

- Electricity and district heating: Comprised of CO_2 emissions resulting from the (often combined) production of electricity and district heating. For reasons of confidentiality, there is no further subdivision of these emissions when downscaled to regional level (SMED, 2022).

- Work Machines: Comprised of CO_2 emissions from work machines used in industry and construction (including road work) (39%), agriculture and forestry

[10] The territorially based categories for emissions are used by "Nationella Emissionsdatabasen" (SMHI 2023), which is the main source of regional and local emissions data in Sweden.

[11] Process emissions from Sweden's cement factories removed as these are already taken as a global overhead. All other industrial emissions (such as process emissions related to iron and steel production) included here. To produce a strictly energy-only budget for Sweden, the process emissions from all industrial sectors would need to be removed. On a global level, these emissions are dwarfed by the emissions related to cement production, while in Sweden it may make some difference whether these are included or not, although not a decisive one.

(30%), airports and seaports etc. (11%), commercial and public activities (9%), households (6%), fishing boats (3%), snowmobiles and ATVs (3%).

- Own heating of houses and buildings: Decentralized heating of commercial and public buildings (49%), households (34%) and buildings related to agriculture and forestry (18%).

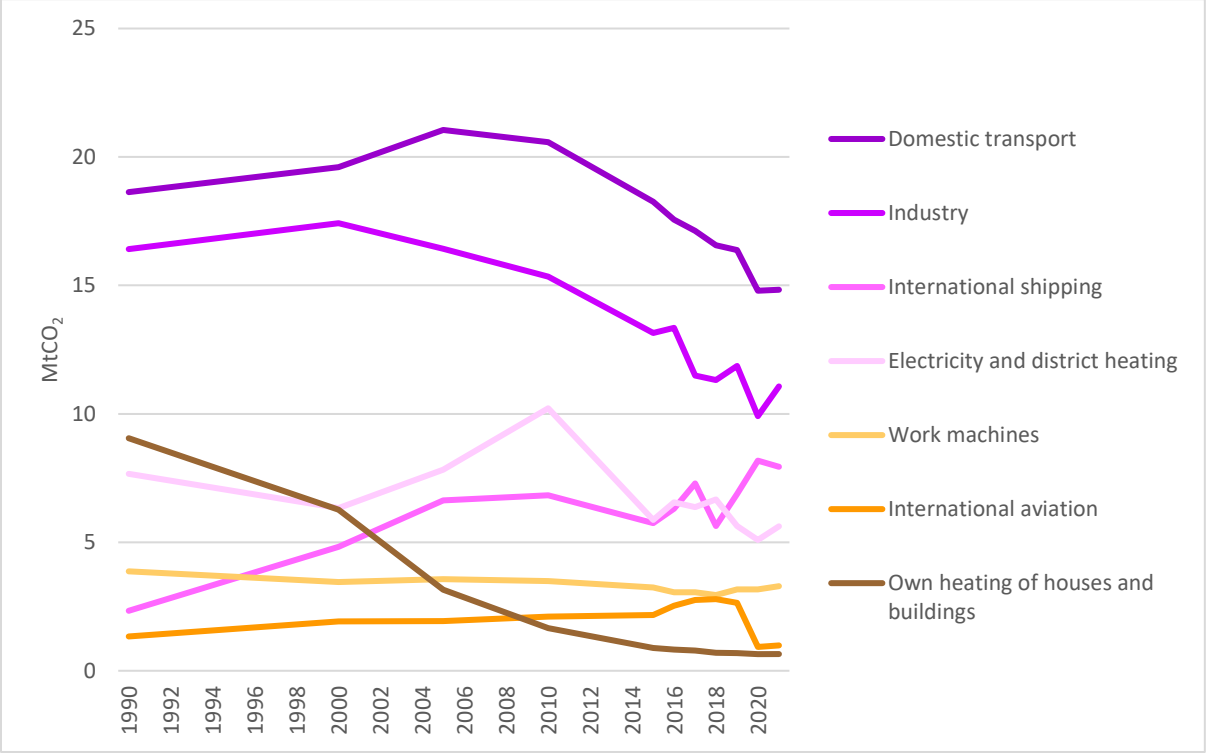
- International shipping and aviation: Comprised of CO_2 emissions resulting from the combustion of fossil fuels sold in Sweden and used in international shipping (78%) and aviation (22%) (often referred to as bunker fuels). Included in the Swedish carbon budget, as an otherwise strictly territorial division of a global carbon budget between the countries of the world, omits these very emissions. Bunker fuel statistics should only when appropriate be taken as a rough proxy for the emissions that could be attributed to the activities and needs of a country's population. In the case of Sweden, the shipping emissions are likely to be somewhat exaggerated using this approach (not least as Swedish producers have recently increased their share on the bunker-fuel market) while aviation emissions are significantly downplayed[12]. In this report we have provisionally assumed that these differences cancel each other out.

- Other: Comprised of CO_2 emissions from waste (from cremation and combustion of hazardous waste), agriculture (mainly from liming of arable land) and product use (mainly from solvent use in various operations). These emissions are relatively insignificant compared to the other categories above (just over 1% of total CO_2 emissions included in the CO_2-budget).

The evolution of the major sources of CO_2 included in the Swedish carbon budget and as detailed above can be seen in Figure 2.

[12] For an interesting attempt to take full account of the emissions resulting from Swedish citizen's international aviation, see Larsson et al. (2019).

Figure 2: Swedish CO_2 emissions per sector 1990-2021



Swedish territorial, fossil CO_2-emissions 1990-2020, including international transports (bunker-fuels). Data from Statistics Sweden (SCB 2023) with process emissions from Sweden's cement factories (Naturvårdsverket 2023a) removed from industrial emissions. CO_2 emissions from waste, agriculture and product use not included in this graph as they are all relatively insignificant (only ~0,1MtCO_2 each) compared to other emission sources in 2021.

Emissions that are not included in the Swedish carbon budget

CO_2 process emissions related to cement production as well as CO_2 emissions (and uptake) related to land use, land use change and forestry (LULUCF) are not included in the Swedish national carbon budget as these are considered as global overheads in our analysis. This does not make the sectors responsible for such emissions exempt but rather impose stringent requirements for them to also adhere to and make their fair contribution to staying within the global emissions space assumed for these emission sources (see section 2 above).[13]

In a similar fashion, emissions of other greenhouse gases than CO_2 are only indirectly included in the national carbon budget for Sweden through assumptions of future non-CO_2 emission in the IPCCs calculation of remaining global carbon budgets. For Sweden, in 2021, these are mainly methane (CH_4) and nitrous oxide (N_2O) associated

[13] E.g. for the cement industry this may entail changing the make-up of the clinker or installing Carbon Capture and Storage (CCS) of the process emissions. For the forestry sector, this also means taking into account emissions related to processing and transport, the very short time-frame of relevance for delivering on the Paris Agreement, as well as the long-term ecosystem health and resilience of Swedish forests (also in line with the Swedish environmental goals).

with agriculture and to a lesser degree waste disposal as well as hydroflourocarbons (HFCs) associated with solvents and other product use.

Another set of emissions that are not accounted for directly within the scope of the Swedish carbon budget are those related to the total consumption of goods (including those produced in other countries); so-called consumption-based emissions. For a country like Sweden using this accounting scheme leads to significantly higher emission levels than the territorial emissions used as a basis for this report.[14] Consumption based accounting includes more uncertainties than the territorial accounting, but may be more appropriate to make use of should another allocation principle than grandfathering have been selected (e.g. between the developed country parties).

A quantification of Swedish Paris-compliant budgets for these other sources of emissions (such as cement process CO_2 and non-CO_2) and accounting schemes (consumption based) is beyond the scope of this report, but could be an important area for further research.

Downscaling the national carbon budget to Sweden's counties

Having outlined the emissions included in the Swedish national carbon budget, the next step is to determine which emissions are then to be downscaled to a more local level (in our case Sweden's 21 counties) and which are to remain as a national overhead. Various practical, political and governance-related considerations can play in to determine what is most appropriate and effective in a given context. For the case of simplicity and clarity, in this report bunker fuel emissions from international and aviation and shipping are kept as a national overhead while all other emissions are downscaled to the county level, to provide a set of provisional headline regional carbon budgets. This strictly territorial approach is also used by the emissions database (SMHI 2023) which provide the regional emissions statistics for our calculations. In this database there is a small amount of emissions that are not possible to attribute geographically to a specific county (hereafter referred to as non-attributable), which we therefore keep at the national level.

The next step is to determine which allocation principle to apply to the emissions that are to be downscaled to the county-level. Kuriakose et al. (2022) have studied the effect of applying different allocation principles in downscaling global and national Paris-

[14] E.g. 83% larger than territorial emissions in 2021, according to Naturvårdsverket (2023d).

compliant carbon budgets to the subnational level (in the U.K.). Out of the allocation principles applied in their analysis (grandfathering, egalitarian[15] and capability[16]), grandfathering by far exhibited the lowest variation when it comes to the resulting sizes of different subnational carbon budgets and their associated annual mitigation rates required (varying between 7% and 16% between the regions). In their analysis, applying the capability and egalitarian principles resulted in unworkable levels of annual mitigation rates for some of subnational regions (from 50% and as high as 98% in one case). So, the pragmatic merits of grandfathering between "developed country parties" to enable delivery on increasingly small Paris-compliant global carbon budgets, also seem to hold for the context of downscaling a national budget to subnational regions.[17] Whilst there are important differences between the U.K. context which was the empirical focus of the study by Kuriakose et al. (2022), and our focus on Sweden, the small size of the remaining national carbon budget in both countries lends weight to our decision to also apply grandfathering as our headline allocation method.

Having chosen an allocation principle, the final step is to determine the year(s) on which the allocation principle is to be applied. In our case we apply the principle of grandfathering to the Swedish national carbon budget (from January 2020) using emissions data from 2019.[18] This results in carbon budgets with associated rates of annual mitigation that are equal for all counties (and national overheads), starting in January 2020. Removing emissions between 2020-2021 and estimated emissions between 2022-2023[19], results in the carbon budgets and associated mitigation pathways for all Sweden's counties (and national overheads) as presented in Table 3.

[15] Also known as equal-per-capita where the region's share of the total population of the nation in question determines the size its carbon budget.

[16] In their analysis operationalized in economic terms where the subnational region's share of the total Gross Value Added of the nation in question determines the size its carbon budget.

[17] But could of course be combined with principles factoring in e.g. capability, population, and even historical responsibility, as long as the resulting budgets and mitigation rates make it impossible to stay within the national carbon budget.

[18] Another valid option would have been to grandfather from the average emissions between e.g. 2015-2019, resulting in slightly larger regional carbon budgets for most counties (~+1-8%), and significantly larger for two counties, Jämtland and Kalmar (~+23%), but would also result in even more onerous mitigation rates for international transport (see table 3), to stay within the Swedish Paris-compliant budget.

[19] Naturvårdsverket (2023e) has estimated the changes in CO_2e emissions between 2021 and 2022. We have assumed the same percentage changes for CO_2, meaning that territorial emissions in 2022 are 5.34% lower, and international bunker fuel emissions 3.1% higher, in 2022 than in 2021. Emissions in 2023 are assumed to be the same as in 2022.

Table 3: Paris-compliant carbon budgets for Sweden's counties (and national overheads)

County	**Carbon budget from January 2020** (in $ktCO_2$)	**Provisional remaining carbon budget from January 2024** (in $ktCO_2$)	**Years of current CO_2 emissions in remaining budget**	**Exponential decline pathway:** (% annual reduction rate)	**Linear / straight line reductions pathway:** (real zero year)
Blekinge	3 265	1 795	4.8	17.3	2033
Dalarna	12 629	7 645	6.3	13.8	2036
Gotland	8 830	5 765	7.9	11.2	2039
Gävleborg	9 759	6 123	6.9	12.6	2037
Halland	9 613	5 909	6.5	13.3	2037
Jämtland	3 466	2 180	7.0	12.5	2038
Jönköping	10 289	6 340	6.6	13.2	2037
Kalmar	6 902	4 360	7.0	12.5	2038
Kronoberg	5 501	3 491	7.1	12.3	2038
Norrbotten	48 797	29 289	6.2	14.0	2036
Skåne	36 165	22 165	6.5	13.4	2037
Stockholm	36 883	24 095	7.7	11.5	2039
Södermanland	26 896	17 868	8.0	11.1	2040
Uppsala	10 972	7 191	7.8	11.4	2039
Värmland	8 785	5 357	6.4	13.6	2036
Västerbotten	11 136	6 883	6.6	13.1	2037
Västernorrland	11 134	6 783	6.3	13.6	2036
Västmanland	9 675	5 971	6.5	13.3	2037
Västra Götaland	76 516	45 906	6.0	14.4	2035
Örebro	9 585	5 837	6.3	13.7	2036
Östergötland	15 381	9 351	6.3	13.7	2036
Regional Total	**372 182**	**230 306**	**6.6**	**13.2**	**2037**
National Overheads					
International aviation and shipping	89 883	53 433	5.8	14.7	2035
Non-Attributable	1 935	1 364	9.9	9.3	2043
Sweden Total (Overheads and Regional)	**464 000**	**285 113**	**6.4**	**13.5**	**2036**

Regional carbon budgets and implications for mitigation pathways in Sweden's 21 counties, as well as budgets and pathways for emissions kept as national overheads. Swedish Paris-compliant carbon budget in 2020 was first allocated using the grandfathering principle and based on emissions levels in 2019. Post-2023 budgets and pathways developed by removing determined (2020-2021) and estimated (2022-2023) emissions, with regional data provided by "Nationella emissionsdatabasen" (SMHI 2023) and national bunker fuel data from Naturvårdsverket (2023b).

Considerations for adjusting regional carbon budgets

As can be seen in Table 3, the required annual mitigation rates for the counties generally vary between ~11-14% (exponential decline pathway) with real zero year (if linear pathway is followed instead) of 2036-2039. One notable outlier is Blekinge county with a significantly more challenging mitigation challenge in January 2024. This is mainly the result of a significant increase in emissions from an oil-fired power plant (Karlshamnsverket) in 2021, with yet another doubling of emissions in 2022. Karlshamnsverket has the task of providing reserve power to the Swedish national grid during electricity shortages, but is also in production when electricity prices are high (i.e. when it is profitable). This raises the question if, and to which degree, point source emissions such as Karlshamnsverket, that provide some level of service to other regions within Sweden, should be considered as a national overhead (or that the burden of these emissions is spread out to the relevant counties).[20] There are certainly industrial emissions attributed to certain regions under a strictly territorial accounting scheme that would be more appropriate to consider as the responsibility also of other regions (e.g. cement production on Gotland used for new construction in other parts of Sweden) or as a national responsibility.[21] As many of these industrial production facilities also provide regional services (e.g. in the form of district heating) it might make sense to apportion a part of their emissions to a regional (and/or municipal) carbon budget and the rest to other jurisdictions.

As was seen in Figure 2 above, domestic transport is the single largest source of fossil CO_2 emissions within Sweden. Whilst there are many limitations (from a CO2 transport emissions perspective) with the strict geographical focus of the regional emissions database[22] (SMHI 2023), one could envision how it could be used to attribute thoroughfare emissions (approximated with emissions from traffic on major road-networks) to a national overhead, whilst the remaining transport emissions remain

[20] Foreign ownership of the facilities producing the emissions (which is the case with Karlshamnsverket and other large point sources of emissions such as e.g. the cement factories in Slite on Gotland and in Skövde), is another important factor to consider here.

[21] Or on the EU level, as under the current Emissions Trading Scheme, if the EU would have developed a Paris-compliant carbon budget framework.

[22] This is especially true for emissions that don't have a direct local environmental impact (such as CO2 emissions) and whose sources could be attributed to other regions (such as transport emissions). The strict geographical approach means that emissions are attributed to the geographical area where they are released whether this is from a car, a truck or even an airplane. For an alternative to this approach, that instead attributes the emissions to the geographical area of the owner of the vehicle, see Willerström (2019).

within a regional or municipal carbon budget. The quality of the national level data as well as the allocation methods used in the emissions database are considered to be good, even if riddled with certain uncertainties (especially for the category work machines) (SMED 2022). However, as Willerström (2019) also notes, an awareness of the shortcomings of the data and the geographical allocation method is important to not warrant an uncritical use of the database.

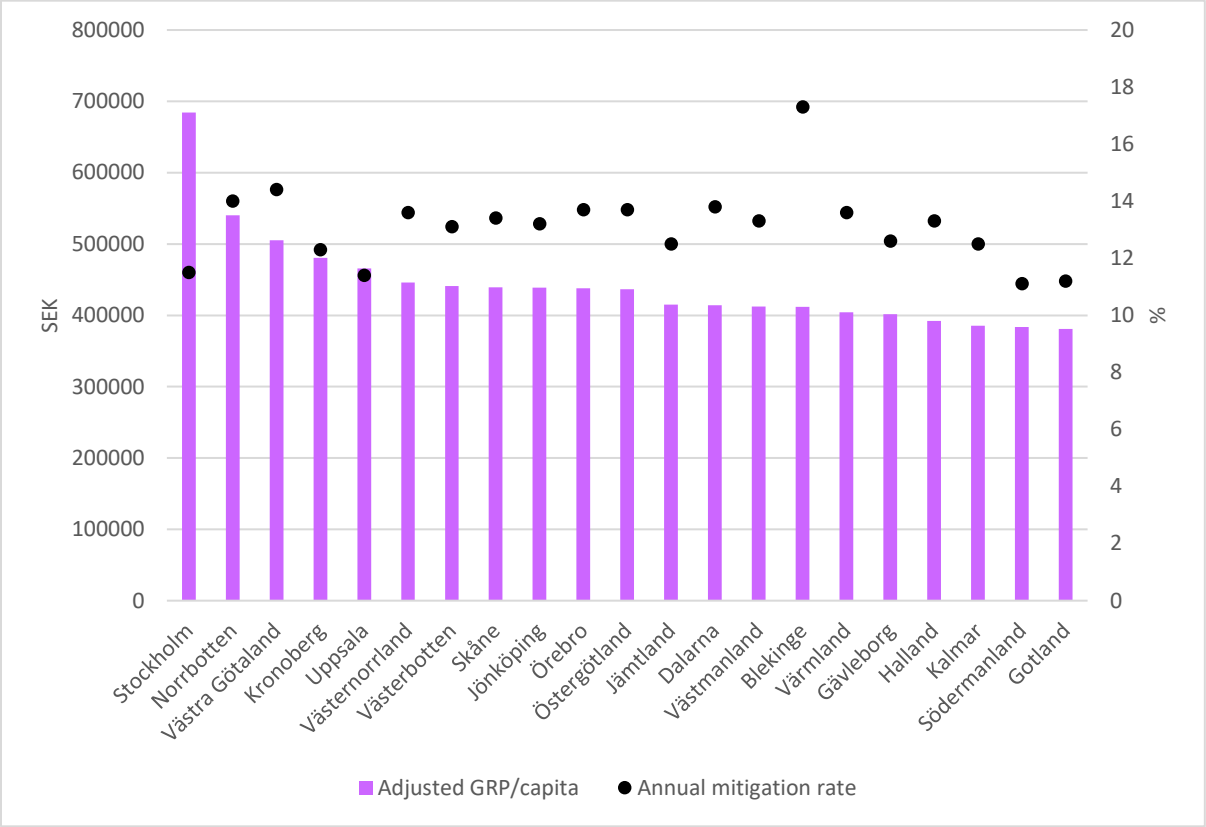
In line with our earlier work (Anderson, Stoddard et al 2017, 2018), and the ensuing carbon budgets developed by Klimatsekretariatet (Climate Visualizer 2023), another reasonable adjustment to the carbon budgets presented in Table 3 could be to downscale the international aviation and shipping emissions to the subnational level, based on a simple straight-forward per-capita allocation, or combined with some measure of capability (e.g. statistics on wealth/income at the regional, municipal or even post-code level[23]).

This brings us to a final consideration, namely if economic capability should influence the allocation of a national carbon budget subnational levels. In Sweden there is already a system for municipal and regional economic equalization that has been in place since 2005, where differences in income-levels and other structural differences are not to be in the way of providing similar levels of service to inhabitants, regardless of where you live. Taking this existing redistribution system into consideration[24], Figure 3 plots an adjusted Gross Regional Product (GRP) per capita and the required annual mitigation rates for all Sweden's counties. The plot suggests there may be an argument to be made that the carbon budgets be adjusted slightly, but considering the very high mitigation rates already required from all Sweden's counties there is very little room to play with in this regard.

[23] For an example of the use of post-code data to estimate (consumption-based) emissions, see: www.sei.org/tools/konsumtionskompassen.

[24] Using data from 2019, the equalization increases all counties' Gross Regional Product (GRP) per capita increases between 0 and 5,6% (with Stockholm at the low end and Gotland at the top end of receiving additional economic support).

Figure 3: Economic capability and annual mitigation rates for Sweden's counties



Economic Capability of Sweden's 21 counties as measured in an adjusted Gross Regional Product (GRP) per capita where the economic equalization system in Sweden has been accounted for, plotted alongside the annual mitigation rates required to stay within the Paris-compliant national carbon budget. Economic data used is for 2019 and taken from Statistics Sweden (SCB 2022) and mitigation rates from Table 3 in this report.

4. Comparing Paris-compliant pathways with current plans and projections

Whatever the choices made in terms of which emissions to downscale to the subnational level and how this is to be done, the fundamental challenge to stay within the national Paris-compliant carbon budget of 285MtCO_2 remains. To highlight the gap of ambition, this budget can be compared to estimates of the total cumulative CO_2 emissions that would result should current targets, plans and projections instead be followed. Three different estimates are developed here, based on the climate targets of the current climate policy framework (Regeringskansliet 2017), projections of CO_2 emissions up until 2050 (with existing measures) by the Swedish Environment Protection Agency (Naturvårdsverket 2023) and targets and estimates on future global CO_2 emissions from international transport by the International Maritime Organisation (IMO) (IMO 2023) and the International Civil Aviation Organisation

(ICAO) (ICCT 2023). The total cumulative CO_2 emissions[25] across the century from three estimated pathways range from a highly optimistic 455MtCO_2, up to as much as 1055MtCO2 when only existing measures are considered.

- Current pathway 1 (most optimistic): Sweden's overall national climate target (and sub-target for domestic transport in 2030) is reached, without the use of complementary measures, following linear reduction pathways from January 2024 until zero territorial CO_2 emissions is reached in 2045. Emissions from bunker fuels for international shipping follows the most ambitious mitigation target of the IMO (40% reduction in 2030 and 80% reduction in 2040, compared to 2008 levels) (IMO 2023), reaching (highly optimistic) zero emissions in 2050. Emissions from bunker fuels for international aviation follows ICAOs projections under their 2050 net-zero target (ICCT 2023) which is estimated at 63% lower in 2050 (cf. 2023), reaching zero emissions in 2075. This leads to estimated cumulative emissions of 455MtCO_2.

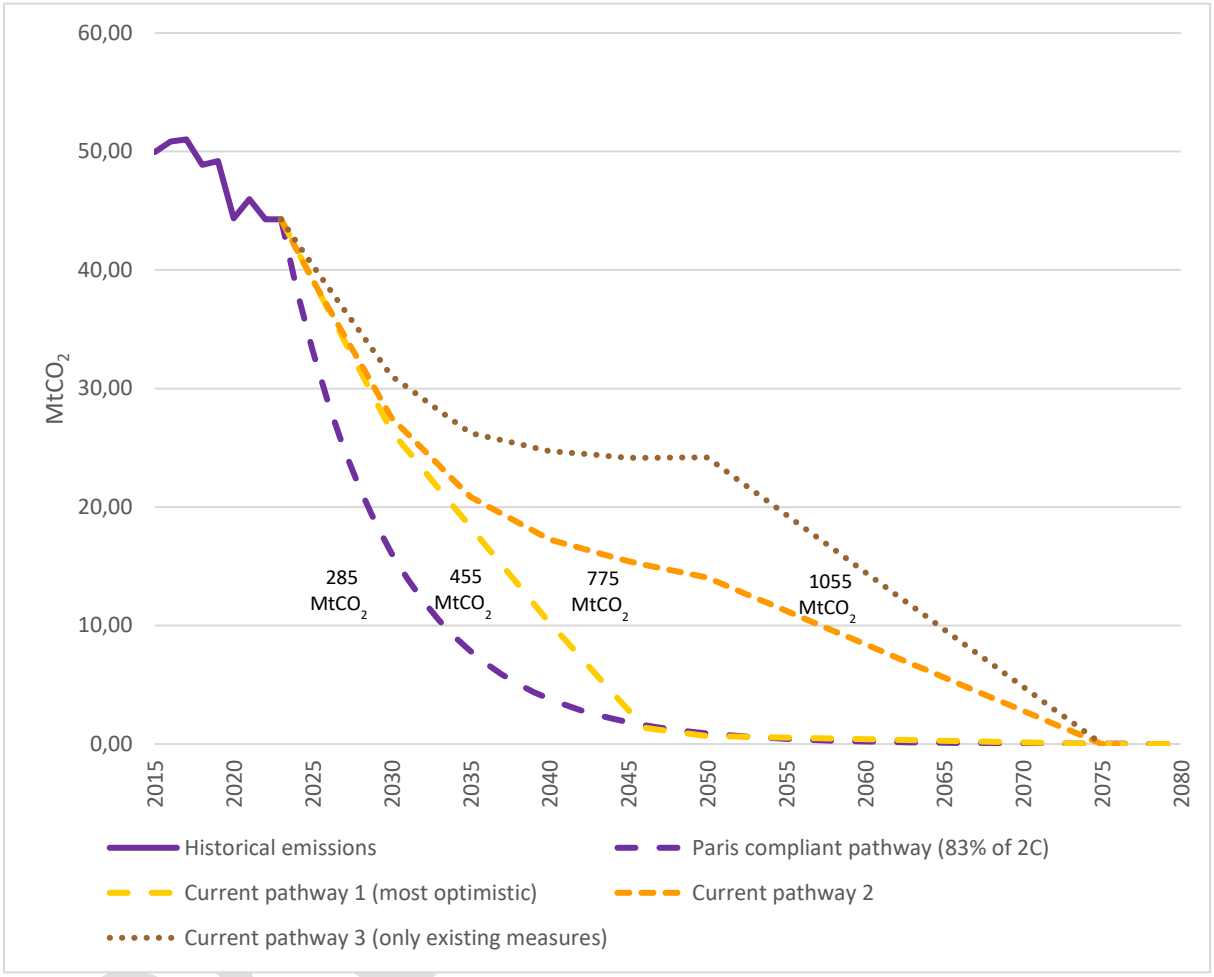
- Current pathway 2: This pathway follows the Swedish Environment Agencies' most recent projections for future territorial emissions of CO_2 (up until 2050) when only existing measures[26] are considered (Naturvårdsvetket 2023c). Emissions from international aviation and shipping are here assumed to follow the same, highly optimistic, trajectories as in the previous pathway. Emission remaining in 2050 (~14MtCO_2) remaining in 2050 are thereafter assumed to decrease in a linear fashion, until zero emissions is reached in 2075. This leads to estimated cumulative emissions of 775MtCO_2.

- Current pathway 3 (only existing measures): This pathway also follows the Swedish Environment Protection Agency's most recent projections for territorial CO_2 emissions when only existing measures are considered, but also include their projections of emissions associated with international shipping and aviation (Naturvårdsverket 2023c). Emission remaining in 2050 (~24MtCO_2) are thereafter assumed to decrease in a linear fashion, until zero emissions is reached in 2075. This leads to estimated cumulative emissions of 1055MtCO_2.

[25] From the same emission sources as included in the Swedish Paris-compliant carbon budget (see section 3 above).
[26] As of 30 June, 2022.

Figure 4 compares a Paris-compliant pathway following an exponential decline to stay within the national carbon budget of 285MtCO2, with the three pathways described above and their respective cumulative emissions of CO_2 across the century.

Figure 4: Paris-compliant pathway vis-à-vis projections following current plans



A Paris-compliant mitigation pathway for Sweden's emissions of fossil CO_2 compared to three different projected pathways following current plans and existing measures. Emissions in all pathways are territorial, excluding cement process emissions but including bunker fuels for international shipping and aviation. The associated cumulative emissions for each pathway indicated under each curve shows the large difference in their respective contribution to further climate forcing. Projected territorial CO_2 emissions calculated using targets in Sweden's climate policy framework (Current pathway 1) and estimates by the Swedish Environment Protection Agency (Naturvårdsverket 2023c) (Current pathway 2 and 3). Projected emissions from international transport based on most optimistic targets and estimates by the International Maritime Organisation (IMO 2023) and the International Civil Aviation Organisation (ICCT 2023)(Current pathway 1 and 2) and estimates by the Swedish Environment Protection Agency (Natuvårdsverket 2023c) (Current pathway 3).

5. Regional carbon budgets and closing the gap in ambition

There are a large number of barriers curtailing the ability to realize the rapid and comprehensive transitions to a fossil-free energy system that follow from the calculation of Paris-compliant carbon budgets (at the global, national or subnational level). What has become apparent is that the speed of a Paris-compliant energy transition poses new and very challenging questions concerning the role that technology and behavioral change alone can play, and that a fundamental shift away from dominant political framings and practices seems inevitable unless we renege on the commitments made in the Paris Agreement. This is particularly well illustrated in the scope and shape of a set of heuristic future scenarios developed as a corollary to the national and regional carbon budgets developed here (see the report Paris-compliant emission reductions for Sweden by Anderson & Stoddard 2023). These are premised on Sweden being in the process of meeting its Paris-compliant carbon budget for 2°C, and are in the form of narratives rather than detailed blueprints. They draw inspiration from ongoing discussions with civil servants, civil society and research colleagues and other attempts to develop scenarios of Paris-compliant pathways (see Kjellström 2022 and Klimatriksdagen 2022) and low-energy-use futures (see Energimyndigheten 2016).

The lack of sufficient institutional agency, authority and capacity to drive the very rapid emissions reductions called for, has continued to sail up as an important issue during our work with regional actors. Whilst there seems to be increasing understanding and widespread agreement that rapid annual emission reductions are important and climate change is a highly prioritized issue in regional governance, there is still a lack of implementation and uncertainty about appropriate responses and measures. This can lead to delay and a sense of temporal desynchronization between what is seen to be necessary (e.g. through target-setting) and what actually is done (Stoddard & Kuchler, forthcoming).

A few early and preliminary studies (as a part of master thesis work) indicate that Swedish civil servants at the local and regional level initially saw carbon budgets mainly as a tool to communicate the scale, urgency and cumulative nature of the climate challenge (Melander 2019), but that this may be changing as more municipalities and regions start attempting to integrate carbon budgets and associated emissions reductions and pathways into local governance systems (Garfield 2021). This is also the focus of another 4-year research project (2021-2025) that explores the challenges of integrating carbon budgets into regional planning, also funded by the Swedish Energy Agency. Other ongoing research explores the temporal dynamics that

are induced and reshaped by the urgency to accelerate climate mitigation, and their influence on regional energy planning and development pathways (Stoddard & Kuchler, forthcoming) including how local carbon budgets may contribute to strengthen different narratives of change underpinning responses to the climate crisis and contemporary forms of governance (Gunnarsson 2021).

6. Further information and ways to engage

A full list of publications as well other material related to the project that enabled the writing of this report can be found at: www.cemus.uu.se/carbon-budgets.

More information, including recorded presentations and discussions on the science and politics of carbon budgets can be found at: www.co2-budget.com.

Over the past six years, some sixty municipalities, counties and regions in Sweden have had regional carbon budgets developed, building on principles and methods outlined in this report. For direct inquiries about establishing a regional carbon budget (for a municpality, region or county) contact the not-for-profit Klimatsekretariet; they are experts in developing, digitalising, visualising and updating regional carbon budgets within Sweden. Klimatsekretariatet also work on other ways to bring research, the public sector and civil society together in responding to climate change: www.klimatsekretariatet.se.

"Integration of regional carbon budgets in region climate politics", is a 4-year research project (2021-2025) also funded by the Swedish Energy Agency, which builds on findings from the project reported on here: More information on the project's website: https://mesam.se/projekt/koldioxidbudgetar.

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