

Consumption-based Scenarios for Sweden

- a basis for discussing new climate targets

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Summary

The Swedish Cross-Party Committee on Environmental Objectives has commissioned this report as a basis for discussing Sweden's future climate policy, in general, and consumption-based climate targets, in particular. The work has been performed by 13 researchers at Chalmers University of Technology, IVL Swedish Environmental Institute, and KTH Royal Institute of Technology. The report aims to analyse how greenhouse gas emissions caused by our consumption will change over the next 30 years and to provide an overview of the science of global emission trajectories that meet the Paris Agreement temperature targets and what these mean for Swedish consumption-based emissions in relation to various equity principles.

PART 1 - Consumption-based Scenarios for Swedish Climate-Changing Emissions in 2050

In 2019, Swedish territorial emissions—emissions occurring within the Swedish borders—were 5 tonnes of carbon dioxide equivalent (CO₂e) per person. Consumption-based emissions depart from territorial emissions by including emissions that occur abroad in the production of goods and services imported to be consumed domestically while excluding emissions due to exports. According to the methodology employed by Statistiska Centralbyrån (SCB, Statistics Sweden), consumption-based emissions amounted to 9 tonnes of CO₂e per person in 2019. Previous analyses have shown that 36% of Swedish consumption-based emissions occur in Sweden, 22% occur in countries that are part of the EU Emissions Trading System, and the remaining 42% occur in other countries, including Russia, China, the US, and India, where climate policies are generally weak.

This report analyses specific technology measures and behavioural changes in air travel, passenger car travel, public transport, food, heating, and investments in buildings and transport infrastructure, which together account for 63% of total consumption-based emissions according to SCB.

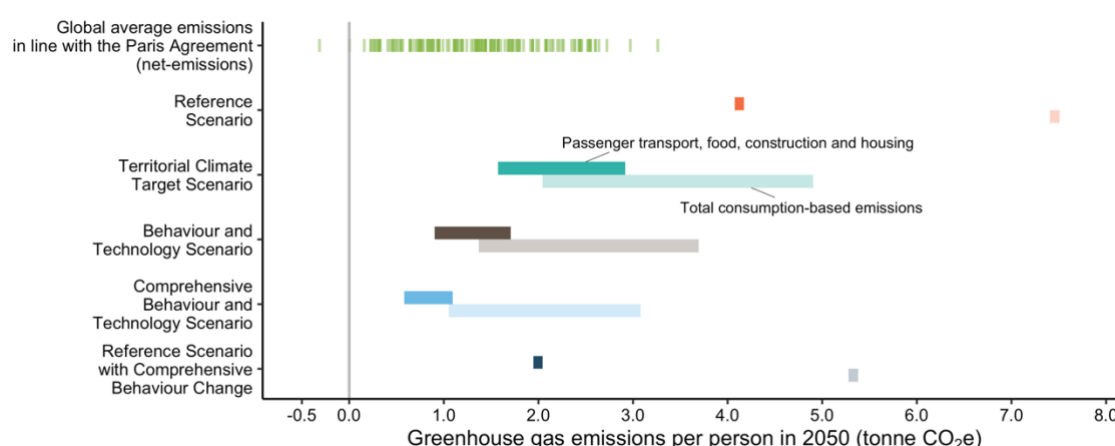
We have developed five scenarios based on different climate policy perspectives; see figure below for results. Future emissions are, of course, strongly influenced by technological developments in the rest of the world. To illustrate this, the figure presents emission ranges. Higher emissions result from continued global development according to current trends and policies. Lower emissions are instead based on a global climate transition in line with the Paris Agreement.

In the *Reference Scenario*, behaviours and technologies develop according to current trends and currently determined policy instruments in both Sweden and abroad. In the *Territorial Climate Target Scenario*, the decisions necessary to achieve the Swedish climate targets are made. For example, there is a transition to zero-emission vehicles, and the construction sector uses partly fossil-free steel. In the lower range, the whole world is assumed to transition in line with the Paris Agreement, resulting in, among other things, lower emissions abroad in the production of the vehicles and food that we import, and international air travel being powered mainly by renewable aviation fuel. At the higher end of the range, Sweden's territorial climate targets are met, but the rest of the world does not adjust to meet the temperature targets of the Paris Agreement.

In the *Behaviour and Technology Scenario*, additional domestic measures are implemented to contribute to lower greenhouse gas emissions from Swedish consumption. Here, international air and car travel are not assumed to increase as in previous scenarios, instead they remain at the 2019 level. Self-driving cars are introduced and regulated so that they do not lead to increased car use. There is a shift in meat consumption where half of all beef consumed is replaced by chicken or plant-based protein sources. Another difference is the halving of new housing construction, which is made possible in part by converting some commercial space into housing.

The *Comprehensive Behaviour and Technology Scenario* illustrates the impact of sharp reductions in flying, driving, consumption of beef and dairy products, and construction of roads and housing, but using the same technologies as in the previous scenario. In the *Reference Scenario with Comprehensive Behavioural Change*, the effect of these comprehensive behavioural changes is reflected in the emissions, but in this case in combination with the absence of advanced technological changes in Sweden as well as abroad.

The top row in the figure below shows a large number of scenarios for the average global net emissions in 2050 that can be considered in line with the Paris Agreement, if we require the remaining emission budget to be distributed equally per person. The studies were selected by the IPCC, and the density of the bars indicates the number of studies that give a particular result. The lower level of emissions in each range corresponds to limiting the global average temperature increase to below 1.5 °C. The higher level corresponds to a temperature increase below 2 °C with high probability or to a need for significant negative emissions after 2050 in order to reach 1.5 °C in the long term. Note that these are net emissions and thus include contributions from negative emissions under the respective studies, unlike the scenarios in this report.



The ranges for the scenarios shown in darker shades only cover the consumption areas analysed in this report (passenger transport, food, construction and housing). The ranges in lighter shades are estimates of total consumption-based emissions (including other consumption areas and investments). Note, however, that no behavioural changes are assumed for these areas and that this analysis is only intended to illustrate a result for the whole and is not as well substantiated as the other estimates.

The reference scenarios, both with and without major behavioural changes, are projected to result in total consumption-based emissions in 2050 at a higher level than the studies in line with the Paris Agreement temperature target, given the studies' estimated level of emissions in 2050 and that the emission budget is distributed equally per person. The results also indicate that consumption-based emissions in the *Territorial Climate Target Scenario* are higher in 2050 than in the majority of these studies. The *Behaviour and Technology Scenario* broadly corresponds to the studies' estimated emissions level in 2050, but this is under the assumption that the Swedish transition occurs in combination with a global climate transition. The *Comprehensive Behaviour and Technology Scenario* can reach levels so low that they correspond to studies in which the global average temperature increase is limited to 1.5 °C without the need for major negative emissions, but this, too, assumes a global climate transition.

In conclusion, the aggregate consumption-based emissions that can be achieved by focusing on advanced technology development do not suffice to be in line with the Paris Agreement. This is true even if the rest of the world also implements a climate transition. The results also show that comprehensive behavioural change alone, without advanced technologies, is even further away from the Paris Agreement targets. However, a combination of both advanced technologies and some behavioural changes could bring the pathway to a level in line with the average per capita 2050 emissions that correspond to the Paris Agreement targets.

Whether a given nation should decide on a consumption-based climate target as a complement to the territorial target and, if so, how ambitious that target should be, are of course political, not scientific, questions. Note that these scenarios do not include the potential for negative emissions. One possibility is to adopt a net-zero target for consumption-based emissions, too, where supplementary measures, such as negative emissions, compensate for a certain amount of remaining emissions.

PART 2 - Emissions Targets Based on the Paris Agreement and International Principles of Equity

Under the Paris Agreement, national emission reduction targets are to be achieved taking into account (i) that developing countries may need more time to reach their respective emission peaks, (ii) equity, and (iii) sustainable development and poverty eradication. In addition, implementation should be guided by the overarching principle of the UNFCCC of "equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances". However, there is no consensus on how the targets outlined at the global level in the Paris Agreement can be translated into national emission reduction targets.

How global emission reductions should be distributed among the world's nations and how the Paris Agreement and the UNFCCC's goals and principles should be interpreted for Swedish objectives are fundamentally value questions that will require political trade-offs. However, researchers and analysts have contributed with impact analyses of a variety of methods and principles for allocating the remaining emission budget; these have also been discussed in the climate negotiations.

Global average net greenhouse gas emissions of -0.3 to 3.3 tonnes CO₂e per person in 2050 could be in line with the Paris Agreement temperature target, see the first row, based on IPCC scenarios, in the figure above. However, this assumes that emissions are reduced in line with the respective scenarios already in 2020 and that the negative emissions needs of each scenario are met. A higher level of emissions around 2050 and a slower rate of emission reductions until then imply significant net negative emissions after 2050 if the ambition is to limit the long-term global average temperature increase to 1.5 °C. It is therefore important to take the emissions trajectory from now until a possible target year into account, as well as the period beyond, when considering an emission reduction target.

The equity principles of the UNFCCC and the Paris Agreement provide arguments for Sweden to adopt a more ambitious target than globally equal emissions per person, but no single level can be determined. An assessment of emission reduction potentials and, to the extent possible, an analysis of the cost-effectiveness of the measures from a global perspective, can provide a minimum level for actual reductions of consumption-based emissions. A further increased level of ambition, taking into account historical responsibilities and national transition capabilities, could be achieved either through support for measures to reduce emissions in other countries, negative emissions, and/or through accelerated reductions in consumption-based emissions.

Preface

The background to this report is that Sweden's Cross-Party Committee on Environmental Objectives has [been tasked with](#) "proposing an overall strategy for reducing the climate impact of consumption in order to achieve low-carbon consumption patterns in a cost-effective and socio-economically efficient manner. The climate impact of consumption refers to greenhouse gas emissions from Sweden's demand for goods and services" (our translation).

Based on this, Chalmers has been commissioned to produce a report outlining different scenarios for the most climate-intensive consumption areas (Part 1) and the best available research regarding a trajectory and level in 2050 for Swedish consumption-based emissions in line with the Paris Agreement and its temperature targets (Part 2).

The work has been led by Jörgen Larsson (Associate Professor in Sustainable Consumption patterns) and Johannes Morfeldt (PhD in Energy Technology), who both work in the Division of Physical Resource Theory in the Department of Space, Earth and Environment at Chalmers University of Technology. Thirteen researchers at Chalmers University of Technology, IVL Swedish Environmental Institute, and KTH Royal Institute of Technology collaborated on the report.

Part 1, the analysis of the scenarios, is based on existing models for different consumption areas that have been harmonised and adapted to the task and to the scenario narratives that are the starting point for this report. Jörgen Larsson and Johannes Morfeldt have worked on all parts of the analysis; the other researchers have mainly contributed to individual sections as follows:

- Air travel: Jonas Åkerman (PhD, KTH), Jonas Nässén (Associate Professor, Chalmers)
- Passenger car travel: Daniel Johansson (Associate Professor, Chalmers), Frances Sprei (Associate Professor, Chalmers)
- Public transport: Cecilia Hult (doctoral student, Chalmers)
- Housing and construction: Johan Rootzén (PhD, IVL), Ida Karlsson (doctoral student, Chalmers)
- Food: Stefan Wirsenius (Associate professor, Chalmers), Fredrik Hedenus (Professor, Chalmers), Erik André (doctoral student, Chalmers)
- Bioenergy calculations: Markus Millinger (PhD, Chalmers)

Johannes Morfeldt and Daniel Johansson analysed the emissions trajectory and 2050 level for Swedish consumption-based emissions in line with the Paris Agreement (Part 2).

Professor Göran Finnveden (KTH) reviewed Part 1 and Professor Christian Azar (Chalmers) reviewed Part 2.

The researchers chose to extend the analysis beyond the scope of the assignment from the Cross-Party Committee on Environmental Objectives. Funding for this extra work comes from the research programmes Mistra Sustainable Consumption and Mistra Carbon Exit.

PART 1 - Consumption-based Scenarios for Swedish Greenhouse Gas Emissions in 2050

Introduction and scenario narratives

How will greenhouse gas emissions from our consumption evolve in the future—will they remain high or are there significant emission reductions in sight over the next 30 years? How much will achieving the Swedish territorial climate targets reduce consumption-based emissions? How much could major behavioural changes contribute to emission reductions in consumption areas that are particularly challenging from a climate perspective? These are the kinds of questions we try to highlight in this report, but they do not, of course, lend themselves to unambiguous answers. We therefore sketch various pictures of the future based on five coherent, simplified scenario narratives for future Swedish climate policy. The answers to the questions also depend on broader developments, for example, what a global transition in line with the Paris Agreement might look like.

The aim of the report is to provide a basis for discussing Sweden's future climate policy, in general, and consumption-based climate targets, in particular. The aim is to analyse, on the basis of the best available science, future greenhouse gas emissions from a consumption perspective based on different climate policy pathways in Sweden, taking into account the inertia in the system and climate policy developments globally.

Where do the emissions from Swedish consumption take place?

A country's greenhouse gas emissions are typically estimated based on a territorial perspective, i.e., counting the emissions that occur within the country's borders. This report uses a so-called consumption perspective instead. This includes the emissions in other countries from the production of the goods and services that we consume and excludes emissions in our country from production destined for export. It also includes emissions from international transport by air and sea.

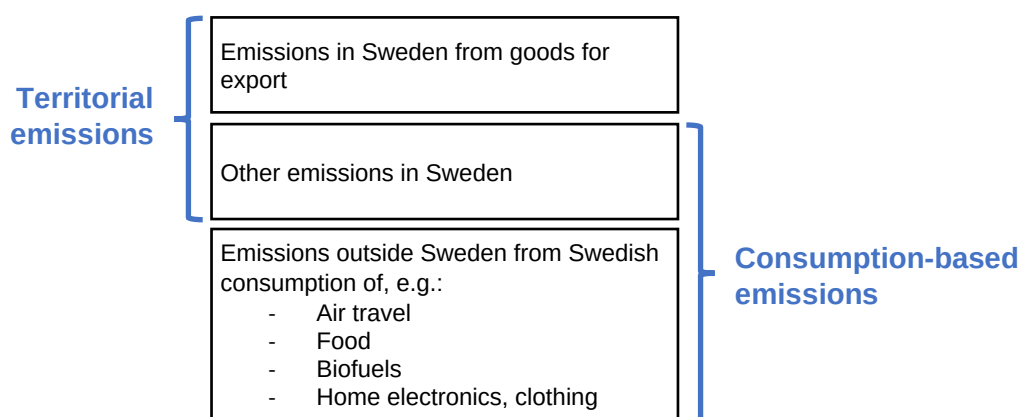


Figure 1. Territorial versus consumption-based perspective on emissions.

According to the SCB annual estimate, Sweden's consumption-based emissions amounted to 93 million tonnes of CO₂e in 2019¹, which compares to territorial emissions of 51 million tonnes of CO₂e

¹ SCB, 2021. [Växthusgasutsläpp från inhemsk efterfrågan i Sveriges ekonomi minskade 2019](#) (Greenhouse gas emissions from domestic demand in the Swedish economy decreased in 2019).

in 2019². This corresponds to 9 and 5 tonnes of CO₂e per person, respectively, and in both cases excludes emissions and removals in land use, land use change, and forestry (LULUCF).

Consumption-based analyses attribute emissions to the final consumer regardless of where the emissions occur. Below, Swedish consumption-based emissions are shown according to whether the emissions occur in Sweden, in countries that participate in the EU Emissions Trading System (EU ETS), or elsewhere. These three categories represent differences in climate policy stringency.

Combining all the consumption areas in the figure below, the analysis shows that 36% of consumption-based emissions occur in Sweden, and these emissions are covered by Sweden's territorially based climate targets. 22% of emissions occur in countries that are part of the EU ETS and that also have other national or EU-regulated climate policy instruments. In both the EU and Sweden, there is also an intensification of climate policies aimed at achieving stricter emissions targets. Overall, this means that 58% of consumption-based emissions occur in countries where there are concrete climate targets and relatively strong policy instruments. However, even though a country may be included in the EU ETS, this does not mean that all of its emissions are. For example, emissions from agriculture and land-based transport are not included in the EU ETS.

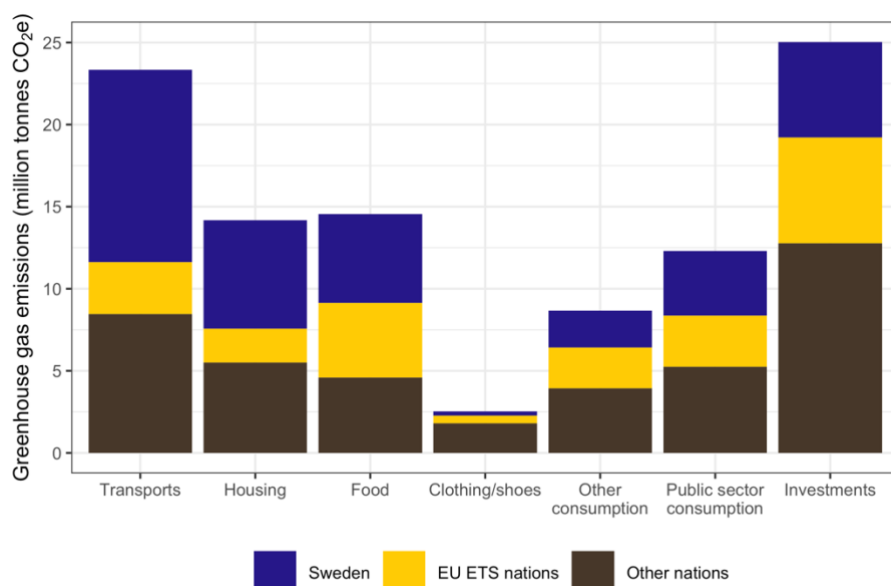


Figure 2. Consumption-based emissions by location. Source: SCB³

The remaining 42% of consumption-based emissions occur in other countries, including Russia, China, the US, and India, where climate policies are generally weak. The breakdown by consumption sector shows that clothing/shoes stands out, with as much as 71% of emissions occurring in countries with weak climate policies or none at all (although absolute emissions in this sector are low compared to other consumption sectors).

Methodology

² Naturvårdsverket (the Swedish Environmental Protection Agency), 2021. [Territoriella utsläpp och upptag av växthusgaser](#) (Territorial emissions and removals of greenhouse gases).

³ The location of emissions is not normally reported by SCB. The current dataset has been created specifically for a Mistra Sustainable Consumption project (2021). However, the figures differ from the official statistics on consumption-based emissions. For example, the results show that 36% of emissions occur in Sweden compared to 43% according to the [Swedish Environmental Protection Agency](#).

In this report, we estimate consumption-based emissions with a so-called bottom-up approach that is well-suited for scenario analyses. This is a different method from the one employed by SCB⁴. We use statistics to map the climate impact of current consumption. In the scenarios, we then calculate in detail the changes in emissions that various specific technology measures and behavioural changes may produce in the future. The calculations are based on earlier studies of emission reduction potentials in different production and consumption sectors and use previously developed calculation models:

- Passenger car travel: Prospective lifecycle analysis based on a model of the national car fleet⁵.
- Air travel: Scenario analysis based on backcasting to describe future scenarios for Swedish aviation⁶.
- Construction and housing: Material flow analysis of the construction process value chain combined with stakeholder workshops to identify potentials for emission reductions⁷.
- Food: Systems analysis of agricultural and agro-industrial processes capturing greenhouse gas emissions and resource use along food value chains^{8,9}.

The calculation models for residential and commercial heating and public transport have been developed specifically for this report. All calculation models have been adapted and harmonised based on the assumptions and scenario narratives of this report. The calculations also take into account inertia in the systems when estimating the pace at which new emission reduction measures can be introduced (see [here](#)).

The majority of all consumption-based emissions are covered in this report, including air travel, use of passenger cars, public transport, food, energy for residential and commercial heating, and investments in new buildings and transport infrastructure. However, some consumption-based emissions (37%) are not covered, mainly emissions from the production of other consumer goods (e.g., clothing, furniture, electronics, flowers, pharmaceuticals, shoes, hair and skin care products and pet food) and emissions related to certain business investments¹⁰.

⁴ SCB uses so-called multiregional input-output models (MRIO), such as [EXIOBASE](#), combined with national statistics. The statistics are reported by both [SCB](#) and the [Swedish Environmental Protection Agency](#).

⁵ Morfeldt, et al. 2021. [Carbon footprint impacts of banning cars with internal combustion engines](#). Transportation Research Part D: Transport and Environment.

⁶ Åkerman et al. 2021. [Low-carbon scenarios for long-distance travel 2060](#). Transportation Research Part D: Transport and Environment

⁷ Karlsson, et al. 2020. [Roadmap for decarbonization of the building and construction industry—A supply chain analysis including primary production of steel and cement](#). Energies.

⁸ Searchinger, et al. 2021. [A Pathway to Carbon Neutral Agriculture in Denmark](#). World Resources Institute.

⁹ Wirsén, et al. 2020. [Comparing the Life Cycle Greenhouse Gas Emissions of Dairy and Pork Systems Across Countries Using Land-Use Carbon Opportunity Costs](#). World Resources Institute.

¹⁰ The difference between the method used by SCB and the one used in this report is described [here](#).

Five scenario narratives

There are many kinds of scenarios. Some are forecasts¹¹, while others are goal-oriented and describe ways of achieving a predefined goal¹². The scenarios analysed here instead analyse various climate policy aims based on coherent, simplified narratives of how the climate impact of consumption and production might be managed in the future.

For each of these five scenarios, we assume specific technology and behavioural changes and, based on these assumptions, calculate the climate impact. The five scenarios are:

1. *Reference Scenario* – behaviours and technologies develop according to current trends and currently determined policy instruments in Sweden and the rest of the world.
2. *Territorial Climate Target Scenario* – Sweden's territorial targets are achieved mainly through technology changes and the necessary decisions are taken to achieve the targets.
3. *Behaviour and Technology Scenario* – in addition to changes to achieve Sweden's territorial targets, additional measures (both in terms of technology and behaviour) are implemented to contribute to lower climate impact beyond Sweden's borders, too.
4. *Comprehensive Behaviour and Technology Scenario* – sharp reductions in flying, driving, beef and dairy consumption, and in the construction of new roads and housing.
5. *Reference Scenario with Comprehensive Behavioural Change* – sharp reductions without advanced technology changes in Sweden or abroad.

The scenario analysis covers the period 2019 - 2050. Future consumption-based emissions are, of course, strongly influenced by technology developments worldwide, such as whether aircrafts run on renewable fuels, and whether the steel in our new cars is produced without fossil fuels. In order to consider how technology and global developments affect the consumption-based emission scenarios, two different global development pathways are analysed. The scenarios (except the Reference Scenario, see below) are therefore presented in a span from high to low emissions. The higher end results from the world continuing to develop according to current trends and policies. The lower end is instead based on a global climate transition in line with the Paris Agreement. This means that the world as a whole is assumed to adjust at a rate equivalent to limiting the temperature increase to 1.8 degrees (or 1.5 degrees if substantial negative emissions are realised). This pathway means that the world reaches net zero for all greenhouse gas emissions by 2070. The two development paths are mainly based on two International Energy Agency (IEA) scenarios: the *Stated Policies Scenario* and the *Sustainable Development Scenario*¹³.

The five simplified scenario narratives are described below, with a focus on consumption areas with high climate impact, their core concepts and how these have been implemented in the scenario assumptions. We then present the [results of](#) the analysis and finally a detailed description of the assumptions and results for the specific areas of [passenger transport](#), [construction and housing](#), and [food](#).

¹¹ Cf. Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#) (Forecast for passenger traffic 2040 – Trafikverket's Basic Forecasts 2020-06-15).

¹² For example, the scenarios for achieving long-distance travel in line with the goals of the Paris Agreement described in Åkerman et al. 2021: [Low-carbon scenarios for long-distance travel 2060](#). Transportation Research Part D: Transport and Environment.

¹³ IEA, 2019. [World Energy Outlook](#).

Reference Scenario

The core idea is that future development continues in line with prior trends and currently determined policy instruments. The logic behind this is that the global and national pressures to reduce emissions continue to be too weak relative to the mechanisms that sustain the fossil society, such as the economic interests of countries that own fossil resources and companies that produce products that use fossil fuels, and that consumers continue to demand products such as petrol, for example. This means that historical trends towards increased efficiency and policies that explicitly regulate emissions lead to some reductions in average emissions per good/service, but the volume of goods and services consumed increases. For instance, Swedish consumption-based emissions are at about the same level today as they were in the early 1990s; while emissions per good/service have decreased, the increased volume of consumption has compensated for this¹⁴.

However, the Reference Scenario assumes that decisions already made will be honoured, which means, among other things, that emissions from electricity generation will decrease and the use of renewable fuels for both road and air transport will increase¹⁵. Emissions per kilogram of food and per square metre of new housing will continue to decrease at the same (relatively slow) rate as before. The volume of new construction of buildings and infrastructure remains at the same level as in 2019 and there are no changes in what we eat. Passenger car travel increases in line with Trafikverket's (the Swedish Transport Administration's) projections¹⁶, corresponding to an increase by 20% per person by 2050. Air travel returns to stable levels in 2025 according to Transportstyrelsen's (the Swedish Transport Agency's) projections¹⁷. We assume that in 2025, international flights will be at the same level as in 2019 and that they will increase at the same rate as before, which means a doubling per capita by 2050. For domestic flights, we assume that the level in 2025 will be 30% lower than the 2019 level, mainly due to reduced business flying. Thereafter, we assume that it remains at this lower level while rail travel continues to increase.

Territorial Climate Target Scenario

In this scenario, Sweden makes the decisions needed to reach the goal of net-zero domestic greenhouse gas emissions by 2045. The effect of the net-zero target on various emitting sectors is interpreted based on the indications¹⁸ provided by the government (e.g., transport and energy-related emissions within Sweden are assumed to reach close to zero by 2045), which also affects the emission intensity of different goods and services within each consumption area. Emission reductions are mainly achieved through technology change, although marginal behavioural change, mainly through changes in relative prices, occurs as a result of, for example, the EU ETS.

The increased volumes of driving and flying are assumed to be the same as in the Reference Scenario, but advanced technologies are assumed to break through in Sweden. The majority of all vehicles are powered by electricity, and the remaining passenger cars, trucks, and machinery with internal combustion engines run exclusively on renewable fuels after 2040.

¹⁴ Although there are large uncertainties in the calculations, the overall picture is that emissions are at about the same level as before. The time series from 1993 and an analysis of the underlying explanatory factors can be found in [Konsumtionsrapporten 2019](#) (The Consumption Report 2019), page 55.

¹⁵ Under the EU ETS cap and agreed revisions to the [reduction obligation](#) for [petrol and diesel](#) and [kerosene](#).

¹⁶ Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#) (Forecast for passenger traffic 2040 - Trafikverket's Basic Forecasts 2020-06-15).

¹⁷ [Transportstyrelsen](#).

¹⁸ [Klimatpolitisk handlingsplan \(Climate Policy Action Plan\)](#).

Construction of housing and infrastructure is at the same level as in 2019, but emissions from production have decreased significantly in Sweden as a result of, among other things, the use of fossil-free steel and cement production with carbon capture. In terms of food, there are no dietary changes, but Swedish agriculture implements some mitigating measures, such as fossil-free commercial fertiliser, feed additives, and reduced emissions of nitrous oxide and methane from manure.

The level of consumption-based emissions in this scenario also depends on developments in the rest of the world. The upper range of emissions results from the assumption that developments abroad follow current trends and policies. The lower range means that a global climate transition has started, which among other things is assumed to mean that the above-mentioned changes in agriculture are also implemented in the countries from which we import food (albeit more slowly than in Sweden), and that emissions from aviation are reduced through the extensive use of renewable fuels, the use of electric flights for shorter trips, and the reduction of the so-called high-altitude effects of flying.

Behaviour and Technology Scenario

In this scenario, Sweden goes beyond what is needed to reach the territorial climate targets to also limit emissions in other countries that result from Swedish consumption, thereby contributing more to the Paris Agreement. These additional efforts are achieved through additional technology changes as well as some moderate behavioural change—essentially discontinuing to increase those behaviours that are currently particularly damaging to the climate. This means that per-capita driving and flying remain at 2019 levels (compared to +20% driving and +100% flying in the *Reference Scenario*). In terms of food, this scenario implies a shift in meat consumption, with half of beef replaced by chicken (or a plant-based protein source).

In terms of technology change, self-driving cars are assumed to have taken hold, and strong policy measures are used to ensure that they do not lead to increased driving. These vehicles are shared in cities to reduce the overall fleet and are also used to some extent to enable ride sharing. Train traffic is expected to increase substantially both nationally and to continental Europe. With respect to food, technology measures such as fossil-free fertilisers and feed additives contribute to emission reductions. For new construction, apart from fossil-free steel and cement with capture of carbon dioxide, less material is generally used as a result of material efficiency measures. However, the largest change is that new construction of both buildings and infrastructure in 2050 is half that of 2019; this is in part possible through the conversion of commercial space to housing.

Comprehensive Behaviour and Technology Scenario

This scenario illustrates what large-scale behavioural changes could mean for future emissions. The focus is on a few consumption categories with particularly high climate impact (air travel, cars, beef, dairy). Here, driving is reduced by 20% compared to 2019. Cycling and public transport replace some car use and working remotely expands to allow for less commuting. Total air travel is halved, and domestic flights are cut by even more. There is instead a sharp increase of domestic rail travel, and trips to continental Europe are also sometimes by train. Trips to the Mediterranean are less frequent, and intercontinental travel becomes a once- or twice-in-a-lifetime event. New construction of both buildings and infrastructure decreases dramatically, made possible by an emphasis on maintenance and renovation and on the conversion of commercial space into housing, with the average living space falling by 10%. In terms of food, this scenario includes a 75% reduction

in beef, lamb, and liquid dairy products. In addition, cheese consumption is cut by half. Consumption of pork and chicken remains at the same level as in 2019, while that of plant-based protein-rich products grows.

The technology adopted in this scenario is the same as in the previous scenario. The wider world either develops along the lines of current trends and policies or undergoes a global climate transition in line with the Paris Agreement. The latter variant illustrates by how much emissions can be cut if comprehensive behavioural change is combined with the most advanced technology development possible both in Sweden and abroad (as assumed in this report).

Reference Scenario with Comprehensive Behavioural Change

This scenario illustrates a future in which advanced technology change is not implemented in Sweden or abroad; instead, significant behavioural changes are implemented. The technologies are the same as in the *Reference Scenario* and follow current trends and policies, which means, among other things, that Sweden's territorial climate targets are not met. The behavioural changes assumed are the same as in the *Comprehensive Behaviour and Technology Scenario*.

Scenario analysis assumptions – Overview

Below, we briefly summarize the key analysis assumptions in terms of changes in 2050 relative to 2019. These and many other assumptions are described in detail later in the report.

Table 1. Key scenario assumptions. Refers to changes on a per capita basis between 2019 and 2050. The range shows differences in assumptions if the world develops according to current trends and policies or, instead, in line with the Paris Agreement. Electric vehicle figures refer to the entire vehicle fleet and renewable fuel share refers to average use for each area.

	Reference Scenario	Territorial Climate Target Scenario	Behaviour and Technology Scenario	Comprehensive Behaviour and Technology Scenario	Reference Scenario with Comprehensive Behavioural Change
Air Travel	Renewable fuel 11% Share of elec. flights 0% High altitude effect, as in 2019	Renewable fuel 26-63% Share of electric flights 0-30% of SE/EU flights Reduced high-altitude effect 0-60%	Renewable fuel 26-63% Share of electric flights 0-30% of SE/EU flights Reduced high-altitude effect 0-60%	Renewable fuel 26-63% Share of electric flights 0-30% of SE/EU flights Reduced high-altitude effect 0-60%	Renewable fuel 11% Share of elec. flights 0% High-altitude effect, as in 2019
	Air travel: Domestic -30% International +100%	Air travel: Domestic -30% International +100%	Air travel: Domestic -50% International, as in 2019	Air travel: Domestic -70% International -50%	Air travel: Domestic -70% International -50%
Cars	Share purely electric cars 50% Renewable fuel 59%	Share purely electric cars 100% Renewable fuel 100%	Share purely electric cars 100% Renewable fuel 100% Self-driving cars 5% Car share/ride share travel 34%	Share purely electric cars 100% Renewable fuel 100% Self-driving cars 5% Car share/ride share travel 34%	Share purely electric cars 50% Renewable fuel 59% Car share travel 34%
	Car travel +19%	Car travel +19%	Car travel as 2019	Car travel -20%	Car travel -20%
Train and Bus	Share electric buses for regional transport: 68%	Share electric buses for regional transport: 93% Renewable fuels 100%	Share electric buses for regional transport: 93% Renewable fuels 100%	Share electric buses for regional transport: 93% Renewable fuels 100%	Share electric buses for regional transport: 68%
	Public transport +22% Rail+bus +37%	Public transport +22% Rail+bus +37%	Public transport +35% Rail+bus +121%	Public transport +78% Rail+bus +245%	Public transport +78% Rail+bus +245%
Residential Heating	Reduced energy use 21-64% No fossil fuels	Reduced energy use 21-64% No fossil fuels	Reduced energy use 6-71% 25% of small houses, 50% of multi-family buildings/commercial space switch to heat pump	Reduced energy use 6-71% 25% of small houses, 50% of multi-family buildings/commercial space switch to heat pump	Reduced energy use 21-64% No fossil fuels used
	Heated area as in 2019	Heated area as in 2019	Heated area as in 2019 8% live in converted premises	Heated area -10% 20% live in converted commercial space	Heated area -10% 20% live in converted commercial space
Buildings & Infrastructure	Materials efficiency 14% Energy efficiency 14% Increased share of biofuels (but no electrification) for machinery and heavy transport.	Produced in Sweden: 100% cement with CCS 100% fossil-free steel Imported: 0-100% CCS cement 0-100% fossil-free steel Machinery 100% electric or biofuels Efficiency as in Reference Scenario	Produced in Sweden: 100% cement with CCS 100% fossil free steel Imported: 0-100% CCS cement 0-100% fossil-free steel Machinery 100% electric or biofuels Materials efficiency 26%	Produced in Sweden: 100% cement with CCS 100% fossil-free steel Imported: 0-100% CCS cement 0-100% fossil-free steel Machinery 100% electric or biofuels Materials efficiency 26%	Materials efficiency 14% Energy efficiency 14% Increased share of biofuels (but no electrification) for machinery and heavy transport.
	Construction volume as in 2019	Construction volume as in 2019	New construction and infrastructure -50%	New construction and infrastructure -70%	New construction and infrastructure -70%
Food	Higher productivity leads to 14% lower emissions	Technology change: 35-44% lower emissions –fossil-free fertilizer –feed additives –reduced nitrous oxide emissions –reduced manure emissions	Technology: as in <i>Territorial Climate Target Scenario</i> Diet: half of beef consumption replaced by chicken (or plant-based) Milk -50%	Technology: as <i>Territorial Climate Target Scenario</i> Diet: 75% of beef replaced by plant-based alternatives Milk -75% Cheese -50%	Higher productivity leads to 14% lower emissions Diet: 75% of beef replaced by plant-based alternatives Milk -75% Cheese -50%
	Diet: as in 2019	Diet: as in 2019			

Future consumption-based emissions – results and discussion

Here, we present the results for all consumption areas taken together for the five scenarios described above. In-depth descriptions of assumptions and results are provided later in the report, see [Passenger Transport](#), [Construction and Housing](#), and [Food](#). As described above, Swedish consumption-based emissions of greenhouse gases depend heavily on technology developments abroad. We therefore present the scenarios based on two different assumptions about global developments. We first assume that the world continues to develop according to *Current Trends and Policies*. Then, we instead assume a *Global Climate Transition in Line with the Paris Agreement*.

Scenario temperature impacts and implications for an objective in line with the Paris Agreement

Put simply, there is a linear relationship¹⁹ between cumulative emissions of carbon dioxide and the impact on global average temperatures. A consequence of this is that stabilising the global average temperature at a certain level (such as 1.5 °C or 2 °C above pre-industrial levels) requires that carbon dioxide emissions reach net zero in the long term, see more on this in the [section on global development in line with the Paris Agreement](#). This means that no more carbon dioxide molecules are added to the atmosphere than are taken up by negative emissions, such as certain net removals of carbon dioxide from forests and soils or carbon capture and storage from biomass burning. Similarly, the sum of all long-lived greenhouse gases (with an atmospheric lifetime of more than about 100 years), such as nitrous oxide and carbon dioxide, also needs to reach a net-zero level.

However, emissions of short-lived climate forcers (such as methane emissions and the formation of contrails and other aviation-induced cloudiness that is part of the so-called high-altitude effect) do not need to reach zero for the global average temperature to stabilise. Therefore, we can maintain a certain amount of annual emissions of short-lived substances and still be in line with the Paris Agreement temperature target. Of course, the greater these emissions are, the greater their contribution to the global average temperature, and the lower the cumulative emissions of carbon dioxide need to be to achieve a given temperature target.

The consequences of emissions of various types of greenhouse gases makes it misleading to analyse only their sum, presented in carbon dioxide equivalents (CO₂e), where each contribution is summed according to its global warming potential over a 100-year period (Global Warming Potential at 100 years – GWP-100). To assess whether net emission targets are in line with the Paris Agreement, we also need to analyse the mix of short-lived and long-lived emissions of different substances and any negative emissions.

Figure 3 shows the distribution of emissions between short-lived emissions from aviation (high-altitude effect) and agriculture (methane emissions) and other emissions (mainly carbon dioxide) from passenger transport, construction and housing, and food. We see that the shares are roughly the same in 2050 as they are today.

¹⁹ This relationship is called the Transient Climate Response to cumulative carbon Emissions (TCRE).

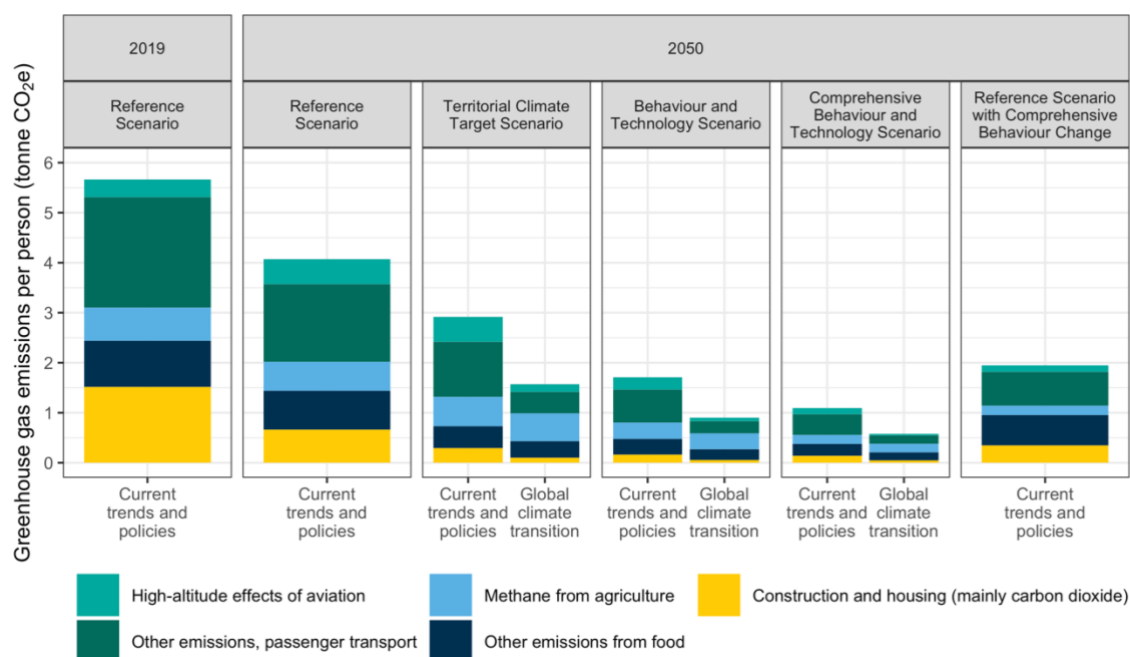


Figure 3. Climate impact emissions in 2050 per capita for each scenario compared to the base year 2019 and divided into high altitude effect for aviation, methane emissions in agriculture, and other emissions (mainly carbon dioxide). Agricultural methane emissions and the high-altitude effect of aviation are considered the main contributors to short-lived greenhouse gas emissions for the consumption areas analysed.

The results of the scenario analysis are presented briefly in Figure 4 below and in relation to the average global net emissions in 2050 that can be considered in line with the Paris Agreement (upper range) assuming globally equal greenhouse gas emissions per person. The results correspond to net emissions from -0.3 to 3.3 tonnes CO₂e per person in 2050, and the density of the bars indicates the number of studies showing a certain result. For a more detailed description of how the Paris Agreement can be interpreted and the effect of other allocation policies, see [Part 2](#). At the low end, the range corresponds to limiting the global average temperature increase to below 1.5 °C (with 50-66% probability), and the upper range corresponds to limiting it to 2 °C (with greater than 66% probability). Based on the principle of globally equal emissions per person and the Swedish population projections, this would imply net greenhouse gas emissions of -3.5 to 39 million tonnes of CO₂e in 2050.

The range of scenarios shown in darker colours only covers the consumption areas analysed in this report (passenger transport, food, construction and housing). The ranges shown in lighter colours cover total consumption-based emissions (including other consumption and business investments).

The 2050 results for consumption-based emissions in other consumption²⁰ and business investments have been calculated based on SCB's 2019 emissions statistics for these consumption areas²¹, scaled up to 2050 to take into account projected economic growth²² of 1.4% per person per year (which is equivalent to about 1.9% when population growth is included). For other consumption, the emission reduction rate is assumed to follow the same trend as the global electricity mix (see [here](#)). For

²⁰ In the statistical classification, this refers to the so-called COICOP 03, 06, 08-10 and 12.

²¹ SCB, 2021. [Växthusgasutsläpp från inhemsk efterfrågan i Sveriges ekonomi minskade 2019](#).

(Greenhouse gas emissions from domestic demand in the Swedish economy decreased in 2019).

²² Swedish Government Official Reports (SOU), 2019. [Långtidsutredningen 2019](#). (Report on the long term) SOU 2019:65.

business investments, emissions are assumed to decrease at the same rate as for buildings and transport infrastructure (see [here](#)). This means that the emission intensity for each area follows the assumptions about the global transition and is therefore shown as a range in the figure. Note, however, that no behavioural changes are assumed for these consumption areas and that the volume is thus assumed to increase in line with economic growth and that this analysis is only intended to illustrate a result for the whole and cannot be considered as well substantiated as the other calculations.

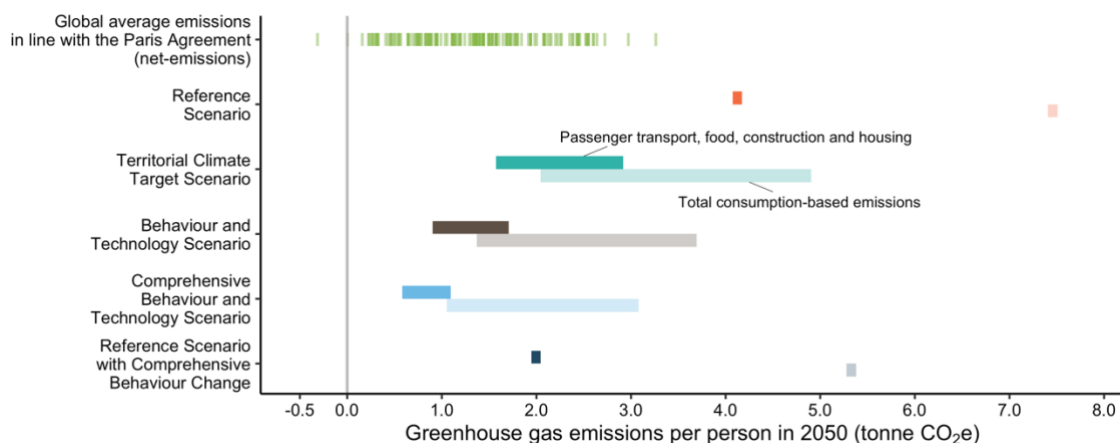


Figure 4. Top row: Global average emissions in line with the Paris Agreement assuming globally equal emissions per person. Other rows: Swedish consumption-based emissions for the five scenarios, first from the analysed consumption areas of passenger transport, food, and construction and housing, and then for all consumption areas (lighter shade). Upper end of range: the world develops in line with current trends and technologies. Lower end of range: a global climate transition in line with the Paris Agreement

Of course, future emissions will be strongly influenced by technological developments in the rest of the world. To illustrate this, a range of high and low emissions is presented. The higher end of the range is the result of the world continuing to develop according to current trends and policies. The lower end of the range is instead based on a global climate transition in line with the Paris Agreement.

The results show that the reference scenarios, both with and without major behavioural changes, are projected to result in total consumption-based emissions in 2050 that exceed the level in line with the Paris Agreement temperature target, given the studies' estimated level of emissions in 2050 and that the emission space is distributed equally on a per capita basis. The results also indicate that the 2050 consumption-based emissions in the *Territorial Climate Target Scenario* are higher than in the majority of these studies. The *Behaviour and Technology Scenario* broadly corresponds to the studies' estimated emissions level in 2050, but this assumes that the Swedish transition is combined with a global climate transition. The *Comprehensive Behaviour and Technology Scenario* can reach emission levels low enough to correspond to results in studies in which the global average temperature increase is limited to 1.5 °C without a need for significant negative emissions, but again this assumes a global climate transition. Note, however, that none of the scenarios for Swedish consumption-based emissions take possible net removals of carbon dioxide in forests and soils or negative emissions into account, unlike the IPCC emission trajectories.

Depending on the allocation principle applied to the global emission budget, if all consumption sectors are taken into account, the remaining emissions in 2050 may have to be offset by negative emissions. This could be done similarly to the current net-zero territorial emissions target, for which remaining emissions are to be covered by additional measures. Vägvalsutredningen (The roadmap study) has proposed a strategy along with targets for additional measures for the territorial climate

targets²³. Next steps include analysing the impact of the strategy and targets from a consumption perspective and how the strategy could be adjusted to also capture the need for complementary measures for possible consumption-based climate targets.

Scenario results – global development in line with current trends and policies

We now shift the focus from total consumption to the consumption areas that have been analysed in detail in this report. In what follows, all figures presented refer to passenger transport, food, and construction and housing, and exclude other consumption and business investments.

Baseline 2019 - Our results show that consumption-based emissions from personal transport, food, and construction and housing account for 5.7 tonnes of CO₂e per person in 2019. According to official statistics, this compares to total consumption-based emissions of 9.0 tonnes CO₂e for the same year²⁴. However, our analysis does not include other consumer goods (clothing, furniture, electronics, etc.) and some private investments (in particular, business investments are not included). Our analysis and the official statistics use completely different methodologies, but despite this, the results are relatively close (see [more here](#)).

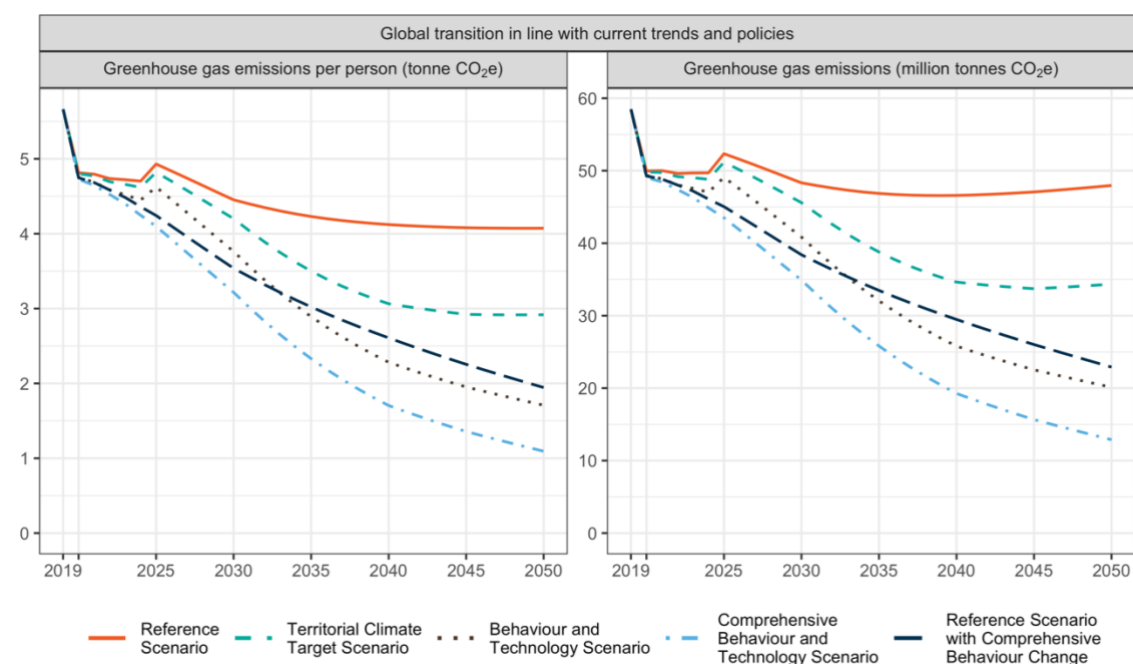


Figure 5. Swedish consumption-based emissions from passenger transport, food, and construction and housing in the five scenarios — assuming that the world develops in line with current trends and policies.

Short-term trends – In the results, emissions fall dramatically from 2019 to 2020, mainly due to the radical reduction in flying. Emissions do not increase overall in 2020-2024, despite the assumption of a relatively rapid recovery in aviation, as changes in other consumption sectors, notably reduced emissions from passenger car transport, counteract the trend. However, in 2025 emissions increase slightly due to increased aviation. For the *Reference Scenario*, the drop in emissions continues for another decade before levelling off at 4 tonnes CO₂e per person.

²³ SOU, 2020. [Vägen till en klimatpositiv framtid](#) (The pathway to a climate positive future). SOU 2020:4

²⁴ [SCB](#)

Territorial Climate Target Scenario – This scenario highlights the importance of consumption-based emissions if Sweden's territorial climate target is met. Per capita emissions are halved by 2050, corresponding to a level of 2.9 tonnes of CO₂e per person. The reduction is relatively rapid until 2040, including a shift to zero-emission vehicles in passenger transport and fossil-free steel. Thereafter, further reductions are offset by the assumption that international aviation will continue to grow at its historical rate (+100% by 2050). Developments in the rest of the world here follow current trends and policies, which means that imports continue to cause large emissions abroad, contributing to emission reductions levelling off.

Behaviour and Technology Scenario – The scenario highlights the impact of additional measures introduced to help mitigate emissions beyond Sweden's borders. Under these assumptions, emissions could reach 1.7 tonnes CO₂e per person in 2050. Differences relative to the *Territorial Climate Target Scenario* include international aviation remaining at the 2019 level and a dietary shift so that half of all beef consumed is replaced by chicken (or a plant-based protein source). Another difference is the halving of new housing construction, which is made possible in part by the conversion of commercial space into housing. *Comprehensive Behaviour and Technology Scenario* – This scenario illustrates the impact of large-scale reductions in flying, driving, consumption of beef and dairy products, and construction of roads and housing. The technology adopted in this scenario is the same as in the previous scenario. Consumption-based emissions reach 1.1 tonnes CO₂e per person in 2050. For the *Reference Scenario with Comprehensive Behavioural Change*, we find emissions of 1.9 tonnes CO₂e per person.

Scenario results – global development in line with the Paris Agreement

The pace of technology development abroad naturally affects Swedish consumption-based emissions. For example, the type of aircraft used for international travel, whether fossil fuels are still used for the production of electric cars, and the production methods for imported food. This section presents the effects of *Global Climate Transition in Line with the Paris Agreement*, whereas the section above described the results should the world not implement a climate transition. The global scenario is mainly based on an International Energy Agency (IEA) scenario²⁵ that achieves net zero global emissions for all climate drivers by 2070. This implies that the energy systems for all countries essentially become fossil-free with significant measures to mitigate agricultural emissions and international aviation and shipping. For each scenario narrative, the following section describes the effect on future Swedish consumption-based emissions of a global development in line with the Paris Agreement. For ease of comparison, we also show the emissions that follow a development in line with current trends and policies (the upper end of the range).

²⁵ IEA, 2019. [World Energy Outlook](#).

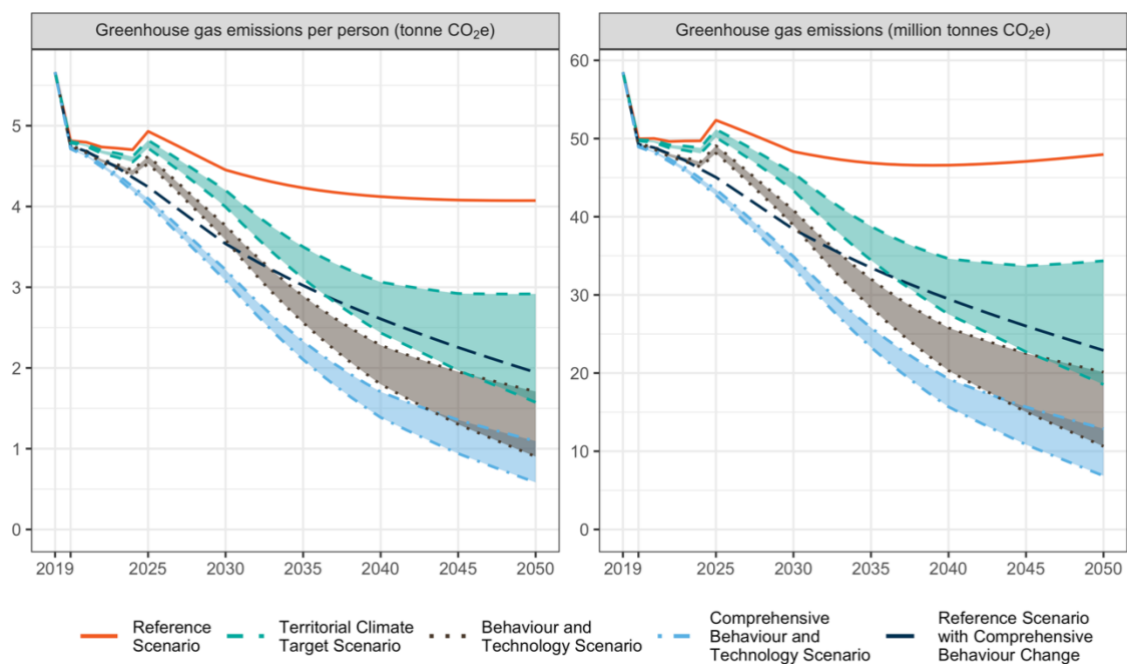


Figure 6. Swedish consumption-based emissions from passenger transport, construction and housing, and food in the five scenarios. Upper range: the world develops in line with current trends and technologies. Lower end of range: there is a global climate transition in line with the Paris Agreement.

Territorial Climate Target Scenario – Should Sweden develop in line with the territorial climate target, combined with a global climate transition consistent with the Paris Agreement, our results show emissions reaching 1.6 tonnes of CO₂e per person in 2050. Emissions thus fall from 2.9 tonnes if the world develops in line with current trends and policies to 1.6 tonnes given a global alignment with the Paris Agreement. The difference is due in part to lower emissions abroad from the production of our imported vehicles and batteries as well as food, along with the use of renewable fuel in aviation.

Behaviour and Technology Scenario – If the changes in this scenario, including less new construction and no increase in aviation, are combined with global developments in line with the Paris Agreement, emissions are estimated to reach 0.9 tonnes of CO₂e per person in 2050.

Comprehensive Behaviour and Technology Scenario – In this scenario, consumption-based emissions reach 0.6 tonnes CO₂e per person in 2050. The scenario combines comprehensive behavioural change with technologically advanced developments in both Sweden and abroad that are in line with the Paris Agreement and illustrates the reductions that can be achieved through a combination of comprehensive measures that cover both technologies and behaviours. However, this combination poses major challenges: Strong policy instruments are needed both for changes in behaviour and to stimulate the necessary technology development and deployment. The magnitude of the challenge will vary by consumption area. Reduced consumption of goods that, in general, are also produced domestically may affect incentives to invest in new technologies, but many industries are global and have high growth rates. A sustainable and equitable aviation sector could for instance entail a doubling of global flying while Swedish flying is cut by half.²⁶

²⁶ Åkerman, et al. 2021. [Low-carbon scenarios for long-distance travel 2060](#). Transportation Research Part D: Transport and Environment

Rebound effects and other behavioural change

The behavioural changes in terms of reduced driving, flying, meat consumption, and living space in the *Behaviour and Technology Scenario* and the *Comprehensive Behaviour and Technology Scenario* are likely to result in significantly lower overall household expenditures²⁷. This is particularly the case in the *Comprehensive Behaviour and Technology Scenario*, which has significantly greater behavioural changes. Societal developments that change norms and policies in this direction would also likely be associated with other forms of resource-efficient lifestyles, such as more sharing and lower material consumption of, e.g., clothes, furniture, and home electronics. This in turn would lead to even lower household expenditures. But how would the money saved be used instead and what would the climate impact be? As the scenarios of large-scale behavioural change cover all of the most important types of consumption with high climate impact today, we assume that there will not necessarily be a large-scale rebound effect in the form of an increase in other types of emission-intensive consumption. Instead, there are three other possible paths:

- Increased private consumption of goods and services with a relatively low climate impact²⁸, such as eating out, cultural events, courses, personal care, household services, as well as consumption of more expensive variants of goods such as clothing and furniture with both higher quality and higher environmental and social sustainability;
- Reduction in private consumption leveraged by an increased tax rate and increased public consumption of, for example, health care, schools and social services (which have a much lower climate impact per SEK compared to average private consumption); or
- Reduction in household expenditure combined with a general reduction in working time. For most people, the expenditure reduction would probably cover the loss of real wage growth that a reduction in working time could bring. Such a development would lead to an absolute reduction in consumption (relative to the *Reference Scenario*) and thus to reduced emissions²⁹.

Biofuel use in the scenarios

Biofuels are conceived of as a measure to help achieve the territorial climate targets as well as reduce the climate impact of international aviation. In a world recalibrating in line with the Paris Agreement, we assume that second generation biofuels will gain market share and contribute to making biofuels more available and lowering emissions from their production. Although second-generation biofuels increase the potential for biofuel production from a wider variety of bio-resources, their efficiency (i.e., how much liquid biofuel can be obtained from a unit of bio-resource) is significantly lower (up to 45%) compared to current liquid biofuel production (around 60%)³⁰. Given that the availability of sustainably produced biofuels is limited and their actual climate impact is controversial³¹, scenarios aimed at achieving the Paris Agreement targets should take into account the biofuel demand of the analysed measures. For simplicity, we here assume that direct emissions

²⁷ If the reduction is achieved through high taxes on consumption, spending may remain at a similar level, but then other taxes may be reduced (e.g., VAT), reducing total household expenditures.

²⁸ Larsson & Nässén, 2019. [Konsumtionens klimatpåverkan - trender, mål och styrmedel](#). (Climate impact of consumption - trends, targets and instruments). A chapter in *Konsumtionsrapporten 2019* (Consumption Report 2019).

²⁹ Holmberg, et al., 2011. [Klimatomställningen och det goda livet](#) (Climate change and the good life). Chalmers.

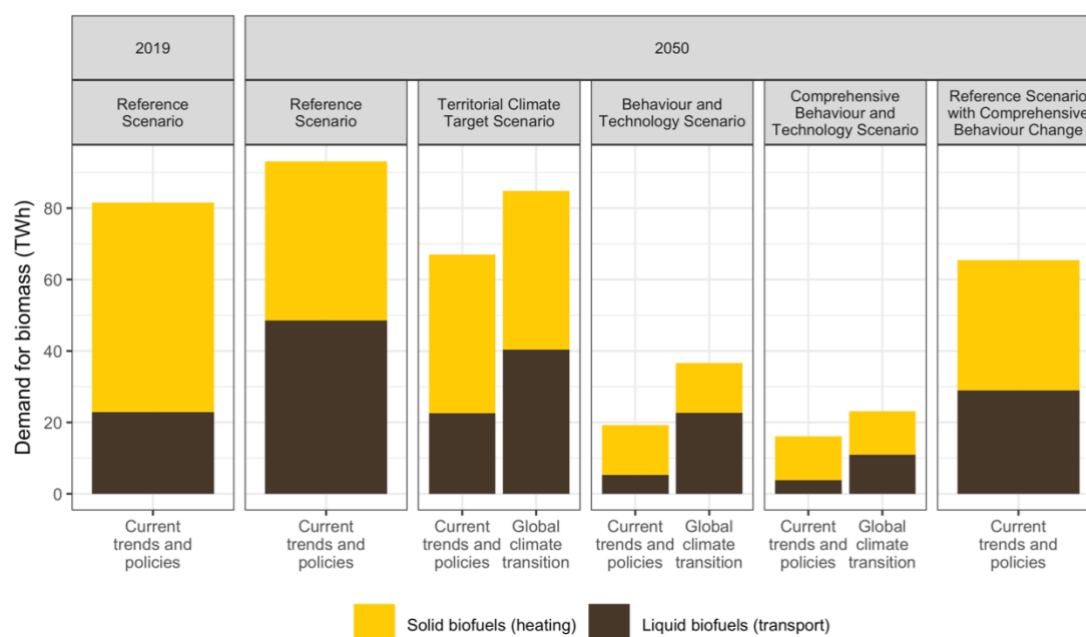
³⁰ Millinger, et al., 2017. [Competitiveness of advanced and conventional biofuels: Results from least-cost modelling of biofuel competition in Germany](#). Energy Policy.

³¹ Cintas, et al., 2016. [The climate effect of increased forest bioenergy use in Sweden: Evaluation at different spatial and temporal scales](#). Wiley Interdisciplinary Reviews: Energy and Environment.

from biofuel combustion do not have a climate impact (see details [here](#)). Note, however, that renewable electrofuels offer another option that can be used in existing infrastructure, produced by using captured carbon dioxide and electricity.

Today, biofuels are mainly used for heating (wood burning or as fuel in district heating plants), and for transportation (mainly HVO and ethanol). Taking into account the efficiency of biofuel production for each type of use, the 2019 demand for bio-resources amounts to more than 80 TWh for the sectors we include in the analysis (corresponding to 50% of the total Swedish demand for biofuels³²), see Figure 7. Note that fuel used for machinery and heavy transport (incl. shipping) as well as in the forestry and manufacturing industries for each scenario is not included in the figure.

In the *Reference Scenario*, biofuel use increases mainly in passenger cars and aviation due to policies requiring actors to meet emission reduction quotas. In the *Territorial Climate Target Scenario*, biofuel use becomes more prevalent in European aviation as well as internationally depending on the global climate transition. However, this is offset in the total by reductions in biofuel use following the electrification of passenger car and regional bus travel. The *Behaviour and Technology Scenario* assumes a lower need for biofuels for aviation given the lower volume of flights and that biofuels for heating are reduced in favour of heat pumps (individual or large-scale for district heating). Here, too, the global climate transition affects the amount of biofuels in international aviation. The *Comprehensive Behaviour and Technology Scenario* shows the impact of the assumed behavioural changes on the use of biofuels given weak and strong global technology developments. Finally, for the *Reference Scenario with Comprehensive Behavioural Change*, we see extensive biofuel use, which is interesting, since this scenario results in high emissions in 2050, and is mainly due to the mandated reductions combined with limited electrification of passenger car travel.



³² Fossilfritt Sverige, 2021. [Strategi för fossilfri konkurrenskraft - bioenergi och bioråvara i industrins omställning](#) (Strategy for fossil-free competitiveness - bioenergy and bioresources in industrial transformation).

Figure 7. Demand for biomass³³ in each scenario and solid and liquid biofuels.

In addition to the biofuel use shown in Figure 7, biofuels in the forestry and manufacturing industries and in machinery and heavy transport (including shipping) should also be considered in order to assess the full demand for biofuels. Fossilfritt Sverige (Fossil Free Sweden)³⁴ estimates that the demand for biofuels for the Swedish forestry and manufacturing industry in 2045 may be 106 TWh plus an additional 35 TWh for marine fuel bunkered in Sweden and about 5-30 TWh for machinery and road transport depending on the degree of electrification, where the uncertainty is greatest around the electrification of machinery and trucks. However, those estimates are for domestic production and thus include production of export goods but not biofuel use in other countries for production of goods imported to Sweden.

³³ The biofuel use in each consumption area is converted to biomass demand based on the efficiency of the relevant fuel production process. Where values are uncertain, the higher efficiency is chosen, which may result in a slight underestimate of the demand for biomass.

³⁴ Fossilfritt Sverige, 2021. [Strategi för fossilfri konkurrenskraft – bioenergi och bioråvara i industrins omställning](#) (Fossil-free Sweden: Strategy for fossil-free competitiveness - bioenergy and biomass in the industry transition).

In-depth description of assumptions and results for individual consumption areas

This section provides detailed descriptions for passenger transport, housing and infrastructure, and food, i.e., in-depth descriptions of the scenarios described above and in Table 1.

Passenger transport

The future greenhouse gas emissions from passenger transport in the five different scenarios are described in the figures below. Comments on these results are provided in the subsequent sections, which are divided into air, passenger cars, and public transport. These sections also provide detailed information on the various assumptions on which the analysis is based.

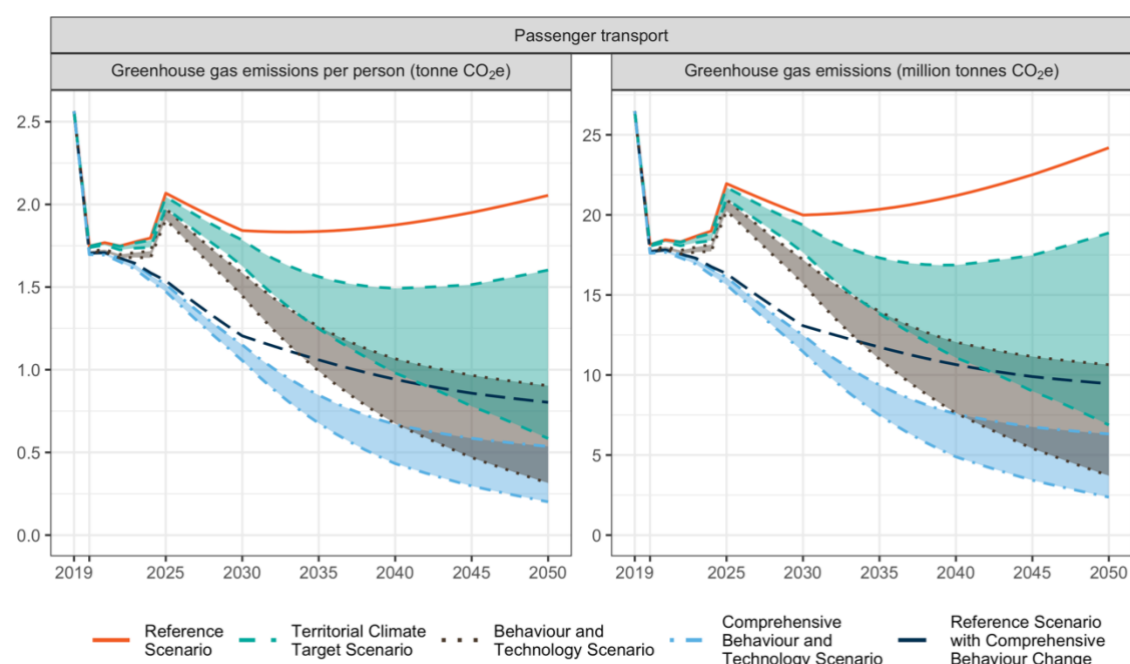


Figure 8. Swedish consumption-based emissions from passenger transport in the five scenarios.

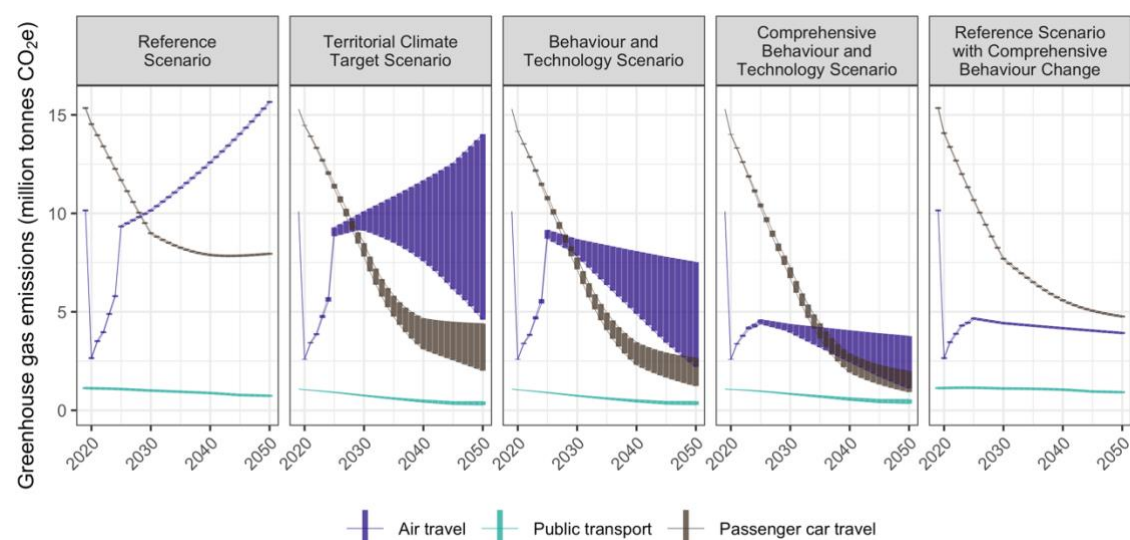


Figure 9. Swedish consumption-based emissions from air travel, public transport, and passenger cars in the five scenarios.

Air travel

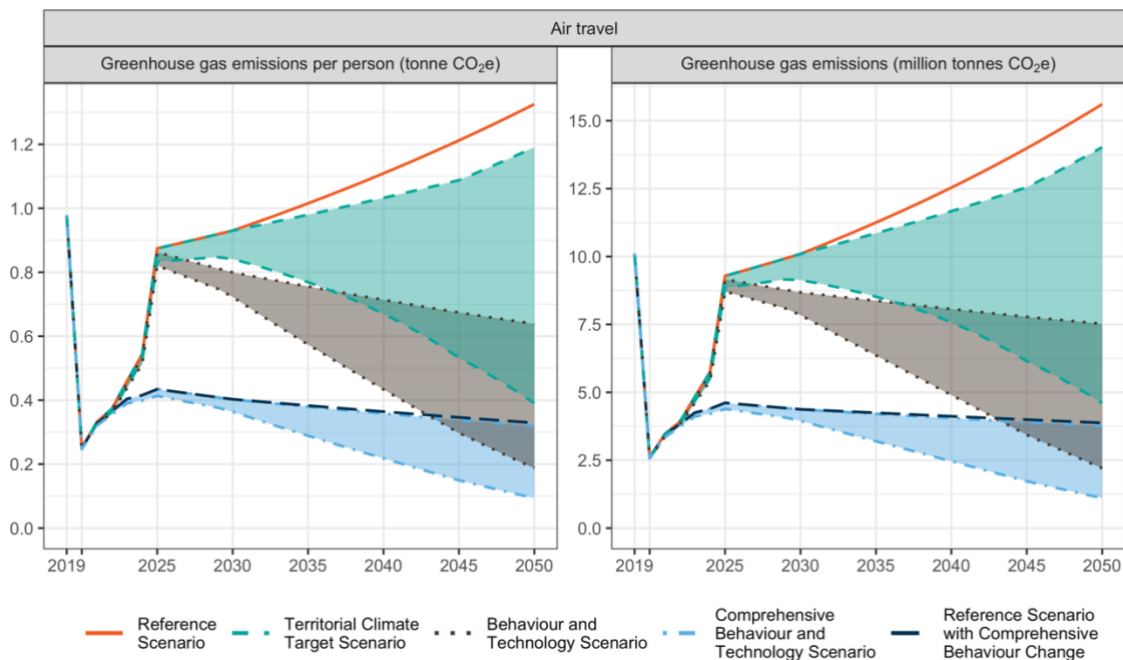


Figure 10. Scenarios for future consumption-based emissions for Swedish air travel.

In 2019, Swedish air travel (domestic and international) caused the emissions of 10 million tonnes of CO₂e. We assume that the volume will recover from the pandemic by 2025, with international flights reaching the 2019 level and domestic flights levelling off at a level 30% lower due to fewer business trips.

In the *Reference Scenario* and the *Territorial Climate Target Scenario*, the historical growth rate of international aviation is then assumed to continue, doubling by 2050. For the *Reference Scenario*, the increase in volume leads to an increase in emissions by more than 50% by 2050, due to merely moderate technology improvements.

The results of the *Territorial Climate Target Scenario* show that this sharp increase in aviation could either increase or decrease emissions by 2050. The higher figure of 14 million tonnes of CO₂e corresponds to all refuelling in Sweden using renewable fuels, while all refuelling that takes place abroad uses fossil fuels. The lower figure of just under 5 million tonnes of CO₂e is instead based on renewable fuels accounting for the majority of aviation fuel worldwide, electric flights covering some travel within the EU, and measures to reduce high-altitude effects having a major impact. The wide range of 5-14 million tonnes illustrates the uncertainty in technology development in the aviation industry and its future climate impact.

The *Behaviour and Technology Scenario* uses the same alternative technology development scenarios as above, but the volume of international flights is assumed to remain at the 2019 level throughout the period. This leads to estimated emissions from just over 2 to 7 million tonnes of CO₂e in 2050. In the scenarios with comprehensive behavioural change, the volume of international flights is instead assumed to be reduced by half compared to the 2019 level. Depending on the technology used, the *Comprehensive Behaviour and Technology Scenario* is estimated to lead to emissions from about 1 to 4 million tonnes of CO₂e in 2050. In the *Reference Scenario with*

Comprehensive Behavioural Change and very limited technological development, emissions are estimated to be around 4 million tonnes.

Baseline 2019

Greenhouse gas emissions from Swedish flying draw on an analysis that uses, among other things, Swedavia's traveller surveys³⁵. These estimates cover emissions for the entire trip to the final destination, which distinguishes them from emissions statistics based on refuelling at Swedish airports³⁶. The latest estimate is for 2017, and these figures have been adjusted downwards to take into account the latest research on the high-altitude effects of aviation³⁷. We apply a lifecycle perspective in this report (unlike the study described above), so emissions from the extraction, refining, and transport of aviation fuels are also included³⁸, see more [here](#). The 2019 emission figures also take into account the reductions in flying that took place between 2017 and 2019, the reduction for domestic flights was 12% in total and for international flights 0.5%³⁹. Based on this, emissions from Swedish flying (private and business travel, domestic and international) are estimated at around 10 tonnes CO₂e in 2019. About 7% stem from domestic flights, while 51% stem from travel to destinations within the EU and 42% to destinations outside the EU⁴⁰.

Fuels and aircraft types in the future

Future emissions from aviation largely depend on the technology used. Here we review the assumptions we use about energy efficiency improvements, renewable fuels, and new aircraft types. We assume annual energy efficiency improvements of 1.0% or 1.3% per year up to 2050 (this varies among the scenarios). The figures are based on ICAO's "moderate" and "advanced" scenarios⁴¹ but are adjusted to take into account a certain increase in the cabin factor, which is not explicitly addressed in the calculations.

Renewable fuels encompass a variety of possible feedstocks and production systems⁴². In the short term, mainly biofuels with feedstocks similar to today's HVO-diesel are available, but in the future, other fuels, such as cellulosic fuels, may be considered. Renewable electrofuels are another option, produced by using captured carbon dioxide and renewable electricity to produce a liquid aviation fuel that can be used in existing aircraft. In the longer term, hydrogen produced with electricity from, for example, wind, could be used in the aviation sector, but this would require new types of

³⁵ Kamb & Larsson (2018) [Klimatpåverkan från svenska befolkningens internationella flygresor 1990 – 2017](#) (The climate impact of Swedish international air travel 1990-2017); Larsson et al. (2018). [Measuring greenhouse gas emissions from international air travel of a country's residents](#). Environmental Impact Assessment Review.

³⁶ This does not include flights after stopovers or the high-altitude effect, but does include emissions from foreign visitors' flights.

³⁷ A reduction of the weighting from 1.9 to 1.7, based on Lee et al. (2021) [The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018](#). Atmospheric Environment. (see further under the heading High-altitude effect, below). We have also assumed that historical emissions reductions per person-kilometre continue, a reduction of 1.9% per year.

³⁸ However, climate impacts from aircraft manufacturing and airport investments are not included, but they are assumed not to have a significant impact on emissions per passenger-kilometre.

³⁹ Please note that these changes are based on changes in the total number of passengers, which also includes visitors from other countries. This introduces uncertainty. Source: Swedavia [2018](#) and [2019](#).

⁴⁰ Larsson et al. 2019. [International and National Climate Policies for Aviation: A review](#). Climate policy.

⁴¹ These scenarios are 0.96% and 1.16% in ICAO (2019) Destination Green - The Next Chapter. 2019 Environmental Report.

⁴² For an analysis of the alternatives and their costs see [Dahal et al. 2021 Techno-economic review of alternative fuels and propulsion systems for the aviation sector](#). Renewable and Sustainable Energy Reviews.

aircraft, placing implementation in the more distant future. Different renewable fuels have different climate impacts. We have assumed that renewable fuels on average have 78% less climate impact than fossil fuels (in global climate change scenarios, advanced biofuels are assumed to have achieved market penetration, increasing the average reduction to 90% compared to the fossil equivalent in 2050), see more [here](#).

The amount of renewable fuels used varies among the scenarios. For the *Reference* scenarios, we assume that the share of renewable fuels increases to a relatively low level, namely 34% by 2030 (which is the mix required to achieve the 27% emission reduction required by the decided upon reduction commitment) and then remains constant. The reduction obligation applies to airlines refuelling in Sweden. For EU flights, only outbound biofuel blending is assumed and for flights to the rest of the world, no biofuel blending is assumed. These assumptions mean that 11% of Swedish flying in 2030 will be done with biofuels.

For the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, the share continues to increase after 2030 to reach 100% in 2045 in domestic aviation as it is covered by the Territorial Climate Target. For international aviation, we assume a share of renewable fuels ranging from 26% to 63% by 2050, depending on the pace of the global transition. The lower figure assumes that all aviation fuel refuelled in Sweden is renewable but that no significant increase in the use of renewable fuels occurs abroad. The higher figure is intended to reflect a global climate transition in line with the Paris climate targets; here we assume that all international travel (return trips) is by aircraft using an average of 63% renewable fuel. This figure is based on the European Commission's proposal for a quota obligation of 63% renewable fuel in aviation by 2050. We assume that this level applies worldwide. For comparison, in the International Energy Agency's Sustainable Development Scenario, aviation emissions in 2050 are 62% lower than in the Stated Policy Scenario⁴³.

Battery-powered flights and *fuel-cell flights* may become popular for shorter flights in the future. For this, the battery energy density by weight needs to increase. One study indicates that if the energy density of batteries is quadrupled, the market segment for flights up to 1,100 km could be electrified, covering 15% of global air travel by 2060⁴⁴. Another technology solution is the use of hydrogen in combination with fuel cells. In addition to the challenge of getting these aircraft into service, new production and distribution systems for renewable hydrogen are needed. In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, we assume that 30% of passenger-kilometres for domestic and EU travel in 2050 are either battery or fuel cell flights. Battery electric flights are likely to launch first, with hydrogen/fuel cells only being implemented by the end of the period. We assume a decrease of 1.3% per year in specific electricity use for electric planes.

High-altitude effect

The high-altitude effect is very uncertain. Beyond CO₂, contrails and other induced impacts on cloud cover are the greatest contribution to the overall climate impact of aviation. In this report, we use the most established estimate that the total climate impact of aviation, based on the global warming potential over a 100-year time horizon (GWP-100), is about 1.7 times greater than the impact of carbon dioxide emissions alone⁴⁵. However, the warming effect of contrails and of other impacts on

⁴³ IEA, 2019. [World Energy Outlook](#).

⁴⁴ Schäfer et al. 2019. [Technological, economic and environmental prospects of all-electric aircraft](#). Nature Energy.

⁴⁵ Lee et al. 2021. [The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018](#). Atmospheric Environment.

cloud cover is continuously revised. A recent observational study, which analysed changes in aviation before and during the pandemic, indicates that the high-altitude effect could be significantly weaker⁴⁶.

One way to reduce high-altitude effects is to change flight paths to avoid airspace prone to the formation of persistent condensation trails, in terms of temperature, pressure, and humidity. Studies indicate that this can halve the high-altitude effects but with the drawback of increasing carbon dioxide emissions by a few percent⁴⁷. A complementary approach, highlighted in a European Commission/EASA report, is to reduce the aromatic content of aviation fuel⁴⁸. In the scenarios involving a global shift in line with the Paris Agreement, the high-altitude effects are assumed to be reduced by 60% by 2050, while for the other scenarios no reduction is assumed.

Future aviation volumes

There is of course a great deal of uncertainty about how flight volumes will develop over the next several years. The airline trade association IATA is the most bullish about recovery, estimating that air traffic in Western Europe will reach 2019 levels no later than 2024⁴⁹. Eurocontrol and Swedavia estimate that this will happen at some point after 2025⁵⁰. The forecast from Transportstyrelsen is the most sluggish⁵¹. They forecast that the number of departures from Swedish airports after the pandemic will level off at a level 35% lower than in 2019. Thereafter, they assume an increase of about 3% per year, which means that volumes would not reach the 2019 level until 2038⁵². We have not used this forecast as it lacks sufficient explanation for these sharp reductions⁵³.

All forecasters point to the shift to digital meetings in the workplace as the main factor affecting future flight volumes. This means that business travel in particular will be affected, with a greater impact on domestic than on international flights. Analysis of data from Tillväxtverket (the Swedish

⁴⁶ Digby et al. 2021 [An Observational Constraint on Aviation-Induced Cirrus from the COVID-19-Induced Flight Disruption](#). Geophysical Research Letters.

⁴⁷ Teoh, R. (2020). [Climate forcing of aircraft contrails: uncertainty quantification and mitigation potential](#). Yin, F., et al (2018). [Verification of the ozone algorithmic climate change functions for predicting the short-term NOx effects from aviation en-route](#).

⁴⁸ European Commission 2020. [Updated analysis of the non-CO2 effects of aviation](#)

⁴⁹ IATA 2021 [Air Traffic Movement Outlook - Europe August 2021](#)

⁵⁰ Described in Ds 2021:25. [Bromma flygplats – underlag för avveckling av drift och verksamhet](#) (Bromma Airport - basis for decommissioning operations and activities).

⁵¹ Transportstyrelsen 2021. [Passagerarprognos 2021–2027 – Trafikprognos för svensk luftfart](#) (Passenger forecast 2021-2027 - Traffic forecast for Swedish aviation).

⁵² Described in Ds 2021:25. [Bromma flygplats – underlag för avveckling av drift och verksamhet](#) (Bromma Airport - basis for decommissioning of operations and activities).

⁵³ The reason for the lower level indicated by Transportstyrelsen is mainly that virtual meetings are replacing physical meetings. As business travel constitutes a greater share of domestic travel, the 35% reduction needs to be allocated across domestic and international aviation, e.g., a 50% reduction for domestic travel and a 25% reduction for international travel. A halving of domestic travel would mean that business travel would largely cease. Nor is there any justification for a sharp reduction in international travel (80% of which is for leisure). However, increased climate engagement among individuals could contribute to a change. This was also a strong factor in 2018 and 2019 before the pandemic, contributing to reduced flying, although to a much lesser extent than in Transportstyrelsen's forecast. Between 2017 and 2019, domestic travel fell by 12%, and international travel by 0.5%. Sources: [2018](#) and [2019](#).

Agency for Economic and Regional Growth) and SCB shows that the share of business travel is about 30% overall⁵⁴, while it is about 60% for domestic flights and about 20% for international flights⁵⁵.

The Swedish Civil Aviation Administration is conducting an analysis specifically of domestic flights and estimates that they will level out at 30% less than before the pandemic⁵⁶. If this were realised mainly through reduced business travel, it would mean that business travel would be roughly halved. This is in line with an analysis based on business travel activity, which finds that two thirds of business air travel could be replaced by travel-free meetings. The reference scenario assumes domestic air travel at 30% below 2019 levels from 2025 onwards.

For international flights, business travel accounts for a relatively small share of passenger-kilometres, so a reduction here will not have as much impact. We assume that in 2025 international flights will reach the same level as in 2019. This is about 20% lower than the pre-pandemic projections. An analysis⁵⁷ of Swedish travellers shows a realistic potential emission reduction of about 25% based on travellers' acceptance of changing destination choices (flying to destinations that are not as remote) and/or modes of transport (mainly rail instead of air).

Assumptions for the volume of aviation by 2050 vary by scenario. In the *Reference Scenario* and the *Territorial Climate Target Scenario*, we assume that from 2025 on, domestic flights are at a level that is 30% lower per person than the 2019 level and that international flights in 2025 are at the same level per person as in 2019. We assume that international flights increase by 2.9% per year per person thereafter, which was the growth rate between 1990 and 2017⁵⁸. For international flights, this means that the volume of flights per person in 2050 is twice as high as in 2019.

In the *Behaviour and Technology Scenario*, volumes are assumed to be lower, thereby contributing to achieving the Paris Agreement climate targets. Domestic flights are assumed to stabilise at half the 2019 level, and international travel is assumed to remain at the same level from 2025 to 2050 as in 2019. Achieving such a scenario, combined with rising real wages, is likely to require changes in social norms, strong policy instruments, and improved alternatives to air travel (the increase in rail in this scenario is described later in the report as part of [public transport](#)).

In the *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change*, we assume that international flights per person in 2050 are 50% below the 2019 level, while domestic flights are 70% below the 2019 level. In this scenario, a quarter of intra-EU trips are made by train. However, achieving a halving of air travel would require a reduction in the number of intercontinental trips, as they currently account for around 40% of passenger-kilometres. When this halving of flight volume is combined with highly advanced

⁵⁴ Note that business trips are on average shorter than leisure trips, which means that business trips account for about 20% of passenger-kilometres. Source: Kamb et al. 2019. [Flygresorna och klimatet](#) (Air travel and the climate).

⁵⁵ Our own analysis of air travel based on the Swedish travel survey, [Svenskars resande](#) (How Swedes travel).

⁵⁶ Described in Ds 2021:25. [Bromma Airport - basis for decommissioning of operations and activities](#) (Bromma flygplats – underlag för avveckling av drift och verksamhet).

⁵⁷ Kamb et al. 2019. [Flygresorna och klimatet](#) (Air travel and climate) and 2020 [Potentials for reducing climate impact from tourism transport behavior](#). Journal of Sustainable Tourism. NOTE: The analysis was performed before the pandemic.

⁵⁸ Kamb & Larsson, 2018. [Klimatpåverkan från svenska befolkningens internationella flygresor 1990 – 2017](#) (The climate impact of Swedish international air travel 1990 – 2017).

technology developments, the scenario is close to those a recent study⁵⁹ identified as compatible with the Paris Agreement targets when analysing variants of advanced technological developments and showing that a 38-59% reduction in flying is needed to bring climate change impacts in line with the Paris Agreement.

⁵⁹ Åkerman et al. 2021. [Low-carbon scenarios for long-distance travel 2060](#). Transportation Research Part D: Transport and Environment

Passenger cars

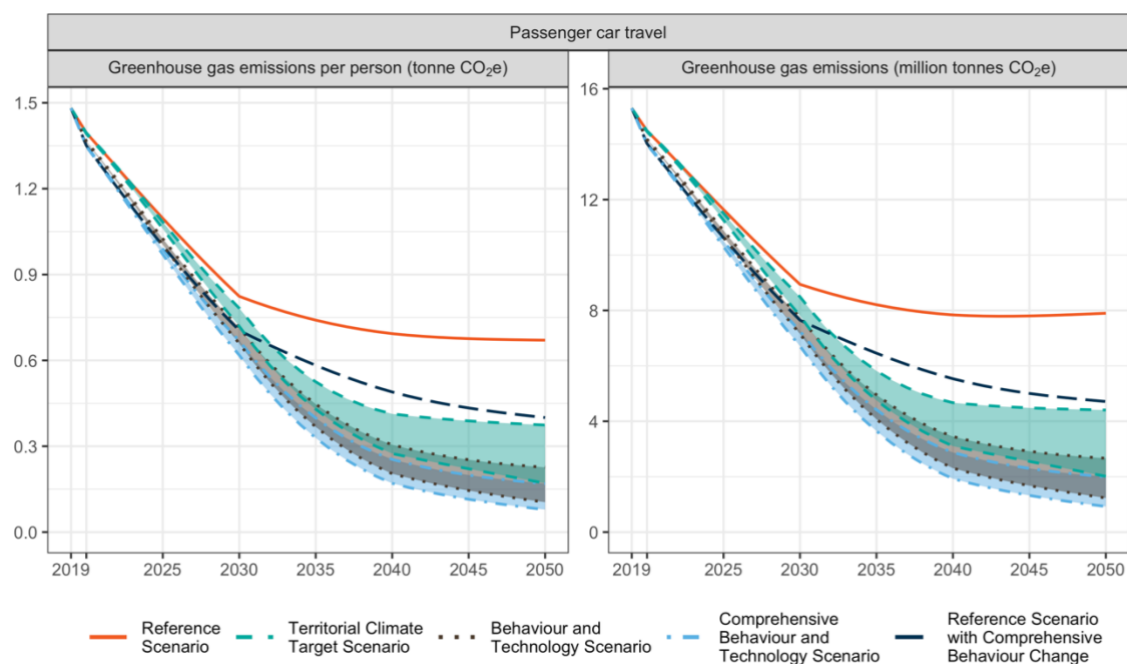


Figure 11. Scenarios for future consumption-based, greenhouse gas emissions from car use in Sweden.

Passenger car travel accounted for direct emissions of 10.1 million tonnes of CO₂e in 2019; these are emissions from the tailpipe of passenger cars due to the combustion of fossil fuels. In addition to direct emissions, we also include emissions of 2.1 million tonnes of CO₂e from vehicle and battery manufacturing and 3.1 million tonnes of CO₂e from the production of fuels and electricity used for propulsion.

In the *Reference Scenario*, total emissions from Swedish car use decrease by 2030 and stabilise at about 7.9 million tonnes of CO₂e. The increase in car use is compensated for by an increased mix of biofuels under the agreed revision of the emission reduction quota obligation by 2030. Electrification of passenger car travel is assumed to be slow and only driven by EU emission requirements for passenger cars. Internal combustion engine cars will continue to be sold in 2050.

The *Territorial Climate Target Scenario* assumes that the proposal by Utfasningsutredningen (the phase-out report)⁶⁰ are implemented, leading to a rapid rate of electrification—cars with internal combustion engines are no longer sold after 2030—and fossil fuels being completely phased out by 2040. Emissions decline until the mid-2030s and then start to level off at between 2.0–4.4 million tonnes of CO₂e depending on the global transition.

In the *Behaviour and Technology Scenario*, emissions decrease faster and stabilise at a lower level than in the *Territorial Climate Target Scenario* due to a more subdued increase in transportation by passenger car and the introduction of self-driving cars that enable both car sharing and ride sharing

⁶⁰ Swedish Government Official Reports, 2021. [I en värld som ställer om – Sverige utan fossila drivmedel 2040](#) (In a global transition – A fossil-free Swedish transportation system 2040). SOU 2021:48

in metropolitan regions. Emissions stabilise at a level between 1.2 and 2.7 million tonnes of CO₂e depending on the global transition.

The scenarios with major behavioural changes assume car sharing in metropolitan areas and a reduction in passenger car travel. The *Comprehensive Behaviour and Technology Scenario* assumes the same technology development as the *Behaviour and Technology Scenario*; here, emissions decrease continuously over the period, reaching a range of 0.9-2.0 Mt CO₂e in 2050. In the *Reference Scenario with Comprehensive Behavioural Change* and very limited technology development, emissions are instead about 4.7 Mt.

Baseline 2019

The calculation of lifecycle emissions from passenger car travel is based on a fleet model and emissions estimate covering passenger car operation, vehicle, and battery manufacturing and fuel production. The model is described in detail in Morfeldt et al.⁶¹ The model simulates the Swedish passenger car fleet from 1950 onwards based on the annual transport work, average lifetime and annual mileage, occupancy rate (average number in the car), and the share of cars with internal combustion engines, plug-in hybrids, and electric cars in new car sales. The simulated composition of the passenger car fleet is reconciled with 2019 statistics. The share of biofuel used is based on an estimate of the total share of biofuels in liquid fuel for 2019.

Assumptions about new car types and fuels in the future

Both internal combustion and electric cars are expected to become more efficient in the future. By 2030, the energy consumption of new internal combustion cars is expected to fall by 30% per kilometre, and for new electric cars by 10%.

We make the following assumptions for the introduction of new car types, fuels, and car sharing and ride sharing.

Reference Scenario (both with and without major behavioural changes)

- Electric cars and plug-in hybrids are introduced in a manner consistent with decisions already made in the EU⁶². For Sweden, this means an increase in the share of plug-in cars in new car sales from 31% in 2020 to 39% in 2030 and that the share of electric cars in plug-in cars sold increases from 30% to 50% over the same period. No further increase is assumed after 2030.
- The share of biofuels in liquid fuel use increases in line with the agreed reduction obligation, resulting in an increasing average share from 23% in 2019 to 59% in 2030. No further increase is assumed after 2030.
- Self-driving cars, car sharing, and ride sharing are assumed not to have an impact in this scenario.

Territorial Climate Target Scenario

- Share of zero-emission vehicles – The proposal by Utfasningsutredningen for a zero-emission vehicle target is assumed to be implemented and therefore no internal combustion engine

⁶¹ Morfeldt, et al. 2021. [Carbon footprint impacts of banning cars with internal combustion engines](#). Transportation Research Part D: Transport and Environment.

⁶² EU regulation [2019/631](#) on fleet average emissions per km.

cars will be sold after 2030. The share of plug-ins⁶³ in new car sales increases from 31% in 2020 to 100% in 2030 and stays at that level.

- The share of biofuels in the use of liquid fuels is assumed to increase in line with the ambition of Utfasningsutredningen to phase out fossil fuels from the transport sector by 2040. It is implemented as the average share of biofuels in liquid fuels increasing from 23% in 2019 to 100% in 2040.
- Self-driving cars and car and ride sharing are not assumed to have an impact in this scenario.

Behaviour and Technology scenario

- Share of zero-emission vehicles – as Territorial Climate Target Scenario
- Share of biofuels – as Territorial Climate Target Scenario
- Self-driving cars will be introduced in the early 2030s and account for 44% of the passenger car fleet by 2050. There are significant uncertainties about the technology behind self-driving cars and how it will be received by users, but it is assumed to expand relatively quickly if it comes to market^{64,65}. Self-driving technology could also have a range of potential impacts by making driving more attractive. We assume that policies and regulations are in place to ensure that driving does not increase but rather decreases. For people living in metropolitan areas, there is a shift from individual car ownership to shared mobility, including ride-sharing. By 2050, it is estimated that about 5% of the national passenger car fleet will be shared cars, covering about 34% of national transport. We assume that a shared car on average replaces 6.25 individually owned or leased cars, and we further assume that the shared self-driving cars drive 20% extra to pick up passengers and park, etc.

Comprehensive Behaviour and Technology scenario

- Share of zero-emission vehicles – as Territorial Climate Target Scenario
- Share of biofuels – as Territorial Climate Target Scenario
- Self-driving cars and car and ride sharing – as Behaviour and Technology Scenario

Reference scenario with Comprehensive Behavioural Change

- Electric cars and plug-in hybrids: As in the *Reference Scenario*
- Share of biofuels: As in the *Reference Scenario*
- Car sharing is expected to increase in metropolitan areas; by 2050 about 6% of the car fleet will be shared cars, resulting in about 34% of national transport work being done by shared cars. We assume that on average one shared car replaces five individually owned or leased cars. Self-driving cars are assumed to have no impact in this scenario.

The volume of passenger car travel in the future

In the *Reference Scenario* and the *Territorial Climate Target Scenario*, transport work is assumed to follow Trafikverket's baseline forecast⁶⁶. The baseline forecast corresponds to an increase in

⁶³ Other types of zero-emission vehicles may take some market share, but this is not expected to have a significant impact on the results.

⁶⁴ Quarles, m. fl., 2021. [America's fleet evolution in an automated future](#). Research in Transportation Economics.

⁶⁵ Pernestål, et al., 2019. [Where will self-driving vehicles take us? Scenarios for the development of automated vehicles with Sweden as a case study](#). Autonomous Vehicles and Future Mobility.

⁶⁶ Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#) (Forecast for passenger traffic 2040 – Transport Administration's Basic Forecasts 2020-06-15).

passenger car travel of 36% in 2050 compared to 2019. If population growth is taken into account, this corresponds to a 19% increase in person-km per person.

The *Behaviour and Technology Scenario* assumes that the person-km per person value stays constant. Taking into account projected population growth, this corresponds to a 14% increase in passenger car travel in 2050⁶⁷. The assumption is based on an observed historical trend showing a decoupling between economic growth and car use. Passenger car travel per person has remained more or less constant since the early 1990s despite strong economic growth⁶⁸, see Figure 12. Despite this, a link between economic growth and increased transport use is one of the starting points in Trafikverket's baseline forecast⁶⁹. Here, in this scenario, the historical trend of constant passenger car travel per person is assumed to continue despite projected continued economic growth; i.e., passenger car travel per person remains constant from 2019 onwards. This scenario assumes that the overall costs of driving will remain the same or increase, which may imply the need for new taxes as electric and self-driving cars gain market share.

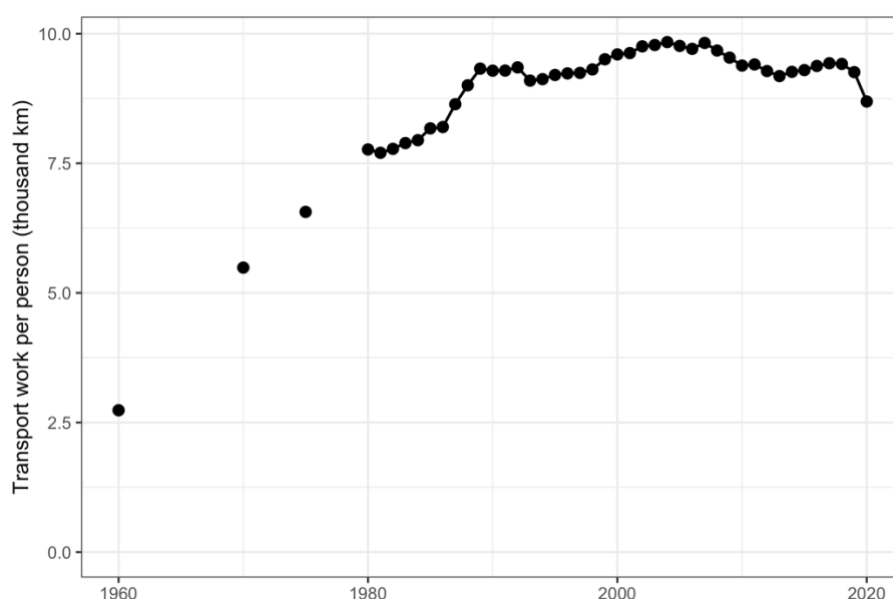


Figure 12. Passenger car travel per person. Source: Trafikanalys (the Swedish government agency Transport Analysis)⁷⁰ and SCB.⁷¹

The *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change* go a step further and assume strong policy measures are implemented to realise the potential for reduced passenger car travel. The scenarios assume a 20% reduction in passenger car travel, measured in person-km per person, by 2050 compared to 2019. Taking population growth into account, this means that car use reduces by 7% during this period⁷².

⁶⁷ This development corresponds to an evolution midway between Trafikverket's baseline forecast (in which transport work increases by 36% in 2050 compared to 2019) and Utfasningsutredningen's low case (in which transport work is constant from 2018 onwards).

⁶⁸ SCB, 2021. [BNP per capita](#) (GDP per capita).

⁶⁹ Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#) (Forecast for passenger traffic 2040 – Transport Administration's Basic Forecasts 2020-06-15).

⁷⁰ Trafikanalys, 2021. [Transport arbete](#) (Transport work).

⁷¹ SCB, 2021. [Befolkningsstatistik](#) (Population statistics).

⁷² This represents a greater reduction in transport work for passenger cars than in Utfasningsutredningen's low case.

Below, we analyse the purposes and durations of passenger car trips and identify the potential for reductions. The scenario assumption is based on this analysis. Figure 13 below shows how current passenger car travel is distributed across the various purposes. The majority (66%) of transport is for leisure, recreation, and holidays or for commuting.

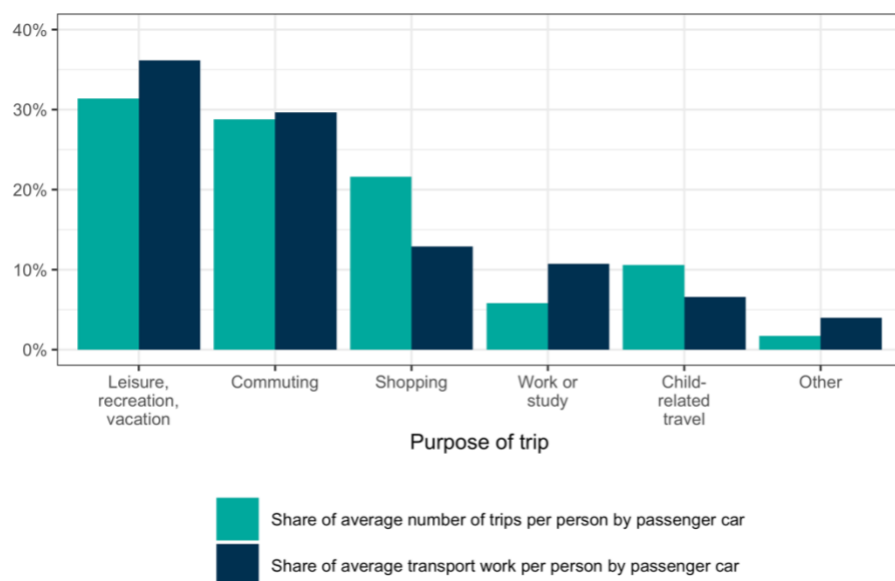


Figure 13. Share of trips and share of transport work for passenger cars by use. Source: Trafikanalys⁷³

Figure 14 shows that a relatively large share of transport for leisure, recreation and holidays takes the form of relatively long trips. More than 25% of the transport work in this category is for trips greater than 200 km. This contrasts with commuting trips, for which a large share of the work is for short trips. Half of the transport work for commuting trips is for trips under 25 km and about 75% is for trips under 50 km.

⁷³ Trafikanalys, 2021. [Resvaneundersökningen 2011-2016](#). (The travel behaviour survey 2011-2016)

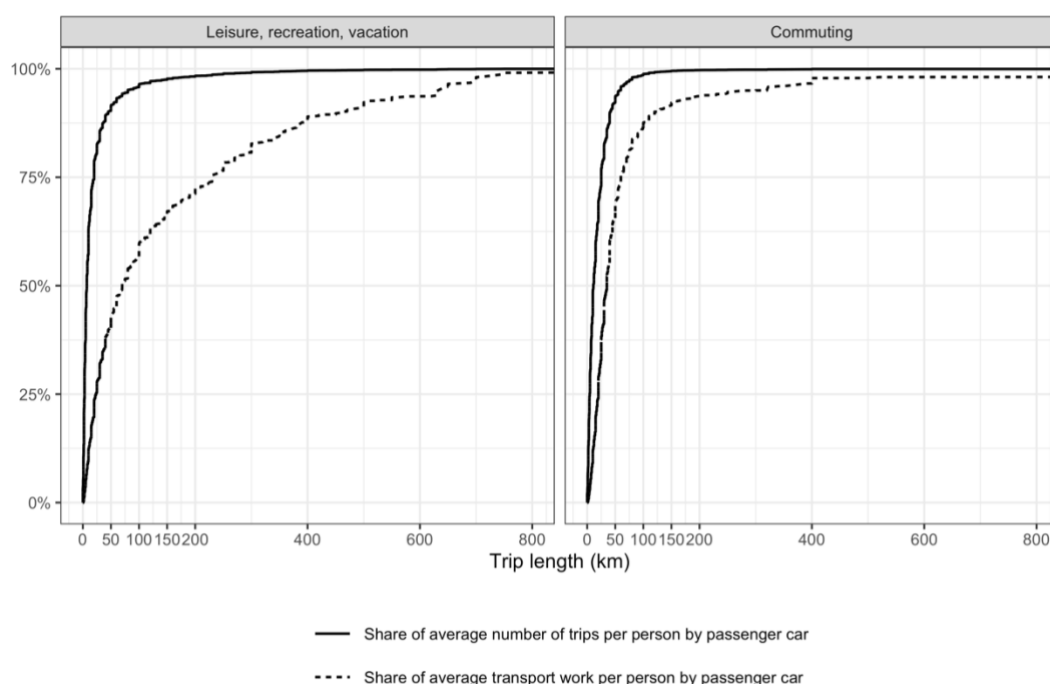


Figure 14. Share of trips and share of transport work by car for leisure, recreation, and vacation and for commuting by length of trip. Source: Trafikanalys⁷⁴

Reducing the amount of transport needed for leisure, recreation, and holiday trips would therefore either mean foregoing these trips or largely shifting them to long-distance public transport. Given that this scenario also assumes a significant reduction in air travel abroad (see [here](#)) and that some of this can be assumed to shift to domestic travel, the potential for shifting leisure, recreation, and vacation and passenger car travel to long-distance public transport is limited. If we illustratively assume that leisure and vacation trips longer than 2 000 kilometres are cut by 50% (this is only 1.5% of the number of trips in this category), the average total passenger car travel per person could be cut by 9% compared to 2019.

In terms of commuting, trips are short enough that some can be shifted to short-distance public transport and, to some extent, bicycling. If regional public transport travel is assumed to increase by 50% and if around 30% of car commuting is shifted to bicycling, this would result in a 10% reduction in total car travel per person compared to 2019. Fact Box 1 has more information on the modal shift to public transport.

The pandemic has led to better technical and organisational capabilities and greater acceptance for working remotely. If we assume that half of those who commute by car have the opportunity to work from home and that they do so two days per week, this could result in a 5% reduction in the average total Swedish car travel per person compared to 2019.

Although there is a significant opportunity to shift car travel to public transport and eliminate some leisure trips and commuting, the measures are difficult to implement. Above, we provided examples that could reduce car travel per person by 20% or so compared to 2019. But the impact of the individual measures cannot simply be summed without a deeper analysis. Given the inertia of the passenger car system, in terms of current infrastructure and in terms of the norms shaped by

⁷⁴ Trafikanalys, 2021. [Resvaneundersökningen 2011-2016](#). (The travel behaviour survey 2011-2016)

relatively constant per capita car use over the last 30 years, strong policies would be needed to implement individual measures.

FACT BOX 1 - Governmental analyses of transition from passenger cars to public transport

The potential for a modal shift from cars to public transport is controversial. On the basis of the FFF study⁷⁵, Trafikverket has updated the opportunity for a modal shift to public transport achievable through various measures in public transport. Trafikverket⁷⁶ estimates that an 8% reduction in car traffic in 2030 compared to the baseline forecast would be possible. Using the 2020 baseline forecast for cars, this would mean a reduction of about 9 billion passenger-kilometres in 2030⁷⁷. Compared to the baseline forecast, that modal shift would increase public transport travel by more than 40%. However, Trafikverket's estimate has been criticised for not taking into account the effect of double counting, for not evaluating feasibility and instead mainly assuming that decided targets are met (in particular the so-called doubling target), and for not being well substantiated in terms of how much of the increase in public transport stems from a shift away from cars and how much stems from additional traffic.^{78,79}

Since the transport work performed by cars is significantly greater than that performed by public transport, even small shifts away from car travel can mean substantial increases in public transport. Transferring 1% of regional transport work performed by cars to public transport would increase the latter by 5%. In Trafikverket's scenarios for the 2030 climate target⁸⁰, a move to public transport is instead exemplified by traffic forecast C, in which public transport work in 2040 increases by about 7% more than in forecasts A and B⁸¹. Forecasts A and B are assumed to correspond to the baseline forecast, in terms of traffic developments. Given the relationship above, if all the traffic growth were to come from cars, a 7% increase in travel by public transport would correspond to about a 1.5% decrease in travel by car. If some of the increase comes from increased travel or from walking and bicycling, the reduction in car travel is even less.

⁷⁵ Statens offentliga utredningar, 2013. [Fossilfrihet på väg](#) (On the road to freedom from fossil fuels). SOU 2013:84.

⁷⁶ Trafikverket, 2016. [Styrmedel och åtgärder för att minska transportsystemets utsläpp av växthusgaser - med fokus på transportinfrastrukturen](#) (Policy instruments and measures to reduce greenhouse gas emissions from the transport system - with a focus on transport infrastructure) 2016:043.

⁷⁷ Assuming a car occupancy rate of 1.5.

⁷⁸ Merkel, 2020. [Bygger transportsektorns utsläppsmål på välgrundade antaganden om framtidens trafikarbete på väg?](#) VTI Working Paper (Are transport sector emissions targets based on sound assumptions about future road transport?)

⁷⁹ Kågeson, 2019. [Klimatmål på villovägar? En ESO-rapport om politiken för utsläppsminskningar i vägtrafiken](#). (Rapport till Expertgruppen För Studier i Offentlig Ekonomi 2019:5) (Climate targets on the wrong track? An ESO report on emission reduction policies in road transport. Report to the Expert Group for Studies in Public Economics 2019:5).

⁸⁰ Trafikverket, 2020. [Scenarier för att nå klimatmålet för inrikes transporter](#) (Scenarios for achieving the climate target for domestic transport), 2020:080.

⁸¹ In projections A and B, public transport will increase by 50% in 2040 compared to 2014, and in projection C by 60% compared to 2014.

Public transport

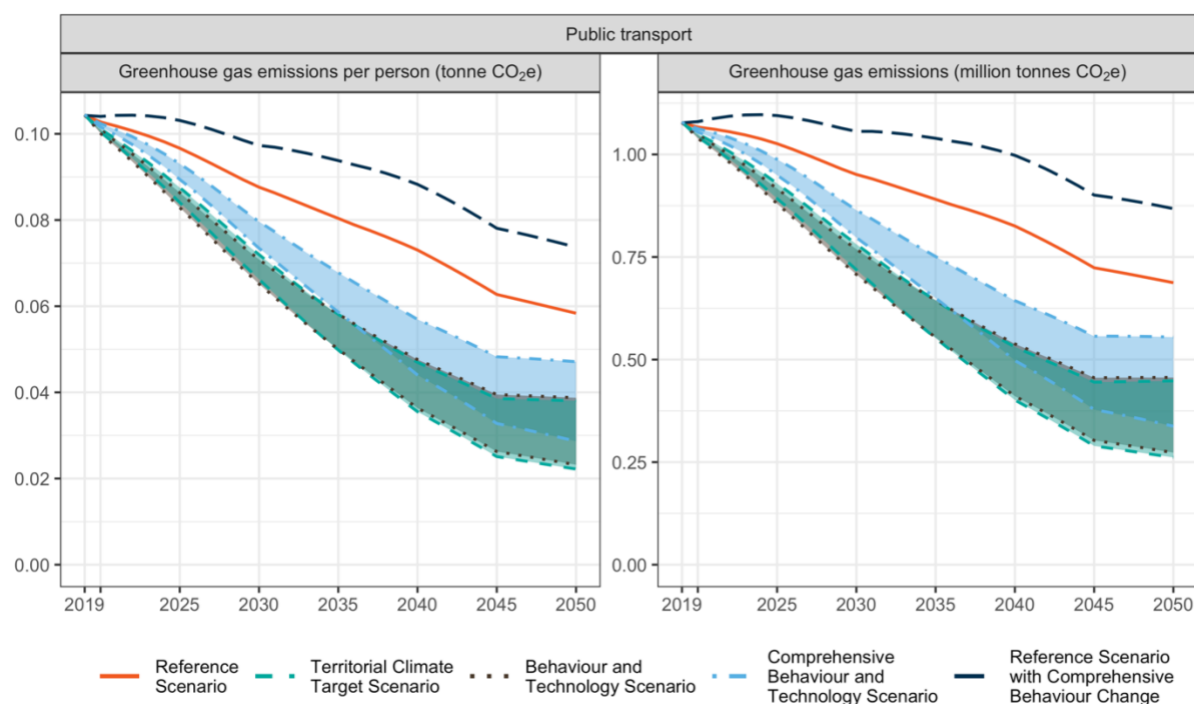


Figure 15. Scenarios for future consumption-based, greenhouse gas emissions for Swedish public transport travel.

Public transport emissions are relatively low compared to other consumption sectors and are estimated at 1.0 million tonnes CO₂e in the baseline year 2019. In the *Reference Scenario*, emissions are assumed to decrease due to a continuous, but slow, electrification of the regional bus fleet and reach 0.6 million tonnes CO₂e in 2050. In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, emissions decrease further due to a faster electrification rate and increased biofuel blending for domestic bus travel. The reduction is achieved despite a higher level of public transport travel due to a shift from travel by air or car. Emissions reach 0.3-0.4 million tonnes CO₂e in 2050, depending on the global climate transition.

In the *Comprehensive Behaviour and Technology Scenario*, public transport travel increases further as a result of an even greater shift from travel by air and passenger car. This therefore leads to higher emissions from public transport in particular, reaching 0.3-0.6 million tonnes CO₂e in 2050, depending on the global transition. In the *Reference Scenario with Comprehensive Behavioural Change*, emissions are higher, namely 0.9 Mt CO₂e, due to the more moderate electrification, biofuel use, and efficiency improvement rates.

2019 baseline

Regional public transport (<100 kilometres)

The estimated 2019 baseline is based on data collected^{82,83} for traffic and transport work by bus, tram, regional train and ferry, as well as the estimated average transportation supply⁸⁴ and occupancy rates. Data on the share of electric power and the share of biofuels per mode are based

⁸² Trafikanalys, 2020. *Regional linjetrafik 2019*. (Regional regular traffic 2019).

⁸³ Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#). (Forecast for passenger traffic 2040 – Transport Administration's Basic Forecasts 2020-06-15).

⁸⁴ The number of seat-kilometres per vehicle-kilometre.

on the FRIDA database for 2019⁸⁵, to which the regional transport companies report data, combined with data from SL's (Stockholm Public Transport's) annual report. Energy use for rail and internal combustion buses is based on FRIDA and SL, while energy use for electric buses is based on data⁸⁶ for Norwegian electric buses, which are considered representative for Swedish conditions.

Long-distance public transport (>100 kilometres, excl. flights)

Domestic long-distance public transport by train is based on Transportstyrelsen's statistics⁸⁷ for 2018 together with a projection to 2019 based on quarterly statistics from Trafikanalys⁸⁸. The resulting starting point in 2019 is a demand for 755 person-km of domestic long-distance train travel per person. According to Trafikverket, long-distance bus traffic is 290 person-km per person⁸⁹. International trains and buses have been estimated at 20 and 129 person-km per person, respectively, for 2019 based on the number⁹⁰ of trips made in 2018 and an estimated average trip length of 2 000 km and 1 200 km, respectively. The starting point for ferry trips (55 person-km) is based on our own processing of data from a travel survey.⁹¹

Assumptions about new vehicles and fuels in the future

Regional public transport (<100 kilometres)

The introduction of electric buses in regional public transport assumes a minimum level⁹² of 22.5% in 2021-2025 and 32.5% in 2026-2030. In the *Reference Scenario*, the share of electric buses increases to reach full-scale penetration in 2070, which means that about 70% of buses purchased in 2050 are electric buses. In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, the share of electric buses increases faster and reaches full-scale penetration by 2040. We assess the impact of introducing electric buses using a simplified model of the bus fleet based on an average bus lifetime of 12 years.

In the *Reference* scenarios, we do not assume any efficiency improvement per vehicle-km (any engine efficiency improvement is assumed to be offset by larger and longer buses); in the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, we assume a 1% annual efficiency improvement per vehicle-km. This is less than the EU requirements for heavy vehicles, but many of the measures planned for trucks⁹³ are aerodynamic and do not affect buses to the same extent as they are driven at lower speeds. No efficiency improvement is assumed for electric buses per vehicle kilometre.

In the reference scenarios, the share of biofuels is assumed to remain constant at today's level for buses and ferries, corresponding to 80% and 14%, respectively. In the *Territorial Climate Target*

⁸⁵ Svensk kollektivtrafik (Swedish Public Transport Association), 2020. [FRIDA database](#). Retrieved 2021-08-18.

⁸⁶ Hjelkrem, et al. 2021. [A battery electric bus energy consumption model for strategic purposes: Validation of a proposed model structure with data from bus fleets in China and Norway](#). Transportation Research Part D: Transport and Environment.

⁸⁷ Transportstyrelsen 2020. [Transportmarknaden i siffror 2019](#) (Transport market in figures 2019).

⁸⁸ Statistics from [Trafikanalys](#).

⁸⁹ Trafikverket. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#) (Forecast for passenger traffic 2040 - Trafikverket's Basic Forecasts 2020-06-15) Table 3.

⁹⁰ Trafikverket 2020:113. [Underlagsrapport till Nattågstrafik till Europa](#) (Supporting report to Night train services to Europe), page 34.

⁹¹ Trafikanalys national [travel demand survey](#), data from 2016.

⁹² https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

⁹³ Meszler, et al. 2018. [European Heavy Duty Vehicles: Cost Effectiveness of Fuel Efficiency Technologies for Long Haul Tractor Trailers in the 2025-2030 timeframe](#). International Council on Clean Transportation.

Scenario and the *Behaviour and Technology Scenario*, the share increases to 100% in 2040, in line with the proposal by Utfasningsutredningen.

For simplicity in estimating emissions from vehicle manufacturing and maintenance, we assume that the manufacture of buses, trains/tubes and trams gives rise to 0.11, 1.5, and 1.0 thousand tonnes of CO₂e per vehicle, respectively, based on the available literature^{94,95,96}. The number of vehicles needed per year for rail traffic is estimated based on the lifetime of the respective vehicles⁹⁷. The number of new buses is estimated using the simplified model of the Swedish bus fleet. Emissions are projected to decrease for vehicle production depending on the global transition according to the same trajectories as for passenger cars⁹⁸. For electric buses, we assume a 400 kWh battery, and the emissions in battery production are calculated according to the same assumptions as for passenger cars⁹⁹.

Long-distance public transport (>100 kilometres, excl. flights)

In the *Reference* scenarios, we assume that the historical improvement in the efficiency of heavy vehicles of 0.6% per year continues¹⁰⁰; in the scenarios with advanced technology, the efficiency improvement per year instead doubles. The efficiency of long-distance trains does not improve.

The share of biofuels is assumed to increase in the *Reference* scenario in line with the latest mandated reduction for domestic buses and ferries, which means an increase to 59% in 2030. In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, the share increases to 100% in 2040 in line with the proposal in Utfasningsutredningen¹⁰¹. For bus and ferry services abroad, we do not assume any biofuel blending.

Future public transport volume

Regional public transport

The starting point for the volume of regional public transport is Trafikverket's base forecast for the entire time period 2019-2050. The effect of the pandemic on public transport (lower ridership and lower occupancy) is therefore not reflected in the estimates. However, the pandemic has not had a major impact on the actual traffic and the transportation supply (seat-km) was roughly the same in 2020 as in 2019¹⁰², which also means that emissions were virtually unchanged.

In the *Reference Scenario* and the *Territorial Climate Target Scenario*, travel develops based on Trafikverket's baseline forecast¹⁰³ for regional bus, rail, and other rail transport, corresponding to an

⁹⁴ Chester & Horvath, 2009: [Environmental assessment of passenger transportation should include infrastructure and supply chains](#). Environmental Research Letters.

⁹⁵ Lie, et al, 2021. [The carbon footprint of electrified city buses: A case study in Trondheim, Norway](#). Energies.

⁹⁶ del Pero, et al., 2015. [Life Cycle Assessment of a heavy metro train](#). Journal of Cleaner Production.

⁹⁷ This results in an average purchase of 15 new commuter trains, 15 new trams and 10 new metro cars assumed to be purchased per year for Sweden as a whole.

⁹⁸ Morfeldt, et al. 2021. [Carbon footprint impacts of banning cars with internal combustion engines](#). Transportation Research Part D: Transport and Environment.

⁹⁹ Morfeldt, et al. 2021. [Carbon footprint impacts of banning cars with internal combustion engines](#). Transportation Research Part D: Transport and Environment.

¹⁰⁰ International Energy Agency, 2008. [Energy technology perspectives 2008](#).

¹⁰¹ Swedish Government Official Reports, 2021. [I en värld som ställer om – Sverige utan fossila drivmedel 2040](#) (In a global transition – A fossil-free Swedish transportation system 2040). SOU 2021:48

¹⁰² Trafikanalys, 2021. [Regional linjetrafik 2020](#) (Regional regular traffic 2020).

¹⁰³ Trafikverket, 2020. [Prognos för persontrafiken 2040 - Trafikverkets Basprognoser 2020-06-15](#).

increase of 6%, 43%, and 29% in public transport travel per person by 2050 for the respective modes. Overall, public transport travel per person increases by 22% in 2050 compared to 2019. The baseline forecast does not include a projection for passenger transport by ship; we instead assume the same increase as for travel by bus. In the *Behaviour and Technology Scenario*, travel by public transport per person is instead assumed to increase by 35% by 2050.

In the *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change*, public transport is reduced by 5% per person due to measures for a low-travel society, such as digital meetings for reduced business travel, remote work, and reduced commuting, and e-commerce for reduced shopping travel. For simplicity, we assume that the reduction is the same for all modes. The reduction in travel is offset by a shift in travel from passenger car to public transport. Overall, regional public transport travel is assumed to increase by 78% per person by 2050 compared to 2019 in the *Comprehensive Behaviour and Technology Scenario*. Traffic is distributed proportionally according to the current mode shares in the *Behaviour and Technology Scenario*, while growth is slightly higher for bus travel in the *Comprehensive Behaviour and Technology Scenario* and slightly lower for rail and tram. This is because, for rail and public transport, the trip growth is constrained by track availability.

Despite the increase in travel by public transport in the *Behaviour and Technology Scenario* and the *Comprehensive Behaviour and Technology Scenario*, the number of vehicle-kilometres is not assumed to increase at the same rate. This is because this travel involves an increase in traffic, but also a gradual increase¹⁰⁴ in occupancy rates for all vehicle types. Therefore, in both scenarios, the occupancy rate increases by 1% per year compared to 2019, which corresponds to approximately the same occupancy rate in 2030 as in 2013 and in 2050 as in 2009. In the two other scenarios, the occupancy rate remains unchanged¹⁰⁵.

Long-distance public transport (excl. flights)

In the *Reference Scenario* and the *Territorial Climate Target Scenario*, domestic long-distance train trips are assumed to increase at the same rate as in Trafikverket's baseline forecast, i.e., by 1.3% per person per year¹⁰⁶. International train trips are assumed to increase from 20 to 100 person-km per person per year by 2050 due to the policy initiative of state-procured travel Stockholm-Hamburg from 2022 onwards¹⁰⁷.

In the *Behaviour and Technology Scenario*, long-distance domestic rail and bus travel, as well as international bus travel, are assumed to double by 2050 and international rail is assumed to increase to 300 person-km per person per year (equivalent to 10% of current EU air travel). In the

¹⁰⁴ In 2019, the occupancy rate varied by county by about 15-30% (Trafikanalys, 2020), which indicates a potential for increased average occupancy rates (even counties that are in part rural have occupancy rates at the higher end). In addition, public transport ridership over the 2000s has largely increased through increased supply and constant or lowered occupancy rates (Trafikanalys (2020), Transportstyrelsen (2019)), supporting the assumption that there is room for higher occupancy rates.

¹⁰⁵ The baseline forecast does not include a forecast for bus traffic (and therefore of occupancy rates), but in other contexts traffic (vehicle-kilometres) is assumed to grow at the same rate as transport work (person-kilometres).

¹⁰⁶ According to the reference forecast by Tillväxtverket, the growth rate for long-distance trains is 1.8%/year until 2040 and 1.0% thereafter. Between 2019 and 2050, this means an increase of 61%. As the population is assumed to increase by 14% during this period, the net increase per person is 47%, i.e., about 1.3% per year.

¹⁰⁷ Trafikverket 2020:113. [Underlagsrapport till Nattågstrafik till Europa](#) (Supporting report to Night train services to Europe)

Comprehensive Behaviour and Technology Scenario, long-distance domestic rail travel and bus travel and international bus travel are assumed to triple by 2050, and international rail increases to 600 person-km per person per year (equivalent to 20% of current EU air travel). In both scenarios, the development is assumed to be a consequence of a shift away from aviation (see [here](#)).

Construction and housing

The figures below describe the future greenhouse gas emissions from construction and housing in the five scenarios. In the subsequent sections, we comment on these results, distinguishing between on the one hand residential and commercial space heating and on the other buildings and infrastructure. These sections also provide detailed information on the different assumptions supporting the analysis.

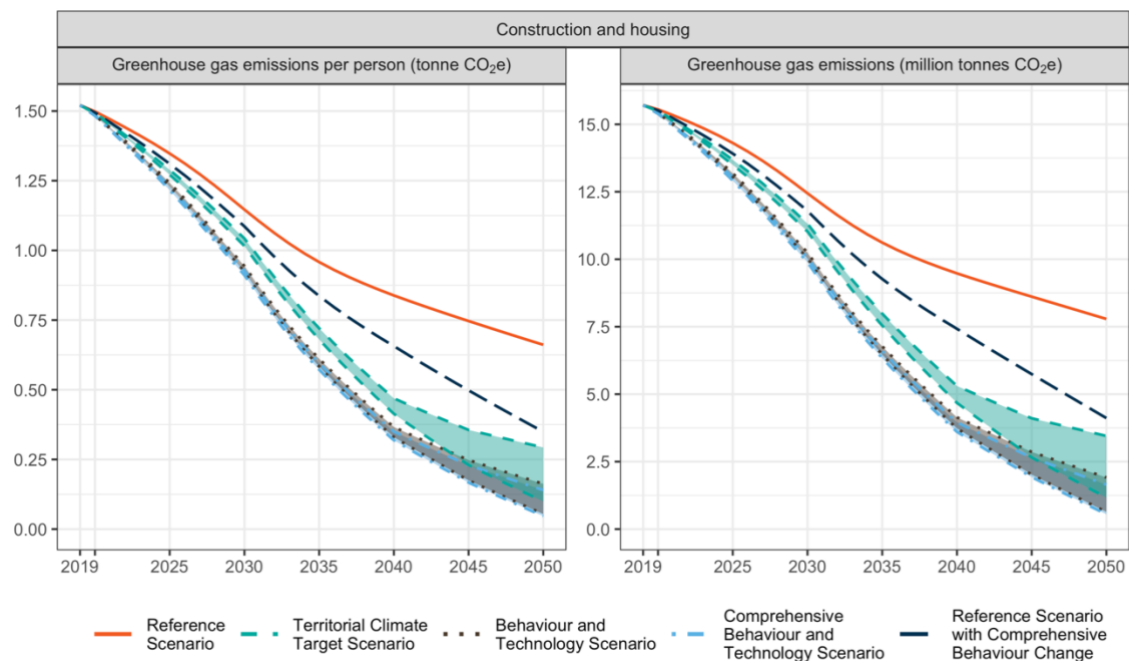


Figure 16. Swedish consumption-based emissions from construction and housing in the five scenarios.

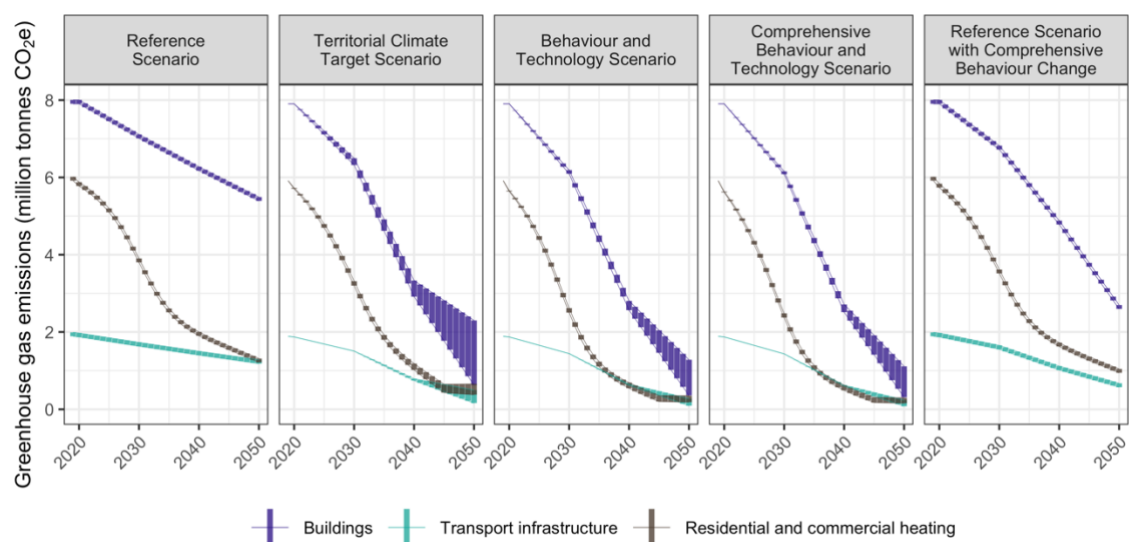


Figure 17. Swedish consumption-based emissions from buildings, transport infrastructure, and heating of residences and commercial space.

Residential and commercial heating

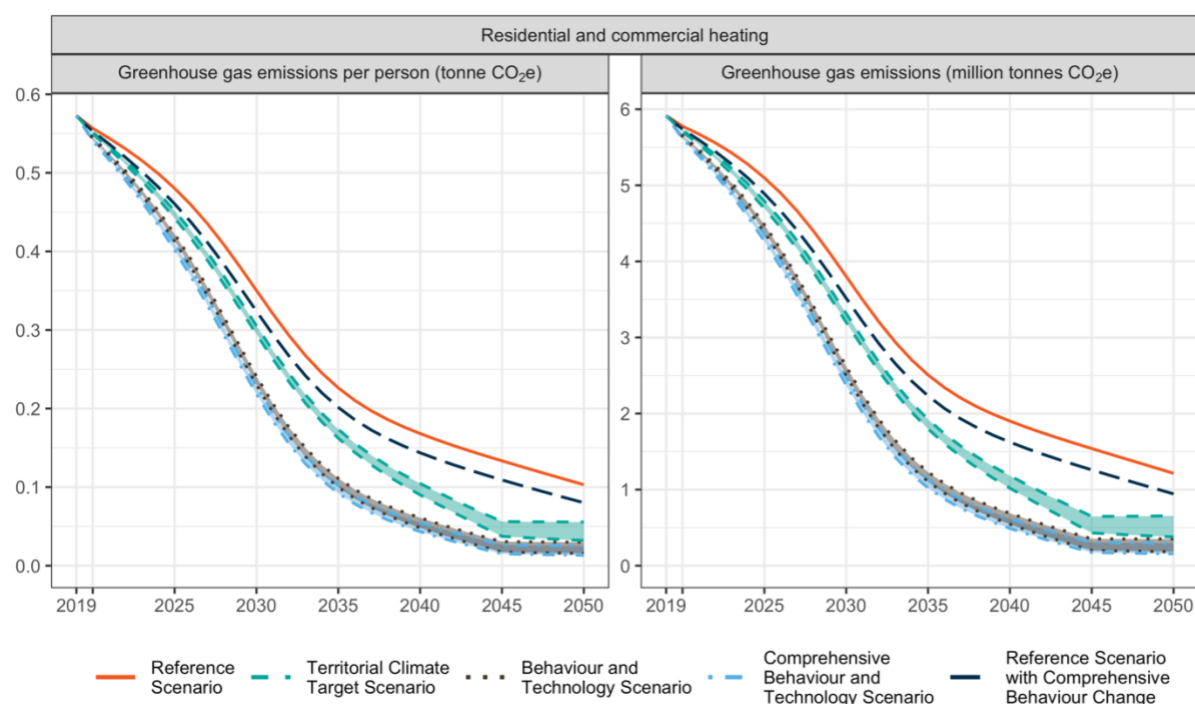


Figure 18. Scenarios for future Swedish consumption-based, greenhouse gas emissions for residential and commercial heating.

Emissions from heating homes and commercial space are estimated at 6 million tonnes of CO₂e in 2019. Future emission pathways depend largely on the transition of electricity and district heat production, which in the *Territorial Climate Target Scenario* and the *Behaviour and Technology* scenarios drop drastically and reach near-zero emissions in 2045. In the *Reference Scenario*, emissions are instead assumed to evolve in line with the currently adopted EU ETS emissions cap, which is projected to reach zero emissions around 2058.

2019 baseline

The analysis is based on 2019 statistics¹⁰⁸ for energy use for small houses, multi-family buildings, and commercial space, average living space¹⁰⁹ per person for small houses and multi-family buildings, respectively, and the number of persons¹¹⁰ living in small houses and multi-family buildings, respectively. District heating accounted for the majority of energy use for heating multi-family buildings and commercial space in 2019, while small houses were mainly heated by electricity (direct or heat pump) and biofuels, see Figure 19.

Assumptions about new technologies in the future

In the *Reference Scenario*, average energy use is assumed to gradually decrease to reach the levels decided in Boverket's (Swedish National Board of Housing, Building, and Planning's) building

¹⁰⁸ Energimyndigheten (Swedish Energy Agency), 2021. [Energistatistik för småhus, flerbostadshus och lokaler](#) (Energy statistics for small houses, multi-family buildings, and commercial space).

¹⁰⁹ SCB, 2021. [Genomsnittlig bostadsarea per person efter region, hushållstyp och boendeform](#). (Average residential space per person by region, type of household, and type of residence).

¹¹⁰ SCB, 2021. [Antal personer efter boendeform, ålder och kön](#). (Number of persons by type of residence, age, and gender).

regulations in 2050, which corresponds to 55 kWh/m² for small houses, 90 kWh/m² for multi-family buildings, and 80 kWh/m² for commercial space. In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, the average energy use is assumed to decrease more drastically, in line with the levels estimated by Boverket as achievable for near-zero energy buildings, corresponding to 45 kWh/m² for small houses, 50 kWh/m² for multi-family buildings, and 45 kWh/m² for commercial space.¹¹¹

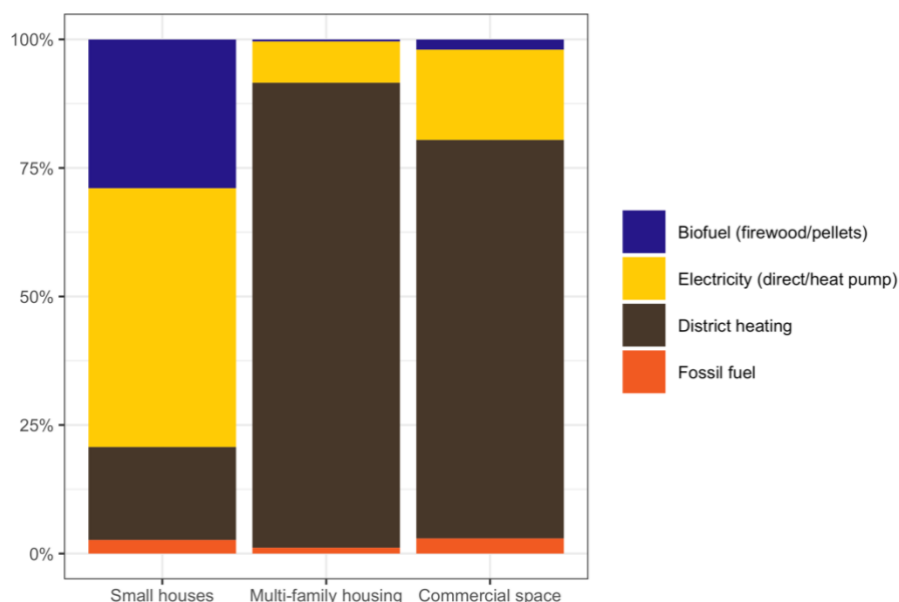


Figure 19. Type of heating for small houses, multi-family buildings, and commercial space for 2019. Source: Energimyndigheten¹¹².

All scenarios assume that direct fossil fuel use for heating homes and commercial space is completely phased out by 2045, in line with the trend since the 1990s. In the *Reference Scenario*, current trends in district heating and electricity use continue. To compensate for the phase out of fossil fuels, the share of district heating increases slightly for small houses and commercial space, along with the share of electric heating for multi-family buildings and commercial space.¹¹³

In the *Territorial Climate Target Scenario* and the *Behaviour and Technology Scenario*, as well as the lower range of the *Comprehensive Behaviour and Technology Scenario*, the phase-out of fossil fuels is assumed to occur in parallel with a drastic reduction in the share of bio-based district heating and direct combustion of biofuels for heating. This is assumed to be due to the high demand for biofuels in other sectors in these scenarios, the introduction of second-generation liquid biofuels, and the low efficiency of second-generation liquid biofuel production¹¹⁴—all of which are assumed to contribute to increased biomass prices and hence increased costs for both wood burning and district heating as heating methods. Instead, electric heating is assumed to increase, mainly through the use

¹¹¹ Boverket (Swedish National Board of Housing, Building, and Planning), 2015. [Förslag till tillämpning av nära-nollenergibygnader - Definition av energiprestanda och kvantitativ linje](#). Rapport 2015:26 (Proposal for the application of near-zero energy buildings - Definition of energy performance and quantitative line).

¹¹² Energimyndigheten (Swedish Energy Agency) [Energistatistik för småhus, flerbostadshus och lokaler](#) (Energy statistics for small houses, multi-family buildings, and commercial space).

¹¹³ The Swedish Environmental Protection Agency, 2021. [Utsläpp av växthusgaser från egen uppvärmning av bostäder och lokaler](#). (Greenhouse gas emissions from own heating of homes and commercial space).

¹¹⁴ Millinger, et al. 2017. [Competitiveness of advanced and conventional biofuels: Results from least-cost modelling of biofuel competition in Germany](#). Energy Policy.

of heat pumps—both direct-generation in buildings and large-scale heat pumps for district heating¹¹⁵, which can also help stabilise the electricity grid in the event of high solar and wind power penetration¹¹⁶.

Total area to be heated in the future

Both the *Reference Scenario* and the *Territorial Climate Target Scenario* assume a constant living space (42 m² per person, which has remained constant over the last 10 years) and commercial floor space (20 m² per person) and that the share of dwellings in small houses and multi-family buildings is constant (52% and 48%, respectively). This means that the total heated living space and commercial space increases with the population growth, which corresponds to an increase of 14% compared to 2019.

In the *Behaviour and Technology Scenario*, the living space per person is also constant. The housing needs of the population growth are partly met by converted commercial space, as new construction is half as high in this scenario as in the *Reference Scenario*. 8% of the housing is assumed to be converted commercial space in 2050.

In the *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change*, new construction is assumed to decrease by 70%, while the total amount of living space is maintained at the current level. To meet the housing needs of population growth, both the amount of living space and the amount of space per person need to decrease by 10% by 2050, and the share of people assumed to live in converted commercial space in 2050 is assumed to be 20%. We assume that the increase in remote working will free up space that was previously office space. The amount of commercial space decreases by 34% compared to today (including industrial space) and by 43% compared to the *Reference Scenario*.

¹¹⁵ David, et al. 2017. [Heat Roadmap Europe: Large-scale electric heat pumps in district heating systems](#). Energies.

¹¹⁶ Helin, et al. 2018. [Improving district heat sustainability and competitiveness with heat pumps in the future Nordic energy system](#). Energy Procedia.

Buildings and transport infrastructure

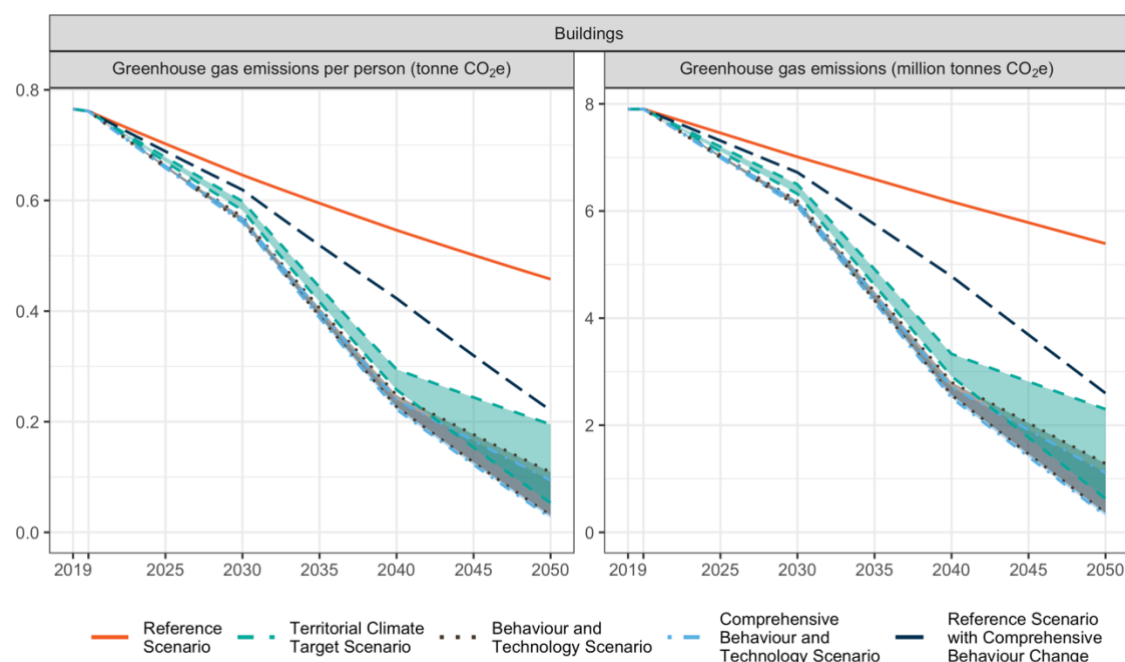


Figure 20. Scenarios for future consumption-based, greenhouse gas emissions for construction of buildings in Sweden.

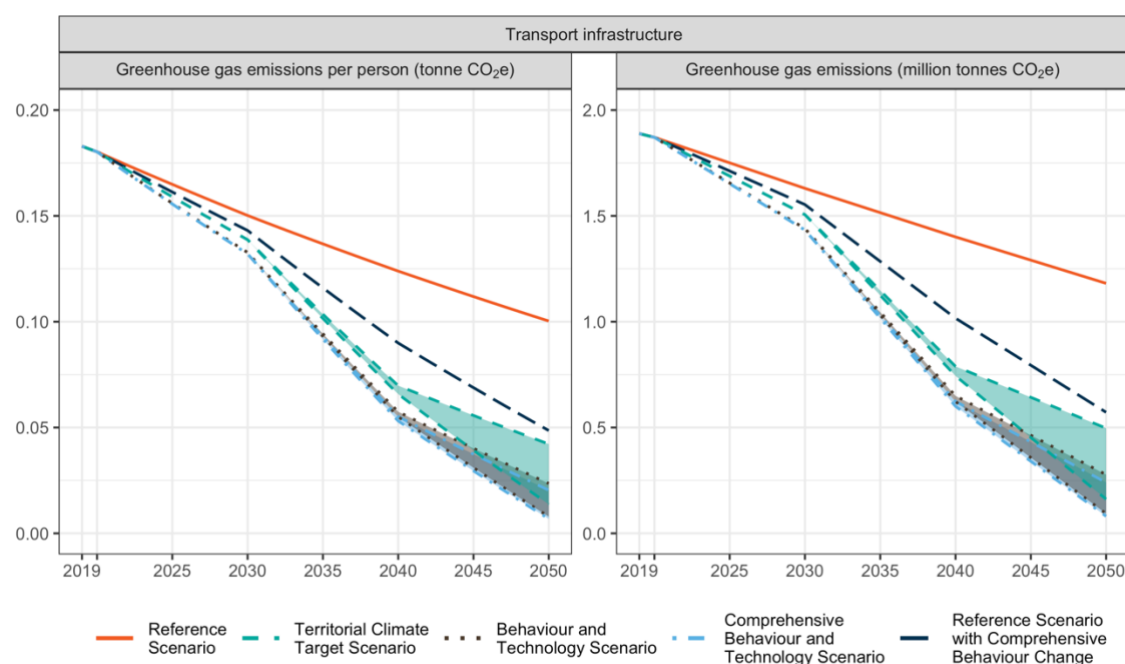


Figure 21. Scenarios for future consumption-based, greenhouse gas emissions for construction of transport infrastructure in Sweden.

The end-user in the construction and infrastructure sector (the individual household or transport infrastructure user) often has a limited ability to influence the greenhouse gas emissions generated by new construction and reinvestment in buildings and infrastructure. What ends up being built, how much of it, and with what materials and methods is influenced by broader societal trends (population growth, urbanisation, etc.) and societal and political priorities. At the same time, there is considerable potential, perhaps particularly at the client level, to reduce the climate impact of

construction, for example by prioritising refurbishment over new construction and by setting requirements on how materials are used and which (see e.g. Pauliuk et al.¹¹⁷).

2019 baseline

Total emissions from the construction sector in Sweden are estimated at around 10 million tonnes of carbon dioxide equivalent per year (including emissions related to imported construction products), of which the construction sector is estimated to account for around 75% and the civil engineering sector for around 25%. The scenarios developed here for the development of greenhouse gas emissions associated with new construction and renovation/reinvestment in buildings and infrastructure are based on a scenario tool developed by Karlsson et al.¹¹⁸ as part of the Mistra Carbon Exit research programme.

The split between domestic production and imports is assumed to be constant in all scenarios over the period studied. The following assumption has been made for each type of building material:

- Cement¹¹⁹: 80% domestic production, 20% imports from the EU, 0% imports from the rest of the world;
Steel¹²⁰ (from iron ore or recycled): 20% domestic production, 40% imports from the EU, 40% imports from the rest of the world;
- Other materials: 50% domestic production, 40% EU imports, 10% imports from the rest of the world.

Measures to increase the production efficiency for all building materials are assumed to result in a reduction of specific emissions (t CO₂/t product) by 0.5% per year¹²¹.

Assumptions about future construction methods and materials

The scenarios presented here distinguish between technology changes (technology changes in the production of construction materials, machinery, and vehicles used for the transport of construction materials) and behavioural change among developers and clients resulting in more efficient use of materials.

Technical changes

- Cement/concrete: The majority of greenhouse gas emissions related to concrete come from the production of cement, which acts as a binder in the concrete. More than half of the direct emissions from cement production are process-related (carbon dioxide is emitted when limestone is burnt) and just under half come from fuel combustion. Therefore, handling the fuel-related emissions is not enough to reduce carbon dioxide emissions to zero, and tackling process-related emissions will require investment in carbon capture and

¹¹⁷ Pauliuk, et al. [Global scenarios of resource and emission savings from material efficiency in residential buildings and cars](#). Nature Communications.

¹¹⁸ Karlsson, et al, 2020. [Roadmap for decarbonization of the building and construction industry—A supply chain analysis including primary production of steel and cement](#). Energies.

¹¹⁹ Estimate based on data from [The Global Cement Report](#) (2019).

¹²⁰ Rough estimate. Currently, there are no comprehensive public statistics describing steel use in the Swedish construction sector (volumes, steel grades, product categories, end use, etc.). The bulk of domestic steel production is currently exported and the majority of steel imported comes from the EU, see <https://www.jernkontoret.se/sv/stalindustrin/branschfakta-och-statistik/utrikeshandel/>.

¹²¹ In line with what is commonly used in the literature (see, e.g., Phylipsen et al. 2002. [Benchmarking the energy efficiency of Dutch industry: an assessment of the expected effect on energy consumption and CO₂ emissions](#). Energy Policy.

storage (CCS)¹²². Cementa (part of the Heidelberg group), the only cement producer in Sweden, has announced plans to introduce CCS from 2030, and several other cement producers inside and outside Europe have similar plans. Measures to reduce the proportion of cement in concrete¹²³ and to reduce the use of concrete per functional unit, e.g., by minimize structures (see description of Material Efficiency Measures below)¹²⁴, are also important for reducing emissions related to the use of cement and concrete.

- Steel (based on iron ore or recycled): two production processes account for the bulk of steel production today, iron-ore-based production (where iron ore is reduced in a blast furnace using coal/coke as fuel and reducing agent) and scrap-based production (where scrap and steel elements are melted in electric arc furnaces using electricity as the primary energy carrier).¹²⁵ For the iron and steel industry, four main technology developments are discussed that could lead to zero or near-zero greenhouse gas emissions¹²⁶: (i) Replacement of fossil coal with biochar/biocoke; (ii) Carbon Capture and Storage (CCS); (iii) Direct electrification either through increased recycling and an increased share of scrap-based steel production¹²⁷, or electrowinning (where iron ore is reduced by electrolysis); and (iv) Indirect electrification of steel production based on direct reduction of iron ore with hydrogen (e.g., through the HYBRIT process¹²⁸). SSAB has recently invested in a pilot plant for direct reduction of iron ore with hydrogen and aims to phase out its blast furnaces gradually in order to become climate neutral by 2045¹²⁹. Several European and international steel producers have similar plans¹³⁰.
- Other materials (insulation, gypsum, asphalt, etc.) — As cement/concrete and steel account for the bulk of the material-related emissions in the construction sector¹³¹, no detailed description has been made of technology developments in other building materials industries. The scenario tool used in the analysis only describes the technology development of these other materials on an aggregated level. Here we assume that emissions can be gradually reduced through fuel switching and electrification.
- Work machinery — For work machinery, diesel is currently the dominant energy carrier and the internal combustion engine is the near-exclusive technology¹³². However, the

¹²² Hasanbeigi et al. 2012. [Emerging energy-efficiency and CO₂ emission-reduction technologies for cement and concrete production: A technical review](#). Renewable and Sustainable Energy Reviews.

¹²³ For instance by better adapting the concrete recipe for the specific application or by increasing the proportion of alternative binders (e.g., fly ash or granulated blast furnace slag)

¹²⁴ See, e.g., Habert et al. 2020. [Environmental impacts and decarbonization strategies in the cement and concrete industries](#). Nature Reviews Earth & Environment.

¹²⁵ Morfeldt et al. 2014. [The impact of climate targets on future steel production – an analysis based on a global energy system model](#). Journal of Cleaner Production.

¹²⁶ See, e.g., Fishedick et al. 2014. [Techno-economic evaluation of innovative steel production technologies](#). Journal of Cleaner Production.

¹²⁷ See, e.g., Milford et al. 2013. [The roles of energy and material efficiency in meeting steel industry CO₂ targets](#). Environmental Science & Technology.

¹²⁸ See, e.g., Pei et al. 2020. [Toward a Fossil Free Future with HYBRIT: Development of Iron and Steelmaking Technology in Sweden and Finland](#). Metals.

¹²⁹ [SSAB](#)

¹³⁰ See <https://www.industrytransition.org/green-steel-tracker/>

¹³¹ With the exception of the plastics industry, where the raw material also needs to be replaced, it is reasonable to assume that a fairly large part of the 'rest' of the building materials industry can become climate neutral through electrification (or the introduction of biofuels). See, e.g., Madeddu et al. 2020. [The CO₂ reduction potential for the European industry via direct electrification of heat supply \(power-to-heat\)](#). Environmental Research Letters.

¹³² WSP, 2017. [Fossilfrihet för arbetsmaskiner](#) (Fossil-free work machinery). On behalf of Energimyndigheten.

introduction of biofuels (in the short to medium term) and the electrification (including fuel cells and hydrogen) of the work machinery fleet¹³³ (in the medium to long term) are expected to contribute to significant emission reductions over the period analysed, with the right policy instruments.

- Heavy transport — Trucks account for the bulk of transport-related emissions linked to the construction sector. As in the case of work machinery, diesel is now the predominant energy carrier and the internal combustion engine is almost entirely dominant. In the truck segment, the phasing in of biofuels has already started, but biofuels are expected to continue to play an important role in reducing greenhouse gas emissions from heavy transport in the medium to long term. In the slightly longer term, electrified trucks (including, trucks with fuel cells) can contribute to radically reducing emissions from heavy transport.¹³⁴

There is also a significant potential to reduce climate impact through behavioural change among developers and clients. This includes reducing waste and the amount of material per square metre or kilometre of transport infrastructure built¹³⁵. There is also a great potential for emission cuts by increasing the share of materials with a low carbon footprint, in particular by replacing steel and concrete with wood. However, in this report, only a small part of this potential is included in the scenarios (and then as part of the assumed material efficiency). The overall material efficiency improvement by 2050 is 14-26% for the various scenarios compared to 2019. The scenario assumptions on construction methods and materials are described below.

In the *Reference* scenarios (both with and without major behavioural changes), we do not assume any technology shifts in the building materials industry (only some energy efficiency improvements of 0.5% per year and material efficiency improvements of 0.5% per year). We do assume a gradual increase in the share of biofuels (but no electrification) for machinery and heavy transport.

The *Territorial Climate Target Scenario* assumes that Swedish cement production uses 100% CCS and that steel production is 100% fossil-free from 2030 onwards. In the EU and the rest of the world, how the industry (cement, steel, and other materials) develops depends on how the rest of the world transitions. If the rest of the world follows current trends and policies, there are no technology shifts in this industry. Machinery and heavy transport largely switch to biofuels, but electrification is limited. If the rest of the world develops in line with the Paris Agreement, the construction materials industry in the rest of the EU is expected to follow Sweden and introduce 100% CCS for cement and 100% fossil-free steel from 2040 onwards. Machinery and trucks are expected to be electrified after 2030.

The *Behaviour and Technology Scenario* follows the same technological evolution as the *Territorial Climate Target Scenario* and assumes better material management (reduced waste, reduced amount of material per unit area), resulting in increased material efficiency (1% per year).

¹³³ SMED, 2006. [Kartläggning av eldrivna arbetsmaskiner](#) (Survey of electric work machinery). On behalf of the Swedish Environmental Protection Agency.

¹³⁴ See, e.g., Fossilfritt Sverige, 2020 (Fossil Free Sweden, 2020). [Färdplan tunga fordon](#) (Roadmap heavy vehicles) and [Åkerinäringen](#) (Hauler industry).

¹³⁵ See, for example, World Green Building Council, 2019. [Bringing embodied carbon upfront - Coordinated action for the building and construction sector to tackle embodied carbon](#).

The higher emission level of the *Comprehensive Behaviour and Technology Scenario* follows the same limited technological development as in the *Reference Scenario* but here, too, we assume better material management (reduced waste, reduced amount of material per unit area) resulting in increased material efficiency (1% per year). With the lower emissions, the scenario follows the same technological evolution as the *Territorial Climate Target Scenario*.

Future construction volume

The *Reference Scenario* and the *Territorial Climate Target Scenario* assume a constant construction volume over the entire period, i.e., approximately the same amount of buildings, road, and rail infrastructure will be built in 2050 as in the reference year (2019).

Housing accounts for the largest share of construction investment; in 2019, this type of investment was at a level comparable to that of the 1970s or 1980s, following a significant decline in the 1990s and a slow recovery in the early 2000s. Boverket has estimated construction demand to be roughly equivalent to a maintained level of new construction and renovation over the period 2020-2029¹³⁶. Assuming a constant construction volume at the 2019 level for residences is therefore reasonable in the near term, and, although it might be a little high in the longer term, it can allow for the possibility that the upward trend in construction investment in commercial space continues. Investment in the construction of commercial space has been increasing continuously since the early 1990s, with a few exceptions.¹³⁷ While investment in construction is not directly translatable into material use and climate impact, it can give an indication of historical trends.

Of course, it is difficult to predict what infrastructure investment will look like three decades from now, and there have been significant fluctuations historically. Both total road and rail investment and the split between road and rail have varied over time¹³⁸. Over the period 2010-2017, new investment¹³⁹ and greenhouse gas emissions related to rail deployment decreased, while investment in state and municipal road networks remained more stable. However, this trend can be expected to reverse if investments in new main lines between the three metropolitan regions—Stockholm, Gothenburg and Malmö—become a reality¹⁴⁰. A study by Liljenström et al.¹⁴¹ estimates total greenhouse gas emissions from investments (including new investments, reinvestments, and maintenance) in infrastructure (road, rail, airports, and ports) at 2.8 million tonnes CO₂, of which road investments are estimated to account for 66% of emissions and rail investments 22%¹⁴². Estimates are based on data from the period 2010-2015.

In the *Behaviour and Technology Scenario*, construction volume decreases in 2030-2050. The focus is on rebuilding, renovation, and maintenance of existing stock and only half as much new construction (buildings and infrastructure) takes place in 2050 as in 2019.

¹³⁶ Boverket, 2020. [Bostadsbyggnadsbehov 2020-2029](#) (Demand for residential construction 2020-2029). Report 2020:32.

¹³⁷ Byggföretagen, 2021. [Totala bygginvesteringar](#) (Total investment in construction).

¹³⁸ See, for example, Konjunkturinstitutet, 2012. [Nivån på infrastrukturinvesteringarna i Sverige](#) (The level of infrastructure investment in Sweden).

¹³⁹ General government investment and capital stock PROP. 2017/18:100 Annex 4

¹⁴⁰ Over the next twelve years (2022-2033), the [Government](#) wants to invest almost SEK 900 billion in roads and railways. Around half of this is proposed to be spent on investment in new roads and railways, with most of this, 85%, allocated to new railways.

¹⁴¹ Liljenström, et al. 2019. [Annual climate impact and primary energy use of Swedish transport infrastructure](#). Journal of Transport and Infrastructure Research.

¹⁴² The remaining emissions come from investments in airports, ports and shipping lanes.

For the *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change*, even larger reductions in construction volume are assumed in 2030-2050 as a result of renovation/refurbishment/reinvestment replacing new construction, lifetime extension through renovation/maintenance, and a reduction of living space (and commercial space) of 10% per person in 2050¹⁴³. New investment (buildings and infrastructure) is 70% lower in 2050 compared to 2019.

A reduction in new investments (-50% and -70% respectively) therefore also applies to infrastructure. Assuming a doubling of rail travel but no change in car use in the *Behaviour and Technology Scenario* and a tripling of rail travel and a reduction in car use (-20%) in the *Comprehensive Behaviour* scenarios, this represents an evolution in which the bulk of the remaining new investment is in rail investment.

¹⁴³ Compare to Hagbert, et al. 2018. [Framtider bortom BNP-tillväxt](#) (Futures beyond GDP growth). KTH, which assumes a halving of residential and office space per person by 2050 compared to today in one scenario.

Food

We have analysed how emissions from Swedish food consumption might develop based on the five different scenarios described [above](#). This section describes the assumptions and results in detail.

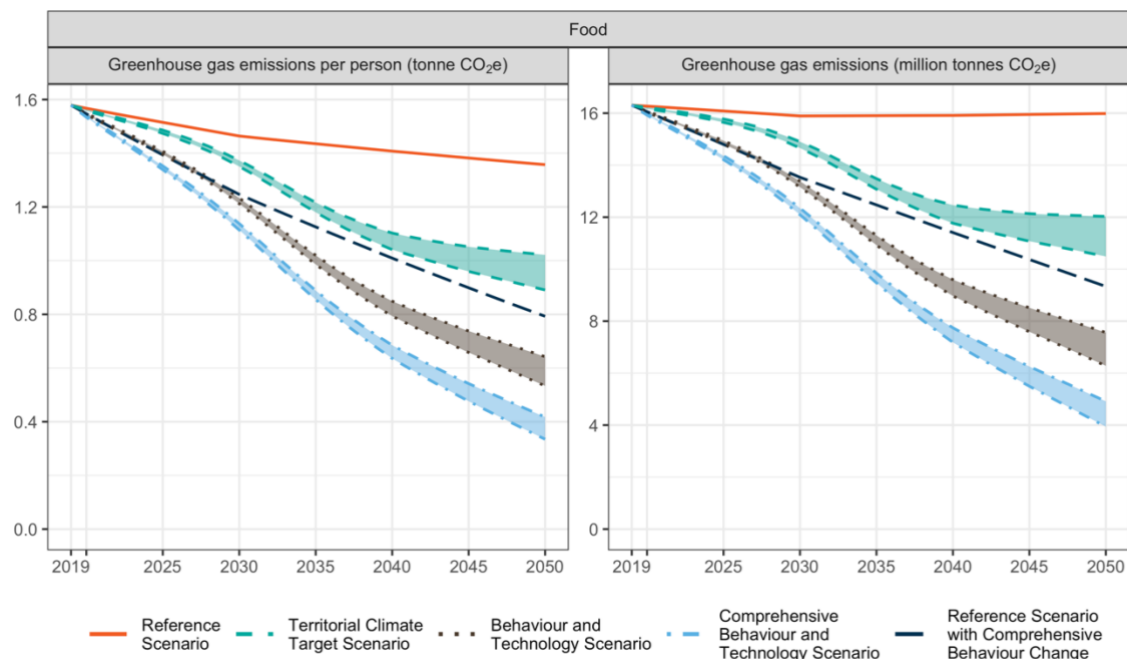


Figure 22. Scenarios for future Swedish consumption-based emissions from food consumption.

The results for the *Reference Scenario* show that the climate impact of Swedish food consumption remains relatively constant at around 16 million tonnes of CO₂e over the entire period. Here, the effect of the increasing population is offset by the expected efficiency gains in agriculture.

Emissions in the *Territorial Climate Target Scenario* are estimated at 10-12 million tonnes of CO₂e in 2050. For food produced in Sweden, this is based on greater efficiency compared to the *Reference Scenario*, completely fossil-free agriculture and transport, and fossil-free fertiliser. The reduction in the *Territorial Climate Target Scenario* (for Swedish-produced food) is of the same order of magnitude as the target scenario developed to support decision-making for the current territorial environmental objectives, where agricultural emissions were assumed to be reduced by 35% by 2045¹⁴⁴.

The *Behaviour and Technology Scenario* results in lower emissions of 6.3-7.6 million tonnes of CO₂e in 2050. This combines the above technological measures with a shift in meat consumption, where half of beef and lamb consumption is replaced by chicken (or a plant-based protein source), and half of milk is replaced by plant-based alternatives.

The *Comprehensive Behaviour and Technology Scenario* achieves lower emissions through cost changes, 3.9-4.9 million tonnes of CO₂e in 2050, depending on the technology measures to reduce emissions that are put in place. Here, beef, lamb, and liquid dairy consumption is reduced by 75% and replaced by protein-rich plant-based products. Cheese consumption is halved. In the *Reference*

¹⁴⁴ SOU 2016:47 [En klimat- och luftvårdsstrategi för Sverige. Del 1 \(A climate and air protections strategy for Sweden. Part 1\)](#), p.337 and Annex 7 in [Part 2](#).

Scenario with Comprehensive Behavioural Changes and very limited technology development, emissions are estimated to be about 9.3 million tonnes.

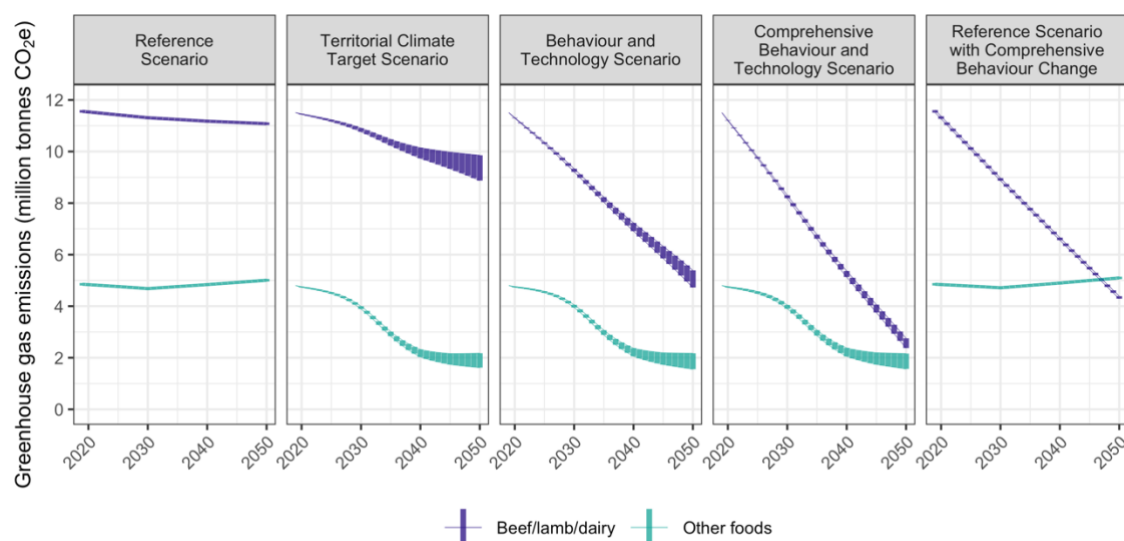


Figure 23. Swedish consumption-based emissions from beef/lamb/dairy and other food in the five scenarios.

Baseline 2019

The calculations are based on the current consumption of food in Sweden according to Jordbruksverket (the Swedish Board of Agriculture)¹⁴⁵. Emissions from different types of food are calculated using a consistent method for modelling lifecycle emissions from farm to store shelf. This means that emissions from transporting food to the home, storing it, and cooking it at home are not included in the calculations. Emissions from these stages are included in the housing and transport categories. Food is divided into categories such as beef and milk and the volumes are multiplied by representative values of kg CO₂ equivalent/kg food product to calculate the total emissions from food consumption. Our method results in a carbon footprint of almost 1.6 tonnes CO₂e/person in 2019. This compares to the consumption-based analyses reported by the Swedish Environmental Protection Agency¹⁴⁶ that show 1.3 tonnes.

Assumptions about new technology measures in the future

The technology measures adopted for the different scenarios are briefly described below. In all scenarios except the *Reference Scenario*, we use two different levels of technology development: moderate and advanced. The graph below shows the current emissions per kilogram of food, along with emissions assuming moderate versus advanced technology developments by 2050.

Overall, the moderate technology changes result in a 14% reduction in greenhouse gas emissions per person, as seen in the *Reference Scenario*. In the *Territorial Climate Target Scenario*, the diet is also assumed to be the same in 2050 as in 2019, but advanced technology measures have been assumed for food produced in Sweden. For imported food, two figures have been developed depending on whether global food production follows current trends and policies or whether a global climate transition is implemented. These two options result in a reduction in greenhouse gas emissions per person of 35-44%.

¹⁴⁵ [Statistics](#) from Jordbruksverket (the Swedish Board of Agriculture).

¹⁴⁶ Naturvårdsverket (Swedish Environmental Protection Agency) [Konsumtionsbaserade växthusgasutsläpp per person och år](#) (Consumption-based greenhouse gas emissions per person and year).

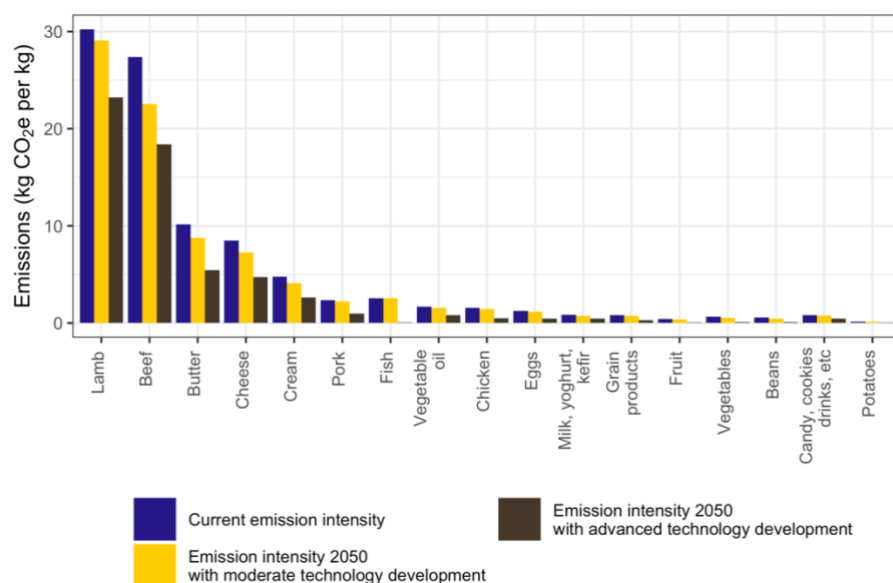


Figure 24. Greenhouse gas emissions per kilogram of product in 2019 and 2050 based on moderate and advanced technology measures.

The moderate technology changes mainly involve higher productivity in beef production and include:

- improved feed quality
- improved animal health and lower mortality
- higher rate of calving
- breeding animals that grow faster and therefore require less feed per quantity of meat.

The advanced technological developments are mainly based on the techno-economic potentials for climate-neutral agriculture described in a report by the World Resources Institute¹⁴⁷.

- Part of this is an even higher increase in productivity, including higher milk yields of dairy cows and advanced plant breeding. In addition, we assume that a wide range of specific measures to reduce greenhouse gas emissions have been partially implemented.
- Nitrous oxide emissions from arable land are reduced by increasing nitrogen efficiency and by the general use of nitrification inhibitors mixed into commercial fertilisers. We assume that technologies to reduce nitrous oxide emissions are introduced now, reaching 90% of their potential by 2070 at the global scale as well as in Sweden.
- Commercial fertilisers are currently produced with natural gas resulting in nitrous oxide emissions. In line with our general [energy assumptions](#), we assume that this natural gas is replaced by fossil-free alternatives such as carbon-free hydrogen or electricity. This transition is assumed to begin in 2030 and have full impact on all commercial fertiliser use in Sweden by 2050, and in the rest of the world by 2070.
- Methane emissions from ruminants are assumed to be reducible by 50% through feed additives. There are a variety of additives currently being evaluated for their potential to reduce methane emissions. We assume that use of the technology will start in 2030 and reach 90% of its potential in 2070 (both in Sweden and globally). Emissions of methane and nitrous oxide from manure management can also be reduced through changes in manure management. We assume that measures are introduced in 2030 and reach 90% of their potential in 2070 (both in Sweden and globally).

¹⁴⁷ Searchinger, et al, 2021. [A Pathway to Carbon Neutral Agriculture in Denmark](#). World Resources Institute.

- For energy-related emissions in agriculture, fossil fuels are assumed to be replaced by biofuels and electricity at the same rate as for [transport fuels](#) in other parts of this report. For energy for heating and drying, we assume a transition to electricity that is fully implemented in Sweden by 2050 and in the rest of the world by 2070.

Many of the measures adopted for biogenic emissions in agriculture are relatively simple technologies that do not require large investments (unlike energy and transport systems). However, several of these measures are not yet commercially available (e.g., feed additives to reduce methane emissions), and in most cases there are no plans or instruments to introduce these measures. In general, agriculture has been excluded from concrete instruments to reduce greenhouse gas emissions. In some cases, technologies can be introduced centrally, such as nitrification inhibitors, while, for example, changes in manure management need to be made through specific adaptations by many small actors. Together, these factors make it very difficult to assess whether, and how quickly, these measures might be introduced. We believe our assumptions are realistic given a clear political will to introduce the measures. However, we do not here assess the prospects for that will, in Sweden and globally.

Future consumption

Over a long period of time, the consumption of meat and cheese has increased, while the consumption of milk has decreased. In recent years, however, meat consumption has declined slightly. In light of this, we do not see a reason for assuming any dietary changes based on trends. In the *Reference Scenario* and the *Territorial Climate Target Scenario*, we assume that the future consumption per person is the same as in 2019, for individual food items¹⁴⁸.

The *Behaviour and Technology Scenario* assumes a shift in meat consumption where half of beef and lamb consumption is replaced by chicken (or a plant-based protein source). This is in line with the declining trend in beef consumption in recent years. The rate of reduction in this scenario is half that of the 2016 to 2020 period¹⁴⁹. Milk consumption has been falling steadily for several decades¹⁵⁰, and we assume that this trend continues at about the same rate resulting so as to be cut by half by 2050. For other types of food, including cheese ¹⁵¹, we assume that consumption remains at the same level as in 2019.

In the *Comprehensive Behaviour and Technology Scenario* and the *Reference Scenario with Comprehensive Behavioural Change*, we assume that the change goes further and that consumption of beef, lamb, and liquid dairy products instead decreases by 75% compared to the 2019 level, and that consumption of cheese is cut by half. This can be compared to the so-called Eat Lancet analysis on health and environmentally sustainable food consumption, which goes much further¹⁵². Their

¹⁴⁸ We also assume that the share of imports for different food products is the same in 2050 as in 2019.

¹⁴⁹ Consumption decreased from 28 kg per capita in 2016 to 24 kg in 2020, i.e., a reduction of 1 kg per year. A halving results in 13 kg of beef and lamb per person in 2050, which gives an average reduction rate of 0.4 kg per year. The figures are taken from Jordbruksverket and refer to total consumption, which refers to carcass weight, which means that bones and other parts of the animal that we do not eat are also included. It also includes wastage and losses between slaughterhouse and fork.

¹⁵⁰ Refers to liquid milk products. Source: [Naturvårdsverket/Jordbruksverket](#).

¹⁵¹ Cheese is a major greenhouse gas emitter and the reason the scenario does not include a reduction in cheese is that its substitutes have not taken off in the same way as liquid dairy products and beef have. This scenario only includes marginal behavioural change, and if substitutes continue to be less attractive, a reduction here would not be seen as marginal.

¹⁵² Stockholm Resilience Center, 2019. [Nordic food systems for improved health and sustainability](#).

recommendation for Sweden implies a reduction of both pork and beef by 85%. However, we do not think that pork and beef should be treated in the same way in climate analyses, as pork is closer to chicken in terms of climate impact (see Figure 24 above).

Table 2. Food consumption per person (kg/person)

	Baseline 2019	Reference Scenario 2050	Territorial Climate Target Scenario 2050	Behaviour and Technology Scenario 2050	Scenarios with Comprehensive Behavioural Change 2050
Meat (carcass)	90.0	89.9	89.8	88.3	69.7
Beef	25.0	25.0	25.0	12.5	6.2
Lamb	1.9	1.9	1.9	1.0	0.5
Pork	39.2	39.2	39.2	39.2	39.2
Chicken	23.8	23.8	23.8	35.6	23.8
Eggs	15.1	15.1	15.1	15.1	15.1
Dairy products	148.0	147.9	147.9	83.9	42.0
Milk, yoghurt, film milk	111.3	111.1	111.1	55.6	27.8
Cream	11.7	11.7	11.7	5.8	2.9
Butter	4.9	4.9	4.9	2.5	1.2
Eat	20.1	20.1	20.1	20.0	10.1
Fish	14.8	14.7	14.7	14.7	14.7
Cereal products	85.3	85.2	85.2	85.2	85.2
Potatoes	73.2	73.1	73.1	73.1	73.1
Vegetable oil	3.7	3.7	3.7	3.7	3.7
Vegetables	73.3	73.3	73.3	73.3	73.3
Fruit	99.2	99.1	99.1	99.1	99.1
Sweets, drinks etc.	180.2	180.1	180.1	180.1	180.1
Beans	19.2	19.2	19.2	19.2	38.4

General assumptions

Introduction of new technologies

The introduction of new technologies can be described by an S-curve (a so-called logistic curve) for the market impact of the technology. The theory behind S-curves is that the diffusion of innovations follows an S-like path as the market matures. Introduction is first slow when the technology is new, the market impact then increases, almost exponentially, and finally slows down as the market impact approaches 100%. There is strong evidence that this type of curve describes the market introduction of new technologies, although the factors underlying this development have not been fully identified^{153,154}. Our calculations use S-curves with a given first year when the technology reaches over 1% market penetration and final year when the technology reaches 99% market penetration, see the example in Figure 25 below.

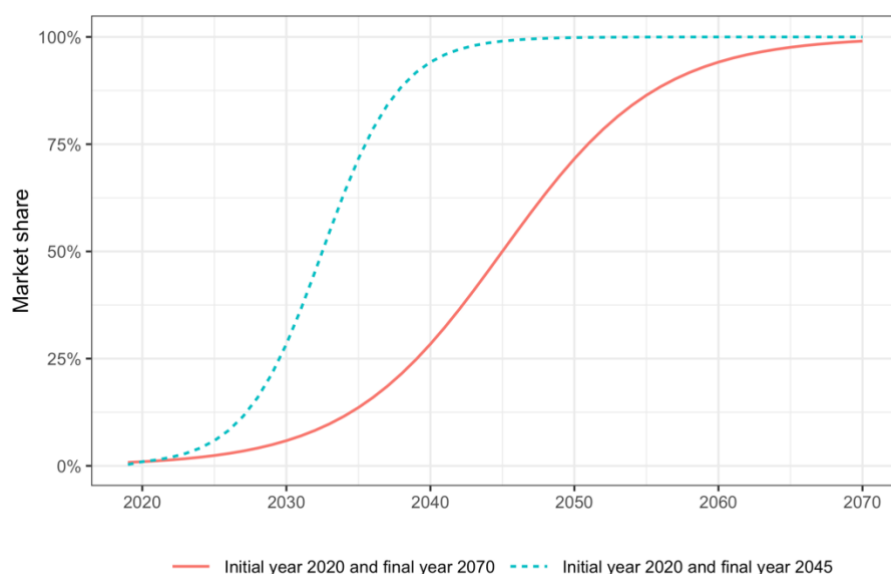


Figure 25. Market share of new technologies.

Energy use and emission intensity

Emissions related to energy use are estimated for both direct emissions from the combustion of fossil fuels and emissions that occur in the extraction, production, and refining of the respective energy carriers (so-called upstream emissions), see the details for each energy carrier in Table 3 below.

When it comes to electricity, we differentiate between average electricity used in Sweden, Europe, and globally. For each geographical region, the projected mix of electricity generation technologies is used, given different scenario assumptions, based on the analyses of the Energimyndigheten¹⁵⁵, the European Commission¹⁵⁶, and the IEA¹⁵⁷. Corrections have been made to account for transmission

¹⁵³ Brooder (1998). [Technology and Global Change](#). Cambridge University Press.

¹⁵⁴ Wilson (2009). [Meta-analysis of unit and industry level scaling dynamics in energy technologies and climate change mitigation scenarios](#). IIASA.

¹⁵⁵ Energimyndigheten, 2019. Scenarios for Sweden's Energy System 2018 - ER 2019:07. Eskilstuna, Sweden.

¹⁵⁶ European Commission, 2018. [In-depth analysis in support of the Commission communication COM\(2018\) 773 - A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy](#). Brussels, Belgium.

¹⁵⁷ IEA, 2019. [World Energy Outlook](#).

and distribution losses. Upstream emissions from maintenance and fuel production in power generation plants are estimated for each technology based on global averages in line with the two scenarios describing the global transition¹⁵⁸. For Sweden, direct emissions are assumed to reach zero in 2045 or 2058 (guided by when the EU ETS reaches zero overall under the current EU directive) depending on the scenario. The resulting emission intensities are presented in Figure 26.

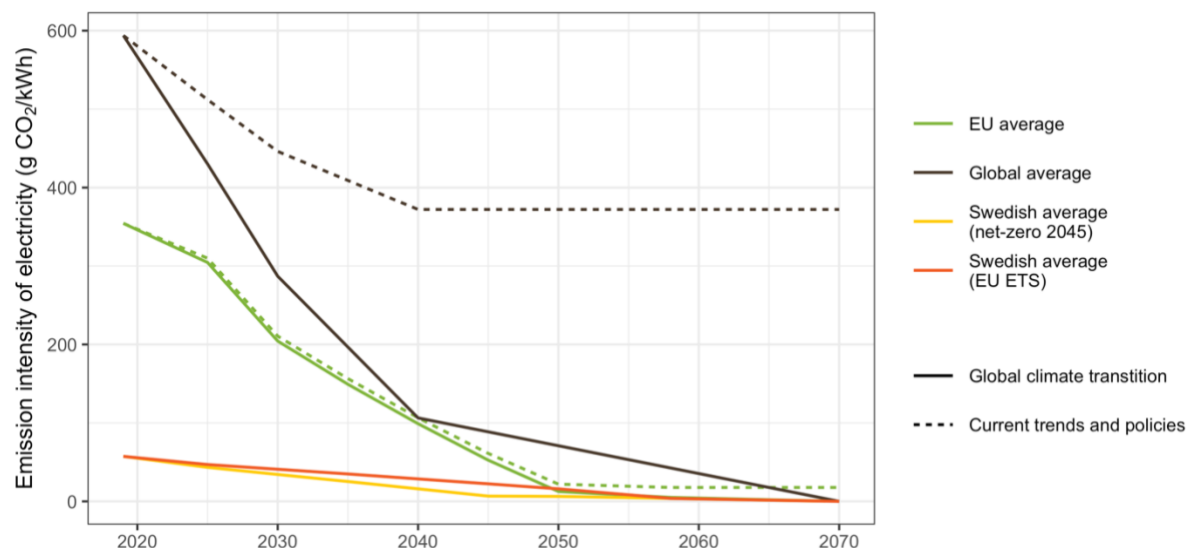


Figure 26. Emission intensity of the average Swedish, EU, and global electricity mix, depending on the external transition.

In terms of fuel use, we simplify to one fossil fuel and one biofuel, except in the modelling of passenger cars and vehicle battery production and building materials, where the split is more detailed. The fossil fuel corresponds to diesel and its upstream emissions are based on global averages for oil extraction and refining and an emission reduction potential equivalent to halving refining emissions.^{159,160}

For district heat use, we use key environmental figures for a district heating company¹⁶¹ that we assume are representative of the average Swedish district heating, as the fuel mix is broadly in line with the Swedish average¹⁶².

¹⁵⁸ Pehl et al. 2017. [Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling](#). Nature Energy.

¹⁵⁹ Jing et al. 2020. [Carbon intensity of global crude oil refining and mitigation potential](#). Nature Climate Change.

¹⁶⁰ Masnadi et al. 2018. [Global carbon intensity of crude oil production](#). Science.

¹⁶¹ Stockholm Exergi, 2020. [Miljönyckeltal Stockholm Exergi 2019](#) (Key environmental figures Stockholm Exergi 2019).

¹⁶² Energimyndigheten, 2021. [Energiläget i siffror 2021](#) (Energy situation stats 2021).

Table 3. Detailed description of assumptions for emission intensities for energy use (g CO₂e/kWh).

		Current trends and policies	Global climate transition
Electricity use	Swedish electricity mix	Emission intensity decreases from 57 g/kWh in 2019 to 14-24 g/kWh in 2050.	Emission intensity decreases from 57 g/kWh in 2019 to 6-16 g/kWh in 2050.
		Direct emissions decrease from 47 g/kWh to 0 g/kWh in 2045 (if Swedish climate targets prevail—scenarios 2 and 3) or 2058 (if EU ETS prevails—scenarios 1 and 4).	Direct emissions decrease from 47 g/kWh to 0 g/kWh in 2045.
		Upstream emissions are assumed to increase from 10 g/kWh to 14 g/kWh in 2050 (if the 2045 climate target is met) and to 24 g/kWh in 2050 (if only the EU ETS is in place).	Upstream emissions are assumed to decrease to 6 g/kWh in 2050 (if the 2045 climate target is met) and increase to 16 g/kWh in 2050 (if only the EU ETS rules), from 10 g/kWh in 2019.
	European electricity mix	Emission intensity decreases from 354 g/kWh in 2019 to 22 g/kWh in 2050.	Emission intensity decreases from 354 g/kWh in 2019 to 13 g/kWh in 2050.
		Direct emissions of 354 g/kWh assumed to reach 0 g/kWh in 2058 when the EU ETS cap reaches zero. Upstream emissions decrease from 23 g/kWh to 18 g/kWh in 2050.	Direct emissions of 354 g/kWh assumed to reach 0 g/kWh in 2058 when the EU ETS cap reaches zero. Upstream emissions decrease from 23 g/kWh to 8 g/kWh in 2070.
	Global electricity mix	Emission intensity decreases from 594 g/kWh in 2019 to 372 g/kWh in 2050.	Emission intensity decreases from 594 g/kWh in 2019 to 71 g/kWh in 2050.
Fuel use	Fossil	Direct emissions of 567 g/kWh, decreasing to 350 g/kWh in 2040 and remaining constant thereafter. Upstream emissions decrease from 27 g/kWh to 23 g/kWh in 2040 and remain constant thereafter. The emission intensity is constant at 319 g/kWh, of which upstream emissions account for 60 g/kWh.	Direct emissions of 567 g/kWh decreasing to 0 g/kWh in 2070. Upstream emissions decrease from 27 g/kWh to 0 g/kWh in 2070 and remain constant thereafter. Emission intensity decreases from 319 g/kWh in 2019 to 310 g/kWh in 2050. The entire reduction occurs in upstream emissions, which decrease from 60 g/kWh in 2019 to 48 g/kWh in 2070 due to reduced emissions from refineries.
	Biofuels	The emission intensity is constant at 69 g/kWh, which consists entirely of upstream emissions as biofuels are assumed to have no direct emissions.	Emission intensity decreases from 69 g/kWh in 2019 to 33 g/kWh in 2050, due to the introduction of second-generation biofuels, which are assumed to reach full market dominance around 2070.
	District heating use	Emission intensity decreases from 65 g/kWh to 17 g/kWh in 2050, of which upstream emissions account for 4 g/kWh. The decrease is assumed to be an effect of the EU ETS emission cap reaching zero in 2058.	Emission intensity decreases from 65 g/kWh in 2019 to 4 g/kWh in 2045 and beyond. The reduction is assumed to be a direct effect of the assumed zero emissions from electricity and district heat production when the net zero target is reached in Sweden and is assumed to be linear.

Comparison with consumption-based figures based on an input-output analysis

The analysis in this report differs significantly from the analyses of consumption-based emissions carried out by SCB¹⁶³, in terms of methodology and the areas of emissions covered. The red bars in Figure 27 show statistics for consumption-based greenhouse gas emissions according to SCB's consumption classifications. The green bars show the results from the bottom-up methods used in this report.

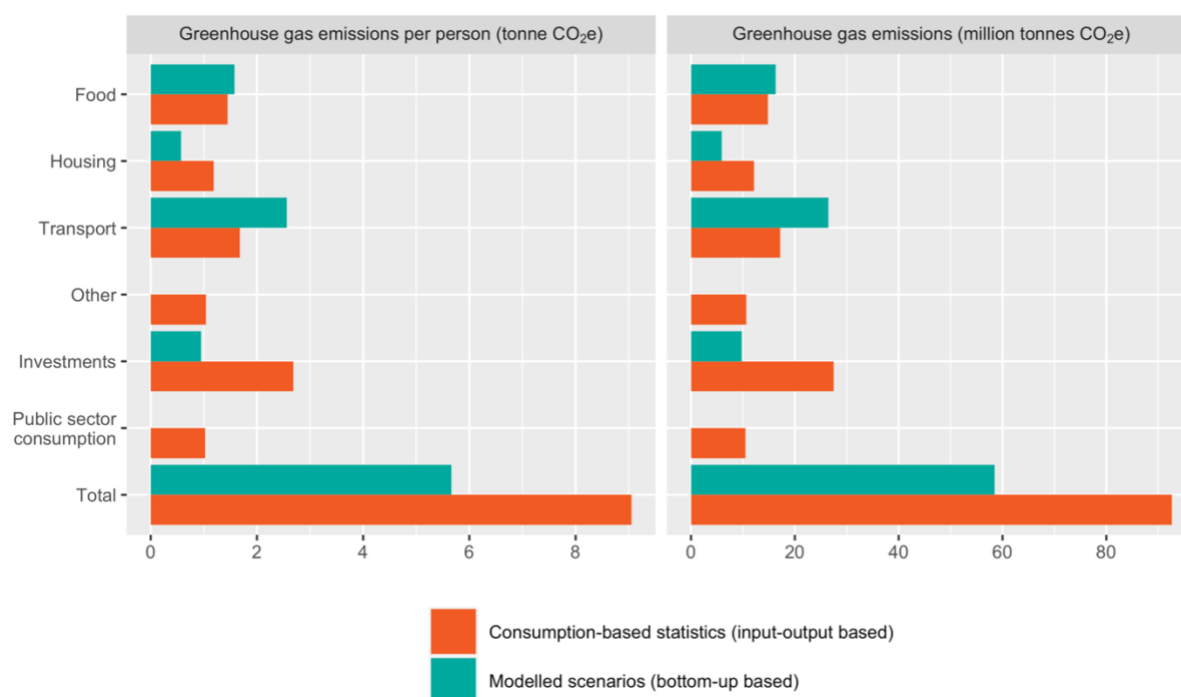


Figure 27. Comparison between consumption-based input-output statistics and the bottom-up method, broken down by COICOP categories according to the [Swedish Environmental Protection Agency's report](#). Source: Our own analyses (modelled scenarios) and SCB¹⁶⁴ (consumption-based statistics).

However, the figure may give the impression that the differences are greater than they are. Consumption-based statistics based on an input-output analysis yield total emissions of 93 million tonnes of CO₂e in 2019, while in this report's scenario analysis the total emissions in 2019 are 58 million tonnes of CO₂e. However, our bottom-up analysis excludes clothing and footwear, other consumption, and some investments (notably business investments), representing a total of 37% of consumption-based emissions. If we take these exclusions into account, the results of are fairly close.

The results for food are relatively close for the two methods. However, transport emissions are significantly higher in the bottom-up analysis compared to the input-output analysis. One explanation for this is that the bottom-up analysis also includes the high-altitude effect of

¹⁶³ SCB uses multi-regional input-output models (MRIO) such as EXIOBASE and are reported by [SCB](#) and [Naturvårdsverket](#).

¹⁶⁴ SCB, 2021. [Miljöpåverkan från hushållens konsumtion efter ändamål COICOP och ämne. År 2008 - 2019](#) (Environmental impact of household consumption by purpose COICOP and substance. 2008-2019).

aviation¹⁶⁵. Another explanation is that the bottom-up analysis cannot distinguish between public and private consumption. The figure above gives the impression that we do not cover public sector consumption, but this is not the case. Most of the climate impact of public consumption is found in the other consumption areas—driving is found in Transport; school meals are found in Food; and heating of public buildings is found in Housing.

The figure also includes investments, divided into private and public investments. It is not clear how investments should be treated in consumption-based statistics. Input-output-based statistics encompass emissions from investments in Sweden, including investments made by industry and the public sector in, e.g., machinery, buildings, and roads, both emissions that can be linked to what is consumed in Sweden and those linked to consumption abroad. Emissions arising from investments in other countries are not included in input-output analysis-based Swedish consumption-based statistics. Increased consumption may require new investments, but this dynamic is not captured by the models. Thus, the figures for imports of consumer goods from, for example, China do not include emissions generated from, for example, the steel and concrete used to build the factories that produce the goods. Those emissions are therefore counted as Chinese investment emissions in the consumption-based statistics as well. Investment accounts for over half of China's total CO₂ emissions, and it is reasonable to believe that a significant share of these emissions is generated by China's growing exports. This means that the consumption-based statistics do not attribute all the relevant emissions to our consumption; some are instead reported as investment.

¹⁶⁵ The high-altitude effect corresponds to 14% of the climate impact reported for Transport in the bottom-up methodology.

PART 2 - Emissions Targets Based on the Paris Agreement and International Equity Principles

Introduction and purpose

Under the Paris Agreement, the temperature and emission reduction targets are to be achieved taking into account (i) that developing countries may need more time to reach their respective emission peaks; (ii) equity as a basis; and (iii) sustainable development and poverty eradication. In addition, implementation should be guided by the overarching principle of the UNFCCC of "equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances". However, there is no consensus on how the targets outlined at the global level in the Paris Agreement can be translated into national emission reduction targets.

Nor is it a scientific matter to determine unambiguously and objectively how the global commitment to emissions reductions should be distributed across the world's nations. Fundamentally, it is a matter of values. However, research can provide perspectives and analyse the potential consequences of different approaches to allocating the emission space. A number of methods and principles have been proposed by scientists and analysts and discussed in the climate negotiations.

This section aims to provide an overview of some of these methods and principles, as well as illustrative examples of how Sweden's emission budget is affected by different allocation methods and principles. However, we re-emphasize that interpreting the Paris Agreement and the objectives and principles of the UNFCCC in terms of Swedish targets is ultimately a political act.

Global average emissions per person in line with the Paris Agreement

The Paris Agreement's long-term temperature goal is "...holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels..." How the target is to be interpreted in detail is still an open question. For example, there is no specification of what "well below" means or what level of probability should be applied to the targets. The wording is interpreted by Mace¹⁶⁶ as a cap on temperature increase at well below 2 °C with an ambition to reach 1.5 °C, or alternatively that 1.5 °C itself is seen as a cap on temperature increase. A common interpretation by scientists, who make quantitative assessments¹⁶⁷ of how the target can be met, is that "well below 2 °C" means that the 2 °C target is met with a probability of more than 66% and that 1.5 °C is met by 2100 with a

¹⁶⁶ Mace, 2016. [Mitigation Commitments Under the Paris Agreement and the Way Forward](#). Climate Law.

¹⁶⁷ Researchers using integrated assessment models that can, among other things, answer how a specific temperature target can be achieved. The models often take both energy and climate systems into account as well as how society and economic systems evolve.

probability of more than 50%^{168,169}, but many different interpretations exist. Several well-known websites¹⁷⁰ with clocks counting down to the end of the global carbon budget assume a budget in line with limiting the average temperature increase to 1.5 °C with a probability of more than 66%. Depending on how the Paris Agreement is interpreted and the level of probability of meeting the target, completely different results can be obtained for the space available for future emissions. These different results strongly influence the interpretation of how much an individual country needs to reduce its emissions. Challenges also arise in interpreting the concepts of fair allocation and historic responsibility.

A 2050 goal and how to get there

The IPCC has compiled global emissions scenarios according to different scenario types that limit the global average temperature increase to below 2 °C or 1.5 °C¹⁷¹. These are listed in Table 4 along with the respective probability estimates for limiting the temperature increase to the specified level. However, the definitions are not formulated in the same way as the Paris Agreement targets. Based on the scientific literature on quantitative assessments of compliance, scenarios that limit the temperature increase to below 2 °C with relatively low probability (50-66%, scenario type e in Table 4) are not compatible with the Paris Agreement. Therefore, results for these are not reported in the remainder of this chapter. The scenarios that can be considered compatible with the Paris Agreement (a-d) correspond to limiting the mean temperature increase to a maximum of 1.7-1.8 °C in 2100 and a max peak of 2 °C in the 21st century (d) if the most likely values are assumed for significant uncertainties, such as climate sensitivity, ocean heat uptake, carbon cycle behaviour, etc.

Table 4. IPCC scenario definitions according to the special report on 1.5 °C global warming.

Temperature targets	Scenario type	Description
In line with 1.5 °C	a) Below 1.5 °C	Scenarios limiting the peak temperature increase to below 1.5 °C over the whole period 2000-2100 with a 50-66% probability
	b) 1.5 °C - low overshoot	Scenarios that limit the median temperature increase for the period 2000-2100 to below 1.5 °C and with a 50-67% probability of a temporary overshoot. Implies less than 0.1 degrees higher peak temperature increase than "below 1.5 °C".
	c) 1.5 °C - high overshoot	Scenarios that limit the median temperature increase to below 1.5 °C and with more than a 67% probability of a temporary overshoot. Implies 0.1-0.4 degrees higher peak temperature increase than "below 1.5 °C".
In line with 2 °C	d) 2 °C - high probability	Scenarios that limit the peak temperature increase to below 2 °C in the period 2000-2100 with more than a 66% probability. No overshoot.
	e) 2 °C - low probability	Scenarios that limit the peak temperature increase to below 2 °C in the period 2000-2100 with more than a 50-66% probability. No overshoot.

If emissions are distributed equally¹⁷² per person, globally, then each group of scenarios (a-d in Table 4) achieves different results in 2050, see Figure 28. Results vary from scenario type (a) requiring net greenhouse gas emissions of -0.3 to 0.9 tonnes CO₂e per person (i.e., net negative emissions of 0.3 tonnes CO₂e per person to net emissions of 0.9 tonnes CO₂e per person) for scenarios limiting the temperature increase to below 1.5 °C (with 50-66% probability), to scenario type (d) where net emissions can be as high as 0.8-3.3 tonnes CO₂e per person for scenarios limiting the temperature

¹⁶⁸ Schleussner et al. 2016. [Science and policy characteristics of the Paris Agreement temperature goal](#). Nature Climate Change.

¹⁶⁹ du Pont et al. 2016. [National contributions for decarbonizing the world economy in line with the G7 agreement](#), Environmental Research Letters.

¹⁷⁰ For example, [Climate Clock](#) and [Carbon Clock](#).

¹⁷¹ Masson-Delmotte et al. 2018. [Global warming of 1.5°C An IPCC Special Report](#). IPCC.

¹⁷² Based on the assumed global population growth for each scenario.

increase to 2 °C with high probability (above 66%), see Figure 28. For comparison, global average net greenhouse gas emissions were 6.3 tonnes CO₂e per person in 2019¹⁷³.

The range for each group of scenarios depends in part on the different pathways to achieve the temperature target and the mix of greenhouse gases. Thus, the Paris Agreement target can be achieved over a relatively wide range of per capita emissions in 2050, depending largely on the emissions trajectory before and after 2050, as well as the long-term temperature level to be reached. This makes clear that emission levels referring only to the year 2050 are just an indication of where we should be heading to be in line with the Paris Agreement.

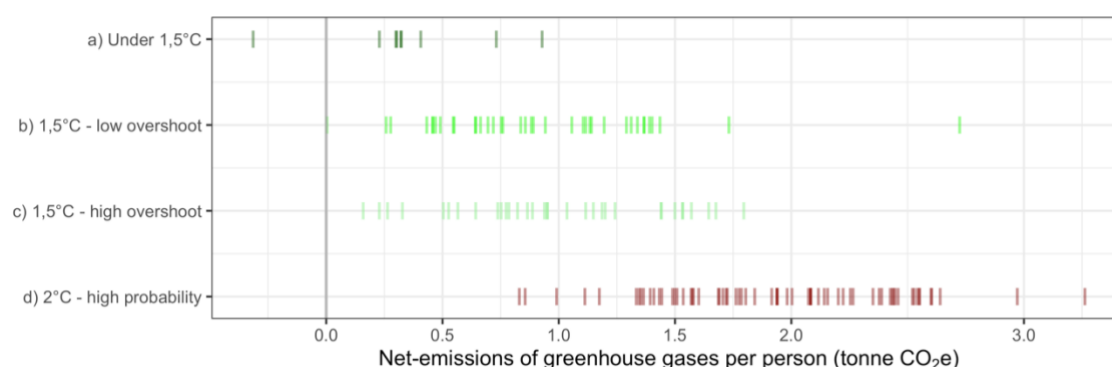


Figure 28. Range of 2050 results in global average net greenhouse gas emissions per person for scenarios achieving different levels of global average temperature increase mitigation (a-d). Source: IAMC¹⁷⁴

With respect to carbon dioxide and other long-lived greenhouse gases (with an atmospheric lifetime of more than 100 years), it doesn't much matter when the emissions occur. These emissions will have the same long-term impact on the temperature level no matter when they are emitted. This is not true for short-lived greenhouse gases (such as methane); therefore, we need to consider an adjustment to how these gases are added to the long-lived gases, mainly carbon dioxide and nitrous oxide, depending on the temperature trajectory.¹⁷⁵

The three groups (a-c) of 1.5 °C scenarios differ on the degree to which the 1.5 °C level is exceeded, and the last group (d) does not achieve 1.5 °C but keeps the temperature increase below 2 °C with a relatively high probability. Scenarios that either do not overshoot 1.5 °C or only do so by a little require rapid reductions in greenhouse gas emissions before and around 2030, see Figure 29. In contrast, scenarios with a large overshoot (c) or those that only limit the increase to 2 °C (d) allow for less drastic emission reductions in the near term. However, in order still to achieve 1.5 °C (c), significant negative emissions in the second half of the century are required to compensate for the slower rate of reductions in the near term. The IPCC also present illustrative scenarios to show the difference between different development paths, a selection of which are shown in the diagrams (b-d) in Figure 29.

¹⁷³ Gütschow et al. 2021. [The PRIMAP-hist national historical emissions time series \(1750-2019\)](#). Potsdam Institute for Climate Impact Research.

¹⁷⁴ Huppmann et al. 2019. [IAMC 1.5°C Scenario Explorer and Data hosted by IIASA](#).

¹⁷⁵ Tanaka, Morfeldt, Boucher (2021). [A new way of comparing greenhouse gases could help us meet the Paris Agreement goals](#). The Conversation - France.

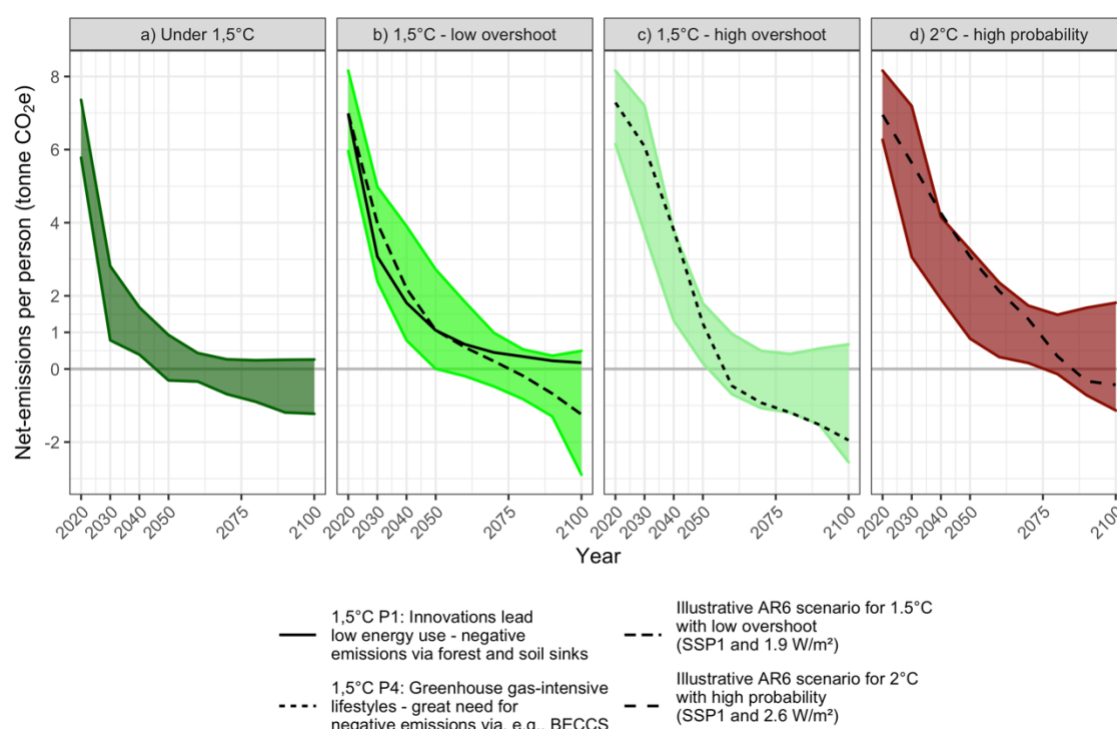


Figure 29. Global average temperature increase limits (a-d) and ranges of scenario results in terms of global average net greenhouse gas emissions per person. Illustrative scenarios show different development paths as reported by the IPCC (IPCC SR1.5¹⁷⁶ and IPCC WG1 AR6¹⁷⁷). Source: IAMC¹⁷⁸ and IPCC¹⁷⁹.

Fair distribution goes beyond equal emissions per person

The principles for how to achieve the objectives of the UNFCCC and the Paris Agreement (found in Article 3 of the UNFCCC and the preamble to the Paris Agreement) are based on "equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances" (also known as CBDR-RC in the climate negotiations). In addition, the Paris Agreement (Article 4.1) states that the objective of the Parties is to reach global peaking in emissions in the near future and to achieve a balance between emissions and removals in the second half of the century, and that this development should be based on equity and take into account sustainable development and poverty eradication.

However, there is no consensus on how to interpret these texts in terms of how the remaining emission budget associated with reaching the Paris Agreement's temperature target should be allocated among countries and actors¹⁸⁰. And this is not the kind of issue that can be resolved with more research as there is no unambiguous, objective truth for scientists to seek. What the research community can do is to propose principles and methodologies and to analyse their implications. Ultimately, the allocation of emission budgets is a value judgement for the parties to the climate

¹⁷⁶ Masson-Delmotte et al. 2018. [Global warming of 1.5°C An IPCC Special Report](#). IPCC.

¹⁷⁷ Masson-Delmotte et al. [Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change](#). IPCC.

¹⁷⁸ Huppmann et al. 2019. [IAMC 1.5°C Scenario Explorer and Data hosted by IIASA](#).

¹⁷⁹ IPCC, 2021. Summary for Policymakers of the Working Group I Contribution to the IPCC Sixth Assessment Report. [Data available at NERC EDS Centre for Environmental Data Analysis](#).

¹⁸⁰ Pan et al. 2015. [Countries' emission allowances towards the low-carbon world: A consistent study](#). Applied Energy.

negotiations and the elected representatives in the individual nations. What can be said with certainty is the generally accepted position that developed countries should take the lead (Article 3.1 of the UNFCCC) and that it will take longer for developing countries to reach their respective emission peaks (Article 4.1 of the Paris Agreement).

Scientists as well as negotiators have proposed a plethora of different policy and allocation keys for dividing up the remaining emission budget. The allocation keys can be categorised according to four aspects (see Figure 30): responsibility, equality, capability/need and cost-effectiveness. These aspects are all clearly anchored in the principles of the UNFCCC.

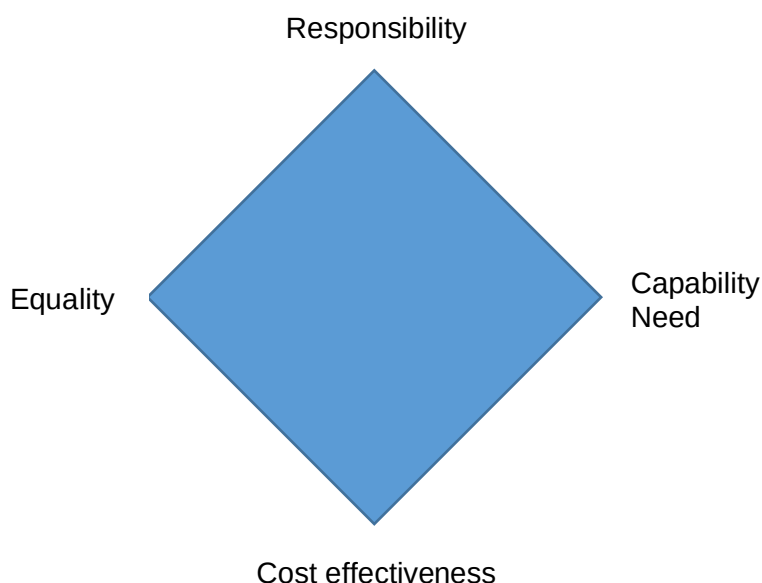


Figure 30. Main categories of allocation principles that can be used to allocate the remaining emission space. Source: Höhne et al.¹⁸¹

The *responsibility* aspect is based on each country's cumulative historical emissions. Already during the negotiations leading to the Kyoto Protocol, Brazil proposed using historical emissions, or the economic development a country has achieved with the aid of them, as the basis for developing emission targets for the future. *Capability and need* have to do with the financial power of a country to implement emission reduction measures. The studies that have proposed allocation based on capability/need have used indicators such as the country's gross domestic product (GDP) and human development index (HDI) in relation to the cost of emission reductions. Allocating according to *equality* is based on equal per capita emissions, either by allocating the emission budget so that per capita emissions are directly equal or so that the emission trajectories converge towards equal per capita emissions over time for each country. *Cost-effectiveness* is based on the potential and marginal costs of emission reduction measures in each country, but requires countries to agree on a common global method of accounting, often based on a common internalisation of the cost of emissions (e.g., a universal carbon tax). A number of studies have attempted to combine the

¹⁸¹ Höhne et al. 2014. [Regional GHG reduction targets based on effort sharing: a comparison of studies](#). Climate Policy.

different aspects, but there is no methodology that provides an unambiguous answer yielding emissions trajectories for individual countries in line with the principles of the UNFCCC.¹⁸²

Although cost-effectiveness has often been discussed as a principle for allocating the emission space, its relevance is questionable. Assuming that a global emissions trading system is put in place (as described in Article 6 of the Paris Agreement), cost-effective implementation can be accommodated regardless of which country is allocated the right to emit and financial resources can be allocated to realise the emission reductions where most beneficial. However, the rules for emissions trading under the Paris Agreement have not yet been fully negotiated, and there is also a risk that countries' emission reduction targets could be undermined if the rules are not sufficiently clear¹⁸³. That said, the measures that are considered cost-effective for a country or region, in order to reach the global temperature target, can be seen as a minimum level for domestic emission reductions¹⁸⁴. If other principles of equity such as historic responsibility and capability to implement the transition are also taken into account, developed countries tend to have the greatest moral obligation to reduce emissions quickly, even to reach net-zero emissions as early as 2030. If such emission reductions are not feasible domestically, these conditions can be interpreted as an expectation that the nations finance emission reductions in other countries to the same extent¹⁸⁵.

The studies referenced above take a territorial perspective on emission targets and reductions, as this is the starting point of the UNFCCC. The methodology used for allocation in a territorial perspective could be applied in a consumption-based perspective. However, in many cases the calculations require available data for both the country in question and other countries, as well as historical time series (to assess historic responsibility), and the availability of such high-quality consumption-based emissions data with a consistent methodology across countries is very limited (e.g., consumption-based CO₂ emissions are only available for 118 out of 218 countries in the Global Carbon Project's¹⁸⁶ annual compilation of global emissions data, although 95% of global CO₂ emissions are covered). These calculations are also not as regulated as the methodology for producing data on territorial greenhouse gas emissions and removals reported by countries under the UNFCCC.

However, based on the available data, it can be said that rich, developed countries generally tend to have higher consumption-based than territorial emissions and that the reverse is generally true for developing countries (see some examples in Figure 31). Thus, a shift to consumption-based allocation may change the starting point for allocating the remaining emission budget. Based on principles related to responsibility, rich, developed countries will generally have a higher responsibility for current activities and emissions when using consumption-based emissions as a starting point, and developing countries will have a lower responsibility.

¹⁸² Höhne et al. 2014. [Regional GHG reduction targets based on effort sharing: a comparison of studies](#). Climate Policy.

¹⁸³ International Institute for Sustainable Development, 2021. [Policy Brief: Delivering Climate Ambition Through Market Mechanisms: Capitalizing on Article 6 Piloting Activities](#).

¹⁸⁴ Zaklan et al. [The EU ETS to 2030 and beyond: adjusting the cap in light of the 1.5°C target and current energy policies](#). Climate Policy.

¹⁸⁵ Höhne et al. 2018. [Assessing the ambition of post-2020 climate targets: a comprehensive framework](#). Climate Policy.

¹⁸⁶ Friedlingstein et al. 2020. [Global Carbon Budget 2020](#). Earth System Science Data.

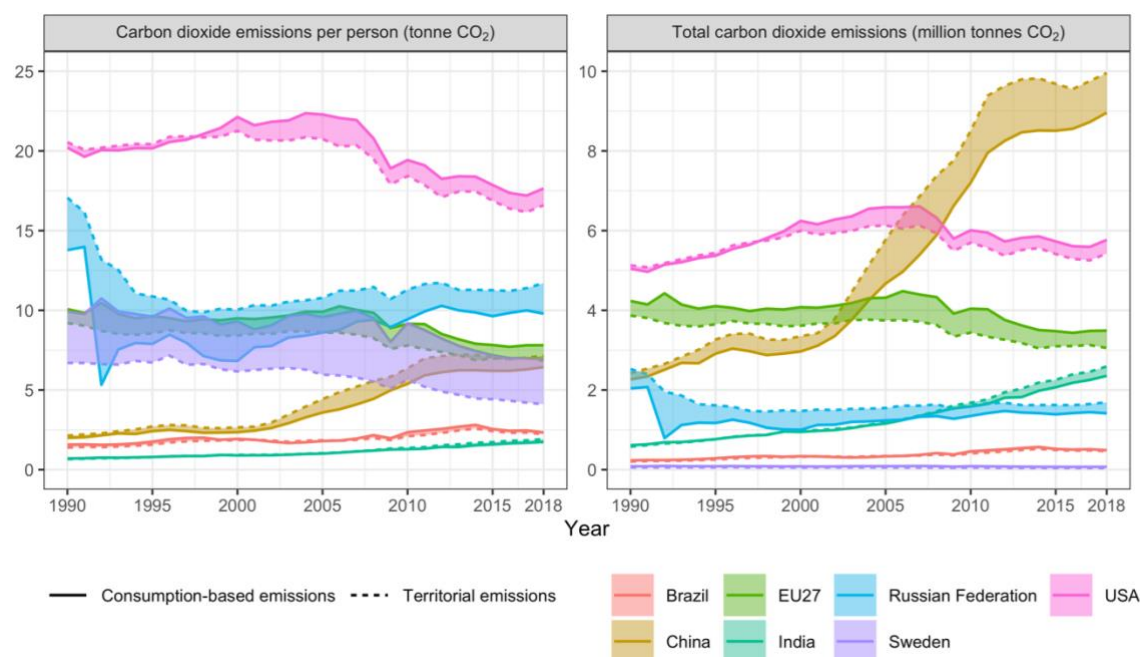


Figure 31. Carbon dioxide emissions for a sample of countries by territorial (dashed line) and consumption-based (solid line) emissions accounting. Source: Global Carbon Project¹⁸⁷, inspired by a figure in the UNEP Emission Gap Report.

Figure 31 (left panel) also shows that the difference between consumption-based and territorial emissions per person is relatively high for Sweden compared to other countries, indicating that Swedish consumption gives rise to relatively large emissions in addition to those that occur within Sweden's borders. However, how these emissions should be treated is not self-evident. Steiner et al.¹⁸⁸ argue that parallel accounting systems (production- and consumption-based) may allow for a more optimal combination of climate policy instruments since both perspectives would be monitored. Examples are policies that minimise carbon leakage through, for example, *Border Carbon Adjustment* measures, which have recently been analysed as an option for Sweden by Kommerskollegium, the Swedish National Board of Trade¹⁸⁹. However, there is a risk that, in the long run, consumption-based accounting of emissions will increase the burden on developing countries if requirements to achieve emission reductions are passed on to where the emissions take place without being linked to support for implementing the emission reduction measures.

¹⁸⁷ Friedlingstein et al. 2020. [Global Carbon Budget 2020](#). Earth System Science Data.

¹⁸⁸ Steiner, et al. 2016. [Multiple carbon accounting to support just and effective climate policies](#). Nature Climate Change.

¹⁸⁹ Kommerskollegium (Swedish National Board of Trade), 2020. [Gränsjusteringsåtgärder för koldioxidutsläpp - En analys av de handelsrelaterade aspekterna och vägen framåt](#) (Border tariffs for carbon dioxide emissions – Analysis of trade-related aspects and the path forward).

Results for Sweden for various allocation principles for the global emission budget

The illustrative scenarios in Figure 29 can be used to show what the development paths would look like if the allocation of emission budget starts out from an equal distribution of emissions per person, globally. If we instead use a convergence principle to reach equal emissions, each country's per capita emission level approaches a global average and reaches it in a given year; this is known as Contraction and Convergence¹⁹⁰. If a country's emission level is close to the global average per person, then its allocation will continue to be around the global average in the future. If, on the other hand, the country's emission level is higher or lower than the global average, its emissions must decrease or increase, respectively, towards the global average per person, which is reached for all in a given year.

Equal emissions per capita have the advantage of simplicity and transparency. Advocates have also suggested the atmosphere be seen as a global commons that guarantees the health of all people and that the only relevant aspect of equity is therefore equal per capita emissions¹⁹¹. Note, however, that any allocation principle based on some variant of equal per capita emissions greatly depends on population projections. Any target decided on the basis of the principle may therefore need to be updated as population projections are revised.

Swedish consumption-based emissions per person are above the global average. Current consumption-based emissions for Sweden correspond to about 9 tonnes CO₂e per person, which compares to the range of 5.8-8.2 tonnes CO₂e per person for 2020 in Figure 29.

If the per capita emission trajectories in Figure 29 are converted¹⁹² to total consumption-based emission trajectories for Sweden, this would result in total net consumption-based carbon dioxide emissions of 1.7 to 25.0 million tonnes in 2050 and net consumption-based greenhouse gas emissions (i.e., if emissions of greenhouse gases other than carbon dioxide are also taken into account based on the global average development) of 12.4 to 36.2 million tonnes in 2050, see Figure 32. Note, however, that the consumption-based emissions statistics (and the scenarios presented in this report) do not take negative emissions or net removals in land use, land use change, and forestry (LULUCF) into account, while these are included in Figure 29 and Figure 32. For a fair comparison between these emission trajectories and the Swedish consumption-based emissions statistics, net territorial removals and future artificial negative emissions would also need to be reallocated to the relevant consumption area.

¹⁹⁰ Meyer, 2004. [Briefing: Contraction and convergence](#). Engineering Sustainability.

¹⁹¹ Zimm & Nakicenovic, 2019. [What are the implications of the Paris Agreement for inequality?](#) Climate Policy.

¹⁹² After adjustment for the Swedish population forecast. SCB, 2021. [Befolkningsframskrivningar](#) (Population forecast).

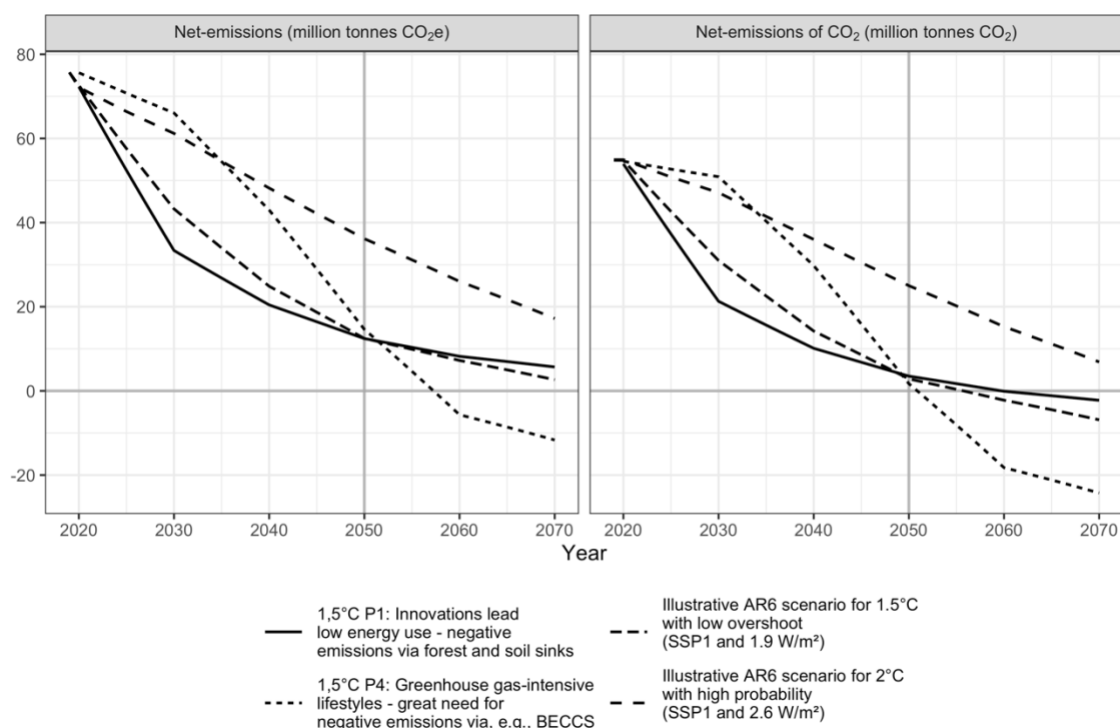


Figure 32. Global development pathways to reach the Paris Agreement temperature targets converted to Swedish consumption-based emissions based on the distribution principle of equal emissions per person. Left panel shows net greenhouse gas emissions and right panel shows net carbon dioxide emissions. Source: Our own recalculation based on respective scenarios (IAMC¹⁹³ and IPCC¹⁹⁴) and Swedish population projections (SCB¹⁹⁵).

Andersson et al.¹⁹⁶ estimate what a fair contribution would require in terms of domestic emission reductions for Sweden based on territorial emissions and conclude that Sweden's emission budget (based on current territorial climate targets) is twice as high as it should be to be in line with the Paris Agreement temperature target. The study starts from the principle that developing countries should be given more time to reverse their emission trends, but does not consider other allocation principles. The methodology comprises two steps, the first of which assumes ambitious but achievable emission reduction rates for developing countries (which are lower compared to developed countries) after they have reached their respective emission peaks. In the second step, developed countries' budgets are allocated based on the principle of *grandfathering* (roughly, the greater the current emissions, the greater the allocated emissions budget). Step two hits Sweden hard because of its relatively low current emissions compared to other developed nations. The rationale for grandfathering considers lock-in effects in fossil infrastructure and the limited space for reforms. The principle gives relatively large emissions leeway to nations like the US that could be considered to have both the capability and historic responsibility to take on a more ambitious budget. If developed countries' budgets were instead allocated on the basis of population, Sweden's emission budget would be more than twice as large and in line with Sweden's territorial climate target (assuming that the emission trajectory follows the target scenario presented in the report of

¹⁹³ Huppmann et al. 2019. [IAMC 1.5°C Scenario Explorer and Data hosted by IIASA.](#)

¹⁹⁴ IPCC, 2021. Summary for Policymakers of the Working Group I Contribution to the IPCC Sixth Assessment Report. [Data available at NERC EDS Centre for Environmental Data Analysis.](#)

¹⁹⁵ SCB, 2021. [Befolkningsframskrivningar.](#)

¹⁹⁶ Anderson et al. 2020. [A factor of two: how the mitigation plans of 'climate progressive' nations fall far short of Paris-compliant pathways.](#) Climate Policy.

Miljömålsberedningen, the Cross-Party Committee on Environmental Objectives¹⁹⁷). The methodology has not been used to develop an allocation based on consumption-based emissions due to the above-mentioned limitations and the lack of data to estimate developing countries' emission reduction potential under the consumption-based approach.

One allocation method that can be used to estimate Sweden's carbon budget based on historic responsibility is equal *cumulative* emissions per capita. The Global Carbon Project¹⁹⁸ reports consumption-based carbon dioxide emissions data for 1990-2018 for Sweden. However, it is difficult to determine the quality of the dataset compared to Swedish official statistics, so the results are mainly illustrative and should be used with caution. Note that the Global Carbon Project estimates the Swedish consumption-based carbon dioxide emissions at about 71 million tonnes CO₂ for 2018, while SCB¹⁹⁹ estimates the Swedish consumption-based greenhouse gas emissions at 97 million tonnes CO₂e for 2018.

If the Swedish consumption-based emissions history is combined with global scenarios for limiting the average temperature increase to 1.5 °C and 2 °C respectively (corresponding to the two illustrative scenarios from IPCC AR6 in Figure 32), the Swedish carbon budget can be estimated based on different starting years for the historic responsibility, see Figure 33. The figure also shows results for Sweden given the allocation of the global emission budget according to its capacity for transition, which in simplified terms corresponds to an allocation based on economic prosperity (GDP in purchasing power parities), and according to equal emissions per person (corresponding to the two IPCC AR6 illustrative scenarios in Figure 32). The methodology used is the same as that of the Paris Equity Check initiative²⁰⁰, which also reports results for Sweden, albeit from a territorial perspective and with statistics up to 2010.

If historic responsibility starts in 1990, the carbon budget for Sweden would be between -130 million tonnes of CO₂ and 370 million tonnes of CO₂, depending on the temperature level. This compares to 770-1270 million tonnes CO₂ for the starting year 2018, which is relatively close to the result for a distribution of the global emission budget according to equal emissions per person per year, see the left-hand side of Figure 33. Note that these estimates have been made on the basis of available emissions data and do not take into account possible net removals of carbon dioxide in forests and soils over the period that may affect the historic responsibility, in terms of net carbon dioxide emissions, for countries with large forest areas, such as Sweden. It is not clear which year should be considered as the starting year for the historic responsibility. One might argue that a country's population is responsible for what happened in that country a few decades ago, but how is a country's responsibility affected if it did not know that what it did led to an environmental problem? This is the kind of question to which research cannot provide unambiguous answers. Note, however, that the Intergovernmental Panel on Climate Change (IPCC) was founded in 1988, and the Swedish carbon tax was introduced in the early 1990s, so the problems associated with climate change impacts should arguably be considered widely known in Sweden since at least the 1980s.

¹⁹⁷ Miljömålsberedningen, 2016. En klimat- och luftvårdsstrategi för Sverige (A climate and air protection strategy for Sweden) (SOU 2016:47).

¹⁹⁸ Friedlingstein, et al, 2020. [Global Carbon Budget 2020](#). Earth System Science Data.

¹⁹⁹ SCB, 2021. [Växthusgasutsläpp från inhemsk efterfrågan i Sveriges ekonomi minskade 2019](#). Greenhouse gas emissions from domestic demand in the Swedish economy decreased in 2015.

²⁰⁰ Paris Equity Check - [Multi-Equity Map](#)

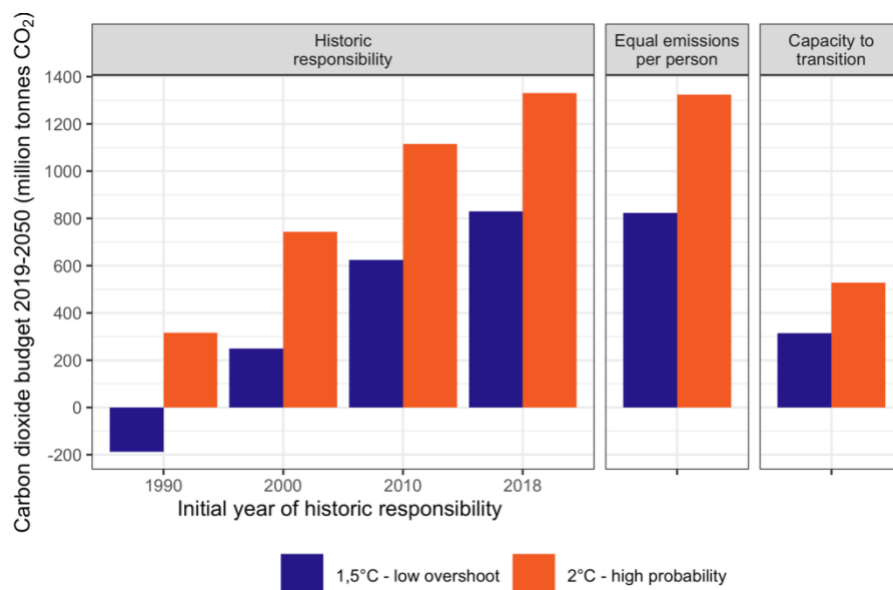


Figure 33. Estimated carbon budget for Sweden based on historic responsibility for consumption-based emissions by when that responsibility starts. Source: Our own calculation. Method: du Pont et al.²⁰¹ Data: Global Carbon Project²⁰², IPCC²⁰³, SCB²⁰⁴.

Romanovskaya and Federici²⁰⁵ reach a similar conclusion as with historic responsibility starting in 1990 for Sweden by allocating the emission budget based on population size, but adjusting for the country's economic development (GDP, where low GDP gives a higher emission space), the country's population density, and climate (temperature). The latter two aspects are justified by the fact that it is more difficult to adjust the transport sector in a sparsely populated country and more difficult to adjust the energy sector in a very cold or very hot country. For Sweden, this would result in a carbon budget of 75-120 million tonnes of carbon dioxide (the range corresponds to emissions at the level of 1.5 °C - low overshoot and emissions at 2 °C - high probability), i.e., about ten times less than the cumulative emissions for Sweden if consumption-based emissions follow an equal distribution per person, but on a par with our calculation given a historic responsibility for emissions from 1990 onwards.

Taking full account of historic responsibilities and national circumstances through domestic emission reductions or through reductions in consumption-based emissions is of course not feasible if there is virtually no emissions budget left. However, the estimates give an indication of the magnitude of historic responsibility and can be used as a starting point for further analysis of a Swedish policy that considers the principles on which the UNFCCC and the Paris Agreement are based.

²⁰¹ du Pont et al. 2016. [National contributions for decarbonizing the world economy in line with the G7 agreement](#), Environmental Research Letters.

²⁰² Friedlingstein et al. 2020. [Global Carbon Budget 2020](#). Earth System Science Data.

²⁰³ IPCC, 2021. Summary for Policymakers of the Working Group I Contribution to the IPCC Sixth Assessment Report. [Data available at NERC EDS Centre for Environmental Data Analysis](#).

²⁰⁴ SCB, 2021. [Befolkningsframskrivningar](#).

²⁰⁵ Romanovskaya & Federici, 2019. [How much greenhouse gas can each global inhabitant emit while attaining the Paris Agreement temperature limit goal? The equity dilemma in sharing the global climate budget to 2100](#), Carbon Management.