Climate investment planning for climate neutral cities

USER GUIDE

VIABLE CITIES REPORT XXXX

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About Viable Cities

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# Intro

## Introduction to the dashboard

Sweden aims to achieve net zero emissions by 2045, which equals to less than 1 tonne of greenhouse gas emissions per person ([Swedish Climate Policy Framework 2017](https://www.government.se/495f60/contentassets/883ae8e123bc4e42aa8d59296ebe0478/the-swedish-climate-policy-framework.pdf)), and cities are essential in supporting and delivering on this target.

This user guide provides insight into how the Viable Cities’ Finance dashboard should be used. This dashboard aims to support all 290 Swedish municipalities with their climate action and investment planning up to 2030. It provides:

1. insights into the current emissions in the cities, from a territorial perspective and a consumption-based perspective (based on household level data);
2. emission forecasts to 2030 using population growth and other socio-economic data, with emissions broken down into different sectors and categories;
3. options for reducing emissions in cities, with associated effects on emissions by 2030 and costs. The necessary costs are computed for different stakeholders, distinguishing between capital expenditure, CAPEX, and operational expenditure, OPEX.

As not just the municipality itself need to transition for the climate neutrality targets to be achieved, but also its citizens and businesses, city-wide emissions and costs are considered. This approach is also crucial to ensure broad stakeholder inclusion and participation to ensure that all key actors are onboard and enabled.

In the below, we describe the model and data used, how to use the dashboard, next steps in the development of the dashboard. We acknowledge that the dashboard is a beta version. Yet, as climate-neutral cities will require collaboration on an unprecedented scale, we published it open access, with our python script available on GitHub (see Annex 2). With this approach, we hope that anyone interested in supporting cities to understand the consequences of climate action (environmental and financial), with coding/modeling skills and can do so free of charge, reaches out to us. We also allow the option for the users to input their data and finetune our assumptions directly through the online dashboard.

The dashboard can be found online here: <https://seivcf.eu.pythonanywhere.com/>.

## August 2023 update

The August 2023 update of the Dashboard was only focused on territorial based emissions. The main updates include:

* Updated emissions data from 2021 instead of 2019
* More emission reduction measures to choose from
* Enhanced detail and increased flexibility to tailor each action to local conditions
* Capability to transparently view and update assumptions directly within the Dashboard
  + This last part is still under development so that the changed assumptions are also directly integrated for the user when making their plans (currently the data is only stored in a database with the modelling team) (there is also an excel option for users to fill in their data and share it by email)
* Improved calculation accuracy for both emissions and costs for each year up to 2030
  + Including an option to delay some actions to a later start year (as e.g. CCS measures are often planned to become operation in the later years toward 2030 and will only cost from then (feature available for a select number of levers)
  + More options to show output both per capita and total as well as for single years and cumulative emissions
* New and more user-friendly layout including with the option to export results to Excel sheets for integration into climate investment plans

More updates are on the way for later versions, including after an Hackathon to make the code run more smoothly that could also inject new ideas for improvements. One current issue is that the calculations are lengthy and take about 30 seconds to perform, so we kindly ask for your patience while working with the tool for now.

# The model and the data

## The model structure

To calculate the financial investments needed for climate-neutral cities, we developed a model that builds on a series of databases and computations (Figure 1).

A diagram of a company's flowchart

Description automatically generated

Figure 1: model structure – Viable Cities’ Finance dashboard

Source: revised from Vanhuyse and Piseddu (2021)

A baseline of current greenhouse gas emissions in the municipality (database 1) are used together with population figures (database 2) and a large set of data-points (database 3) within the municipality to estimate the impact of different mitigation measures and their associated costs (database 4). Based on 3 scenarios and the scenario defined by the user, investment scenarios (and sensitivity analysis) can be developed by the user to estimate the effect of its measures on emissions and costs.

**Baseline emissions data**

Emissions are considered both from a consumption-based approach and from a territorial approach. Territorial based emissions are gathered from the [SMHI national emissions database.](https://nationellaemissionsdatabasen.smhi.se/) This is categorized into 9 sectors (transport, industry, electricity and district heating, agriculture, own heating, work machinery, product use, waste and foreign transport) and 54 sub-sectors and available on a municipal level. More information, including a user guide for municipal staff, is available on [this SMHI](https://www.smhi.se/data/miljo/nationella-emissionsdatabasen/nationella-emissionsdatabasen-1.174774) website.

Consumption-based emissions are intended as the total emissions that result from the economic activity required to meet the municipality's demand for goods and services. The latter dataset is produced by the Swedish Environmental Protection Agency, Naturvårdsverket, and accounts for the emissions from sources located within the municipalities' geographical boundaries. The consumption-based emissions dataset is the result of a project designed at the Stockholm Environment Institute, [Konsumtionskompassen](https://www.sei.org/projects-and-tools/tools/konsumtionskompassen/). This work enables examining data at the city and even at postal code levels. This dataset currently does not contain the emissions from the investment and the governmental sector. Only the households’ consumption-based emissions are considered. The sources of emissions, about 115 activities, are grouped into more significant categories (food, clothing, housing, health, transport services, air transport, communication, recreation, education, restaurants and hotels, vehicles, electricity, district heating, house heating, and “other sources of emissions”) according to the COICOP classification ([Eurostat](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Classification_of_individual_consumption_by_purpose_(COICOP))). Due to restricted data availability, we use 2019 as our baseline for consumption-based emissions and 2021 for territorial emissions.

Data on population growth forecasts for each municipality in the country from 2019 to 2030 are produced by Swedish Statistical Agency, SCB.

### Mitigation measures

Mitigation measures, or “levers” as we call them, for the user to pull and adjust are at the heart of the dashboard. Whenever a lever is pulled, for example, a share of electric cars in the fleet by 2030, the emissions up until 2030 (as well as the costs) are being affected. The levers are organized by sector and tied to an emission category. Each lever has its own “logic” for how it affects the emissions and a corresponding set of data of its abatement potential.

So, what happens when you pull for example the lever “plug-in hybrid cars” to 20% by 2030? As the lever is defined by the share of cars in the 2030 fleet being plug-in hybrid, this means that 20% of cars by 2030 will be plug-in hybrid. We then assume that the 20% will be reached linearly. So, if the baseline year is 2020, 2% of the car fleet will be plug in hybrid in 2021, 4% in 2022 etc. to reach 20% in 2030.[[1]](#footnote-2) By default, we also assume that cars will be sold at the same rate as today based on historical figures for Sweden. If the user believes more cars will be sold than usual (as part of speeding up the transition), that can be specified by the user in the assumptions (more on that later). We then assume that each plug-in hybrid car replaces a car in the existing car fleet with existing average car fleet emissions. Accounting for the emissions of the plug-in hybrid itself, we get the impact of plug-in hybrid cars on emissions by 2030.

The same logic is applied for other vehicles like electric cars, biogas trucks and electric buses. The climate impact of increased use of public transport is captured in reduced use of cars. Adding up all these measures, the total emissions from the transport sector is computed. Similarly, levers for the other categories work by reducing emissions across the sectors. Some measures might not start immediately. For e.g. green hydrogen used in industry implemented with some delay, the user can specify the actual start year of the measure (and from then, a linear progression path towards 2030 follows).[[2]](#footnote-3)

It is crucial to pay attention to the wording of the levers. The electric cars lever, for example, does not specify the percentage of new cars being sold in 2030 being electric but the share of the 2030 car fleet made up by electric vehicles. As a car in the current fleet is only being replaced about 1/17 years, just around half of the car fleet will be replaced by 2030. It will therefore be unlikely that this parameter exceeds 50% by 2030, even if all new cars being sold are electric by 2030.

Similarly for the bio-CCS lever which is specified as the share of current emissions that are being captured by 2030. To correctly apply the lever we must relate the total amount of CO2e captured by 2030 with the baseline emissions of the entire city. We could have allowed the user to directly specify the amount of CO2 that is being captured, but to ensure consistency with other levers and avoid easy mistakes (like the users mixing up the prefix), all levers are defined in whole percentages.

### Socio-economic data assumptions

The socio-economic data assumptions relate both to how the mitigation measures affect emissions and how it relates to costs. This dataset is collected from a literature review from a broad range of sources, Swedish or even more local where possible. The first purpose is to estimate the consequences of climate actions on reduced emissions. It captures the abatement potential of different actions. As an example, plug-in hybrid cars are on average using less fossil fuels than a petrol or diesel car, but how much? Or, if carbon capture and storage (CCS) is installed in the city’s district heating facility, how big is the abatement potential i.e. the share of emissions it manages to capture?

A life-cycle emissions approach was adopted for the analysis of consumption-based emissions, but not from a territorial-based perspective where only emissions occurring within the municipality’s territory is captured. In practice, this means that the emissions related to the production of an electric car is accounted for only in the consumption-based approach (unless the car is produced inside the municipality).

The mitigation measures also have costs. How much each action costs is calculated using a similar dataset of different cost drivers. These are split into investment expenditure (CAPEX), operational expenditure (OPEX) and savings and incomes. A plug-in hybrid car has a purchase price, a certain fuel cost and a fuel saving compared to a gasoline car, but no discernible income. A wind turbine on the other hand also has income from the electricity it generates, aside from capital and operational expenditure.

The dataset on costs is vast and broad. It contains, for example, the number of cars in the municipality and their fuel consumption (Trafikanalys), the composition and the size of the public bus fleet (Svensk Kollektivtrafik), the size of the housing stock (SCB), the district heating supply fuel mix (Energiföretagen). To calculate for example the capex of plug-in hybrid, the lever specifies the share of plug-in hybrids by 2030 in the fleet, which is being intrapolated from zero and accumulated to estimate the total number of plug in hybrids being sold in the municipality in total up until 2030 and lastly multiplied with the price of the car (and finally divided by population to obtain a per-capita estimate).

Within this dataset there is also a set of assumptions that specifies the lever in more detail and allows for more flexibility for the user. For example, are the heat pumps installed in the municipality generating its energy from a mix of air, water and geothermal sources or does the user know it only comes from one source? The negative emissions technologies could in theory also include direct air capture and storage and not just bio-CCS, which could also be specified by the user. If the user is willing to assume that costs of electric vehicles and renewable energy will decline over time instead of sticking to our more conservative assumptions that the prices will remain the same, that can also be adjusted within these assumptions. The same goes if the user believes that an electric cars boom will happen and people are thought to retire their existing cars or buses earlier to jump on the train of electric vehicles, which is not assumed in our baseline.

It also contains some key data to be able to distribute costs between the following actors: citizens, industry, municipal governments, superordinate governments, utility companies, financial institutions and civil society. Key ones are also possible for the user to specify in the assumptions.[[3]](#footnote-4)

These assumptions are primarily derived from academic literature, but if none was found, secondary sources were used to the best of our ability. If local data was missing, a Swedish average was often used. For example, data on dietary distribution downscaled at the municipal level is not available, thus national averages were used instead. And where Swedish data was lacking, European or global values were used, e.g. the investment and operating costs for different types of heat pumps. It should be seen as a starting point that users can collectively refine to obtain better estimates over time. For that reason, there is a tab in the dashboard (called your data), where the user can scrutinize the assumptions and add their own data to overwrite existing figures. This new data will be automatically shared with us, which allows us to improve the assumptions data set for all users. It is very much appreciated if the user uploads data including sources here as the assumptions can always be updated and made more accurate.

Annex 3 contains an overview of the climate action strategies for consumption-based emissions. This includes their average mitigation potential, average capital expenditure, and average operational expenditure, currently included in the model. Hidden costs, such as foregone revenues, accompanying changes in consumption patterns, and their subsequent impacts on the financial performance of some of the businesses are not (yet) considered in the dashboard.

## The forecasts for 2030 emissions

Per-capita emissions by 2030 at the municipal level are forecasted under three alternative scenarios:

1. a business-as-usual scenario (BAU);
2. an increase in emissions;
3. a reduction in emissions.

Under the first scenario, BAU, we assume consumption patterns and the per-capita emissions profile of 2019 (or 2021 in the case of territorial-based emissions) to be the same in 2030. As a result of population growth, the total 2030 emissions in each city will increase. The second scenario is built on the research of Harris et al. (2020). It assumes a per-capita emissions increase of 17% due to increased consumption of goods and services, given anticipated economic growth. The third scenario considers a per-capita emissions reduction of 6%, building on the research of Wood et al. (2020).

It is important to note that these are not our best projections for how (especially territorial-based) emissions will develop until 2030. Given planned policies on national and EU level, we instead expect that territorial-based emissions will decrease. A quick analysis from our side generates the following estimates for emissions reduction from 2021-2030 based on EU and national policies. They can be used to construct a baseline scenario by pulling levers that generate emissions in line with overall emissions reductions below (as a point of comparison between planned action and additional climate action within municipalities):

|  |  |  |
| --- | --- | --- |
| **Sector** | **Remaining emissions in 2030** | **Comment** |
| Total | 65% | Based on national aggregation of categories below, will differ across municipality |
| Transport | 76% | Based on national aggregation of below transport means, will differ across municipalities |
| Cars | 73% | Current national level of sales of electric cars expected to increase with EU minimum to 2030, assuming a reduction obligation of 6% over the whole period, assuming EU ETS BRT implemented in 2027 and car emissions follow the LRF |
| Heavy trucks | 83% | EU target for heavy duty vehicles is 5 percentage points below that of light duty vehicles |
| Light trucks | 78% | EU target for light duty vehicles is 5 percentage points below that of cars |
| Buses | 83% | Assuming the same as for other heavy duty vehicles |
| Air | 73% | Based on national reduction obligation from aviation fuels |
| Other transport | 73% | Assuming similar reduction as Sweden's commitment under the Effort Sharing Regulation |
| Industry | 50% | Based on ETS allowance reduction in line with Commission proposal |
| Agriculture | 73% | Assuming similar reduction as Sweden's commitment under the Effort Sharing Regulation |
| Electricity and DH | 50% | Based on ETS allowance reduction in line with Commission proposal |
| Own heating | 81% | Following EU ETS BRT linear reduction factor from 2027 |
| Work machinery | 81% | Following EU ETS BRT linear reduction factor from 2027 (assuming Sweden chooses to include it) |
| Product use | 73% | Assuming similar reduction as Sweden's commitment under the Effort Sharing Regulation |
| Waste | 73% | Assuming similar reduction as Sweden's commitment under the Effort Sharing Regulation |
| Foreign transport | 73% | Assuming similar reduction as Sweden's commitment under the Effort Sharing Regulation |

Table 1: Quick estimate of how existing EU and national policies could generate emissions reductions across sectors.

## The model’s assumptions

The key assumptions underpinning the computation are described below.

**Territorial-based emissions assumptions**

### *Transport sector*

The dataset contains estimates of fuel prices, driving distances, number of vehicles, purchase price of vehicles (and charging infrastructure), current composition of vehicle fleet, replacement rates of vehicles, emissions per vehicle type, cycling infrastructure data etc. The model assumes that that the current vehicle fleet will gradually become greener, i.e. current fossil fuelled vehicles will be replaced by vehicles with less emissions, in particular electric and biogas vehicles.

One key assumption is that the electric vehicles purchased is replacing another fossil fueled vehicle purchased. If a person is retiring its petrol car or a city is retiring its diesel bus to buy an electric car or biogas bus, the user can overwrite this assumption. Most obvious costs are included, e.g. for cars the purchase price of the car and charger as well as the fuel cost is included. However, the model could still be refined with more details, e.g. including the reduced repair costs of electric vehicles compared to petrol ones. Another example is that currently no costs are included from reduced use of aviation. Users are encouraged to reach out if they find that some costs (or savings/incomes) seem to be missing (and even more appreciated if they have a data source for it!).

When overwriting assumptions it is important to pay close attention to how they are worded. Some datapoints are not the most straightforward at first glance, but rather a result of tying together different sources of incomplete data. One example is the “Heavy truck use of fuel compared to car” which is 4.8, meaning that a heavy truck is assumed to consume on average 5 times the amount of fuel per kilometer travelled than a car (based on European data). The user is encouraged to reach out if any of the assumptions are unclear so that we can update and clarify also for the next user to avoid misunderstandings.

Some factors also vary heavily over time, for example the energy prices. Current prices are used as estimates for the average prices up until 2030. These could also be continuously updated by us or by the user to have the most up to date assumptions.

### *Energy*

A tricky issue is how to estimate the effect of additional electricity production from e.g. solar or wind energy on emissions in a municipality. Some cities have joint electricity and district heating facilities that emit greenhouse gases. We have made an assumption of how much of those greenhouse gases that are tied to electricity production and assumed that the renewable energy will replace some of that. We have thus disregarded any indirect benefits of renewable energy, such as enabling the green transition through primarily hydrogen production, industrial electrification and electrification of the vehicle fleet. When estimating the cost of renewable energy per reduced greenhouse gas we have made assumptions about the average emission factor for electricity production in Sweden.[[4]](#footnote-5) Revenues from these facilities are expected in line with electricity prices, which have been localized (and are possible to adjust if the user has more accurate predictions for the electricity in the future).

The costs of Best Available Technology (BAT) household appliances are estimated using data from large retailers in Sweden. The reduction in emissions of these assets is estimated based on the work of (Dodoo et al. 2018; Dodoo et al. 2017; Dodoo et al. 2017). These energy efficiency measures are expected to reduce the energy needs of the municipality and therefore reduce the emissions within the municipal borders, i.e. external benefits are not considered. Heat pumps are similarly expected to reduce the need for district heating in the city and its associated emissions.

Carbon capture and storage solutions are also considered both for industry and for waste incineration in district heating facilities. 90% of emissions are assumed to be captured by CCS and costs are derived from international studies. There is uncertainty to these as current large scale production is rare globally, however, as these installations are usually part of the EU ETS, the savings from not having to buy emissions allowances are considered (for both industrial and waste CCS-solutions).

***Industry***

The two levers to address territorial-based emissions in industrial facilities are hydrogen and CCS measures. Electrification of processes is also included under the hydrogen lever. Both these estimates are limited as there are a limited amount of large-scale projects up and running already today. As for CCS waste, saving emission allowances is also included for these levers.

***Other categories***

Due to lacking data availability for territorial-based emissions there are currently no specific lever for agriculture. Users are encouraged to support with data on this. An overall lever is however added where the user can specify how much emissions are reduced and at what cost per reduced unit. A baseline assumption has been made based on existing projects under the national government program “Klimatklivet”.

A similar solution was made for work machinery. There are currently no levers available to reduce emissions from product use.

Consumption and material use emissions include the lever of increased recycling where emissions from waste (primarily landfill) is affected. An assumption is made here on what share of emissions are actually related to recycling within the municipality, as landfill sites e.g. can take scrap from different municipalities.

Negative emission solutions are specified in relation to total emissions within the municipality border. If a city emits 100 000 tons of tCO2e per year, a 10% lever means that 10 000 tCO2e are captured by rewetting, carbon credits or bio-CCS. As mentioned above, bio-CCS also allows for the inclusion DACCS. The costs are then tied to costs of these measures per tCO2e collected each year. It is important to consider how the climate neutrality target is defined when analyzing the output of the dashboard, as some cities may have capped how much and through what type of negative emission solutions can contribute. It is possible in the assumptions to limit for example carbon credits if the municipality is not “allowed” to make use of these to achieve its target.

### Consumption-based measures

#### Food consumption

The environmental impacts of different diets compared to the current Swedish one are estimated using the work of Martin and Brandão (2017). Given the little impact of the “Organic”, “Organic Sweden”, “Sweden Incr.”, “All Conv” and “All Organic”, we only consider the “Reduced Meat”, “Vegetarian”, “Vegan” and “Nutrition” diets.

#### Restaurants and hotels

We use the finding by Eriksson et al. (2017) to assume that if restaurants and catering services were able to avoid this food waste, their carbon footprint would be reduced by the same proportion: a Y% reduction in food waste is matched by a Y% reduction of emissions of food waste from restaurants and hotels.

#### Clothing

The impact of the “doubling the lifetime of the life of garments” is assumed to half the emissions from the clothing industry. Behind this assumption is the idea that doubling the lifetime of clothes will halves the demand of new clothes. Reducing clothes consumption by 30%, a reduction that we deemed reasonable, would, in our assumptions, contribute to reduce emissions from the clothing sector by 30%.

#### Household furniture

As with the case of the clothing industry, we assume that reducing the demand of furniture through, for instance, extending the life of the pieces of furniture, will reduce the emissions from this by the same percentage. That implies that halving furniture consumption would halves emissions from the actions associated with this activity.

#### Recreation

We assume that reducing the demand for recreation services will reduce the emissions from these activities by the same percentage. Doubling the life of recreational equipment is assumed to reduce emissions from recreational equipment consumption by 50%.

#### Public transport services

The CAPEX and OPEX investments for the electrification of public buses consider the installation and maintenance of the charging infrastructure. Replacement of the batteries is included too. We do not assess the impact of the spike in electricity demand due to the electrification of a share of the public buses fleet. Likewise, we do not analyze the possibility to sustainably supply the Hydrogenated Vegetable Oil (VHO).

The size of the public fleet by 2030 is forecasted using a fixed public buses/population ratio based on the population forecasts for 2030 provided by SCB. Svensk Kollektivtrafik provides the data on the fuel composition of the fleet. We assume that these ratios will be constant by 2030.

***District heating***

To address consumption-based emissions there is also a measure of cleaning the district heating grid, i.e., replacing the fossil fuels with wood chips and pellets. As in the case of HVO buses, we can assess the feasibility to provide the amount of fuel that is necessary to replace all the production that comes from fossils. The replacement of fossils does not require new investment in burners so no CAPEX will emerge. We take this from the results of the analysis carried out by the Danish Energy Agency (2022), *Technology Data – Generation of Electricity and District heating*. The OPEX investments in this category represent the fuel costs.

**Missing a climate mitigation measure or lever?**

Please feel free to reach out to us if you have concrete measures and available data that you think can be integrated into the model. Some detailed data can be integrated into the existing levers, for example, direct air capture and storage (DACCS) is possible by adjusting the assumption of 100% “Share of negative emission tech related to BECCS (and not DACCS)” downwards for the lever bio-CCS to also incorporate DACCS. But due to lack of data or resources there are other measures that could be specified further. One such example is organic farming, which although already possible to address under the lever “agricultural measure”, but that could benefit from more detailed assumptions. The following data is a good start for a new lever to easily be integrated into the model:

|  |  |  |  |
| --- | --- | --- | --- |
| Lever | Impact on emissions | Assumptions in detail | Costs of making shift |
| Organic farming | e.g 80% of traditional | e.g. assumption of 50% of farms in municipality shift to organic | e.g. 1500 SEK/tCO2e removed in CAPEX and new incomes of 200 SEK/tCO2e per year[[5]](#footnote-6) |

Table 2: Example of data needs to add new lever to the model.

# How to use the tool

## How to interact with the dashboard

The online dashboard contains the territorial emissions and consumption-based emissions (household level only), base year 2021 and 2019 respectively, for all 290 municipalities in Sweden.

The home page briefly presents the concept of our work. At the top, there are three orange buttons (“Learn More”, “Glossary” and “Methodology”) which provide answers to some of the questions that may arise when using the tool. That is also where this user guide can be found!

1. The Learn More button contains links to the Stockholm Environment Institute’s webpage that is dedicated to the project (Viable Cities Finance) and to the website of Viable Cities. Contact details of the model designers are also provided, should the user have any further questions.
2. The Glossary button contains some of the terms mentioned in the tool.
3. The Methodology button briefly presents the data sources and the reasoning behind the model.

On the home page, there are two dropdown menus that allow the user to choose the municipality in focus. On the left, Swedish regions can be used to filter municipalities. On the right, any of the 290 municipalities can be selected. Users can either scroll to the required municipality, or type the first few letters of the municipality (selecting a region first is not mandatory).A screenshot of a computer

Description automatically generated

Two pink tabs follow the blue welcoming banner (circled in red). When opening the tool, the user is by default directed to the consumption-based emissions tab. By clicking on the “Territorial emissions” tab, the focus of emissions is changed to a territorial approach. The components below the tabs are updated whenever a different emissions’ focus is selected.

Graphical user interface, website

Description automatically generated

To see the next output the user must first indicate in the drop down-menu whether it wants to display the emissions in total or per capita. Then a chart will display its current projection, reflecting population growth and the chosen scenario. Below a chart over time shows the emissions after the climate action is taken, to be able to deduce the additional impact of the measure compared to the baseline projection. This is displayed across a range of categories, including a line that shows net emissions, which is total emissions minus negative emissions. The aim is for this blue line to reach below zero by 2030 for the Viable Cities goal to be achieved.

A screenshot of a computer

Description automatically generated

Next, the user can selects its different climate action strategies, leading to different measures to considered. By clicking on any of the sectors in the section on the left, the user can explore climate action strategies. For instance, by clicking on the “Transport” and the “Cars” button, the user can set the share of electric cars by 2030 in the municipality. It is up to the user to make realistic scenarios, the model is only partly designed to limit unreasonable scenarios.Clicking on another sectors closes the collapse button that is currently open, if any, to save space for the graph. As the user begins to modify the sliders that are found under each climate action strategy button in the green vertical banner, the bottom stacked bar chart changes, reflecting the impact of the selected measures. The top bar chart labelled remains static as the benchmark emissions profile. Please note that the units change for per capita and total municipality emissions. Holding your mouse over the bar chart allows you to see the actual numbers behind the bars. Clicking a color in the legend also allows you to sort categories you are not interested in. If you want to save your scenario, please use the “Download data” tab in the bottom, to get all numbers in an excel format for your climate plans.

There is also an option to modify the input assumptions under “0. Your data”. If you want to overwrite any of these numbers, please change them under “user assumption” and please also add a comment or source under “user source” for us to verify. Currently this allows you to share data with us that we can integrate into the dashboard, but the plan is for this data to be automatically integrated in the scenarios you are working on.

Lastly, under the “2. Economic model” sheet, you first need to select if you want to display data per capita or total as well as for what year. Selecting total for the municipality and 2030 cumulative gives you the total costs from today to 2030. The graphs are split across actors (with a total banner to be added), and across the cost types CAPEX, OPEX, income and savings, with categories reflecting which sector the climate action is taken within.

A screenshot of a computer

Description automatically generated

**User guide for consumption-based emissions**

The orange banner named “Emissions” contains two pie charts: the one on the left represents the current emissions per capita in the selected municipality; and the one on the right represents the forecasted emissions in 2030. These are either the BAU forecast; an increased emissions per capita forecast; and a decreased emissions forecast (see section 2.3 for more information). Hovering over each of the pieces that compose the pie, a pop-up message will appear showing the share of emissions coming from that specific sector. For instance, in Stockholm the air transport sector accounts for about 24.3% of the overall consumption-based emissions (household level only).

Graphical user interface

Description automatically generated

Next, the user can play with different climate action strategies leading to different measures to considered. By clicking on any of the sectors in the section on the left (the lateral green banner right under the pink tabs), the user can explore climate action strategies. For instance, by clicking on the “Food” button, the user can set the dietary mix in the municipality. Please make a reasonable use of the strategy mixes, i.e., make sure that the sum of the underlying assets does not cross the 100% threshold. The model still returns a result if you have 100% of the buses running on electricity and 100% of the buses running on HVO. However, this would be unfeasible in real life. The same reasoning applies to all the measures in other sectors.Clicking on other sectors closes the collapse button that is currently open, if any, to save space for the graph. As the user begins to modify the sliders that are found under each climate action strategy button in the green vertical banner, the right pie chart, labelled “2030”, changes, reflecting the impact of the selected measures. The left pie chart labelled “2019”, remains static as the benchmark emissions profile. Every piece of the pie chart also shows the amount of per-capita annual Kg of CO2-eq.

Graphical user interface

Description automatically generated

Under the pie charts, the investments are displayed. On the left is a dropdown menu where the user can select one of the seven relevant actors in the municipality (see section 2.2). The top graph represents the capital expenditure and the bottom one the operational expenditure. If no actor is selected, the CAPEX and OPEX are not visualized. There is also a “Total”, where CAPEX, or OPEX, are aggregated across all actors. The investments are broken down following the same categories identified for the emissions: the COICOP classification for the consumption-based emissions (and the Naturvårdsverket’s approach for territorial emissions).

As we have not been able to identify measures for some of the categories, no investment will be shown. For example, as we did not identify climate action strategies for the health sector, no investment calculation is made. Behavioral change measures, which will reduce emissions, do not require any CAPEX investment. For changes in food consumption, we found no evidence that vegan or vegetarian diets are more priced differently than the current average Swedish diet. For a shift to public transport, abandoning one’s private vehicle does not require any CAPEX investment, yet does require the purchase of public transport tickets (OPEX). Additionally, some of the measures may require investment for one or several actors. For instance, when an electric vehicle is purchased, if the investment is made by a private citizen that is a landlord or a homeowner, the CAPEX will comprise the price of the electric vehicle and the price of the residential charging station. In addition, the municipality is required to provide a suitable public charging infrastructure network, so that a CAPEX investment is estimated for this actor too. When the private citizen decides to give up her private vehicle and switch to public transport, she will face no CAPEX investment, but the public transport company will have to account for this increase in demand by providing more buses. Box 1 presents an example.

## Example of analyses possible with the tool

The model can be used to estimate emissions and costs across actors for various scenarios. It is important to clearly describe the scenarios and the model’s usefulness increases when comparing different scenarios with each other. The below list contains a few ideas for how to construct scenarios:

* What happens if no additional action is taken?
  + E.g. there will still be more electric cars in the car fleet, there may still be existing projects planned like the construction of a solar power park
* What happens if no additional action is taken locally?
  + Here the national and EU level forecast described above (in [Table 1](#_The_forecasts_for)) can be used to understand the costs of existing policies above the municipal level
  + Please note that many EU and national level policies allow flexibility for how targets can be reached. E.g. the reduction in transport emissions to comply with the EU ETS for buildings and road transport as well as the effort sharing regulation can be reached by e.g. reducing traffic and increasing the new sales of electric cars
* What is the best description of how much the different levers are pulled in our current plan?
  + Interesting to analyze here is if the emissions reductions are sufficient to achieve the 2030 target of if additional action is needed
* What is our primary plan to reach our 2030 climate neutrality target?
  + Here the levers should be pulled enough to ensure that the emissions target is reached
  + Total system costs as well as costs across key actors can be analyzed to understand whether the totality and the distribution is realistic and desirable
  + Are the climate mitigation actions (or levers) realistic or which ones are particularly sensitive or vulnerable?
* If the main risk materialize so that the preferred levers cannot be pulled, what is our second-best option?
  + What are the additional costs of taking this path instead?
* Is there any other approach that would also achieve the target that can be analyzed?
  + Other approaches could be to focus more on behavioral change or technical solutions
* How does these costs compare to our internal model?
  + Can be used to analyze if there are any assumptions that have large differences across models and used to improve upon both this model and local assumptions

**Box 1. An example for Stockholm’s consumption-based emissions**

For the city of Stockholm, we focus on consumption-based emissions (households only). Our strategy mix consists of 40% of the people in Stockholm will be vegan by 2030 (with the rest not changing their average diet); 20% of the private cars will be electrified (with the rest keeping the 2019 fuel mix ratios); 20% of the households’ appliances will be replaced by the best available technology (BAT); and in 20% of the dwellings the indoor temperature will be reduced to 20°C.

According to the four strategies selected:

* For food consumption, there is no CAPEX or OPEX for a change in food consumption behaviour as we assume that a vegan diet is as expensive as the current average diet.
* For transport, a CAPEX is required to purchase the 20% of electric vehicles and install a private charging station. OPEX investments are necessary to charge these cars, provide the necessary operational and maintenance checks and replace the electrical battery after its usage lifetime.
* For the electricity sector, buying the BAT requires a CAPEX investment but there is no OPEX investment need. If no Jenson’s paradox is assumed, then OPEX investment would actually be negative, i.e., savings from reduced energy consumption.
* No heating CAPEX or OPEX is returned by the model as lowering indoor temperature is just a behavioural measure that does not require any investment.

Our investment plan shows waterfall graphs with only three columns (total, vehicles, electricity).

* The utility company is not required to make investments.
* The public transport company does not need to make any investment.
* CAPEX and OPEX investments emerge for the change in vehicles for citizens – tenants, citizens – landlords and home owners, and private businesses, as each of these actors own some of the vehicles currently in the vehicle fleet.
* A CAPEX investment need also emerges for the municipality for the installation of a public charging network for the 20% of the car fleet that will be electrified.
* A CAPEX investment emerges for the municipal housing company: it needs to provide the residential charger for the electric vehicles and the BAT household appliances in the dwellings it owns.

**Box 2. An example of what happens when a climate mitigation action is selected**

Let’s say that the city of Borås believes that 40% of its car fleet by 2030 will consist of fully electric cars and the electric cars lever is adjusted to 40%. The model then assumes that those electric cars will replace fossil fuelled cars and that there are no direct climate emissions within the territory boundaries of the city from these electric cars.

**Emissions calculations**

Emissions from cars in Borås in 2021 (latest baseline) is 98 553 tCO2e. In the baseline scenario, these emissions are, with no action, expected to grow with projected population growth in Borås (4,4% in total between 2021 and 2030) to 102 936 tCO2e. A 40% reduction of emitting cars means that only 61 762 tCO2e remains and that 41 174 tCO2e have been mitigated with the climate action (compared to no action). Contrasting this to the projected 2030 population in Borås (119 413), a total of 340 kg of CO2 equivalents per capita has been saved from the climate action. Instead of territorial emissions in Borås increasing (with population growth) by 4,4%, the emissions have now decreased by almost 12% and the city is now closer to reach its climate neutrality target by 2030!

**CAPEX calculations**

To reach 40% electric cars in just 9 years (as 2021 is the baseline year), 4.4% (40%/9) of the car fleet must be replaced with electric cars ever year. We assume that the average life length of a car is 17 years so that 5.9% (1/17) of the car fleet is being replaced every year. This implies that 76% (4,4%/5,9%) of new sold cars each year from 2022-2030 must be electric. Total number of cars in Borås is 53 740 and if 1/17 is replaced every year, that means that 3 161 cars are being sold or used in the city. If 76% of these are electric, and an electric car costs 269 234 SEK more than a fossil fuelled car (including the average cost for charging infrastructure per new car), an additional investment to enable the transition of 643 million SEK (269 234\*3 161\*76%) is needed. This is then distributed to the city’s actors, where 84% of cars are owned by citizens. Thus, the total additional investment cost (CAPEX) for citizens per year is 540 million SEK. Dividing this with the population in 2030, citizens will need to spend on average 4 518 SEK extra per year and person or 41 000 SEK over the entire time-period.

***CAPEX considerations and flexibilities***

If a city is rather interested in the total investment cost and not just the additional cost (which subtracts the price of a petrol/diesel car), that can be specified in the assumptions (“Share of new electric cars causing early replacement of fossil fueled cars”). Please note that if the lever for electric cars is above 53%, this assumption needs to be changed as it will not be possible to reach such fast electrification without retiring existing cars. Please also note that there are likely going to be plug-in hybrids and hydrogen cars in the fleet. Also, if the user believes that the price if electric cars will decline over time, that can be specified in the assumptions (“Electric vehicle new price in 2030 compared to today”). It is also possible to adjust other key assumptions, such as the price of electric cars, the share of the costs borne by citizens or the replacement rate of cars.

**OPEX calculations**

The operational expenses of an electric car consist primarily of the electricity as a fuel, but also a saving from not having to use petrol or diesel. Using assumptions of 0,4 SEK to drive 1 km and a total of 11 000 kilometers being driven by the average car 4 477 will be spent on electricity per year for the average car, compared to a saving of 15 945 SEK that would have been spent on diesel and petrol (similarly derived from the assumptions). In 2022, the total operation saving would then be 27 million SEK (3 161 cars sold \* 76% share electric cars \* 11 468 SEK in lower cost per year (15 945 savings in petrol minus 4 477 cost of electricity)). In 2023, another set of electric cars will be on the market and the total saving would reach 55 million SEK and accumulate over time. Following a similar logic as above, the total operational saving per capita for Borås from 2022-2030 would be about 8 700 SEK. This is clearly lower than the 38 000 SEK that will be invested as the benefits from lower costs after 2030 are not taken into account in this model.

# Next steps

In a next step, we are considering:

* Adding co-impacts in the model, i.e., positive and negative consequences of climate action in cities, for example in the field of reduced health care expenditure, increased energy security and geopolitical resilience, and other.
* Continuously updating the baseline emissions and aligning the assumptions with more accurate and timely data
* Adding a marginal abatement cost curve for the user to analyse the effectiveness of different investments
* Integrating financial indicators of the financial capability as well as funding opportunities for the user to explore when developing its climate investment plan
* Expanding the model to more countries
* Extending the model to include adaptation measures and nature-based solutions

Anyone interested in helping build out the model, please feel free to reach out to the model designers.

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# Annexes

## Annex 1. Data sources

Table with data sources

|  |  |
| --- | --- |
| **Dataset** | **Source** |
| Territorial based emissions | [SMHI National emissions database](https://nationellaemissionsdatabasen.smhi.se/) |
| Consumption-based emissions | [SEI’s Konsumtionskompassen](https://www.sei.org/projects-and-tools/tools/konsumtionskompassen/) |
| Vehicles – ownership and fuels | [Trafikanalys](https://www.trafa.se/) |
| Public buses – numbers and fuels | [Svensk Kollektivtrafik](https://www.svenskkollektivtrafik.se/) |
| Population – current size and forecasts | [Statistikmyndigheten (SCB)](https://www.scb.se/) |
| Dwellings – size and ownership | [Statistikmyndigheten (SCB)](https://www.scb.se/) |
| District heating – production | [Energi företagen](https://www.energiforetagen.se/in-english/) |
| Private car usage | [Trafikanalys](https://www.trafa.se/) |
| Public transport - cost | Regional public transport authorities |
| Public transport - supply | [Trafikanalys](https://www.trafa.se/) |
| Further data sources were used to compute the socioeconomic data assumptions for territorial based emissions. They are available under the ”Your Data” tab directly in the dashboard | |

## Annex 2. Link to Python script

The GitHub repositor with the Python script, the CSS script and the datasets can be accessed [here](https://github.com/tp-SEI/VCF-dash.git).

## Annex 3. Average mitigation potential, capex and opex for different climate action strategies – consumption-based emissions

More details on the territorial based emissions assumptions are available under the “your data” tab.

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure** | **Env. Impact** | **CAPEX (SEK)** | **OPEX (SEK)** |
| Vegetarian diet | 66% of current average diet (Martin and Brandão 2017) | n.a. | n.a. |
| Vegan diet | 33% of current average diet (Martin and Brandão 2017) | n.a. | n.a. |
| Meat reduction | 75% of current average diet (Martin and Brandão 2017) | n.a. | n.a. |
| Nutrition diet | 75% of current average diet (Martin and Brandão 2017) | n.a. | n.a. |
| 30% of clothing consumption reduction | 30% emissions reduction (own assumption) | n.a. | n.a. |
| Doubling clothing life | 50% emissions reduction (own assumption) | n.a. | n.a. |
| Halving furniture consumption | 50% emissions reduction (own assumption) | n.a. | n.a. |
| Electric buses adoption | * 17% of diesel buses emissions (consumption-based emissions) (Nordelöf, Romare, and Tivander 2019) * 7 % of diesel buses emissions (territorial emissions) (Nordelöf, Romare, and Tivander 2019) | 5 809 860; 4 730 886;  4 393 894  (depending on powertrain)  (Bloomberg NEF 2018) | * Battery price (SEK/kWh): 4000 * Energy cost (SEK/kWh): 0,82 * Maintenance (incl. chargers, SEK/Km): 3,3   (Grauers, Borén, and Enerbäck 2020) |
| HVO buses adoption | * 37% of diesel buses emissions (consumption-based emissions) (Nordelöf, Romare, and Tivander 2019) * 30% of diesel buses emissions (territorial emissions) (Nordelöf, Romare, and Tivander 2019) | n.a. (current diesel buses can already be filled with HVO: [Volvo](https://www.volvobuses.com/en/news/2015/jun/news-150255.html), (Dimitriadis et al. 2018)) | - Maintenance (SEK/Km): 3  - Energy cost (SEK/kWh): 3,5  (Grauers, Borén, and Enerbäck 2020) |
|  |  |  |  |
| Hybrid HVO buses | * 28% of diesel buses emissions (consumption-based emissions) (Nordelöf, Romare, and Tivander 2019) * 16% of diesel buses emissions (territorial emissions) (Nordelöf, Romare, and Tivander 2019) | 2 614 437 (Lajunen and Lipman 2016) | * Maintenance (SEK/km): 3 * Energy cost (SEK/kWh): 3.5 * (Grauers, Borén, and Enerbäck 2020) |
| Reduction in air transport | X% reduction in air transport will lead to X% reduction in emissions from this sector (our own assumption) | n.a. | n.a. |
| Doubling the life of recreation equipment | 50% emissions reduction (our own assumption) | n.a. | n.a. |
| Quit package holidays | 100% emissions reduction from this activity (our own assumption) | n.a. | n.a. |
| Reduction of food waste from restaurants and catering services | 33% emissions reduction (Eriksson et al. 2017) | n.a. | n.a. |
| Electrification of private cars | * 35% of diesel car emissions and 25% of gasoline cars emissions (consumption – based emissions) (Energiforsk 2021) * 2.7% of diesel car emissions and 1.9% of gasoline cars emissions (territorial emissions) (Energiforsk 2021) | 595 720,49 (Weiss, Cloos, and Helmers 2020) | * Cost of battery (SEK/KWh): 1659,96 (Nykvist and Nilsson 2015) * Cost of energy (SEK/KWh): 0,861586 (Hagman et al. 2016) |
| Replacement of private cars by public transport | 100% emissions reduction (our won assumption) | n.a. | - Annual ticket to regional public transport |
| Adoption of plug-in-hybrid cars | * 55% of diesel car emissions and 42% of gasoline cars emissions (consumption-based emissions) (Energiforsk 2021) * 39% of diesel car emissions and 28% of gasoline cars emissions (territorial emissions) (Energiforsk 2021) | 587 905,4 (Weiss, Cloos, and Helmers 2020) | * Cost of battery (SEK/KWh): 1659,96 (Nykvist and Nilsson 2015) * Cost of energy (SEK/KWh): 0,861586 (Hagman et al. 2016) |
| Hydrogen cars adoption | * 89% of diesel cars emissions and 67% of gasoline cars emissions (consumption-based emissions) (Energiforsk 2021) * 73% of diesel cars emissions and 52% of gasoline cars emissions (territorial emissions) (Energiforsk 2021) | (As of 2021 only two hydrogen cars available on the markets), average cost: 774 900 | * Cost of hydrogen: 27,37 (SEK/Kg) (Tang et al. 2021) |
| BAT household appliances | * 20,75% emissions reduction compared to the current average energy consumption when all the appliances in (Dodoo, Gustavsson, and Le Truong 2018; Dodoo, Gustavsson, and Tettey 2017; Dodoo, Tettey, and Gustavsson 2017) | Different costs for different appliances. Checked them through the largest retailer in Sweden | n.a. |
| District heating fossil fuels production shifted towards wood pellet | * Reduction computed using the emission factors of the different fuels, available through the Danish Energy Agency (2022), *Technology Data – Generation of Electricity and District heating* | n.a. | - Fixed O&M (€/MWth/year): 211849  - Variable O&M (€/MWh): 6 |
| Indoor temperature reduction | 21% energy demand reduction for single dwellings and 23% energy demand reduction for multi-dwellings (Savvidou and Nykvist 2020) | n.a. | n.a. |
| Retrofitting | Complete retrofitting (roof, walls and windows) can lead to a 26% energy demand reduction in single dwellings and a 27% energy demand reduction in multi-dwellings (Savvidou and Nykvist 2020) | Costs per element are detailed in (La Fleur, Rohdin, and Moshfegh 2019) | n.a. |
| LBG heavy trucks adoption | 19% of the emissions of a diesel heavy truck | 2 718 636,75 (Takman and Andersson-Sköld 2021) | * Maintenance (SEK/Km): 2 * LBG cost (SEK/Kg): 12   (Takman and Andersson-Sköld 2021) |

1. In fact, 2021 is used as the baseline year, so the linear intrapolation happens wiht 2,2% per year from 2022-2030. Please note that as 2021 baseline year is used meaning that actions already taken should be included to get an accurate representation of emissions by 2030. For actions not yet taken, a later start year of an action can be specified in the dashboard to get an accurate representation of the impact on emissions and costs. [↑](#footnote-ref-2)
2. This simplification is also a limitation of the model. If e.g. the municipality’s steel production will switch suddenly in 2027 to being fuelled completely by green hydrogen, and the start year is specified to 2027 with 100% green hydrogen in the lever, the impact is still expected to be gradually implemented linearly between 2027-2030. Please reach out to us if this causes you significant impacts and we can consider making this more detailed, or suggest work-arounds. [↑](#footnote-ref-3)
3. As with many other assumptions, the user is always welcome to reach out to us if they want more flexibility. Some changes are easier to make (e.g. specifying in more detail the cost distribution between different actors). Our intention has been to balance easy of use with flexibility. [↑](#footnote-ref-4)
4. This assumption is rather sensitive as it varies by large factors across Sweden. We encourage anyone with good data availability across the country to share that data with us so that we can refine this data point. [↑](#footnote-ref-5)
5. Important that the cost is related to a unit for which there is data for all municipalities in Sweden, e.g. emissions, number of vehicles etc. [↑](#footnote-ref-6)