

NOWCASTING CO₂ EMISSIONS

early estimates or "nowcasts"
for monitoring changes in
greenhouse gas emissions (GHGs)



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Preface

During the outburst of the Corona pandemic in 2020 followed by a lockdown of society it became clear that the drastic events would also have repercussions on the emission development. Especially transport and to some extent also other economic activities were affected by the pandemic in a way which would also have an effect on emissions. Normally emissions are reported with a time lag amounting to one year or even more. This means that drastic changes in activities or behaviour and the resulting changes in emissions are registered with a substantial time lag based on the official emission inventory system.

The purpose of this project has been to map what kind of quick estimate indicators have been developed lately in order to have a prompt assessment of the greenhouse gas emissions, especially carbon dioxide emissions. The need for more rapid reporting of the emission trends is obvious as contemporary climate policy is more ambitious and also more closely connected to economic policies than earlier. The purpose of the project has also been to evaluate the data basis suitable for making proxy estimates of the emission development.

According to the main findings of the project there are several exercises ongoing which are aiming towards providing more timely emission data. There seems to be a clear potential to develop better nowcasting methods. At the same time, it is important to be aware of the shortcomings of these methods in terms of accuracy.

The report has been prepared by Anthesis AB in cooperation with Real-Zero Consulting HB, PlanMiljö and Kausal Ltd. Members of the Nordic group for Environment and Economy (NME) have provided comments on draft versions of the report during the project. The authors of the report are responsible for the content, and any views and recommendations presented in the report do not necessarily reflect the views and positions of the Nordic governments or of NME.

May 2022

Bent Arne Sæther

Chair of The Nordic Working Group for Environment and Economy

Summary (and keywords)

Introduction

The Nordic Council of Ministers Working Group on Environment and Economics group (NME) has with the help of a team of consultants conducted a survey on the use and the possibility to use early estimates or "nowcasts" for monitoring changes in greenhouse gas emissions (GHGs) with a focus on fossil CO₂.

The purpose of the survey was to provide input and feedback primarily to policy makers, but also to other actors. The more ambitious national mitigation targets become, the more important will it be to have access to good estimates of current GHG emissions.

There are currently three kinds of official emission statistics; the territorial (inventories), production (accounts) and consumption (footprint) perspectives answer different questions about current emissions. A standard for reporting emissions mainly used by cities, companies and organisations is the Greenhouse Gas protocol (GHG protocol) that instead divides emissions into three so called scopes.

The project has centred around the four questions:

1. What is the current methodological status of emission reporting in the Nordic countries?
2. What is the expressed need for more timely emission statistics?
3. What projects and research have potential to timelier inform emission statistics?
4. What data sources could be used for new statistical products?

The project has focussed on surveying Denmark, Finland, and Sweden.

Current emissions statistics and reporting

All Nordic countries are signatories of the Paris agreement and report terrestrial emissions statistics (inventories) to the UNFCCC. Territorial emissions reporting to the UNFCCC is due by 15 April, 16 months after the year in focus and UNFCCC publishes the data later the same year. These statistics can be accessed through the European Environment Agency, Eurostat, and UNFCCC.

Nordic countries report production statistics (environmental accounts) to the EU according to the Regulation on the Governance of the Energy Union and Climate Action (European Commission, n.d.), which replaced EU's Climate Monitoring Mechanism on 1st January 2021. Nordic non-EU members share the same responsibilities, but through the EFTA agreement. Production statistics (Environmental Accounts) are currently published with a time lag of approximately 18 months, with 'early estimates' published with a time lag of approximately 8 months.

Denmark, Finland, and Sweden also produce addition emissions statistics. Finland

has developed a model (ALas) that allocate national territorial emissions on the municipal level, where some adjustments are made for emissions related to flows of energy across municipal borders. Sweden produces consumption-based statistics with a time lag of 23 months and since 2015, Statistics Sweden prepares quarterly greenhouse gas emissions from a production perspective using Environmental Accounts, which are published approximately four months after the relevant quarter.

Demand for now-casting

The policy makers consulted in this project indicate that emissions statistics should:

1. show trends by main economic sector
2. should provide information on the underlying drivers of change in emissions,
3. include emissions from non-energy related processes, e.g., farming, cement production, and
4. include all greenhouse gases and not just CO₂.

Projects developing nowcasting of GHG emissions

The project has identified multiple projects that aim to provide more timely emission statistics. A full list of the identified projects is found in Appendix 2. Some of the projects have a global focus and rely on satellite measurements, while other projects use sensors that can only be used at small scales. Some of the identified projects focus on all emissions, while others are sector specific. The greenhouse gases covered also varies. Which of the identified projects that are of interest to the Nordic countries require further analysis based on a more detailed definition of the countries' specific needs.

Country specific projects

No ongoing projects producing more timely statistics in Denmark and Finland have been identified. In Sweden, Statistics Sweden (SCB) is working on improving the timeliness of consumption-based statistics and have outlined the possibility producing statistics with only six months delay.

Potential data sources to support nowcasting

The report covers data sources available that could be used for developing nowcasting statistics. There is much data available that can be used to monitor emissions from parts of society, both public and openly available or private sources.

One example is official road traffic data that can be used to nowcast transport related emissions which exists in Denmark and Finland. Proprietary data can be obtained from TomTom and possibly Google, Apple and mobile tower operators. Sector specific methods and data is described in the report and coupled to the Global protocol for community-level greenhouse gas.

If terrestrial emission nowcasting would be further developed, it can be noted that road traffic and industry stand for a major share of current CO₂ emissions (approximately 80% in Sweden), and hence can provide a basis for a real-time estimation, provided the remaining emissions could be estimated with good enough accuracy.

Working group

The project has been carried out in collaboration between Anthesis AB, Real-Zero Consulting HB, PlanMiljø Aps and Kausal Ltd.

Recommendations

Based on the findings from this project the following three main areas for further work is suggested:

1. ***Further analysis of the need and possibilities for nowcasting***

Useful nowcasting is dependent on accurate and timely enough data that fits for the purpose. This could be further analysed in desk studies by outlining use cases and developing suggestions based on these cases.

In the development of nowcasting methods it is important that there is a clear understanding of what timely emission estimates will be used for, as the use case will influence the choice of method. Also, the development toward better nowcasting of GHG emissions needs to start off, in a step-by-step procedure, from the easiest possible sector. Finally, it is important to perform an in-depth study of each possible method, to better understand its accuracy as well as administration costs related to gathering and processing of data.

2. ***Instigate a climate policy lab***

Given the complexity to overview and communicate the need and the possibilities for nowcasting data we suggest instigating a Nordic climate policy lab. This could be organised as a project and carried out together with Nordic innovation agencies/actors. This suggestion is in line with using design thinking methodology for system change.

3. ***Create a portal collecting available emission statistics***

Currently it is quite a complex task to overview available emission statistics. Gathering existing emission statistics, easily and openly available, at one place would make it possible for a broader range of actors and individuals to access available statistics. This could either result in actors finding that data already is sufficient or result in a demand for improved statistics. The portal could also host a discussion forum to facilitate collaboration (see e.g. the Swedish National Agency for Public Procurement's questions forum (Upphandlingsmyndigheten, n.d.)). To ascertain long term availability of time

series as well as the potential for the portal to support innovation, ownership and use license of the data is a key issue to pay attention to.

Keywords:

nowcasting, early estimates, CO₂ emissions, GHG emissions

Glossary

Below table 1 provides a list of the terms used within this report.

Table 1. Glossary

Term	Description
API	Application programming interface. An API is a connection between computers or computer programs so that one can automatically fetch data from another.
Carbon budget	Carbon budget is the idea that the critical metric is the total amount of CO ₂ emitted to the atmosphere over time (rather than an emission amount of a particular year). This gives a total amount of global emissions that should not be exceeded.
Emission classification systems	There are three kinds of environmental statistics: territorial/inventories, production/accounts and consumption/footprints. (Eurostat, n.d.)
Emission classification systems - territorial/inventories	Emissions are assigned to the country where the emission takes place. This is used for international monitoring of policies adopted. (Eurostat, n.d.)
Emission classification systems - production/accounts	Emissions are assigned to the country where the company causing the emissions is based. This is used for integrated environmental-economic analyses. (Eurostat, n.d.)
Emission classification systems - consumption/footprints	Emissions are classified by final use of products, also known as 'carbon footprints'. This is used for modelling results that provide further context. (Eurostat, 2022.a)
Greenhouse Gas protocol (GHG-protocol)	The GHG-protocol is a widely used standard for reporting on GHG-gas emissions and establishes comprehensive global standardized frameworks to measure and manage greenhouse gas (GHG) emissions from private and public sector operations, value chains and mitigation actions. The protocol builds on a 20-year partnership between World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), industry associations, NGOs, businesses and other organizations.
NACE	The Statistical classification of economic activities in the European Community, Nomenclature statistique des activités économiques dans la Communauté européenne, abbreviated as NACE, is the classification of economic activities in the European Union (EU).
Nowcasting	A forecast that is as close in time as possible. Nowcasting uses statistical methods like forecasting to make reliable estimates. In addition to the term 'nowcasting', synonyms such as real-time estimates and early estimates are also used. Also refer to Wikipedia for alternative wordings.
Proxy data	Data used to study a situation, phenomenon, or condition for which no direct information - such as instrumental measurements - is available.

1 Introduction

1.1 Motivation

To fulfil the Paris agreement, emission reductions need to be ramped up significantly and reach approximately 8% per annum on a global level¹, and more in industrialized nations. This generates a need for rapid monitoring or now-casting of greenhouse gas (GHG) emissions, which can inform the development and assessment of policies and regulations aiming at minimizing GHG emissions. This demands new ways of using existing data relating to GHG emissions, as well as the development of new ways to measure GHG emissions.

This project was initiated by the NME² during the coronavirus pandemic, which woke interest in new types of GHG measurements, to assess how the pandemic and policy response created rapid changes in behaviour patterns and consequently in greenhouse gas emissions, most notable from the transport sector and from industry. The NME is interested in exploring methodologies and indicators for nowcasting of GHG emissions that enable “real-time” monitoring of the efficacy of the climate policies in the Nordic countries, enabling the identification of rapid changes in emissions. This request can be divided into two main questions.

1. How is emission reporting carried out today (data sources, models, time lag etc.)?
2. What can be done to improve this based on current practices and research?

The first question considers reporting to the EU and United Nations Framework Convention on Climate Change, UNFCCC, for which all Nordic countries have processes in place. The second question seeks to assess how more timely statistics and emission estimates can be developed, and the extent to which potential methods may improve performance on some aspects while reducing it in others. Improvements can address:

1. Time lag: going from more than a year to possibly real time estimates
2. Frequency: yearly, quarterly, monthly or less
3. Sectorial (activity) resolution: total emissions or divided into sectors
4. Coverage (Completeness): can the method produce emission estimate for all emissions or only some
5. Accuracy: how precise is the emission estimate

1. UNEP, 2019

2. The main responsibility of NME, the intersectoral Nordic Working Group for Environment and Economy (NME), approved by the Nordic Council of Ministers' environment and climate sector as well as the finance sector, is to analyse questions related to the environment and the economy that are of interest to the Nordic countries.

1.2 Three perspectives for reporting on GHG emissions

GHG emissions can be calculated from three different perspectives: territorial, production and consumption. These are also called inventories, accounts, and footprints, respectively (Eurostat, n.d.) They all have geographical territories as a foundation to define what physical, organisational or people-related emissions to include.

Territorial emission reporting follows geographical boundaries at some scale (e.g., city, country or group of countries (e.g., EU)) and report on the physical emissions within that boundary. The production perspective reports emissions based on the economic actors operating within the territorial boundary of interest. As such they include physical emissions from operations outside the boundary for those organisations. This is done according to the standard "System of Environmental Economic Accounting 2012 Central Framework (SEEA CF 2012) (United Nations, et al., 2014). The consumption perspective reports on emissions related to the activities undertaken by people and organisations situated within a territorial boundary regardless of where the emissions take place. Territorial emission statistics rely on reporting and monitoring that can be carried out with high accuracy. Production based emission statistics contain more uncertain factors, while consumption-based emission statistics have a higher degree of uncertainty. The different perspectives have their pros and cons depending on the (policy) context.

The three reporting perspectives have different systems (nomenclature) for categorising the emissions. For territorial emissions the system is described by the UNFCCC reporting standard. For the production perspective Environmental Accounts is one standard which categorises emissions according to the economic sector (NACE nomenclature) that drives emissions. For consumption based statistics there is a UN classification system called COICOP (Eurostat, 2019). An overview of these concepts and this terminology is presented in Table 2.

Table 2. Overview of emission classification systems according to Eurostat. Do note that there might be slight differences between the pairs in the head of the table depending on what definition is used.

Territorial/ Inventories*	Production/ Accounts*	Consumption/ Footprints**
Emissions are assigned to the country where the emission occurs.	Emissions are assigned to the country where the company causing the emission is based ('resident').	The EU27 final use of products encompasses consumption by private households and governments as well as the use of products for gross fixed capital formation, or in other words investments, such as buildings, plants and machinery, motor vehicles, and infrastructure.
Emissions are assigned to technical processes, e.g. combustion in power plants, or solvent use.	Emissions are classified by economic activity (using the NACE classification, as used in the system of national accounts).	Emissions are classified by final use of products (using the COICOP classification)

* (Eurostat, n.d.)

** (Eurostat, 2022.a)

1.3 Drivers of GHG emissions

Emissions correlate significantly with real world activities and phenomena, and they are also driven by real world activities and phenomena. If emissions are considered from a day-to-day perspective, the need for heating, and thus heating related emissions, is driven by colder temperatures and windier weather. Therefore, there is a strong seasonal variation in heating related emissions. The transport sector is also affected by weather, but also by holidays, and the day-of-week. From an economic perspective, emissions related to industrial production are affected by, for example, economic booms or recessions.

Depending on what the emission data should be used for, different possibilities exist for preparing the emission data. For example, real-time weather data can be used to model the need for heating and subsequently related emissions. While this could provide real-time heating emission data, changes in emissions would only reflect changes in temperature, unless the underlying relation between heating and temperature is also regularly updated.

Such a model would provide real-time data but there would likely be a lag in updating the correlation between temperature and heating. This can often be the case when calculating emissions where different data sources or factors used are updated at different intervals. This is especially the case for consumption-based statistics, where the monetary flows can be tracked with relatively little time lag whereas the emissions factors for different goods and services sometimes are updated only every few years.

Consequently, designing a real-time emission monitoring system requires a detailed analysis of what the data will be used for, to ensure that the decisions made are based on real world changes (or not) and not on artefacts of the model used. In a potential follow-up project such uses could be elaborated upon, thus enabling a more in-depth analysis on possible new statistical products.

1.4 Measuring and monitoring emissions

GHG emissions are rarely measured directly. Instead, they are calculated using simple or more complex methods or models. In this project, the term 'model' is used to cover both methodological approaches and 'computer models', including calculations undertaken in spreadsheets (e.g. Excel), statistical software (R, SAS, etc.) and other programming languages.

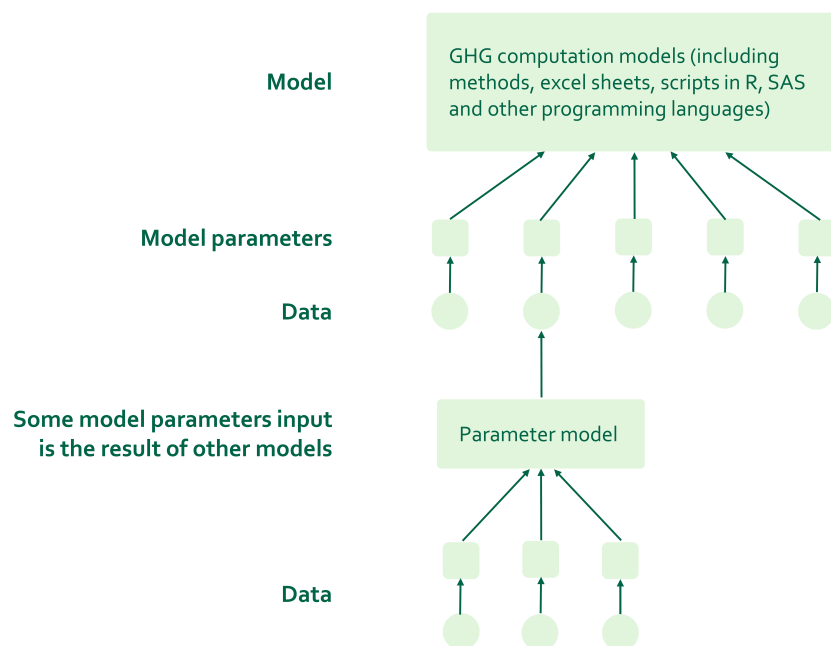


Figure 1. Illustration of a generic model for calculating national emission statistics. Emissions are mostly calculated using an activity metric multiplied with an emission factor (intensity).

To get results from a model, input parameters or variables are needed, see Figure 1. The results of the model, in the form of amounts of GHG emissions, will reflect which of the three perspectives on GHG emissions the model is designed to reflect, as well as any other system boundaries – for example, geographic or sector scope.

2 Project design

2.1 Project research questions

Based on the previous sections, NME's initial question was broken down to the following four research questions creating the scope of the project:

1. What is the current methodological status of emission reporting in the Nordic countries?
2. What is the expressed need for more timely emission statistics?
3. What projects and research have potential for informing more timely emission statistics?
4. What data sources could be used for new statistical products?

2.2 System boundaries of the project

2.2.1 Scope - GHG protocol and emissions

Existing statistics on GHG emissions reflect the system boundaries that follow from the three perspectives mentioned in section 1.2. This project adopts a territorial and a production perspective when investigating potential new methods for providing timelier GHG emissions data. This is a practical decision as calculation of emissions from a consumption perspective tends to be retroactive and is, broadly speaking, a more complicated and less accurate method of GHG emissions calculation.

The GHG protocol is a widely used standard for reporting on GHG emission and is available for companies and organisations as well as cities and nations. In short, the standard employs three "scopes", scope 1 being direct emissions, scope 2 emissions from purchased energy and scope 3 constituting upstream and downstream emissions.

In this project we have mainly covered CO₂ as it is the major climate pollutant. In some cases, other GHGs are also included in the analysis, but the main outcomes of the project focus primarily on national terrestrial fossil CO₂ emissions. This reflects the task description and is a pragmatic decision since terrestrial CO₂ emissions are the simplest nowcast, also taking precision into account. However, when researching current and ongoing work on emissions nowcasting, we have widened the scope and included practises that cover both sub-national boundaries, terrestrial, production and consumption statistics as well as biogenic and non-CO₂ GHGs.

We did not specifically look for methods of artificial intelligence or machine learning, because those are highly sector-specific and require extensive datasets to be trained.

2.2.2 Indicators

The European Union and the Nordic countries collect a lot of data that can be used to inform climate policy making. Indicators can draw on entities that are readily measurable or can be computed by combining different kinds of information. In a more abstract sense, an indicator is the output of a model, which uses predefined input parameters and data, used to help decision making.

The indicators address emissions directly, as well as relevant proxies – such as economic activity or environmental impacts. Some indicators inform on the relationship between emissions and other factors, for example GHG emissions by economic sector, GHG emissions per capita, GHG emissions per unit GDP (or unit economic output for individual sectors), or total GHG emissions trends compared to 2030 or 2050 goals.

There are also many potential indicators which look at drivers of GHGs, for example share of electric vehicles, share of renewable energy in total energy consumption, CO₂ emissions per km of new cars. Indicators addressing these issues can be found on the EEA website (European Environmental Agency, n.d.).

2.3 Approach

A combination of interviews, desk research, literature review and survey has been used to conduct this project. An overview of the activities and methods used to answer the research questions is presented in Table 3, followed by a short description of each of the activities.

Table 3. Overview of research questions and activities/methods used. A list of contacted organisations is available below in section 3.

Question	Activity		
	Interview	Desk research/ Literature review	Survey
1. What is the current methodological status of emission reporting in the Nordics?	x	x	
2. What is the expressed need for more timely emission statistics?	x		x
3. What projects and research have potential for contributing to more timely emission statistics?		x	
4. What data sources could be used for new statistical products?	x	x	

Interviews as well as a survey were conducted with relevant experts at academic institutes and authorities, primarily in the Nordic countries Finland, Norway, and Sweden, but also in other Nordic and European countries.

The following national authorities were contacted:

- Denmark: Danish Ministry of Climate, Energy and Utilities, iCLIMATE Aarhus University, Interdisciplinary Centre for Climate Change, Statistics Denmark
- Finland: Statistics Finland, VTT Research, Lappeenranta-Lahti University of Technology, Natural Resources Institute Finland, Finnish Environment Institute, CarbonLink Ltd, Energimyndigheten
- Sweden: Swedish Environmental Protection Agency, Statistics Sweden, Swedish Energy Agency
- EU: European Environment Agency

The interviews were held to supplement the information found in the literature. The interviews were carried out in a semi-structured manner and were supplemented by a survey designed to identify if and how the authorities and policy makers could benefit from timelier GHG emissions data.

A literature review was carried out to identify the methods/models used today, their input parameters, and the data sources used to generate the values for the input parameters. In addition, a sector-based review of data sources has been produced.

The methods/models were then assessed to identify the most useful sources for generating rapid GHG estimates for different sectors in a Nordic context. This was done through:

- a. an evaluation of data availability for identified methods/models in the Nordic countries.
- b. an assessment of the reliability of the methods/models' suitability (i.e. if the calculation model would reduce the delay in estimating emissions) and usability for decision makers.

3 Results

The following sections outline the results of the project.

3.1 Frameworks and international agreements

As parties to the United Nations Framework Convention on Climate Change, UNFCCC, the Kyoto protocol and the Paris Agreement, the EU, and its member states as well as non-EU member states are required to report to the UN:

- annually on their greenhouse gas emissions, the so called 'greenhouse gas inventories'
- regularly on their climate policies and measures and progress towards the targets, the so called 'biennial reports' and 'national communications'.

The UNFCCC greenhouse gas inventories follow the terrestrial system boundary and requires that parties report emissions inventories at the latest on the 15th of April, two years after the reference year. The inventory shall cover emissions and removals of direct GHGs (carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF₆) and nitrogen trifluoride (NF₃)) from five sectors (energy; industrial processes and product use; agriculture; land use, land-use change and forestry (LULUCF); and waste)³.

For EU member states, this reporting is also governed through the Regulation on the Governance of the Energy Union and Climate Action⁴, which replaced EU's Climate Monitoring Mechanism on 1st January 2021. The Nordic countries are either EU member states (MSs) or part of the EFTA agreement and are all signatories to the Paris agreement and report to the UNFCCC. As such, they share some common statistical frameworks and obligations. The statistical data can be accessed through the European Environment Agency, Eurostat and UNFCCC and fit within the classifications in Table 2.

EU member states must by 31st July report approximate emissions inventories for the previous year (Y-1), but any methodological revisions are not applied to earlier years, and these are generally not made public before October. By 15th January member states must report preliminary emissions inventories for all years through Y-2, and by 15th March final emissions inventories for all years through Y-2⁵. These last reports are made public on 15th April, when they are published by the United Nations Framework Convention on Climate Change⁶.

The EU-27 Member States as well as Iceland, the United Kingdom, Norway, Turkey, and Switzerland report on GHG emissions to the European Environment Agency (EEA). The EEA publish early estimates in September for emissions the preceding year. Unless countries provide their own emission estimates to the EEA by 31st July, the EEA will calculate the estimates. All Nordic countries provide their own estimates to the EEA, the so-called territorial emissions.

3. UNFCCC, n.d.

4. European Commission, n.d.

5. EU, 2018

6. UNFCCC

Initial estimates of annual global GHG emissions are generally delayed by some months as data must be gathered from numerous sources and then be verified. For the European Union, 'early estimates' are published by Eurostat in May of the following year⁷.

In addition to the above-mentioned international reporting obligations, as of 2021, Eurostat also produces early estimates of GHG emissions from the production perspective – GHG emissions accounts based on economic activity, as well as less robust consumption perspective footprints⁸. These are based on the Air Emissions Accounting statistics – a subset of Eurostat's environmental-economic accounts. They offer a detailed breakdown for 64 emitting industries, plus household (based on NACE 2 nomenclature), as defined in the national accounts of EU countries. This early estimate is at the EU level only and is not produced for individual countries.

3.2 Status of emissions reporting in the Nordic countries

Based on the performed interviews and the literature review, this section maps the identified current methods and processes used in the Nordic countries to estimate GHG emissions *in addition* to the accounts reported to the UNFCCC and Eurostat.

The processes currently used by the Danish, Swedish and Finnish authorities to produce GHG emissions statistics are described in sections 3.2.1 – 3.2.2. Nordic countries also employ self-defined standards for calculating GHG emissions in addition to those specified by the EU and the UNFCCC. Table 4 summarizes the statistical framework for GHG emissions in Denmark, Finland, and Sweden, see more information in Appendix 1.

Table 4. List of identified available statistical framework for GHG emissions (additional to UNFCCC and EU) in Denmark, Finland and Sweden

Method/model	Standard	Time lag	Time Resolution	Emission perspective and Sectorial resolution	Emissions included
EEA Proxy GHG emission estimates*	Chosen by country	9 months	annually	Per sector depending on reporting countries	Total GHG emissions
Danish air emissions accounts (production perspective)	SEEA	8,5 months	annually	Relates to the 21 single digit NACE sectors***	CO ₂ , CH ₄ and N ₂ O
ALas model (Finland) (territorial perspective)	Hinku (a modification of GPC)	15 months	annually	75 GPC sectors	CO ₂ e including CO ₂ , CH ₄ , N ₂ O, F gases
Swedish production statistics (production perspective)	SEEA	5 months	quarterly	Relates to aggregated sectors, SNI 2007**	Total GHG emissions

* Nordic countries conform to EU reporting standard.

** Sweden use the SNI which is compatible with the international NACE system, see (Statistics Sweden, n.d.)

*** (UNFCCC, 2014)

7. Eurostat, 2020

8. Eurostat, n.d.

3.2.1 Danish emissions statistics

The Danish air emissions accounts (Emissionsregnskabet) is an annual statement of emissions of greenhouse gases and other air pollutants calculated in tonnes. The statistics are reported by industry. The structure of the emission accounts means that the information can be used immediately for analyses of the connection between economic activities described in the national accounts and related environmental pressures. The statistics are disseminated in Statistics Denmark⁹ news and via the StatBank database.

Accounts in the time series up until two years from current date are based on detailed reporting by industry. The most recent year is nowcast, primarily based on energy statistics that are released in mid-June of the following year. These are provided in GJ of use of the different fossil fuels used by each of the 21 sectors. The emissions coefficients for each fuel (tonnes CO₂ emissions per GJ energy released) and combusting sector are based on the reported coefficients from the previous year.

For non-energy-related emissions, other sources are used. For emissions from animal husbandry, data is used on the relative (%) change in numbers of cows and pigs between the last full report (two years from current date) and the following year (nowcast), multiplied by emissions of methane and N₂O from the husbandry of these two animals respectively (direct emissions from animals and indirect emissions from the break-down of manure).

Cement production releases non-energy-related CO₂ during the conversion of calcium carbonate (CaCO₃) to lime (CaO). Estimates for the most recent year of cement production are based on percentage change in the production index for the cement and brick industries. The production index is based on production turnover deflated by the producer price index to obtain an implicit volume index. Other process industries are assumed to have the same emissions as the last full report (two years from current date). Further information on the details of the Danish emissions accounting can be found at Danmarks statistik¹⁰.

3.2.2 Finnish emissions statistics

Finnish Environment Institute (Syke) publishes ALas model estimates¹¹ for CO₂-equivalent territorial emissions down to municipality level. These are annual estimates and are published in the summer of the following year. However, the model is based on algorithms whose input data could possibly be collected with less delay.

The model covers all of Finland and its municipalities. Annual CO₂e emissions, energy consumption, and vehicle mileages (depending on sector) are available for years 2005–2019. Sectors include transport, buildings, industry (from fuel usage), waste, and agriculture; but it excludes aviation, shipping abroad, non-energy-related industrial processes, LULUCF, and icebreakers.

The ALas model uses a mixed calculation method. The regions' territorial emissions act as the starting point, but some emissions, such as those from electricity use, are

9. Statistics Denmark, n.d.-a

10. Statistics Denmark, n.d.-a

11. SYKE, n.d.

calculated based on consumption, regardless of their geographical area of origin. In broad terms, the calculation is similar to the basic level of GHG protocol's GPC standard, with agriculture, F-gases and grid losses included, but without the local aviation included in the standard.

Local territorial emissions are adjusted by taking into account cross municipal boundary flows of energy as well as LULUCF carbon sinks:

- Wind, solar and biogas power produced within municipality and sold to national grid.
- Biogas sold for transport within or outside municipality; user must be known, and 50/50% allocation between producer and user is used.
- Long-term wind, solar, and biogas power production outside municipality; 50/50% allocation between producer and other municipality.
- Other power production outside municipality; 50/50% allocation between owner and other municipality.
- Carbon sinks in LULUCF must be additional compared with BAU; they must be in Finland; if outside municipality, 50/50% allocation between producer and other municipality.

The estimates are territorial except for district heating, all electricity, industry, waste, private cars, and motorcycles.

Greenhouse gases considered are CO₂, N₂O, and CH₄; and total F gases without sector-specific values. Biofuel emissions are assumed to have zero-emissions for CO₂; other gases are based on their actual emissions. The data for district heating comes from the energy industry¹² and the Municipality association¹³. The remaining emissions are distributed to municipalities to match the total national emission estimate.

Emission factor data comes from Statistics Finland for CO₂, and IPCC EFDB for N₂O and CH₄¹⁴. Separate heating activity (oil, wood, and other) comes from Statistics Finland Energy consumption data. Activity is divided to municipalities based on floor area of different oil-heated building types. This is adjusted for hot water and heat need based on outdoor temperature. Heating oil is assumed to have 0–4% biofuel fraction due to the biofuel requirements. This biofuel is assumed to have zero-CO₂-emission.

The ALas model results become available typically 15 months after the end of the emission year. However, there is a quicker and more robust model ALasPre that has only 6-month delay. ALasPre has the same functionalities as the ALas model in many respects, but there are some key differences: Electricity consumption is estimated based a regression model using these independent variables: a) floor area of different kinds of buildings, b) population size, floor area of greenhouses, c) heating consumption factor (based on the climate conditions of the municipality), and d) electricity consumption of different sectors the year before.

ALasPre reports 17 subsectors with a three-level hierarchy, while ALas reports 75 sectors with two additional levels of hierarchy. Estimates are available before the official emission estimates, so this is closer to nowcasting than the more precise ALas model.

12. Energiatieto: district heating statistics, annual

13. Kuntaliitto: Data on small heat plants

14. IPCC, 2021

3.2.3 Swedish emissions statistics

The Environmental Accounts (production perspective) are compiled within the framework of the System of Environmental and Economic Accounts (SEEA) and show national environmental statistics and economic statistics in the same framework using the NACE industry classification. This is made possible by reworking environmental statistics classifications to harmonise with economic statistics, and by reporting them jointly.

It also enables production of preliminary (early estimates) annual statistics (total quarterly statistics), which is published ahead of the final annual statistics on emissions to air. Calculations include emissions to air by economic activity that takes place in Swedish territory and by transactions across Sweden's borders. Emissions to air are reported by industry, based on the Swedish Standard Industrial Classification¹⁵ and by the public sector, non-profit organisations and households (private consumption). Aggregation of industry subsectors is selected to conform with the National Accounts' quarterly reporting.

The preliminary annual statistics is simply the sum of the quarterly air emissions accounts produced at Statistics Sweden (SCB). Emissions from both stationary and mobile sources are based on quarterly energy surveys. Industrial processes and product use are based on legally mandated environmental reports or emissions inventories related to the European emissions-trading scheme (EU-ETS) and compiled by Swedish Environmental Protection Agency. Emissions from the agricultural sector are added, from the previous year.

The emission factors used are the same factors that are used for annual emissions to air in the environmental accounts, that is emission factors used in the environmental accounts are also used in national emissions statistics (inventories) reported to the United Nations Framework Convention on Climate Change¹⁶ and the Convention on Long Range Transboundary Air Pollution (CLRTAP). Direct emissions by Swedish economic actors are reported here, no matter where in the emissions geographically occur. This means that emissions from international bunkering (aviation and shipping that entered and fuelled at Swedish airports and harbours) are included. Emissions and removals from land use, land use change and forestry and carbon capture and storage are not included.

The Swedish Environmental Protection Agency's statistics on emissions to air present territorial emissions, that is, emissions within Sweden's borders. The sector breakdown is based on the emission type rather than on the industry sector. Emissions and removals from land use, land use change and forestry are included, while emissions from international transport are reported separately. Thanks to the connection with the National Accounts, annual statistics on emissions to air in the environmental accounts are used to produce estimates based on model calculations and input-output analysis of Sweden's consumption-based emissions (or final use according to the National Accounts). The information is produced by environmental accounts at Statistics Sweden for the Swedish Environmental Protection Agency¹⁷.

15. SNI2007, equal to NACE Rev. 2

16. UNFCCC

17. Statistics Sweden, 2016

Statistics Sweden (SCB) produces official statistics on greenhouse gas and other air emissions from a consumption perspective, using simplified single-country national accounts compatible (SNAC) environmentally extended input output analysis. Currently yearly data are produced with a lag-time of almost 23 months between the most recent reference year and the publication date. SCB is investigating the possibility of producing the statistics with a lag-time of only six months, but there are difficulties in gathering international emissions data relation to production of goods consumed in Sweden¹⁸.

3.3 The need for more timely emission statistics

Based on output from interviews as well as a complimentary survey, the following was found regarding need for more timely statistics. First the answers indicate that GHG emissions/carbon reporting - relating to the sector of transport, mobile machinery, industry and production of electricity and heat - are used in policy making and in the tracking progress of emission targets. Second, the interviews and the survey show that there is an interest in more timely emission statistics. This is also stated in a report from Statistics Sweden (SCB) in 2016¹⁹, where it is concluded that, due to a large demand by many different kinds of actors for up-to-date statistics on greenhouse gas emissions, they have provided faster access to statistics in their Environmental Accounts since late 2015.

Finally, the interviews indicate that it is important that more timely emission statistics:

- shows trends by main economic sector,
- it is possible to see/understand the underlying drivers of change in emissions,
- includes emissions from non-energy related processes, e.g., farming, cement production, and
- includes all greenhouse gases and not just CO₂.

The complementary survey was designed and sent to all 12 members of The Nordic working group for Climate and Air (NKL) of the Nordic Council of Ministers, to better understand the need for more timely emission statistics among the end-users such as policymakers and answer the research-question "*What is the expressed need for more timely emission statistics?*". The survey included seven questions and three responses were received. The survey strengthened the understanding of policymakers' need for more timely emission statistics.

3.4 Projects and research leading toward more timely emission statistics

This section provides a brief overview of the most interesting identified ongoing work within the research community in nowcasting GHG emissions. The focus was on innovative methods and the application of models that could inform climate policy makers.

18. Brown, Berglund, Roth, & Statistics Sweden, 2021

19. SCB, 2016

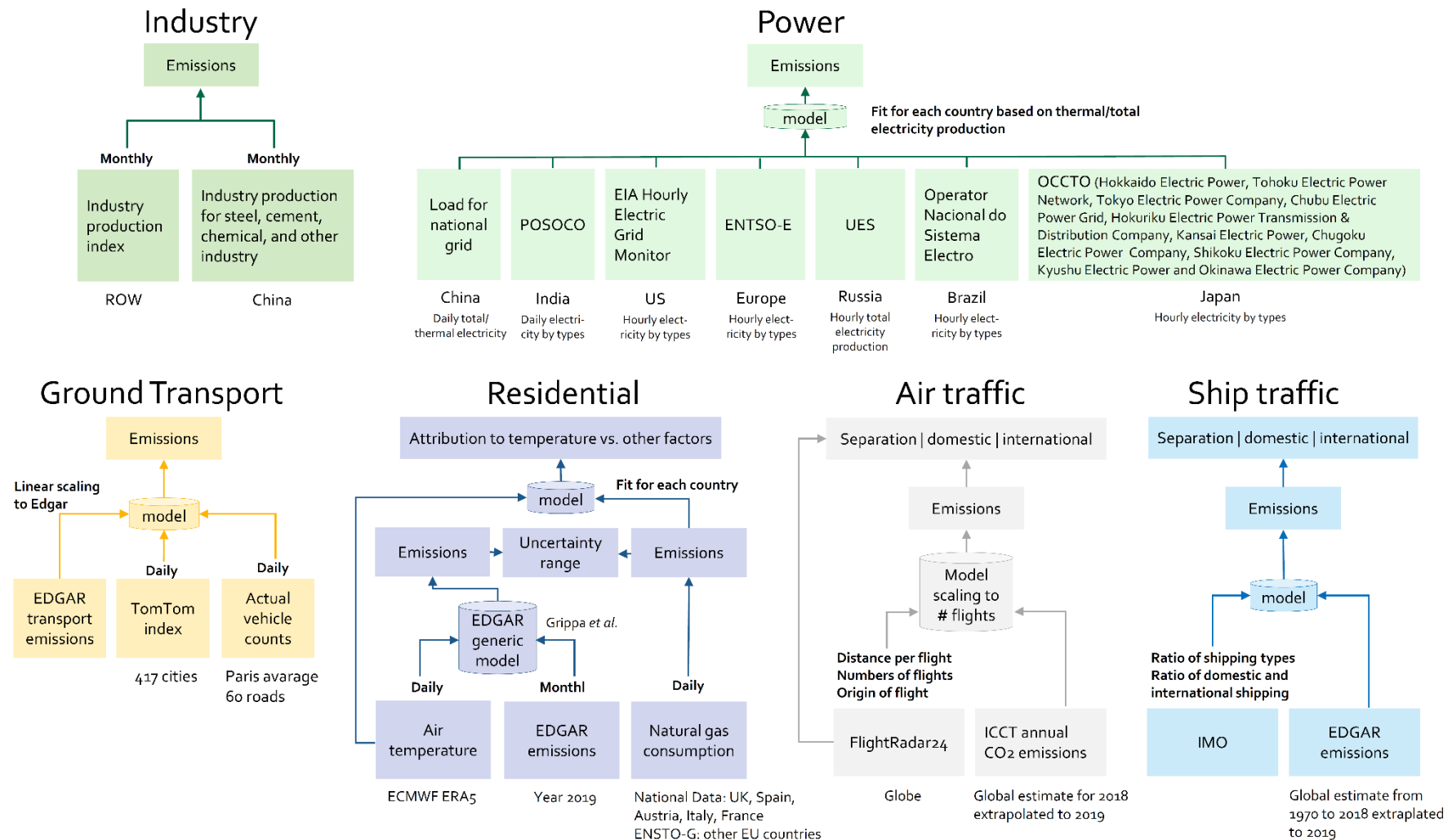
Typically, emissions are either calculated based on energy data, or based on satellite monitoring and/or sensor networks, although other approaches are also employed in some cases. Table 5 provides an overview of some of the projects and research we have identified. A full list can be found in Appendix 2.

Table 5. TA selection of the projects identified and listed in Appendix 2 as well as an analysis of to what extent they provide nowcasting of emissions.

Project	Scope and Potential
ALasPre model (Finland)*	A project owned by the Finnish Environment Institute to development of methods for more rapid emission estimates. Estimates are available before the official emission estimates, so this is closer to nowcasting than the more precise ALas model mentioned in Table 4. Data relevant for Nordic countries.
ClimateTRACE	A partnership between several organisations, Google is a key sponsor, and AI Gore is one of the founders. Aiming at delivering more accurate, detailed and real-time data. The project use satellite data in combination with other data sources and AI/machine learning to model down to weekly (coming soon according to website) emissions data for select sectors and countries. Collected data might be difficult to immediately use , analysing changes in trends not related to other driving factors, without support from the project itself.
Glasgow air-quality monitoring project	A project led by the University of Strathclyde as part of the Global Environmental Measurement and Monitoring Initiative (GEMM). 25 low-cost sensors that can measure greenhouse gases (GHGs) and air quality gases including CO ₂ , carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO ₂), ozone (O ₃) and particulate matter (PM) in real-time has been installed in Glasgow. Not a viable approach for full country assessment but possible approach locally.
The Global Carbon Project	This project is a Global Research Project of Future Earth and a research partner of the World Climate Research Programme that integrates knowledge of greenhouse gases for human activities and the Earth system. Produce total fossil CO ₂ emissions, designed the same way as the Global Carbon Budget, from estimates of the three major fossil-fuel groups – coal, oil, and gas – and emissions from carbonate decomposition in cement production. Several important errors have been discovered in the sub-annual emissions estimates for both oil and coal, while the method used for monthly emissions from natural gas worked very well.
Carbon monitor project	A project led by Tsinghua University, LSCE and UCI aiming at capturing daily variation in emissions due to factors such as lock lockdowns, drops in production and change in behaviour. Provide global daily emission estimates based on a few data sources , see Figure 2. Relatively large uncertainty (±7%).
Electricity map	Since 2016, electricity Map's open-source visualization has been used by millions of people, from students to world leaders, to understand the climate impact of global electricity use. For Europe it makes available data from the ENTSO-E platform holding information about real-time electricity production emissions. Available data and open-source visualization create opportunities to develop further functionalities for e.g. country comparisons.
Open-source Data Inventory for Anthropogenic CO ₂ (ODIAC)	A global high-resolution emission data product for fossil fuel CO ₂ emissions, originally developed under the Greenhouse gas Observing SATellite (GOSAT) project at the National Institute for Environmental Studies (NIES), Japan. Using geospatial proxies such as satellite observations of night-time lights and geolocations of major power plants (Carbon Monitoring for Action list) it calculates monthly CO ₂ emissions on a 1-km grid for the period 2000 to 2019. As of today, it includes emissions from power plants, transportation, cement production/industrial facilities, and gas flares over land regions.
The Global Carbon Grid	Designed to provide open access to uniform, high-quality, and up-to-date data for scientific research, policy assessment, and climate and environmental management. GID could be a powerful tool to track global infrastructure changes for research on climate change and air pollution issues worldwide. Provides global 0.1° × 0.1° CO₂ emission maps of six source sectors: power, industry, residential, transport, shipping, and aviation in 2019. Not real-time. See Figure 3.

*(SYKE, 2021)

Figure 2. Overview of how emissions are calculated in the CarbonMonitor project. Source: (Liu, Z.,Ciais, P., Deng, Z. et al., 2020).



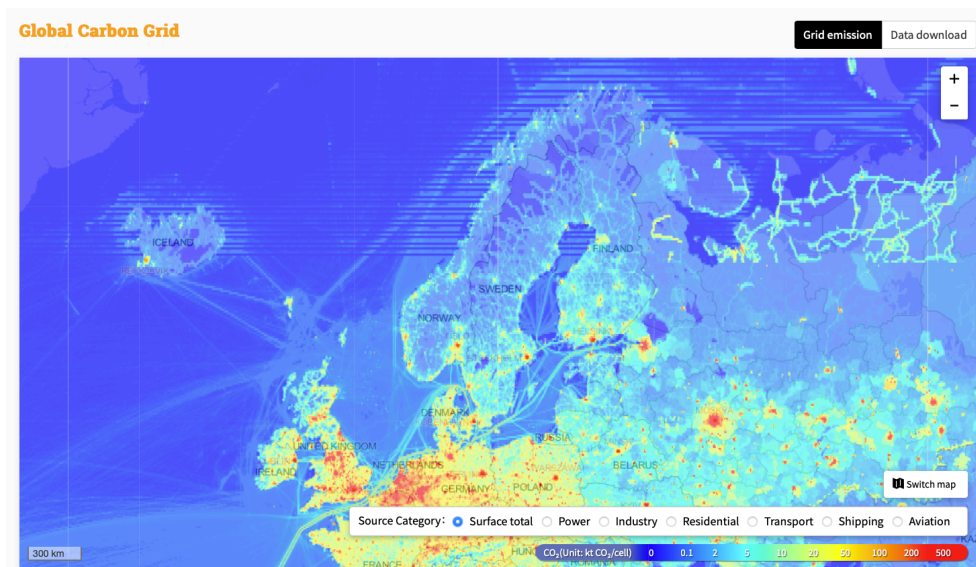


Figure 3. Screenshot from the gidmodel tool. The gidmodel computes emissions stemming from power production, industry operations, residential energy use, transport (land), shipping and aviation. Source: http://gidmodel.org.cn/?page_id=1425.

Statistics Sweden (SCB) is working on improving the timeliness of Swedish statistics on GHG emissions from a consumption perspective. Currently SCB produces official statistics on GHG and other air emissions from a consumption perspective with a time-lag of almost 23 months between the most recent reference year and the publication date. SCB is investigating the possibility to reduce this time-lag to only six months, initially looking at data availability and assessing potential methods to achieve this timeliness improvement²⁰.

Based on this investigation FIGARO and EXIOBASE are the most interesting multiregional input-output databases for nowcasting the international economy outside of Sweden.

EXIOBASE²¹ is a multi-regional environmentally extended input-output database produced in successive international research collaborations, most recently the DESIRE project. The database covers 44 countries (all 27 EU member states, plus 17 other large economies) and five rest-of-world regions, classified according to 163 industry groups or 200 product groups. It includes more than 1 000 different stressors and covers a time period from 1995 up to and including 2022 (future years being a forecast). EXIOBASE is a research product based on high-quality data sources. It has been updated multiple times with a view to extending the time series.

FIGARO²² is an economic multiregional input-output database, developed by Eurostat in collaboration with the Joint Research Centre of the European Commission²³. The database covers the world economy subdivided in 46 regions in total – 27 EU Member States, 18 other major national economies and one rest-of-the-world region. The database contains input-output tables and supply and use

20. Brown, Berglund, Roth, & Statistics Sweden, 2021

21. EXIOBASE, n.d.

22. Eurostat, 2019.a

23. Eurostat, 2019.a

tables, by industry or by product. The temporal coverage is from 2010 to 2019. The data contained in the database is produced according to two main methods, depending on the region covered.

According to the investigation of SCB²⁴ there are many potential sources for emissions data for the international economy, but all the potential sources are lacking either in system boundary (territorial vs. production), geographic coverage (e.g., only European Union member states) or production time. Therefore, the authors propose to implement a method for nowcast based on the Swedish data used in Statistics Sweden's method. For environmental effects arising from Sweden's imports, one method based on EXIOBASE and one method based on FIGARO is proposed.

3.5 Data sources and potential real-time emission estimate methods

Several methods listed in the previous section 3.4 can be applied to the Nordic countries, however not without further development. In this section we cover methods and data currently used mainly at city level using the Global protocol for community-level greenhouse gas (GPC). It is a standard that has been developed to aid GHG reporting for cities (geographical boundary). GPC has published methods and guides on the data that is needed to compute these. The data needed for these methods is often available online. The computation process can be automated after the necessary data integrations and fairly straightforward calculations have been developed. This would only require little or moderate amount of work. This observation could serve as inspiration for a new nowcasting project.

Although the GPC standard was developed for cities, the method is applicable for countries as well, if the necessary data are available. Table 6 contain the most important methods for emission estimation in GPC. When using a different geographical scale, however, it is important to carefully consider the system boundaries to avoid omissions and double counting.

24. Brown, Berglund, Roth, & Statistics Sweden, 2021

Table 6. Methods and corresponding data needs for estimating GHG emissions for different GPC sectors. Modified from GPC protocol (GHG protocol, n.d.-c). The abbreviation (t) means that the input data is time-dependent and determines the time resolution of the emission estimate

Methods related to	Applicable to GPC sectors	Data needed
Fuel consumption	Stationary energy, transportation	Fuel consumption(t), emission factor of the particular equipment
Grid energy consumption	Stationary energy, transportation (electric vehicles and trains)	Energy consumption(t), emission factor of the fuel mix(t)
Fugitive emissions from oil and gas systems	Fugitive emissions from oil and gas systems	Direct measurement or production amount and emission factor for process
ASIF (activity, share, intensity, fuel)	Transportation	Distance travelled by type of vehicle and fuel(t), emission factor by vehicle and fuel
Solid waste disposal	Solid waste disposal	Amount and composition of waste at landfill(t), methane generation potential(t)
Waste management	Biological treatment, incineration, and wastewater	Amount of waste by type and treatment(t), emission factor by waste type and treatment
Direct industrial process	Industrial processes and product use	Direct measurements from industrial sites(t)
Indirect industrial process	Industrial processes and product use	Mass of material input(t) or product output(t), emission factor by input or output
Livestock emission	Agriculture, forestry and other land use (AFOLU)	Number of animals by species and manure management system(t), emission factor per head and per system

An overview of potential measuring focal points is presented below in order of implementation simplicity based on a rough estimate. The focus is on data sources that are relevant for all Nordic countries, although Finland has been used to exemplify the data available in the Nordic countries in some cases. The focal points addressed are electricity, fuel consumption and fuel balance, district heating, transport, food consumption, forest products and carbon sinks, and point source industrial emissions.

3.5.1 Electricity

The European Network of Transmission System Operators for Electricity (ENTSO-E) publishes a database containing data on electricity production, transfer, and fuel use on an hourly basis and in real time (even a forecast for the next day) from the whole of Europe, including Eastern Europe, see Figure 4. It also contains data on transfers to and from countries that are not part of ENTSO-E, such as Russia and Ukraine. This is especially relevant for Finland, who imports large amounts of electricity from Russia. For example, the average imported electric power from Russia to Finland was 1 200 MW during March 2022. From an energy security perspective, it is worth noting that such imports make it possible for Finland to export part of its own production to Sweden and other countries. However, all electricity and natural gas imports from Russia to Finland ended in mid-May 2022 due to Russian's invasion to Ukraine.

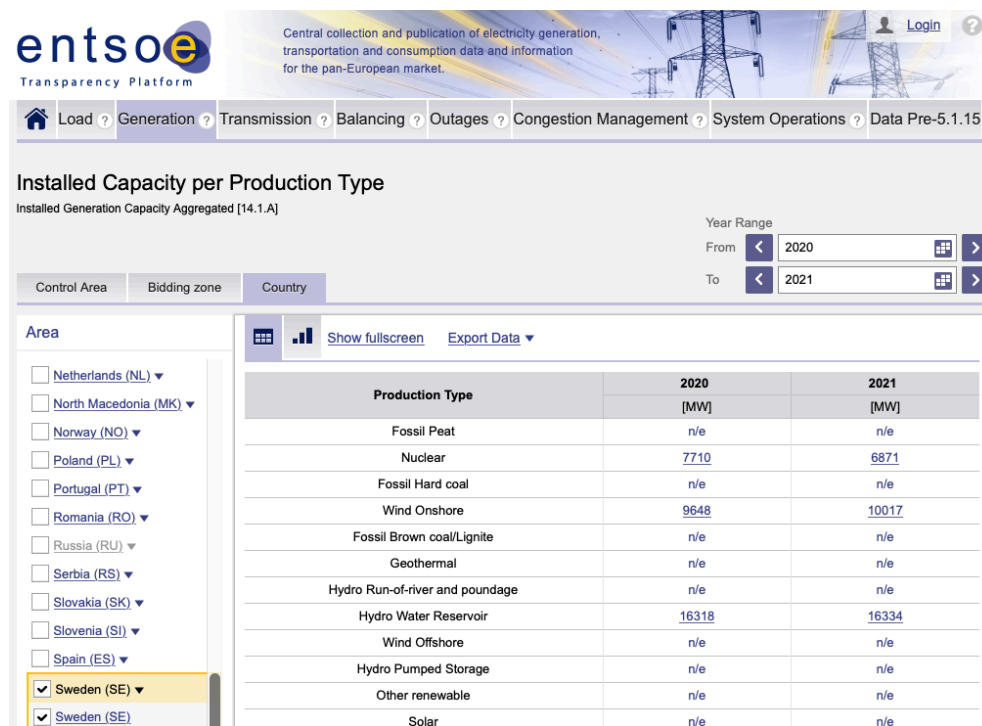


Figure 4. Screenshot from the ENTSO-E platform

Although the ENTSO platform does not directly offer CO₂ emission estimates, the database is a sufficient source of information for calculating CO₂ emission estimates of electricity production or consumption for all Nordic and EU countries. This can be done by using data on electricity production (and which production facilities are in use), emission factors of each production type, and electricity transfers between areas.

An application programming interface (API) enables automatic data download, allowing automation of the calculation of CO₂ emission from electricity for all Nordic countries on an hourly basis. The ENTSO platform provides instruction on the implementation of the API. The data on physical flows can be used free of charge.

without a permission based on the Terms and Conditions of Use²⁶.

Cross-border physical flows or electricity are also available. Therefore, it is possible to calculate emissions and emission factors of either the production or consumption regionally by accounting for cross-border flows.

Electricity generation is categorized in 20 classes based on the fuel (or other primary energy source) used: Biomass, Fossil Brown coal/Lignite, Fossil Coal-derived gas, Fossil Gas, Fossil Hard coal, Fossil Oil, Fossil Oil shale, Fossil Peat, Geothermal, Hydro Pumped Storage, Hydro Run-of-river and poundage, Hydro Water Reservoir, Marine, Nuclear, Other, Other renewable, Solar, Waste, Wind Offshore, Wind Onshore.

In Finland, Fingrid²⁷, the national electricity grid operator publishes even more detailed data. Fingrid publishes real-time (3 min interval) CO₂ emission factors for electricity production²⁸ and electricity consumption²⁹ in Finland. These calculations can also be automated, as there is an open API for data downloads. Fingrid also publishes real-time (3 min interval) electricity production³⁰ and electricity consumption³¹ in Finland. Therefore, real-time CO₂ emissions can be calculated based on the published values. Cost data is also available, e.g. fast frequency reserve cost³² and hourly imbalance price³³. Because these data come directly from the Fingrid monitoring system, it is the most accurate measurement of the electricity consumption and production available.

Energinet, the Danish state-owned company that owns, operates and develops the transmission systems for electricity and natural gas publishes a wealth of data on their data portal – Energi Data Service³⁴. As well as production, consumption and transmission data, Energi Data Service also publishes a net CO₂ emissions per kWh for electricity in five-minute intervals for east and west Denmark.

In addition, electricitymap.org provides a lot of information on electricity based on data sources above.

3.5.2 Fuel consumption and fuel balance

Imports, exports and stocks of fuels are monitored in detail, and Eurostat, see Figure 5, has monthly data available³⁵ with an approximately four-month delay for all EU countries, Norway, UK, and several countries in Eastern Europe. These statistics do not contain data on the use purpose of the fuel, but the data is given by 33 fuel types (according to the Standard International Energy Product Classification SIEC), so the values give a detailed view on the activities. Thus, they are useful in estimating CO₂ emissions and monthly trends from energy consumption

26. entsoe, 2020 https://transparency.entsoe.eu/content/static_content/download?path=/Static%20content/terms%20and%20conditions/201030_TP%20list%20of%20data.pdf

27. FINGRID, n.d.

28. FINGRID n.d. -a <https://data.fingrid.fi/en/dataset/suomen-sahkontuotannon-paastokerroin-reaaliaikatieta>

29. FINGRID, n.d.-b

30. FINGRID, n.d.-c <https://data.fingrid.fi/dataset/electricity-production-in-finland-real-time-data>

31. FINGRID, n.d.-d <https://data.fingrid.fi/dataset/electricity-consumption-in-finland-real-time-data>

32. FINGRID, n.d.-e <https://data.fingrid.fi/en/dataset/nopea-taajuusreservi-hinta>

33. FINGRID, n.d.-f <https://data.fingrid.fi/en/dataset/the-price-of-consumption-imbalance-electricity>

34. Energinet, n.d.

35. Eurostat, 2022.b https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg.nrg_quant.nrg_quantm

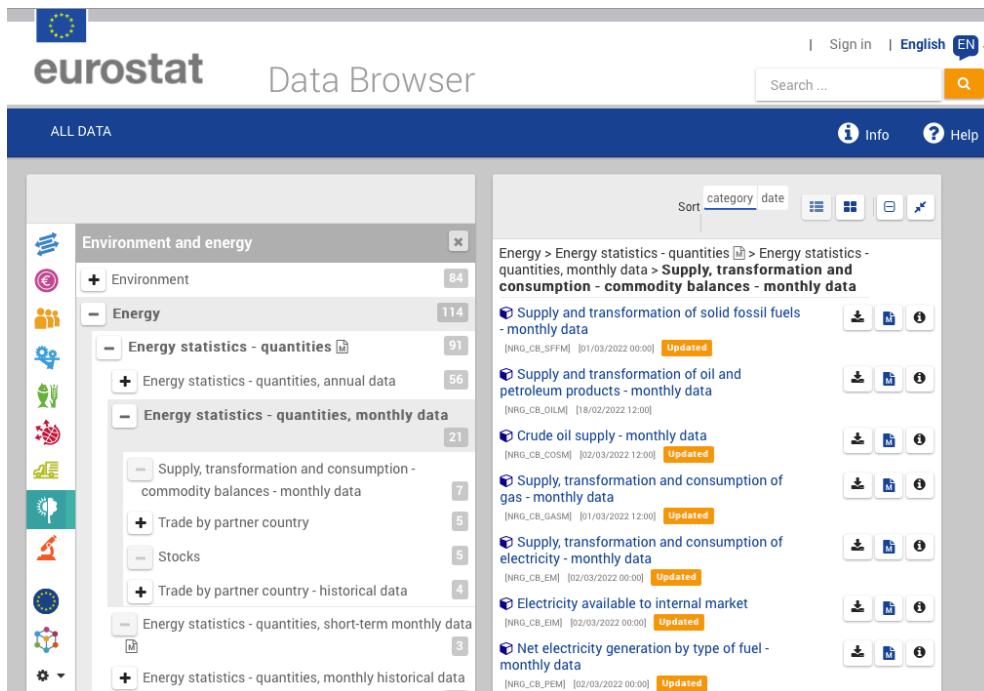


Figure 5. Screenshot from the Eurostat data browser website (Eurostat, 2022.b).

Eurostat offers an API³⁶ to its datasets, so it is possible to develop an automatic calculator for monthly fuel consumptions and CO₂ emissions in European countries.

Statistics Finland collects regular energy statistics³⁷. The most relevant variables are total energy consumption by sector (6-month blocks, ca. 3-month delay); electricity consumption (monthly values, 3-month delay for preliminary estimates and 15-month delay for final estimates); and sales of oil products to Finland and abroad (monthly values, ca. 3-month delay).

3.5.3 District heating

International data sources were not identified for district heating. However, as district heating is common in Nordic countries, it is likely that there are national statistics available. These may be collected by a national statistics authority, or the energy industry sector.

In Finland, Energiategollisuus (a trade organisation of energy producers) publishes a report on district heating in October-November on the previous year's statistics³⁸. The statistics are geographically reported on regional level (19 regions in Finland) and detailed fuel classification (49 fuel classes). Production of district heating is divided between combined heat and power (CHP), heat production, heat recovery, and electricity used for heat pumps. The fuel consumption is presented separately for CHP and heat only production.

The Energiategollisuus' statistics also contain detailed information on 300 individual energy plants in Finland. This includes district heating production, losses, net electricity consumption/production, capacities of different kinds of power plants.

36. Eurostat, 2022.c https://ec.europa.eu/eurostat/online-help/public/en/API_O6_DataQuery_en/

37. Statistics Finland, n.d. <https://stat.fi/til/ehk/index.html>

38. Finnish Energy, n.d. <https://energia.fi/uutishuone/materiaalipankki/kaukolampotilasto.html#material-view>

The data also contains information on the fraction of population using district heating in a municipality, sales statistics, technical information about individual power plants, CHP production, sales between producers, customer information and consumption by customer type, and consumption statistics since 2011.

Based on the capacity data, previous statistics, and temperature data (which can be obtained from the Finnish Meteorological Institute via an open API) it is possible to design a model that would estimate district heating production and consumption and related CO₂ emissions on daily basis in real time. If fuel sources with different emission factors are used, that information would need to be collected to give accurate real-time values. Since this information seems to be available for electricity production (see that section), plants that produce both district heating and electricity might already be covered. Regardless, this would need a development project, and we are not aware of such ongoing development work.

It has not been possible to identify similar data on district heating in the other Nordic countries.

3.5.4 Transport

Eurostat has country-specific data on transport modes³⁹ (measured as percentage of passenger-kilometres). The data includes motorized transport but excludes walking and cycling. Passenger numbers and kilometres are also categorized by trip type: occasional, regular, urban, and interurban; and national and international. Vehicle-kilometres are available for lorries and road trains; motorcycles; passenger cars; and motorcoaches, buses and trolley buses. However, a major problem with these data is that there is a two-year delay. Hence, the Eurostat transport data cannot be used for nowcasting.

TomTom index⁴⁰ is available for 417 cities globally at a detailed level, with e.g., daily traffic patterns and congestion levels. There are even annual CO₂ emission estimates, but only for four European cities, none in the Nordic countries. The data could possibly be used to infer daily emissions from road traffic. However, the data is available for exploration only. For a systematic download and usage, a written permission from TomTom is needed.

Google Mobility Reports⁴¹ describe how people move around based on information from their cell phones. Practically all countries are covered. For some countries, there are regional data as well (the Nordic countries are each divided in 5–21 regions). The data is fairly recent, typically only 2–3 weeks old, and the values are compared with a pre-pandemic 5-week period in Jan-Feb 2020. The mobility is divided in six sectors: retail & recreation; grocery & pharmacy; parks; transit stations; workplaces; and residential. These data do not give information about transport modes or trip lengths, but it can show short-term changes in relative activity. This is a useful proxy for transport activity if it is combined with more detailed annual transport activities and emissions. However, a major uncertainty lies in the fact that Google launched this data service to inform pandemic decisions, and there is no guarantee that the data will be available in the long run. However, it is likely that data could be procured

39. Eurostat, 2021.a https://ec.europa.eu/eurostat/databrowser/view/TRAN_HV_PSMOD__custom_2198958/default/table?lang=en

40. TomTom, n.d. https://www.tomtom.com/en_gb/traffic-index/sweden-country-traffic/

41. Google, n.d. <https://www.google.com/covid19/mobility/>

for any possible implementation.

In Finland, existing open data can be used to calculate near-real-time emissions from transport. Activities can be calculated from Digitraffic⁴² vehicle counts if they are scaled by using historical activity data from the Lipasto database⁴³. Digitraffic collects real-time activity data on Finnish road, railways and waterways (transport activity monitoring operator since 2019). There are 450 automatic traffic monitoring locations in Finland, and the data is available in real time⁴⁴. However, these vehicle counts need to be converted into vehicle kilometres. Also, the monitoring sites are located on major roads, so there is less data available about traffic inside cities. Vöylävirasto⁴⁵ is the authority responsible for the transport and network data.

Transport emission factors have traditionally been available from the Lipasto database, but these values are fairly old and the responsibility for the maintenance of the data has been transferred to the European Environment Agency and its Emission Factor Database⁴⁶. This is useful, as the European data source is more likely to be relevant and usable for all Nordic countries. The database has emission factors also for many other sectors besides transportation.

In Sweden the Swedish Transport Administration (Trafikverket) provides monthly estimates on traffic work (swe. trafikarbete) on state owned roads, as opposed to municipal or private (mainly small roads with little traffic). During the Pandemic this was updated to weekly estimates⁴⁷, however this is decided not to continue. For Stockholm and Gothenburg, the web service Trafiken.nu is available, where you can follow the road traffic situation in real-time in multiple places throughout the two cities through webcams. Digital video analysis could be used to identify the number or type of cars in real-time.

The Danish Road Authority (Vejdirektorat) published real-time data on the traffic on major Danish roads⁴⁸. No real-time data on passenger numbers or on transport more broadly in Denmark has been identified by the project.

3.5.5 Food consumption

Carbon footprint of food consumption, and scope 3 emissions in general, are difficult to estimate, as the emissions cannot be deduced from the end-product. Scope 3 emissions mean indirect emissions that occur upstream or downstream from the monitored activity. These include, e.g., emissions from agriculture, transport of food, and food industry. For example, the carbon footprint of a cucumber varies widely based on the time of year, country of origin, and the method of cultivation. This reduces the precision of carbon footprint factors. As better methods are not available, the best choice is to use as relevant factors as possible, update the data and start using more precise factors when they become available. There is a standard method for calculating scope 3 emissions⁴⁹, as long as the factor values

42. Digitraffic, n.d. <https://www.digitraffic.fi/en/road-traffic/lam/>

43. Lipasto, n.d. <http://lipasto.vtt.fi/en/index.htm>

44. Digitraffic, n.d. <https://www.digitraffic.fi/en/road-traffic/lam/>

45. Vöylävirasto, n.d., Finnish Transport Infrastructure Agency <https://vayla.fi/vaylista/aineistot/avoindata/tiestotiedot/lam-tiedot>

46. EEA, 2022 http://efdb.apps.eea.europa.eu/?source=%7B%22query%22%3A%7B%22match_all%22%3A%7B%7D%7D%2C%22display_type%22%3A%22tabular%22%7D

47. Trafikverket, 2021

48. Vejdirektoratet, n.d.

49. GHG protocol, n.d.-b <https://ghgprotocol.org/standards/scope-3-standard>

needed are found. There are a lot of databases and calculation aids for life cycle assessments⁵⁰.

There are fairly good estimates of carbon footprints of different kinds of food items globally⁵¹ and in Finland⁵². Activity data, i.e., the amounts of different foods consumed at a particular time are typically only available on a yearly basis. However, the large retail companies have detailed data on purchases in their own stores, and this data is also offered for the customers with regards to their own purchases. This data source could produce detailed data on carbon footprint of food consumption on daily basis. One company alone, the S Group has a market share of 46% in 2020⁵³, and the two largest companies combined cover more than 80% of the market. It is worth investigating whether these companies would produce carbon footprint estimates on daily basis or provide data to a project that could make this calculation. Startups are encouraged to submit ideas for improving S Group services by S-LAB⁵⁴. Maybe calculating real-time carbon footprints would be a good service.

The Danish state-sponsored climate thinktank Concito publishes a database of the carbon emissions associated with 500 different food and beverage products based on an LCA approach⁵⁵.

In conclusion, the carbon footprint factors are available at least on a food category level, but it is unclear whether it is possible to obtain near-real-time data about purchasing activity of food. If that succeeds, GHG emissions can be calculated.

3.5.6 Forest products and carbon sinks

Forestry is a complex category, as the activities are not measured directly and "emission factors" include both carbon emissions and sinks. In addition, many activities generate direct and indirect emissions. For example, some but not all wood-based products replace carbon-intensive materials such as concrete in buildings and have a long lifetime and thus form a carbon storage. Also, thinning of a forest produces both raw material for products but also increases the growth of remaining trees.

In any case, it is safe to assume that most of the pulpwood ends up to short-lived products while a part of logs ends up to long-lived timber products.

Finland has good quality statistics covering the forest industry, and roundwood sales are documented at a monthly basis with a one-month delay⁵⁶. Therefore, it is possible to estimate the amount of production of wood-based products, although it is more difficult to estimate their lifetime.

There are also good quality statistics on the status of the forests, although that data is updated only with a ten-year interval, and the newest measurements are from 2018.

50. GHG protocol, n.d.-a <https://ghgprotocol.org/life-cycle-databases>

51. Poore and Nemecek, 2018

52. Climate Guide, n.d.

53. Finnish Grocery Trade Association, 2021 <https://www.pty.fi/paeivittaeistavarakaupan-myynti-ja-markkinaosuudet-2020/>

54. S-LAB contact request, n.d. <https://aitiopaikka.s-kanava.fi/answer?restartApplication&brand=sok&survey=E315940BDA1EC6CCC0EE7A2160C6EF56>

55. Concito, n.d.

56. Luke, n.d. https://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE_04%20Metsa_04%20Talous_02%20Teollisuuspuun%20kauppa_02%20Kuukausitilastot/

In Finland, it should be possible to develop some estimates of changes in carbon sinks based on the marginal impact of roundwood sales in a certain area at a monthly basis⁵⁷. This would be based on detailed sales statistics and background data on which kind of a forest that the wood probably originated from and what its impact will be on the forest growth and product lifetime. This would require further model development. Such a task becomes more complex, if one tries to model ground carbon storages and sinks in addition to those of the trees.

3.5.7 Point source industrial emissions

Today, larger industries are required to report on their CO₂ emissions, biogenic and fossil separate, as well as other air pollutants. The exact requirements depend on national regulations as well as if the industry is subject to reporting obligations under the European Union Emission Trading Scheme (EU-ETS). There are currently no requirements to provide continuous monitoring of CO₂ emissions, which is the case for some other pollutants if certain criteria are met.

For industries using a single fuel at a time, biogenic and fossil CO₂ emissions are calculated from fuel input.

For industries that use mixed fuels, such as district heating plants based on waste incineration and biomass, the situation is more complex. The proportion of fuels and the origin of carbon, biogenic or fossil, that are fed to incineration can vary (more or less) continuously in order to optimise production depending on the fuel's water content and calorific value, and waste can in itself be quite heterogeneous. One way of measuring biogenic and fossil CO₂ emissions is to do it according to the ISO-standard 13833:2013. Since January 2013 equipment has been installed in nine incinerator lines operating at five waste incineration plants in Denmark, and in nine incinerator lines operating at five waste incineration plants in Sweden to get monthly and bi-monthly readings of the biogenic and fossil CO₂ emissions⁵⁸. Current cost level is roughly about 24 000 € per oven line and year with monthly sampling and increasing this to daily sampling would add significant extra cost (personal communication). The samples are currently being analysed in a lab. Therefore, daily measurement would be of little use when it comes to nowcasting, since there would be up to a few days delay before the samples are analysed.

Another technology that might be possible to develop to use on-site is the combination of gas chromatography and mass spectrometry (so called GC/MS) (personal communication). In theory this could provide real-time monitoring of CO₂ and the fossil/biogenic component along with other gases of interests.

There are relatively few large point-source emitters of CO₂. Monitoring merely 60 facilities in Sweden would capture more than 80% of Sweden's industrial emissions and in Finland 30 facilities stand for 80% of the emissions within the EU-ETS⁵⁹.

57. Luke, n.d. https://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__04%20Talous__02%20Teollisuuspuun%20kauppa__02%20Kuukausitilastot/

58. Fuglsang, Pedersen, Mathiasen, Henriksson, & Viberg, 2016

59. The fraction of large facilities was calculated based on the 2021 data from the files at this web page <https://energiavirasto.fi/en/frontpage>

4 Discussion and recommendation

In surveys and discussions held during this project, with representatives from authorities and policymakers, some respondents found it important to have near-real-time estimates of the GHG or CO₂ emissions, while others said that annual emission statistics is sufficient because the current policy cycle does not really demand more up-to-date information. As such, it seems that the current challenge is two-fold: there is a need to develop better emission monitoring/reporting methods, but there is also a need to develop policy processes that could harness that information and be more responsive to the progress (or lack thereof) of climate actions and emission levels. Improving only one of these will not lead to significant changes in policy responsiveness.

This project has not analysed policy practices or capabilities to make use of nowcasting data. However, based on what was found in the project it seems that the development of new methods for nowcasting are rarely interacting with the development of policy practices and tools to analyse the data and its policy implications. For example, how should policy makers utilise the hourly data of electricity production (by production type) and consumption, which are available on at least country level in Europe? Here, the policy processes in the Nordic countries have not shown large activity in answering such questions.

However, the value of a particular piece of information is not in its absolute precision, but in its ability to differentiate between two policy options. An uncertain piece of socioeconomic data is valuable, if it can show that a coal-fired power plant can be shut down if energy poverty is actively managed, in comparison of doing nothing. But the value is decision-specific, as for another decision that data would be irrelevant. Therefore, absolute accuracy is not a good metric for the value of information. Also, the value of information is context specific. This emphasises the importance of open data, as then there will be more opportunities for using a piece of data in a useful way.

A specific, but in this case relevant policy instrument is the use of carbon budgets as climate goals. Using carbon budget goals gives a total amount of global emissions that should not be exceeded, and as a result emphasises the importance of rapid, persistent, and coherent actions. Carbon budgets are currently used by the UK and France at the national level, and at local level by approximately a hundred municipalities and regions in the UK and Sweden. Setting carbon budget targets requires deducting emissions from the budget continuously. If this policy instrument becomes more widely used, this may result in an increased interest for both more timely and higher frequency statistics.

As shown in chapter 3 the possibility to develop near-real-time estimates differ in different sectors, as relevant data is more easily available, for example, for electricity consumption than for food consumption. The focus among policymakers in the Nordic countries is currently on the annual emission inventories, which have delays from a few months to more than a year. However, there are several initiatives that

generate near-real-time estimates of CO₂ emissions. These can roughly be divided into three groups (see section 3 and Appendix 2).

- First, the most straightforward methods monitor fuel or energy consumption and calculate emissions by using emission factors. These include the Global Carbon Project (GCP) and Electricity Map.
- Second, there are several initiatives using satellite data (often in addition to or supplementing more traditional data sources) to estimate local CO₂ emissions. These include Climate TRACE, Carbon Monitor Project, and Open-source Data Inventory for Anthropogenic CO₂ (ODIAC). It seems like these initiatives are becoming more common and producing more accurate estimates. This project has not specifically looked for methods of artificial intelligence or machine learning because those are highly sector-specific and require extensive datasets to be trained.
- Third, there are initiatives with a research or experimental focus, using new kinds of data sources. Examples are projects that are looking at, for example, transportation mode identification and real-time CO₂ emission estimation using smartphones; or real-time traffic CO₂ emission estimation based on intelligent transportation system technologies.

4.1 Recommendations and further work

To make recommendations based on the findings from this project we see a need to define multiple problems that need to be solved. The perceived need for this being more clearly defined has increased during the project, likely because of a gradually better understanding of what is available in terms of methods and data. A possible overarching problem description could be that current emission statistics is not accessible, accurate or timely enough, hindering the necessary climate transition. This is akin to the saying "What gets measured gets managed"⁶⁰.

When it comes to the *agent* that is supposed to act on this information this could be politicians, public servants (policy makers and bureaucrats), businesses, NGOs, and the public, to name a few⁶¹.

Suggestions could be placed across a scale ranging from focussing on "to dig deeper into analysing and understanding how different actors would benefit from "better" emission statistics and how that would support the climate transition" to "to assume that better climate statistics will create new opportunities and initiatives." Probably activities combining the two would be the most effective. This could be achieved by co-creation between the users of data (agents above) and the producers of the data.

It should be noted that there exist a lot of research in the field of what is needed to mitigate climate change which is outside the scope of this project. A starting point into this field can i.a. be found reading about the terms "Information deficit model", "Cultural cognition" and "Low-information rationality" on Wikipedia.

Based on the findings from this project the following three main areas for further work is suggested:

60. Rewritten from William Thomson, Lord Kelvin

61. Mazzucato, 2021

Further analysis of the need and possibilities for nowcasting

The possibilities to develop nowcasting could be further analysed in more detail than what has been the case in this project. Useful nowcasting is dependent on accurate and timely enough data that fits for the purpose. This could be further analysed in desk studies by outlining use cases and developing suggestions based on these cases.

In the development of methods for nowcasting it is important that there is a clear understanding of what timely emission estimates will be used for, as the use case will influence the choice of method. For example, using historic correlations between various activities and processes and CO₂-emissions can result in more timely estimates, but it will miss emission changes that are due to a climate action that changes these correlations. To ascertain that this happens, policy makers searching for near-real-time emissions data needs to be actively involved in projects developing methods for nowcasting, as the development of such methods are highly dependent of how the output of the method is supposed to be used.

Also, the development toward better nowcasting of GHG emissions needs to start off, in a step-by-step procedure, from the easiest possible sector. In this way, it is possible to have a simultaneous progress in sectors where a large part of emissions come from electricity and fossil fuel consumption, even if some other sectors, such as consumer products, food consumption and waste management will require more time and development resources. Also, in most sectors, there will be a trade-off between timeliness and accuracy.

Finally, it is important to perform an in-depth study of each possible method, to better understand its accuracy as well as administration costs related to gathering and processing the data. For some methods it might only be a matter of making use of already existing data, visualising it in ways possible for policymakers to understand.

Instigate a climate policy lab

Due to the complexity of overviewing and communicating the need and the possibilities for nowcasting data we suggest instigating a Nordic climate policy lab. This could be organised as a project, and carried out together with Nordic innovation agencies and actors. The task should be to bring together users of emissions statistics with those producing it. Likely related topics are the use of advanced data science and machine learning (AI) and activities could include hosting 'Hacks'⁶². Further it should also look at nowcasting from a system perspective, addressing the need for approaching the challenge with technical solutions, enabling legislation, policy incentives, and social aspects to name a few.

This suggestion is in line with using design thinking methodology for system change.

62. see e.g. Hack for Sweden (DIGG, n.d.)

Create a portal collecting available emission statistics

Currently it is quite a complex task to overview available emission statistics. Gathering existing emission statistics, easily and openly available, at one place would make it possible for a broader range of actors and individuals to access available statistics. This could either result in actors finding that available data already is sufficient, or result in a demand for improved statistics. The portal could also host a discussion forum to facilitate collaboration⁶³. This could be organised in collaboration between actors tracking national climate mitigation progress⁶⁴. If the portal would be governed by representatives from actors responsible for emission statistics in the Nordics, this would also provide an arena for the development of new projects. The portal could also include explanatory texts clearly describing the current generation of climate statistics.

To ascertain long term availability of time series as well as the potential for the portal to support innovation, ownership and user licenses of the data is a key issue to pay attention to. There is a strong trend toward both national and international demand for publicly funded projects to provide data and tools openly and open-source and under licenses that makes it easy to design other services and applications on top.

63. compare e.g. with the Swedish National Agency for Public Procurement's questions forum (Upphandlingsmyndigheten, n.d.)

64. Nordic EPA's, equivalents to the Swedish Policy Council

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Appendix 1: List of emission estimate methods per sector (community level)

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Who implements the method?</i>	ETC/CME (Climat Mitigation and Energy)	Statistics Denmark	Statistics Sweden	Finnish Environment Institute
<i>For which countries/regions?</i>	EU-27 MS + IS, UK, NO, TR, CH	Denmark	Sweden, national level	Finland, municipality level
<i>Reporting required by law?</i>	Yes: Regulation (EU) 525/2013	No	No	No
<i>Who makes use of the results?</i>	EEA and member countries governments	Various - government departments, consultants etc.	Anyone; openly and available for government departments, consultants etc.	Municipalities at varying degrees
<i>For what?</i>	Checking progress against commitments. Especially for following difference between progress in sectors covered by Emisions Trading Scheme and those not covered by the scheme including mobile sources (transport).	They have no official use but can be used in analyses of climate and environmental economic issues, including investigating the drivers for developments in greenhouse gas emissions and other air pollutants.	They have no official use but can be used in analyses of climate and environmental economic issues, including investigating the drivers for developments in greenhouse gas emissions and other air pollutants.	Visualize emissions, test different scenarios by changing activities by pulling sliders.

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Publish date</i>	September 30th (countries submitting own estimates must do this by 31st July).	Mid September	The preliminary year is simply the sum of the quarterly air emissions accounts produced at Statistics Sweden. Emissions from stationary sources are based on quarterly energy surveys. Emissions from mobile sources likewise. Industrial processes and product use are based on legally-mandated environmental reports or emissions inventories related to the the European emissions-trading scheme and compiled by Swedish Environmental Protection Agency. Emissions from agriculture are drawn from the previous year.	Annually, in spring
<i>Timelag of reporting (publish year, t minus data year)</i>	t-1 (e.g. 9 month delay at point of publishing)	t-1 (e.g. 8.5 month delay at point of publishing)	Production time for Environmental Accounts' annual final statistics on emissions to air is currently one and a half year. To more quickly provide access to statistics, Environmental Accounts has therefore published regular quarterly statistics since 2015 on Swedish economic actors' greenhouse gas emissions and air pollution. Production time for the statistics is approximately four months after the end of the previous quarter.	Pre-estimate around 6 months after the end of reporting year; final estimate around 15 months after.

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Background</i>	Provides an early estimate of the GHG emissions for the preceding year. Estimates are referred to as approximated ('proxy') estimates or inventories as they cover the year for which no official GHG inventories have been prepared. Member States are responsible for the methodological choice regarding their own estimates. Should a Member State not provide their own proxy emission estimate, the EEA produces and uses gap-filled estimates in order to have a complete approximated GHG inventory for the European Union. Non-EU member countries of the EEA are invited to submit their proxy estimates on a voluntarily basis. All Nordic countries provided their own estimates so EEA gap-filling not needed for these countries.	The Danish air emissions accounts (Emissionsregnskabet) are an annual statement of emisisions of greenhouse gases and other air pollutants calculated in tonnes. The statistics are reported by industry. The structure of the emission accounts means that the information can be used immediately for analyses of the connection between economic activities described in the national accounts and related environmental pressures. The statistics are disseminated in Statistics Denmark news and via the StatBank database. The Emission Accounts are consistent with the official emission inventories reported to the United Nations Framework Convention on Climate Change (UNFCCC) Accounts up until t-2 are based on detailed reporting by industry. The final year (t-1) is nowcast.	All of Sweden's various economic actors need to reduce their greenhouse gas emissions if the target for Sweden to have no net greenhouse gas emissions by 2045 is to be met. Good quality and up-to-date data is needed to monitor this environmental policy objective as well as others, and to analyse developments in different parts of Sweden's economy. Quarterly statistics make it possible to monitor current emissions trends. The Environmental Accounts are compiled within the framework of the System of Environmental and Economic Accounts (SEEA) and show.	The purpose of the model is to offer municipalities possibilities to view their emissions and historical trends and study future scenarios by adjusting relevant variables such as energy renovations of buildings or transport modes. The model covers all of Finland and its municipalities. Annual CO₂e emissions, energy consumption, and vehicle mileages (depending on sector) are available for years 2005–2020. Sectors include transport, buildings, industry, waste, and agriculture.

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Short description of the nowcasting method</i>	For gap filling in non-reporting countries, the EEA used EU Emissions Trading Scheme data and Eurostat CO₂ emissions from energy use estimates to carry forward reported emissions from energy and two key industrial processes sectors: the mineral industry and the metal production and processing industry. These two source categories typically account for the bulk of emissions and have the largest annual change. For energy subsectors, the previous year CO₂ value from each Energy subsector was multiplied by the percentage change of CO₂ emissions from energy use between the proxy year and the previous year as given in the Eurostat CO₂ emissions estimates. To estimate CO₂ emissions from the Mineral industries and CO₂, CH₄ and N₂O emissions from the Metal industry, the % change in economic output of each of the sectors at 2-digit NACE level is multiplied by the t-2 reporting year for those sectors For all other sectors, emisisions were assumed to have stayed constant since official reporting year (t-2). The estimates assume no change in emission factors or methodologies as compared to the latest official inventory submissions to the UNFCCC for the year t-2. All emissions of fluorinated greenhouse gases (HFCs, PFCs, SF₆ , NF₃) were assumed to have stayed constant since the previous year	The nowcasting of the final year primarily makes use of energy statistics that are released in mid June for the previous year (t-1). These are provided in GJ of use of various fossil fuels used by each of the 21 sectors. The emissions coefficients for each fuel (tonnes CO₂ emissions per GJ energy released) and combusting sector are based on the reported coefficients from the previous year. For non-energy-related emissions, other sources are used: For emissions from animal husbandry, data is used on the % change in numbers of cows and pigs between t-2 and t-1, multiplied by emissions of Methane and N₂O from the husbandry of these two animals respectively (direct emissions from animals and indirect emissions from the break-down of manure). Non-energy-related CO₂ is emitted during cement production during the the conversion of calcium carbonate (CaCO₃) to lime (CaO). Estimates for the t-1 year of cement production are based on percentage change in the production index for the cement and brick industries. The production index is based on production turnover deflated by the producer price index to obtain an implicit volume index. Other process industries are assumed to have the same emissions as the previous year (t-2).	Calculations include emissions to air by economic activity that takes place in Swedish territory and by transactions across Sweden's borders. Emissions to air are reported by industry, based on the Swedish Standard Industrial Classification (SNI2007, mirroring NACE Rev. 2) and by the public sector non-profit organisations and households (private consumption). Aggregation of industries is selected to conform with the National Accounts' quarterly reporting. Statistics are also summarised to large aggregated industries and as a total. The emission factors are the same as those used in annual emissions to air in the environmental accounts, that is, emission factors used in the environmental accounts are also used in national emissions statistics reported to the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Long Range Transboundary Air Pollution (CLRTAP).	The calculation method of the ALas model is usage-based. The region's production-based emissions act as the starting point, but some operations that generate emissions are calculated based on consumption, regardless of their geographical area of origin. In broad terms, the calculation is similar to the basic level of GHG Protocol's GPC standard, with agriculture, F-gases and grid losses included, but without the local air service included in the standard.

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Link to report(s) describing methods (and results)</i>	https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-1-2020-approximated-eu-greenhouse-gas-inventory-proxy-ghg-emission-estimates-for-2019	https://www.dst.dk/da/Statistik/dokumentation/statistikdokumentation/emissionsregnskab/indhold	https://www.scb.se/contentassets/797953d717504529abc11691d6ba3652/mi1301_2008i14_br_mi71br1604eng.pdf	https://hiilineutraalisuomi.fi/en-US/Emissions_and_indicators/Municipalities_and_regions_greenhouse_gas_emissions/Calculating_the_greenhouse_gas_emissions(56552)
<i>Which emissions included?</i>	total GHG emissions without LULUCF	CO ₂ , CH ₄ and N ₂ O	Total GHG emissions. Direct emissions by Swedish economic actors are reported here, no matter where in the world the emissions occur. This means that emissions from international bunkering, that is, aviation and shipping that entered and filled their tanks at Swedish airports and harbours are included. Emissions and removals from land use, land use change and forestry and carbon capture and storage are not included. The Swedish Environmental Protection Agency's statistics on emissions to air present territorial emissions, that is, emissions within Sweden's borders. Sector breakdown is based on the emission type rather than on the industry. Emissions and removals from land use, land use change and forestry are included, while emissions from international transport are reported separately. Thanks to the connection with the National Accounts, annual statistics on emissions to air in the environmental accounts are used to produce estimates with the help of model calculations and input-output analysis on Sweden's consumption-based emissions (or final use according to the National Accounts). The information is produced by environmental accounts at Statistics Sweden, for instance on commission by the Swedish Environmental Protection Agency.	Greenhouse gases considered are CO ₂ , N ₂ O, and CH ₄ ; and total F gases without sector-specific values. Biofuel emissions are assumed to have zero-emissions for CO ₂ ; other gases are based on their actual emissions.

Name	EEA Proxy GHG emission estimates	Danish air emissions accounts according to SEEA	Environmental Accounts (SCB)	ALas model (Finland)
<i>Emission categorisation</i>	Compiled on the basis of the Member States' approximated greenhouse gas inventories.	Economic per sector, see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)_AND_https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE_REV2&StrLanguageCode=EN	Quarterly emissions of greenhouse gases broken down by different aggregated industries, starting with agriculture, forestry and fishing, followed by manufacturing industry, electricity, gas and heating plants, service industries, public sector, and finally households and non-profit institutions.	ALasPre reports 17 subsectors with a three-level hierarchy, while ALas reports 75 sectors with two additional levels of hierarchy. The sectors mostly follow the GPC categories.
<i>Results differentiated by sector?</i>	Yes – also differentiation is made between sources that are covered by the ETS and those that aren't.	Yes at 20 branch level - this roughly relates to the 21 single digit NACE sectors except that L is divided into two 2-digit sectors – LA and LB – and U and X are omitted as not being relevant.	Based on the Swedish Standard Industrial Classification (SNI2007, equal to NACE Rev. 2)	Yes – also differentiation is made between sources that are covered by the ETS and those that aren't.
<i>Sectors NOT included in overall emissions</i>	International aviation		Emissions and removals from land use, land use change and forestry and carbon capture and storage are not included.	Aviation, shipping abroad, industrial processes, LULUCF, and icebreakers

Appendix 2: Desk study – real time monitoring of CO₂-emissions

The table below presents the results of a brief desk study of real time monitoring of CO₂-emissions.

Search string applied: Real time CO₂-emissions / carbon emissions

Overall, three types of approaches have been identified.

- Energy calculation
- Satellite data/sensors
- Other more 'innovative' approaches to estimate sector emissions.

Project	Project owner	Motivation	Data source	Method	Indicator	Results
ALasPre model (Finland)*	Finnish Environment Institute.	Development of methods for more rapid emission estimates.	Aviation, shipping abroad, ice breakers, industrial processes, LULUCF sector.	ALasPre in many respects has the same functionalities as the ALas model used by the Finnish Environment Institute. The key differences are: Electricity consumption is estimated based on a regression model using these independent variables: a) floor area of different types of buildings, b) population size, floor area of greenhouses, c) heating consumption factor (based on the climate conditions of the municipality), and d) electricity consumption of different sectors the year before.	Not identified	Estimates are available before the official emission estimates, so this is closer to nowcasting than the more precise ALas model.
Climate TRACE (Tracking Real-time Atmospheric Carbon Emissions) (Climate TRACE, 2021)	A partnership of various organisations. Google is a key sponsor, and Al Gore is one of the founders.	"Status quo GHG inventories are often many years out of date, contain gaps, have high levels of uncertainty, are high level and not localised, and are fragmented and not comprehensive." Climate TRACE will deliver more accurate, detailed and real-time data.	Public and private satellite data and remote-sensors, as well as additional not transparent data i.e., "government sources, corporate disclosure forms, Satellite Automatic Identification System (S-AIS) maritime vessel locations, and other sources". Constantly searching for more data.	AI and machine learning are applied to analyse GHG emissions from satellite imageries around the world/ across sectors looking into where assets are located, when emission-causing activities take place and the amount of emissions.	Ton CO ₂ -eq (monthly basis) + various associated indicators, being country or sector specific.	CO ₂ inventory launched in September 2021

* (SYKE, 2021)

Project	Project owner	Motivation	Data source	Method	Indicator	Results
Glasgow air-quality monitoring project (University of Strathclyde Glasgow, 2021)	The project is being led by the University of Strathclyde as part of the Global Environmental Measurement and Monitoring Initiative (GEMM, n.d.), an international project of Optica (formerly OSA and AGU). See also BEACO ₂ N Monitoring Network**	Better informed policy making.	25 low-cost sensors that can measure greenhouse gases (GHGs) and air quality gases including carbon dioxide (CO ₂), carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO ₂), ozone (O ₃) and particulate matter (PM) in real-time have been installed in Glasgow.	Measuring of GHG and air quality with low-cost sensors.	Not identified	Real-time measurement of CO ₂ , carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO ₂), ozone (O ₃) and particulate matter (PM) in Glasgow.
The Global Carbon Project (GCP) (M.Andrew, 2021)	The Global Carbon Project is a Global Research Project of Future Earth and a research partner of the World Climate Research Programme. It was formed to work with the international science community to establish a common and mutually agreed knowledge base to support policy debate and action to slow down and ultimately stop the increase of greenhouse gases in the atmosphere.	The Global Carbon Project (GCP) integrates knowledge of greenhouse gases for human activities and the Earth system. The projects include global budgets for three dominant greenhouse gases — carbon dioxide, methane, and nitrous oxide — and complementary efforts in urban, regional, cumulative, and negative emissions. Aiming towards near real-time, monthly fossil CO ₂ emissions.	Observational data on the consumption of solid, liquid, and gaseous fossil fuels for each country in the EU and conversion of those to CO ₂ emissions using standard emission factors. Monthly production and consumption data for all three fuels are provided by Eurostat with a relatively low lag. For coal, however, these data had an unsatisfactory lag in several important countries, so a parallel approach was developed using data on electricity generation and steel production.	Estimates total fossil CO ₂ emissions, built up in the same way as the Global Carbon Budget, from estimates of the three major fossil-fuel groups – coal, oil, and gas – and emissions from carbonate decomposition in cement production.	Not identified	Several important errors have been discovered in the sub-annual emissions estimates for both oil and coal, while the method used for monthly emissions from natural gas worked very well.

**<http://beacon.berkeley.edu/about/>

Project	Project owner	Motivation	Data source	Method	Indicator	Results
Carbon monitor project (Dou, et al., 2022) & (CarbonMonitor, n.d.)	Led by Tsinghua University, LSCE and UCL.	Corona – and the aim of capturing daily variation in emissions due to factors such as lock lockdowns, drops in production and change in behaviour.	Global Gridded Daily CO ₂ Emissions Dataset (GRACED) from fossil fuel and cement production with a global spatial resolution of 0.1° by 0.1° and a temporal resolution of 1 day. GRACED is made up by the spatial patterns of point source emission dataset Global Energy Infrastructure Emissions Database (GID), Emission Database for Global Atmospheric Research (EDGAR), and spatiotemporal patterns of satellite nitrogen dioxide (NO ₂) retrievals.	Assessment of maps and disaggregation between countries and sectors incl power, industry, residential consumption and ground transport, aviation, shipping sectors.	Unit of kilograms of carbon per day per cell from which daily averages and sectoral yearly emissions are calculated.	The overall uncertainty range of Carbon Monitor is ±7.2% = lower accuracy.
Electricity Map (electricityMap, n.d.)	Since 2016, electricityMap's open-source visualization has been used by millions of people, from students to world leaders, to understand the climate impact of global electricity use.	ElectricityMap believe information precedes action. As such, to push changes regarding electricity emissions, people need to understand them.	For Europe, Electricity map makes available data from the ENTSO-E platform holding information about real-time electricity production emissions.	Not identified	(gCO ₂ eq/kWh)	Actionable data quantifying how carbon intensive electricity is on an hourly basis across 50+ countries. The data can be accessed historically, in real time, or as a forecast for the next 24 hours. You can also explore the real time data on the electricityMap app.

Project	Project owner	Motivation	Data source	Method	Indicator	Results
Open-source Data Inventory for Anthropogenic CO₂ (ODIAC n.d.)	A global high-resolution emission data product for fossil fuel carbon dioxide (CO ₂) emissions, originally developed under the Greenhouse gas Observing SATellite (GOSAT) project at the National Institute for Environmental Studies (NIES), Japan.	Accurately quantifying emissions and their impact on the Earth System is a fundamental task in Earth System Science. One of the key questions to be sought by ODIAC was to understand the sizes and locations of carbon sources and sinks. Since the 1950s, the community has tackled this question using atmospheric observations, and later computer modelling. In the last decade, the community has begun observing CO ₂ from space more broadly and frequently in order to increase the capability to study the carbon cycle.	Geospatial proxies such as satellite observations of night-time lights are related to emission data relating to geolocations of major power plants (Carbon Monitoring for Action list).	ODIAC pioneered the combined use of space-based night-time light data and individual power plant emission/location profiles to estimate the global spatial extent of fossil fuel CO ₂ emissions.	Monthly CO ₂ emissions on a 1-km grid for the period 2000 to 2019, as of today, including emissions from powerplant, transportation, cement production/industrial facilities, and gas flares over land regions.	With the innovative emission modelling approach, ODIAC achieved a picture of global fossil fuel CO ₂ emissions at a 1x1km. As seen in several publications in the literature, the ODIAC emission data product has been widely used by the international research community for a variety of research applications (e.g., CO ₂ flux inversion, urban emission estimation and observing system design experiments).

Project	Project owner	Motivation	Data source	Method	Indicator	Results
The Community Emissions Data System (CEDS) *** / Climate Model Inter-Comparison Program (CMIP6) (WCRP, 2020)	The CEDS is an education data management initiative. CMIP is a project of the World Climate Research Programme (WCRP)'s Working Group of Coupled Modelling (WGCM). Over the last decades, significant progress has been made in model evaluation. The CMIP community has now reached a critical juncture at which many baseline aspects of model evaluation need to be performed much more efficiently to enable a systematic and rapid performance assessment of the large number of models participating in CMIP. Such an evaluation system will be implemented for CMIP6. CMIP's central goal is to advance scientific understanding of the Earth system.	The purpose of CEDS is to streamline the understanding of data within and across P-20W institutions and sectors. The initial goal for CMIP is that two capabilities will be used to produce a broad characterization of CMIP DECK and historical simulations as soon as new CMIP6 model experiments are published to the Earth System Grid Federation (ESGF).	CEDS is a toolkit for data mapping. Since 1995, CMIP has coordinated climate model experiments involving multiple international modelling teams worldwide.	Resolution of up to 0.1°, including sectors of energy transformation and extraction, industry, residential, commercial, transportation, agriculture, solvent production and application, waste, shipping, and other	Not identified	CMIP has led to a better understanding of past, present and future climate change and variability in a multi-model framework. CMIP defines common experiment protocols, forcings and output. CMIP has been developed in phases, with the simulations of the fifth phase, CMIP5, now completed, and the planning of the sixth phase, i.e. CMIP6, well underway. CMIP model simulations have also been regularly assessed as part of the IPCC Climate Assessments Reports and various national assessments.

*** https://www.epa.gov/sites/default/files/2017-11/documents/community_emissions.pdf

Project	Project owner	Motivation	Data source	Method	Indicator	Results
Emission Database for Global Atmospheric Research (EDGAR) (European Commission, n.d.)	The current development of EDGAR is a joint project of the European Commission JRC (Joint Research Centre) and the Netherlands Environmental Assessment Agency (PBL) . and the Netherlands Environmental Assessment Agency (PBL) (PBL, n.d.) .	EDGAR is a multipurpose, independent, global database of anthropogenic emissions of greenhouse gases and air pollution on Earth.	EDGAR provides independent emission estimates compared to those reported by European Member States or by Parties under the United Nations Framework Convention on Climate Change (UNFCCC), using international statistics and a consistent IPCC methodology.	1) Calculation of emissions using a technology-based emission factor approach consistently applied for all world countries. 2) Consistent set of activity data for calculating various substances, greenhouse gases and air pollutants, important for UNFCCC, CLRTAP and the co-benefits of air quality and climate policies.	EDGAR provides both emissions as national totals and grid maps at 0.1 x 0.1-degree resolution at global level, with yearly, monthly and up to hourly data.	Emissions are calculated for the following substances: Direct greenhouse gases, Ozone precursor gases, Acidifying gases, Primary particulates, Mercury and Stratospheric Ozone Depleting Substances.
The Global Carbon Grid (GID, n.d.)	The Global Infrastructure Emission Database (GID) is a unit-level dataset of CO ₂ - and air pollution-emitting infrastructure worldwide, developed and maintained by Tsinghua University, China since 2020.	It is designed to provide open access to uniform, high-quality, and up-to-date data for scientific research, policy assessment, and climate and environmental management. GID is thus a powerful tool to track global infrastructure changes for research on climate change and air pollution issues worldwide.	Based on multiple data flows, including point sources, country-level sectoral activities and emissions, and transport emissions and distributions.	The Global Carbon Grid is built upon a framework that integrates multiple data flows including point sources, country-level sectoral activities and emissions, and transport emissions and distributions, all of which will be updated regularly on an annual basis to provide the most up-to-date global emission maps.	Provides global 0.1° x 0.1° CO ₂ emission maps of six source sectors: power, industry, residential, transport, shipping, and aviation in 2019.	The Global Carbon Grid establishes high-resolution maps of global CO ₂ emissions from fossil fuel combustion and cement production, which aim to provide accurate anthropogenic CO ₂ emission maps for modelling (forward and inverse), monitoring, and designing mitigation strategies.

Project	Project owner	Motivation	Data source	Method	Indicator	Results
eCO₂mix - All of France's electricity data in real time (RTE, n.d.)	Rte. France's transmission system operator.	To help consumers better understand and more effectively consume electricity.	Consumption of primary fuel used on power plants located in France. Includes cross-border electricity trading.	Tracks all of France's electricity data in real-time.	CO ₂ -emission/kWh of electricity generated in France	Monitoring of power generation by energy source in France.
Fingrid (FINGRID, n.d.)	Fingrid Oyj is Finland's transmission system operator owned by the Finnish state and Finnish pension insurance companies.	Their mission is to secure the supply of energy in our society in all circumstances and to promote a clean, market-based power system.	Real-time production and import/export data from Fingrid's operation control system as well as specified emission coefficients.	The emissions from Finnish electricity production are obtained by adding up the product of the coefficient and production volume of each form of production and dividing this sum by the total electricity production in Finland (Formula I). The emissions from the electricity consumed in Finland are calculated by considering Finnish electricity production, the import of electricity into Finland and the export of electricity from Finland to other countries (Formula II).	Not identified	Real-time CO ₂ emissions estimate from Fingrid's transmission system for electricity.

Project	Project owner	Motivation	Data source	Method	Indicator	Results
Transportation mode identification and real-time CO ₂ emission estimation using Smartphones (Manzoni, et al., n.d.)	A research project including SENSEable City Lab in Sweden, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, and Dipartimento di Elettronica e Informazione, Politecnico di Milano, Milan, Italy.	In a context where personal mobility accounts for about two thirds of the total transportation energy use, assessing an individual's personal contribution to the emissions of a city becomes highly valuable. Prior efforts in this direction have resulted in web-based CO ₂ emissions calculators, smartphone-based applications, and wearable sensors that detect a user's transportation modes. Yet, high energy consumption and ad-hoc sensors have limited the potential adoption of these methodologies. This is what the project wants to change.	Inertial information gathered from mobile phone sensors.	The method estimates in real-time the CO ₂ emissions, using inertial information gathered from mobile phone sensors. An algorithm then automatically classifies the user's transportation mode into eight classes using a decision tree. The algorithm is trained on features computed from the Fast Fourier Transform (FFT) coefficients of the total acceleration measured by the mobile phone accelerometer.	Not identified	A working smartphone application for the Android platform has been developed and experimental data have been used to train and validate the proposed method.
Estimating Real-Time Traffic Carbon Dioxide Emissions Based on Intelligent Transportation System Technologies (Chang, et al., 2013)	A research project using a bottom-up vehicle emission model to estimate real-time CO ₂ emissions using intelligent transportation system (ITS) technologies.	Not identified	In the proposed model, traffic data that were collected by ITS are fully utilized to estimate detailed vehicle technology data (e.g., vehicle type) and driving pattern data (e.g., speed, acceleration, and road slope) in the road network.	The road network is divided into a set of small road segments to consider the effects of heterogeneous speeds within a road link. A real-world case study in Beijing, China, is carried out to demonstrate the applicability of the proposed model. The spatiotemporal distributions of CO ₂ emissions in Beijing are analysed and discussed.	Not identified	The results of the case study indicate that ITS technologies can be a useful tool for real-time estimations of CO ₂ emissions with a high spatiotemporal resolution.

Monitoring requirements

"Initial estimates of annual global carbon dioxide (CO₂) emissions are generally delayed by some months as data must be gathered from numerous sources and then verified. For the European Union (EU), 'early estimates' are published by Eurostat – the statistical office of the European Union – in May of the following year (Eurostat, 2020) . EU member states must report by the 31st of July approximate emissions inventories for the previous year (Y-1), but any methodological revisions are not applied to earlier years, and these are generally not made public before October. By 15th of January member states must report preliminary emissions inventories for all years through Y-2, and by the 15th of March final emissions inventories for all years through Y-2 (EU, 2018). These last reports are made public on the 15th of April when they are published by the United Nations Framework Convention on Climate Change (UNFCCC)." (M.Andrew, 2021)

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