# Design of a household emissions calculator

## Who is the calculator for?

Any emission calculator has to make a trade-off between usability and complexity. The calculator in this document is aimed at the *average* Norwegian *household* with the goal of giving consumers an understanding of how their daily lives generate greenhouse gas emissions. Some will find the calculator lacks detail, others will find the calculator far too complex. We have strived to strike a balance and as always this will undoubtedly leave some users disappointed. Before giving the calculator harsh judgments, please take the time to understand the intended audience and the compromises that this entails.

The calculator is focused solely on greenhouse gas emissions and global warming and does not cover other very relevant environmental impacts. We have used hybrid Life-Cycle Assessment to estimate household emissions using data from a variety of sources. Often better data may exist, but we have strived to do our best in the time available. We have covered all areas of household consumption and have not focused on any particular area.

## Who is this document for?

As with the calculator, this document is a compromise. Our aim is to provide an overview of the data and methods in the calculator without going into specific details which could take years to write. In most cases we have taken data from published sources, so before critiquing the calculator please read the referenced documentation.

## Overview of the calculator

There are many greenhouse gas emission calculators available on the internet, but they often provide conflicting emission estimates [*Kollmuss and Lane*, 2008; *Murray and Dey*, 2007]. The differences usually arise from variations in methods, definitions, system boundary, desired application, and so on. To some degree, differences are expected between calculators since they have different objectives, but it is important that the emission estimates are verifiable and comparable.

We decided that the calculator should include indirect emissions in the production of products and consequently be based on Life-Cycle Assessment (LCA). There are different methods of doing LCA and these can be classified as top-down or bottom-up approaches:

- **Bottom-up approaches** use detailed and specific activity estimates and from these build up an estimate of emissions. Greater detail is provided, but at the expense of full coverage.
- **Top-down approaches** start in the opposite direction and take a grand overview of the system and then allocate emissions to specific activities. Greater coverage and completeness is obtained, but at the expense of less specific detail.

To take advantage of both approaches, hybrid methods can be used [*Minx et al.*, 2007]. In this report we will use a hybrid approach by dividing the calculator into Level I (top-down) and Level II (bottom-up):

- **Level I**: Gives an overview of the emissions of a household or person based on simple socio-economic data such as income, household type and so on. The socio-economic data is used to estimate activity levels based on the survey of consumer expenditure (SCE) from Statistics Norway and a global emission model is then used to estimate the emissions based on the activity data.
- **Level II**: Provides more specific bottom-up detail on the emissions from specific activities such as transportation, housing, food consumption, and so on. More detailed activity data is used to estimate emissions.

The level structure of the calculator offers many advantages in designing a calculator as it gives the user a quick estimate of their emissions and provides them the opportunity to zoom into areas of interest to obtain more detail and information.

## Logic of the calculator

You can choose to account your personal emissions, or you can choose to account the emissions of your household.

In many respects, consumers behave on behalf of a household. For example, if a family lives together then they will generally buy food for each other and not food individually. Expenditure on clothes may be for their children and not for their personal use. If a family lives in a house, they will share it and not live in separate parts of the house. In essence, Norway consists of 2.1 million households and not 4.7 million individuals. This is the rationale used in the calculator and this will deviate from what many people may expect.

The calculator begins by asking the user to enter the characteristics of their household. Based on the number of adults and children in the house and the net income, we estimate the activity level of the household using a variety of official statistics. These estimates, or "defaults", are to make the calculator more useable. The user is then free to adjust the defaults to their own particular household. To make this easier we have split the calculator into four core components which cover all the household emissions: household energy, transportation, food, and general consumption.

As a general rule, emissions are always calculated as follows:

Emissions = Activity Level * Emission Factor

For example, the Activity Level may be "driving 100km" and the Emissions Factor would be the emissions to drive one km. By combining the two gives the emissions for that specific activity. The calculator has a variety of options to enter the Activity Level such as number of km, number of trips, and so on. We internally do conversions to give the Activity Level and the Emission Factor consistent units.

The remainder of the documentation explains the Activity Levels and Emission Factors for the different parts of the calculator.

# Concept and design of the calculator

The concept of the calculator was developed by CICERO, NTNU, Misa and Netlife Research. The concept was tested in user tests and further developed, in order to make it as user friendly as possible still keeping the scientific correctness. The calculator gives the user an immediate response by showing a temporary emission number after typing in two types of information on page 1 (number of people and income). This emission number is based on consumption data for the average Norwegian consumer, and average consumption data is pre-filled in the calculator. From then on, the user can follow how this number changes when he/she adjusts and personalizes the consumption data.

The calculator design was developed by Netlife Research and Oslo kodebyrå (OKB). OKB did the programming of the calculator.

# Calculator Modules

The calculator is divided into four models which covers all the greenhouse emissions from an average household: household energy, transport, food, and general consumption.

## Transport (Main Responsible: TØI with input from MiSA and CICERO)

### Bicycle

We assume the greenhouse emissions to use and produce a bicycle are negligible in the context of the remainder of the calculator

### Cars

#### Activity Level

The average distance travelled by a Norwegian car in a year is 13300km (http://www.ssb.no/english/subjects/10/12/transpinn_en/tab-2008-06-25-01-en.html).

#### Emission Factor

Emissions are based on the following formulas:

Litres used = (Distance Travelled) * (Litres per kilometre)

Emissions = (Litres used) * (Emissions per Litre)

The default litres per kilometre was taken as 0.09L/km.

The emission factors for the different fuel types were (www.ecoinvent.org, http://www.ssb.no/nos_utslipp/nos_d312/tab/tab-8.html):

- Petrol: 2834,2 grams $CO_2$-eq per litre
- Diesel: 3099,6 grams $CO_2$-eq per litre

These numbers include both indirect and direct emissions related to production and combustion of these fuels. Therefore, the numbers are higher than for combustion only.

Indirect emissions must be added to these figures to cover production, maintenance and disposal for cars and roads: 31 g $CO_2$-eq per person-km (www.ecoinvent.org).

### Comment

Many will wonder why we did not include biofuels, electric cars, LPG, and so on. There are two key reasons. First, this calculator is for the *average* Norwegian household and we did not the majority of users to have to search a detailed list of options covering every conceivable option to propel a car. Second, although passionately debated, emission factors for different fuel-types and propulsion methods are debatable! For example, what electricity mix should we choose to charge an electric car (coal or hydropower) and our choice will certainly be critiqued. Likewise, where and how were the biofuels produced (which will either make them good or bad)? For these two key reasons we decided to cover only petrol and diesel, by far the most common fuels used in Norway. We will obviously be critiqued for this choice by some interest groups, we understand your concerns and arguments, but we decided to leave these components out.

## Bus

### Activity Level

Default activity levels from the TØI National Transport Survey

### Emission Factors

Kortdistanse (by): 103 grams $CO_2$-eq per person-km including both direct and indirect emissions.

Langdistanse (ekspress): 52 grams $CO_2$-eq per person-km including both direct and indirect emissions.

Source: LCA-database EcoInvent v.2.0 (www.ecoinvent.org)

## Rail

### Activity Level

Default activity levels from the TØI National Transport Survey

### Emission Factors

Train: 0.12 kWh/pkm * emissions per kWh (see electricity) [*Andersen*, 2007] with indirect emissions of 7 grams $CO_2$-eq per person-km (www.ecoinvent.org).

Metro: 0.263 kWh/pkm * emissions per kWh (see electricity) [*Andersen*, 2007] with indirect emissions of 15 grams $CO_2$-eq per person-km (www.ecoinvent.org).

In the calculator, the numbers above are multiplied with the emission factor for electricity mix.

## Passenger Ferry

### Activity Level

Default activity levels from the TØI National Transport Survey

### Emission Factors

Slow: 205g $CO_2$-eq per person-km [*Andersen*, 2007] without indirect emissions.

Fast: 803g $CO_2$-eq per person-km [*Andersen*, 2007] with indirect emissions.

**Air**

### Activity Level

Default activity levels from the TØI National Transport Survey

### Emission Factors

For flight emissions, emission factors from the British Department of Environment, Food and Rural Affairs (DEFRA) are used. These emission factors are official for the British state and are used for offsetting, DEFRA's CO2 calculator and for business reporting. DEFRA's emission factors are:

- 158 g $CO_2$ per person-km for domestic/Scandinavian flights
- 130,4 g $CO_2$ per person-km for short international flights (European)
- 105,6 g $CO_2$ per person-km for long international flights (intercontinental)

Source: DEFRA, http://www.defra.gov.uk/environment/business/envrp/pdf/passenger-transport.pdf

These emissions were multiplied by a "height factor" of 1.8 to adjust for the fact that the emissions occur at altitude and have additional climate effects.
http://www.cicero.uio.no/fulltext/index.aspx?id=5903&lang=no

Indirect emissions have been added to these numbers (www.ecoinvent.org)

- 56 g $CO_2$ per person-km for domestic/Scandinavian flights
- 52 g $CO_2$ per person-km for short international flights (European)
- 48 g $CO_2$ per person-km for long international flights (intercontinental)

IMPORTANT: Indirect emissions should not be and are not multiplied with the height factor.

## Housing (Responsible: CICERO with input from MiSA)

The emissions from housing are due to the direct energy consumption of a household, such as, electricity for lighting and cooking, heating, and so on. This section is broken into two parts. First, a discussion on the electricity mix to use in Norway. Second, a description on estimating the emissions from direct household energy consumption.

### Electricity (Responsible: NTNU)

It is somewhat tricky to estimate the emissions from electricity consumption since Norway is connected to an electricity grid which includes production outside of Norway. The "mix" of electricity production in any given year varies tremendously depending largely on weather. In a *highly unusual situation*, it is *conceivable* that Norway only exports electricity and does not import. In that case, Norwegian electricity production would be based almost exclusively on hydropower with very low emissions. In a more common year, Norway exports electricity at some times of the year (or even day) and imports at other times. Thus, the electricity mix will include nuclear, coal, and other forms of electricity generation in the Nordic grid. The emissions from this are measurable, but *vary from year to year, day to day, hour to hour, etc depending on weather*.

It is also possible to have other less measurable electricity mixes to meet often more political agendas. It is possible to use the so called *marginal* mix which will change depending on temporal scales and definitions. The marginal mix reflects the emissions by increasing electricity consumption marginally (for example, if electricity consumption increases 1kWh who will on average provide that additional electricity). The marginal mix will change depending on the time frame and the goal of the study. For example, the marginal mix at this exact point in time to turn on a light will differ to the marginal mix under which a high speed train would operate in Norway in 2020 which will depend primarily on global political developments. It is important to note that it is unlikely to derive a unique marginal mix as it is really a *scenario* about the future and thus the time frame and assumptions are crucial. It is also important to note that almost any marginal mix can be defended depending on the assumptions you make.

The reason a marginal mix is often used, is that policy developed now will apply in the future. Thus, the policy should consider what the electricity mix will be in the future. A low marginal mix, might favour policies for electric cars while a high marginal mix may favour biofuels. Thus, when selecting the marginal mix, care needs to be taken not to give perverse incentives in an unwanted direction. In terms of electricity, perhaps a better choice for policy is to consider energy content and not emissions.

Since Norway is connected to an electricity grid which extends beyond Norway it is hard to determine whether the electricity in a given household at a given came comes from hydropower, nuclear power or coal power. Thus, it is defendable to use a Nordic or European average electricity mix in this calculator. However, in these cases, if other countries do not follow this principle, the total estimated emissions over all households will be greater than the actual emissions. It would also be defendable to use the mix of Norwegian production + imports, as this is what would be correct if you add all Norwegian households (and industries) together.

After a discussion between researchers and organisations involved in this project, it was recommended to let the user of the calculator choose which electricity mix to use – if the user would like this. However, as one wants the tool to be user friendly for a broad range of users, it was decided to operate with a default, and it was recommended to use Nordic power mix as a default in the calculator.

We identified the following possible options to use in the calculator:

| **Electricity consumption:** kg $CO_2$-eq per kWh: | |
|---|---|
| Norwegian production+ imports: | 0,05 |
| Nordic power mix: | 0,21 |
| European power mix: | 0,56 |

The numbers are 2004-numbers from the database EcoInvent. They include net loss.

### Energy consumption in the household (Responsible: CICERO)

In the calculator, we estimate energy consumption based on the size of the house or apartment. The total energy consumption of a household depends on its age, size, insulation, temperature, thermal properties, and so on. The average energy consumption in Norway has been estimated as 229 kWh/$m^2$ for a small house and 218 kWh/$m^2$ for an apartment [*Pettersen et al.*, 2005]. The following table shows the average direct energy consumption for various activities in Norway:

| Supplied energy (kWh/$m^2$) | Small house Average | Apartments Average |
|---|---|---|
| Heating | **140** | **126** |
| Tap water | **37** | **34** |
| Fans and pumps | **1** | **1** |
| Lights | **23** | **23** |

| | | |
|---|---|---|
| Electrical equipment | **29** | **29** |
| Total | **229** | **218** |

It is possible to further break this information into types of housing, ages, etc.

To simplify the calculator, we split the energy use into energy for heating and other, all of which depend on floor area:

Energy use (kWh/m$^2$/year):

| | Flat | House |
|---|---|---|
| ...heating | 126 | 140 |
| ...other | 92 | 89 |

There are several technologies in use in Norway to deliver energy to the household, such as electricity, district heating, heat pump and so on. Depending on the technology in use, the emissions will vary substantially. In most cases, except for heating, electricity will be the main energy provider. The following are emission estimates for various energy types:

- Electricity. Multiply the energy use (kWh) by the chosen electricity mix in the previous section. For example, if electricity is used for heating, then 126*0,21=26,46 kg $CO_2$-eqv for the Nordic mix.
- Fyringsolje/Parafin: Using the Norwegian average energy efficiency of 65%[1], the total emissions are 0,309 kg $CO_2$-eqv /$kWh_{OLJE/PARAFIN}$, or 0,309/0,65 = 0,475 kg $CO_2$-eqv /$kWh_{Delivered}$. For example, if all heat is provided by heating oil, then the emissions are 126*0,475=59,9 kg $CO_2$-eqv. The average of heating oil and parfin is used [*Spielmann et al.*, 2007].
- District Heating: The average across all of Norway is 0,176 kg $CO_2$/kWh [*Pettersen et al.*, 2005].
- Wood: A new wood stove 0,077 kg $CO_2$-eqv /$kWh_{Delivered}$ and an old wood stove is 0,110 kg $CO_2$-eqv /$kWh_{Delivered}$ [*Solli et al.*, 2008].

## Food Consumption (Responsible: Østfoldforskning with input from MiSA and CICERO)

### Activity Level

Since food is heterogeneous and covers numerous products it is difficult for the average consumer to estimate the amount and type of food they consumed. For example, did I eat 100grams or 200grams of meat last night? To simplify estimates for the user we decided to estimate food consumption based on the amount and size of the meals. The emission factors will therefore contain information on the average meal size in addition to the emission factor per unit weight consumed.

### Emission Factors

The emission factors were a combination of process and economic data. We took initial bottom-up LCA estimates from Østfoldforskning on red meat, white meat, fish, and vegetables. These values

[1] http://www.regjeringen.no/nb/dep/oed/dok/NOU-er/1998/NOU-1998-11/22/6/1.html?id=349174

were scaled up to capture the full supply chain using data from another study [*Hertwich and Peters*, 2009] which is described below (General Consumption). We then used physical data from the survey of consumer expenditure (SCE) from Statistics Norway (SSB) to estimate the weight of different meals. This resulted in the following emission factors:

| **Meal** | **Emission Factor (kg $CO_2$-eq/kg)** |
|---|---|
| Breakfast | 3.51 |
| Lunch | 3.76 |
| Dinner with meat | 29.90 |
| Dinner with fish | 25.20 |
| Vegetarian dinner | 3.12 |
| Snacks | 4.16 |

The emission factor for dinner is normalized on the content of meat or fish. This means that the ratio of meat/fish to side dishes (potatoes, rice, vegetables) is fixed since this is already “baked into” the emission factor.

### Additional references on food

- Foster, C.; Green, K.; Bleda, M.; Dewick, P.; Evans, B.; Flynn, A. and Mylan, J. (2006) *Environmental Impacts of Food Production and Consumption: A report to the Department for Environment, Food and Rural Affairs*. Manchester Business School. Defra: London
- Different life cycle data from SIK (www.sik.se), Østfoldforskning (www.ostfoldforskning.no) and the project LCA Food from Denmark (www.lcafood.dk).

## General consumption (Responsible: CICERO)

For the purpose of the calculator, “consumption” refers to products not covered in transport, housing, and food. It covers issues ranging from purchase of clothing to getting a hair cut. The consumption part of the calculator combines information from the Survey of Consumer Expenditure (http://www.ssb.no/emner/05/02/fbu/) with a detailed model of emissions by sector and region [*Hertwich and Peters*, 2009; *Peters et al.*, 2004; *Peters et al.*, 2006; *Peters and Hertwich*, 2006].

### Activity Levels

The activity levels are estimated from the survey of consumer expenditure (SCE) freely available from Statistics Norway (SSB). The SCE is a survey of households to monitor their consumption habits. Households are randomly selected to cover a wide-range of socio-economic backgrounds. Each surveyed household must monitor its consumption and activities for a two-week period and answer a questionnaire on other major purchases outside of the survey period. Each year, around two thousand households take part in this survey distributed over different times of the year. The results of the survey are then aggregated to give an overview of the average expenditure of households by various socio-economic indicators. The key socio-economic variables used in the SCE are:

- Income and expenditure
- Number of people in the household
- Region
- Type of house
- Age
- …and so on

Within each category it is known how much money is spend on several hundred different products and activities. Further information can be obtained from SSB (http://www.ssb.no/emner/05/02/fbu/).

For the calculator we estimated the consumption of each household based on the number of adults and children in the household and net income. This ensures the user gets a quick answer, while still retaining the flexibility for the user to enter specific data when known. It also helps the user estimate how much they may spend on different categories.

## Emission Factors

Once the expenditure on different products and services is known, it can be linked to a global emissions model to estimate the emissions. In a top-down approach, it is most common to use environmental input-output analysis [*Lenzen*, 1998; *Lenzen et al.*, 2006]. Important for a small, import dependent country like Norway is an accurate estimate of the emissions from the production of imported products [*Peters and Hertwich*, 2006]. This requires the use of an environmental multi-region input-output (MRIO) model [*Hertwich and Peters*, 2009; *Peters*, 2008]. The global coverage and regional detail provided by such a model is far in excess of what can be provided by traditional life-cycle assessment (LCA). However, the MRIO model does not provide the necessary sector detail demanded by many interested parties. The database for the MRIO model used for the calculator contains detail on 57 industry sectors and 70 individual countries and 17 aggregated regions [*Dimaranan*, 2006]. The emission database includes data for all greenhouse gases [*Minx et al.*, 2008].

Multi-regional input-output (MRIO) analysis is used to allocate emissions to households. The input-output analysis describes the relationships between different industries and hence enumerates the global supply chain of different products (57 sectors are separated in the model). The multi-regional component covers the technology in a variety of countries and regions to reflect the production methods used to produce imports (87 countries and regions are separated in the model). Calculations of the indirect emissions is essentially a distribution of Norway's global greenhouse gas emissions to individual households – that is, if a pie represents Norway's global footprint, then the methodology allocates a slice of that pie to individual households based on their activity levels.

The underlying emission factors for different sectors in Norway are described elsewhere [*Hertwich and Peters*, 2009]. For the calculator, the emission factors need to be converted to retail prices and adjusted to 2008 prices. Conversions were based on data provided directly via Statistics Norway.

The detailed data was aggregated to the following sectors for use in the calculator:

| Sector | kg $CO_2$eq/NOK2008 |
| --- | --- |
| Clothing and textiles | 0.0618 |
| Durable items, non-electric | 0.0418 |
| Durable items, electric | 0.0388 |
| Chemicals (health, medicine, clearing, ...) | 0.0694 |
| Services (health, education, communication, etc) | 0.0219 |
| Other | 0.0615 |
| Weighted average for average household | 0.0393 |

## Conclusion

In this document we have briefly described the rationale and logic behind the calculator in addition to providing the methods and data for the calculator. As with the calculator, we hope the document is simple enough for the layperson to understand, but provides enough detail to keep the expert interested. The overarching goal of the calculator is to give the average consumer information on how they impact the environment via greenhouse gas emissions. We sincerely hope that we meet our goal.

# References


Andersen, O. (2007), Transport, miljø og kostnader. Oppdatering av database for energibruk, utslipp til luft, samfunnsøkonomiske kostnader og ulykkesrisiko ved persontransport.

Dimaranan, B. V. (Ed.) (2006), *Global Trade, Assistance, and Production: The GTAP 6 Data Base*, Center for Global Trade Analysis, Purdue University.

Hertwich, E. G., and G. P. Peters (2009), The Carbon Footprint of Nations - A global, trade-linked analysis, *Environmental Science and Technology*, *In press*.

Kollmuss, A., and J. Lane (2008), Carbon Offsetting & Air Travel. Part 1: $CO_2$-Emissions Calculations, Stockholm Environment Institute.

Lenzen, M. (1998), Primary energy and greenhouse gases embodied in Australian final consumption: An input-output analysis, *Energy Policy*, *26*, 495-506.

Lenzen, M., et al. (2006), A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan, *Energy*, *31*(2-3), 181--207.

Minx, J., et al. (2007), Methods review to support the PAS process for the calculation of the greenhouse gas emissions embodied in goods and services, Report to the UK Department for Environment, Food and Rural Affairs (DEFRA, London), Stockholm Environment Institute at the University of York and Departmnet for Bio-based Products at the University of Minnesota.

Minx, J., et al. (2008), GHG emissions in the global supply chain of food products, in *The 2008 International Input-Output Meeting on Managing the Environment (IIOMME)*, edited, 9-11 July, Seville, Spain.

Murray, J., and C. Dey (2007), Carbon neutral – sense and sensibility, Centre for Integrated Sustainability Analysis, Sydney, Australia.

Peters, G., et al. (2004), Pollution embodied in Norwegian consumption, Working Paper, Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Peters, G. P., et al. (2006), Environmental Impacts and Household Characteristics: An econometric analysis of Norway 1999-2001, paper presented at Proceedings: Sustainable Consumption and Production: Opportunities and Threats, Wuppertal, Germany.

Peters, G. P., and E. G. Hertwich (2006), The importance of imports for household environmental impacts, *Journal of Industrial Ecology*, *10*(3), 89--109.

Peters, G. P. (2008), From Production-Based to Consumption-Based National Emission Inventories, *Ecological Economics*, *65*, 13-23.

Pettersen, T. D., et al. (2005), Energimerking av boliger, Byggforsk og SINTEF Bygg og Miljø.

Solli, C., et al. (2008), Life Cycle Assessment of Wood-based Heating in Norway, Submitted.

Spielmann, M., et al. (2007), Transport Services, Swiss Centre for Life Cycle Inventories, Dübendorf.