Ninas part of the AI-samgods project: Implementation of emissions

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1 Model structure

The last step in the model chain, after vehicle movements are calculated, is the emission calculation. This is done by retrieving data from the emission calculator NTMcalc for each of the vehicles on each road links.

2 About NTMcalc

NTMcalc is a tool which is maintained by NTM (Network for Transport Measures). A description of the tool is available at their website: https://www.transportmeasures.org/en/wiki/manuals/. A basic version is available for free and an advanced tool only for NTM members. In this project, we use the advanced version (in the rest of the text we refer to the advanced version when we refer to NTMcalc). NTMcalc calculates the fuel consumption and emissions for a vehicle travelling a certain distance. Both freight and passenger transport are included in NTMcalc. Both direct emissions during driving (tank-to-wheel=TTW) and the emissions from the fuel production (well-to-tank=WTT) are calculated. For electric trains, the electricity consumption is also given. The following emissions can be calculated: fossil CO2, CO2 of non-fossil origin, total CO2 (fossil+non-fossil), CO2-equivalents, sulfur dioxide (SO2), nitrogen oxides (NOx), nitrous oxide (N20), methane (CH4), hydrocarbons (HC) and particulate matter (PM). Also energy use and fuel consumption can be retrieved The emissions can be calculated in different ways, either allocated to the goods (weight or volume) or to the vehicle. In the first case, the results are given in eg. CO2/tonne goods. When the fill factor increases, the emissions decrease. It is assumed that the transported goods can be shared between several vehicles if needed. In the second case, the results are given in eg. CO2 for the whole vehicle travelling a certain distance. When the fill factor increases, the emissions increase. Several vehicles for all transport modes are included. There are 12 different types of road freight vehicles, 11 freight ships, tens of different freight aircrafts and one diesel and one electric cargo train.

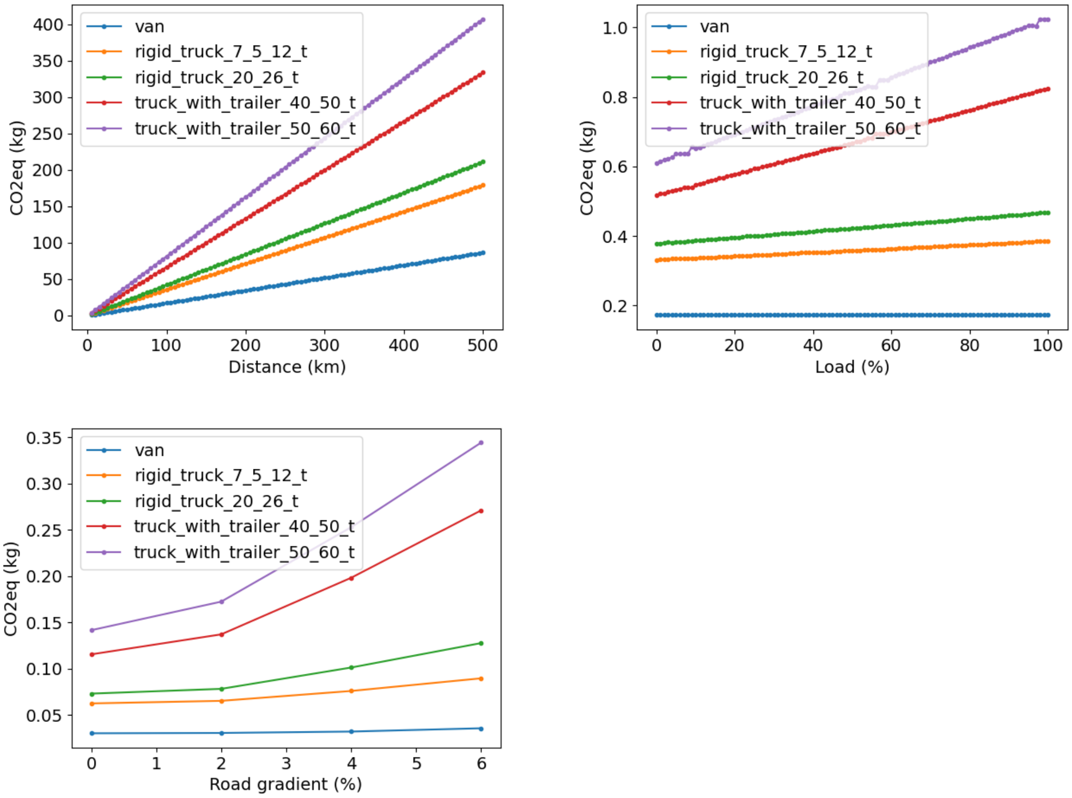

Figure 1: CO2 equivalents as a function of distance, load and road gradient for a set of road vehicles. When not varied, the load is 50 %, the distance 1 km and the road gradient 0. The model *vehicle operation distance* is used. In NTMcalc there is no speed dependance, only on road type.

3 Retrieving road traffic emission data from NTM-calc

To retrieve data from the NTMcalc api, a request has to be made. Each request takes approximately 0.1 seconds and can only retrieve one data point. This means that it would take very long time to retrieve all the needed data in this way, for example 2.8 hours for 100 000 vehicle movements. Instead, data from NTMcalc is downloaded beforehand into a local database, which takes on the order of tens of minutes for road vehicles and about the same for ships. Many of the relationships between the variables are linear, which limits the amount of data needed. Figure 1 shows examples of CO2 emissions retrieved from the NTMcalc api with the *vehicle operation distance* model. This model calculates the total emissions for a specific vehicle with a specific load (instead of per unit of goods). The increase in emissions with distance is linear for each vehicle, while the increase in load factor is almost but not exactly linear.

Figure 2 shows the greenhouse gas emissions for the different road types for a set of vehicles. As can be seen, it varies somewhat between the vehicles. For the van and the smaller rigid truck, emissions are highest when driving on motorway,

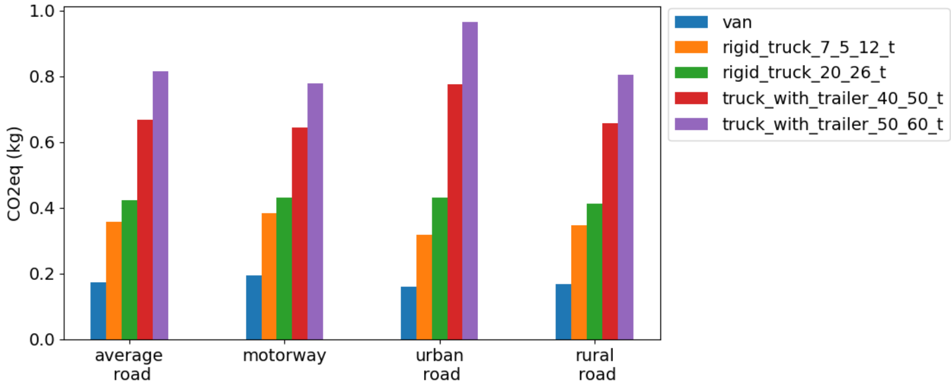

Figure 2: CO2 equivalents for different road types and different vehicles. The load is 50 %, the distance 1 km and the road gradient 0.

while for the two largest vehicles, the emissions are highest when driving on urban roads. Since we do not have a road classification we assume that roads with speed limit 30-60 km/h are urban roads, roads with speed limit 70-100 km/h are rural roads and roads with speed limit 110-120 km/h are motorways. The links which do not fit in any category are assumed to be average roads.

Some data are the same for all road vehicles:

- Euro class 6 is chosen for all vehicles where it is possible, euro class 5 otherwise. Based on statistics from the HBEFA model this is a reasonable assumption. The statistics show that around 45 % of the heavy goods vehicles and around 32 % of the light goods vehicles have euro class 6.
- The chosen fuel for all vehicles is swedish diesel with 7 % biofuel.
- The road gradient i 0 %

We retrieve data for greenhouse gas emissions from NTMcalc by using the field CO2-equivalents, which includes fossil CO_2, CH_4 and N_2O. At this stage, only data for cargo road traffic are retrieved, including ferry traffic if the truck is transported via ferry. The emissions are calculated with the model *vehicle operation distance*.

From the earlier modelling steps in AI-samgods, the following data are delivered for each vehicle: vehicle type, goods weight and all the links which this particular vehicle travel. For each link, the distance and the mode of transport are given. If the mode of transport is road, the allowed speed limit on that link is given. If the transport mode is ferry, the deadweight of the ship is given. Since the vehicle types in AI-samgods are different from the ones in NTMcalc, they have to be matched together. Table 1 and 2 shows the characteristics of the vehicles and how they are matched together. Since there are fewer vehicles in the Samgods data than in NTMcalc, there are most often several vehicles that match each Samgods vehicle. When this is the case, the smallest matching which can accommodate the weight of the cargo is chosen. This does not take into account the volume of the

Table 1: Description of Samgods road vehicles, which are used in the modelling chain. The last column shows which NTMcalc vehicle they are matched against. The vehicles marked with a star are not matching in size, but included anyway to be able to accommodate the load.

vehicle IDs	Vehicle descriptions	Max gross weight (tonnes)	Load capacity (%)	Matching NTMcalc vehicles
LGV3	Light goods vehicle two axles	<3.5	2	Van, Rigid_truck_7_5_t*
MGV16	Heavy goods vehicle without trailer, two axles	3.5-16	9	Rigid_truck_7_5_t, Rigid_truck_7_5_12_t, Rigid_truck_12_14_t
MGV24	Heavy goods vehicle without trailer, 3 axles	16-24	15	Rigid_truck_14_20_t, Rigid_truck_20_26_t
HGV40	Heavy goods vehicle with trailer, 3 axles on car and 4 on trailer	25-40	30	Truck_with_trailer_20_28_t, Truck_with_trailer_28_34_t, Truck_with_trailer_34_40_t, Truck_with_trailer_40_50_t*
HGV60	Heavy goods vehicle with trailer for timber, car with 3 axles and 4 on trailer	25-60	41	Truck_with_trailer_20_28_t, Truck_with_trailer_28_34_t, Truck_with_trailer_34_40_t, Truck_with_trailer_40_50_t, Truck_with_trailer_50_60_t
HGV74			52	No match

cargo, so for low-density cargo it might choose a truck that is too small. There are also some cases where there is no matching vehicle. The Samgods HGV60 vehicle can accommodate 41 tonnes, while the largest vehicle in NTMcalc can only accommodate 40 tonnes. In the case that there is an HGV60 with more than 40 tonnes load, only the cargo up to 40 tonnes is included and a warning is written out in the outdata file. The largest vehicle in Samgods, HGV74 has no match in NTMcalc. If this vehicle is used, no calculations are performed and a warning is written out in the outdata file.

On segments where the truck is transported by ferry, the total weight of the truck (vehicle+goods) is calculated. The emission during the ferry trip is then given by the model *shipment transport weight* for a ro-ro ship, meaning that the emission estimate does not give the emissions for the whole ferry, but only for the weight of the truck. The ro-ro ship is assumed to have a fill factor of 70 %, which is the default value in NTMcalc. The ship size (in deadweight tonnage) is given as input. The fuel can be varied between residual oil with 2.7 % or 1 % sulphur or marine distillates with 0.1 % sulphur. The different fuels can also be mixed. Sweden lies in the SECA area, which includes the Baltic Sea, the North Sea and the English channel, where a maximum sulphur content of 0.1 weight-% is allowed, and therefore the marine distillates is chosen. However, the difference in CO2 emission

Table 2: NTMcalc vehicles (https://www.transportmeasures.org/en/wiki/manuals/road/vehicle-types-and-characteristics/)

Vehicle IDs	Max gross weight (tonnes)	Load capacity (tonnes)
Van	3.5	1.5
rigid_truck_7_5_t	≤7.5	5
rigid_truck_7_5_12_t	7.5-12	6
rigid_truck_12_14_t	12-14	9
rigid_truck_14_20_t	14-20	12
rigid_truck_20_26_t	20-26	15
truck_with_trailer_14_20_t	14-20	12
truck_with_trailer_20_28_t	20-28	16
truck_with_trailer_28_34_t	28-34	22
truck_with_trailer_34_40_t	34-40	26
truck_with_trailer_40_50_t	40-50	33
truck_with_trailer_50_60_t	50-60	40

between the fuels is small. 3 shows the variation with shipment size, distance and ship size. Both variation with distance and shipment weight are linear.

4 Retrieving shipping emission data from NTM-calc

In NTMcalc there are 11 ship types. Figure 4 shows how the climate impact of the different ship types vary with distance, size and fill factor using the model *vehicle operation distance*. The fuel can also be varied, but as for ro-ro ships, marine distillate oil is chosen for all ships. As can be seen, the CO2 emissions vary non-linearly with ship size and varies linearly or is constant with fill factor.

In Samgods, there are 6 ship types, each of which can also be divided into different sizes. Table 3 shows the Samgods ships, which are used in the model, and the matching NTMcalc ship. Table 4 shows the characteristics of the NTMcalc ships. The Samgods ship *other vessel* is matched with different types of ships depending on type of goods, as shown in 5. In the cases where there is no match, a warning message is written and no CO2 is calculated (i.e. for the Samgods ships *barge for inland waterways*, *rail ferries* and *road ferries*).

For each ship, the weight of the transported goods is divided by the size of the vehicle to get a fill factor. Note, that this is an approximation which is not fully correct, since the load of the vehicle probably is a bit higher in reality than only the goods load. It should also include the staff, provisions etc that are needed on the journey.

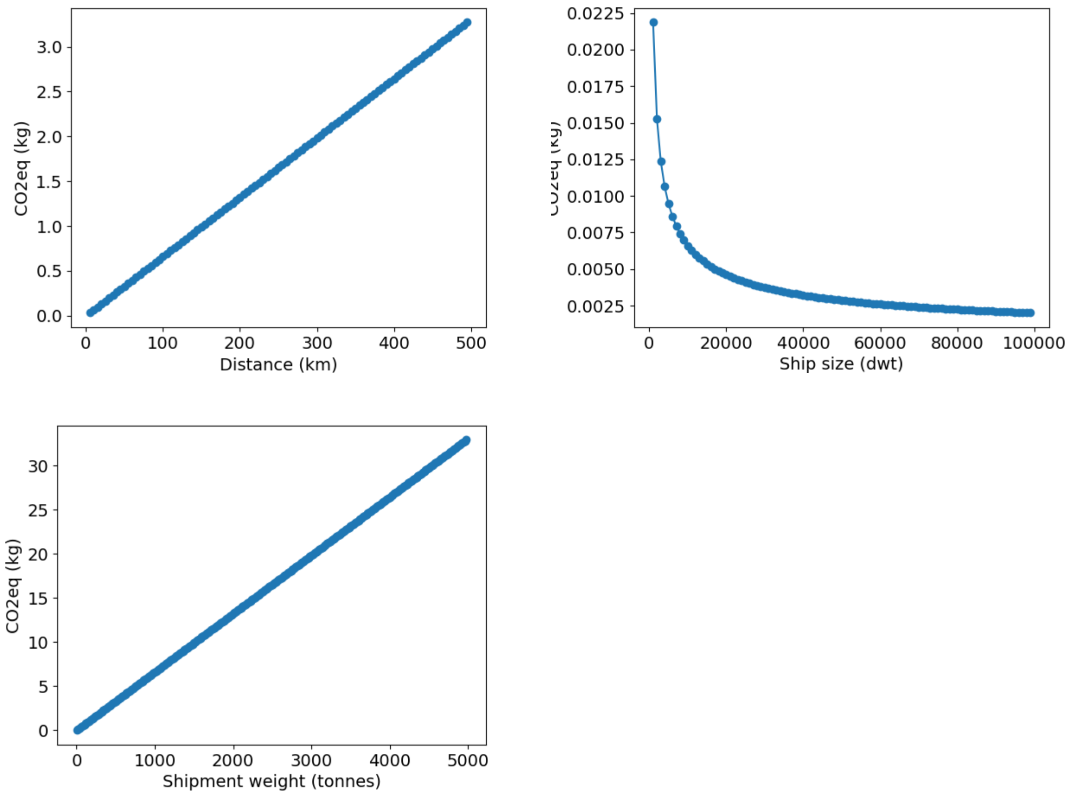

Figure 3: CO2-equivalents for a ro-ro ship as a function of distance, ship size and shipment weight. When not varied, parameters are set to ship size = 10 000 dwt, shipment weight = 1 tonne, fill factor = 70 % and fuel = 100 % marine destillates with 0.1 % sulphur.

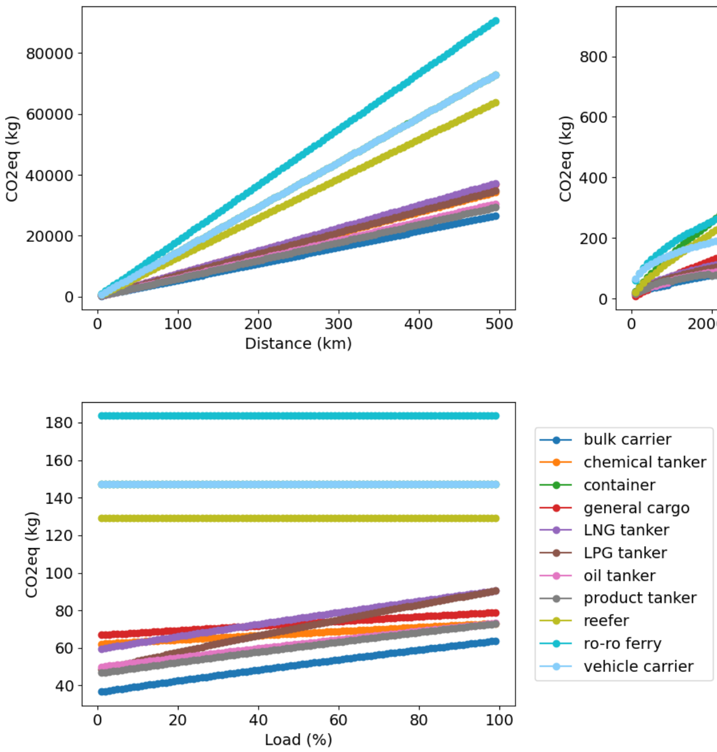

Figure 4: CO2 equivalents as a function of distance, ship size and load for all different ships in NTMcalc. When not varied, the distance is 1 km, the size 10 000 dwt and the load is the default for each ship category. (In a, the container ship is hidden below the vehicle carrier, the chemical tanker is behind the LPG tanker and the general cargo ship behind the LNG tanker. In b, the LNG tanker is behind the LPG tanker and in c, the container ship is behind the vehicle carrier.)

Table 3: Description of Samgods ships and their matching NTMcalc ships.

Samgods ID	Samgods name	Load capacity (dwt)	Matching NTMcalc vehicle
CV5, CV5_CONTAINER	Container vessel	5 300	Container ship
CV16, CV16_CONTAINER	Container vessel	16 000	Container ship
CV27 CV27_CONTAINER	Container vessel	27 200	Container ship
CV100, CV100_CONTAINER	Container vessel	100 000	Container ship
INW	Barge inland waterway	1 750	No match
OV1	Other vessel	1 000	Different depending on goods
OV2	Other vessel	2 500	Different depending on goods
OV3	Other vessel	3 500	Different depending on goods
OV5	Other vessel	5 000	Different depending on goods
OV10	Other vessel	10 000	Different depending on goods
OV20	Other vessel	20 000	Different depending on goods
OV40	Other vessel	40 000	Different depending on goods
OV80	Other vessel	80 000	Different depending on goods
OV100	Other vessel	100 000	Different depending on goods
OV250	Other vessel	250 000	Different depending on goods
RAF5	Rail ferry	5 000	No match
RO3, RO3_CONTAINER	Roro vessel	3 600	Ro-ro
RO6, RO6_CONTAINER	Roro vessel	6 300	Ro-ro
RO10, RO10_CONTAINER	Roro vessel	10 000	Ro-ro
ROF2	Road ferry	2 500	No match
ROF5	Road ferry	5 000	No match
ROF7	Road ferry	7 500	No match

Table 4: Characteristics of the NTMcalc ships.

NTMcalc ship	Size (dwt)	Average capacity utilization (%)	General information about the ship type from the internet
Bulk carrier	0-10 000, 10 000-100 000, 100 000-	60, 55, 50	For transport of unpacked bulk cargo, such as grain, coal, ore, rice, sugar, timber
Chemical tanker	all	64	For transport of liquid chemicals and other liquid products which require a high standard of tank cleaning in bulk (eg. chemicals, acids, oils, biofuels)
Container ship	All	70	For transport of containers
General cargo	all	60	For transport of packaged goods of different types, packed in eg. goods in bags, boxes, barrels etc. They have several decks. They are equipped with loaders and cranes
LNG tanker		48	
LPG tanker	all	48	
Oil tanker	all	48	
Product tanker	0-10 000, 10 000-20 000, 20 000-	45, 50, 55	For transport of petroleum products and chemicals (smaller than crude oil tankers)
Reefer	all	50	Refrigerated cargo ship
Ro-ro	all	70	
Vehicle carrier	all	70	

Table 5: NTMcalc ship chosen for different type of goods

Type of goods	NTMcalc ship
Agriculture	Bulk carrier
Basic metals	Bulk carrier
Cole	Bulk carrier
Coke	Bulk carrier
Food	General cargo ship
Furniture	Container ship
Machinery	Container ship
Metal	Bulk carrier
Other mineral	Bulk carrier
Secondary raw	Bulk carrier
Textiles	Container ship
Timber	Bulk carrier
Transport	Vehicle carrier
Wood	General cargo ship

5 Results

Table 6 shows the summarized results of the simulation of one year, divided into different types of cargo and transport modes. The last row shows a comparison to Swedish national emission statistics for the year 2023 (retrieved from SCB).

The resulting climate impact from road transport is underestimated by 59 % compared to the national statistics. There can be several reasons for the underestimation. One is that all roads are assumed flat in the model. The variation with road gradient is different for different vehicles. For example, for a rigid truck 14-20 tonnes, an increase from 0 to 2 % gradient increases the climate impact with 5 % and an increase from 0 % to 4 % gradient increases the climate impact by 32 %. Another reason may be the difference in the methods between the two estimates, more on that further down. A third reason may be that the model gives a more optimized transport system compared to the real world. For example, it is assumed that a truck of suitable size is always available.

The resulting climate impact from shipping is instead very much overestimated, both for domestic and international shipping. However, it is not clear what is included in domestic and international shipping in the Samgods model. Combining the domestic and international shipping, the model gives 1400 % higher emissions than the national statistics. Since the model is calibrated to the number of ships, the overestimation should not be the result of too many ships. However, it is noted that the ships are often filled only by a few percent of its maximum load capacity. An explanation could therefore be that the model chooses an unnecessarily large vessel or a vessel of the wrong type. Therefore, a test is made where the *bulk carrier* is always chosen, since this is the ship with lowest emissions. The smallest available vessel (choosing from the sizes in the samgods model for *other vessels*: 1000, 2500, 3500, 5000, 10000, 20000 or 40000 dwt) is also chosen. This

Table 6: Resulting emissions for the included cargo types for road and sea transport, divided into domestic and international freight. The last row shows the corresponding values from the Swedish national emission database.

Cargo type	Domestic road transport (kt CO2e)	International road transport (kt CO2e)	Domestic shipping (kt CO2e)	International shipping (kt CO2e)
Agriculture	93.7	40.7	1355.6	5793.7
Basic metals	178.3	101.7	711.0	7205.8
Chemicals	193.9	115.2	1518.5	7788.9
Coal	37.7	37.0	865.4	2036.3
Coke	44.9	42.0	1153.2	3359.9
Food	165.8	64.2	480.7	6004.4
Furniture	142.6	35.5	567.8	3905.5
Machinery	134.4	111.0	65.4	2621.3
Metals	114.2	112.4	1942.5	10 706.0
Other minerals	112.4	19.3	1106.8	5814.3
Secondary raw	35.5	8.8	273.4	2284.4
Textile	8.1	8.5	42.2	1287.1
Timber	186.4	32.4	552.8	3332.3
Transport	44.4	36.9	192.8	2995.6
Wood	248.6	105.9	985.5	7765.8
SUM	1 741	872	11 814	72 901
SCB, year 2023	4 197 (light and heavy trucks)	-	519 (commercial shipping)	5 434

represents a possible case with close to minimum emissions. However, most of the ships will not be fully or even 50 % loaded. This gives a value of 2 388 kt for domestic shipping and 11 840 kt for international shipping, giving a total overestimation of 239 %. Thus, it gives a very large reduction compared to the modelled base case, showing that the optimization of ferry type and size can be very important.

As described earlier, some of the Samgods vehicles had no match in NTMcalc and no climate impact were calculated for these. To asses the impact of these vehicles they were approximated with a rigid truck 14-20 tonnes for road transport and a general cargo ship of 10 000 dwt for shipping respectively. For road transport there are sometimes also omitted tonnes from a full truck. These are counted, and recalculated into a number of trucks. Thus, this gives a very rude estimate of the omitted CO2 of 32 kt CO2e, i.e. only a small fraction of the total.

The national statistics are prepared by the Swedish environmental protection agency with data an calculations from various other authorities. The statistics represent official Swedish data that is reported UNFCC and CLRTAP.

Road traffic emissions are estimated by the HBEFA model (read more at hbefa.net), with indata from the Swedish national vehicle register, official statistics on vehicle mileage, yearly odometer readings within the Swedish inspection and maintenance program, national survey on Swedish domestic road goods transport, data on trip lengths from instrumented vehicles and other surveys [1]

Shipping emissions are estimated by a combination of the Shipair model (for domestic shipping) and different surveys (monthly survey of fuel supply statistics sent to fuel suppliers in Sweden, a survey to Swedish non-cargo shipping companies and surveys regarding leisure boats) [1]. The international shipping is estimated as the difference in total fuel sold in Sweden and what is estimated to be used in Sweden.

Thus, there a many differences between national statistics and the model results, regarding for example the models used, the emission factors, the vehicle types, the driving patterns etc.

Fig 5 and 6 shows the total yearly road and shipping emissions per km of different types of goods at each link. Note the different scale between road transport and shipping.

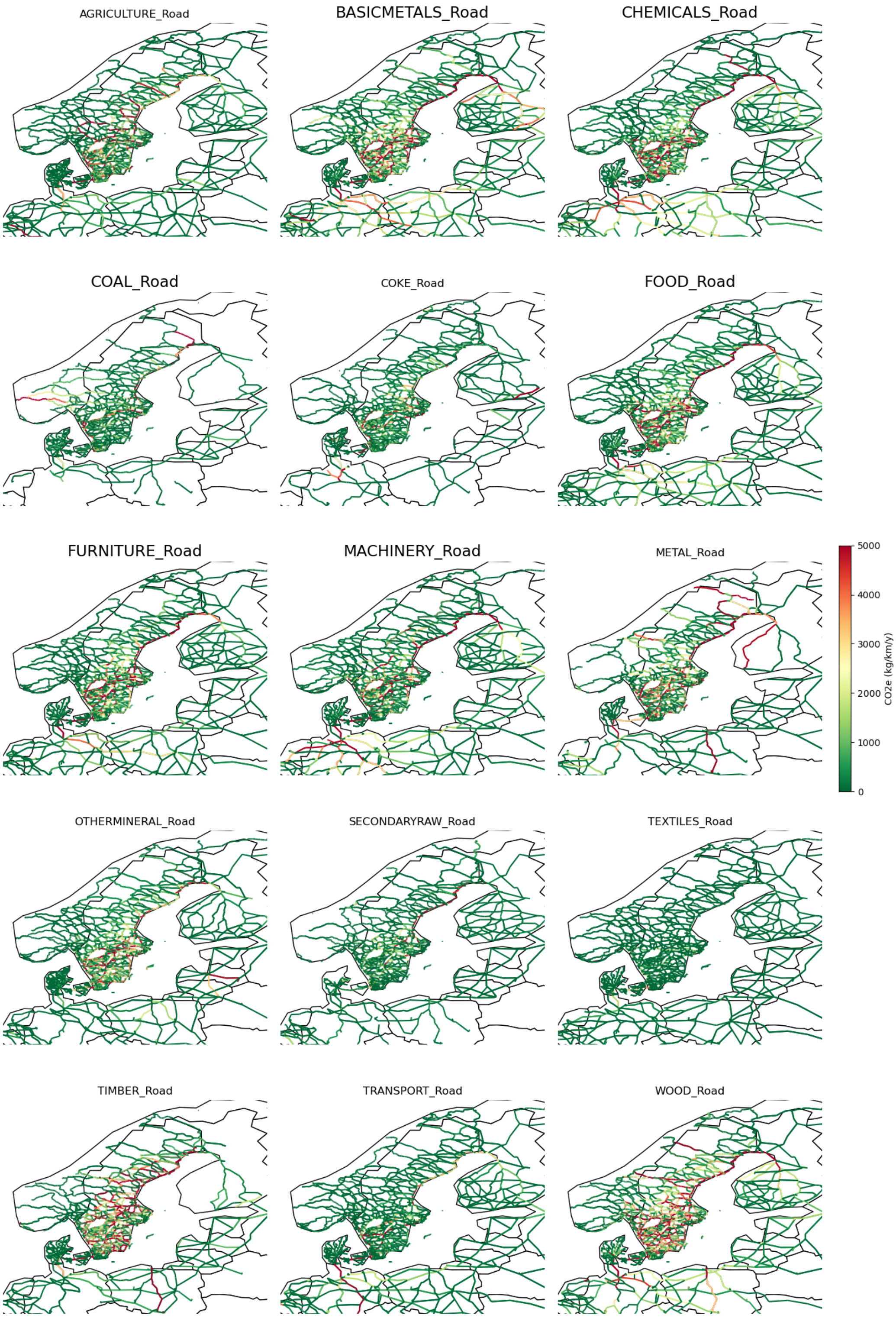

Figure 5: Yearly greenhouse gas emissions from road transport at each link

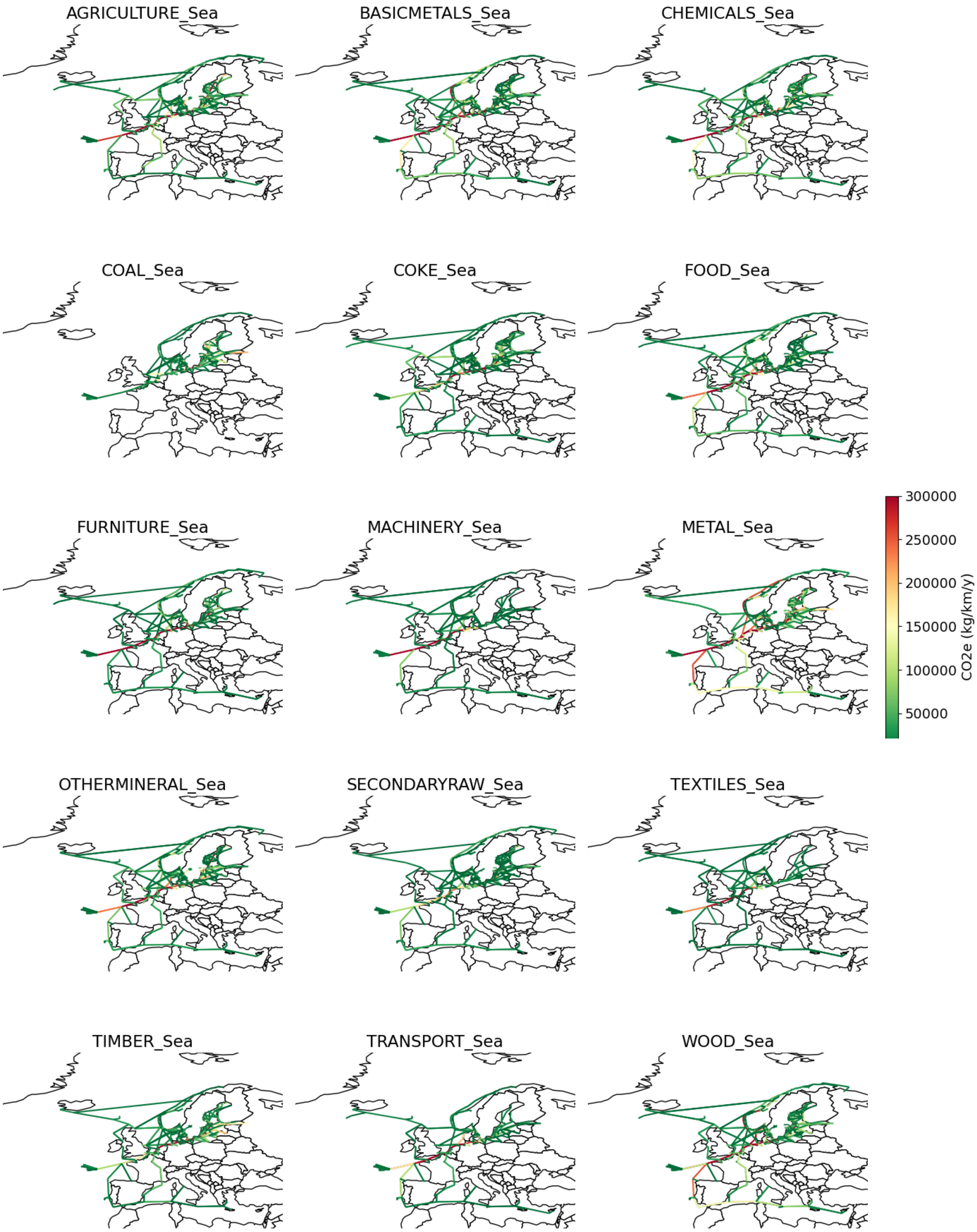

Figure 6: Yearly greenhouse gas emissions from shipping at each link

References

[1] Swedish environmental protection agency, 2024. National inventory report Sweden 2024: Annexes - Greenhouse gas emission inventories 1990-2022.