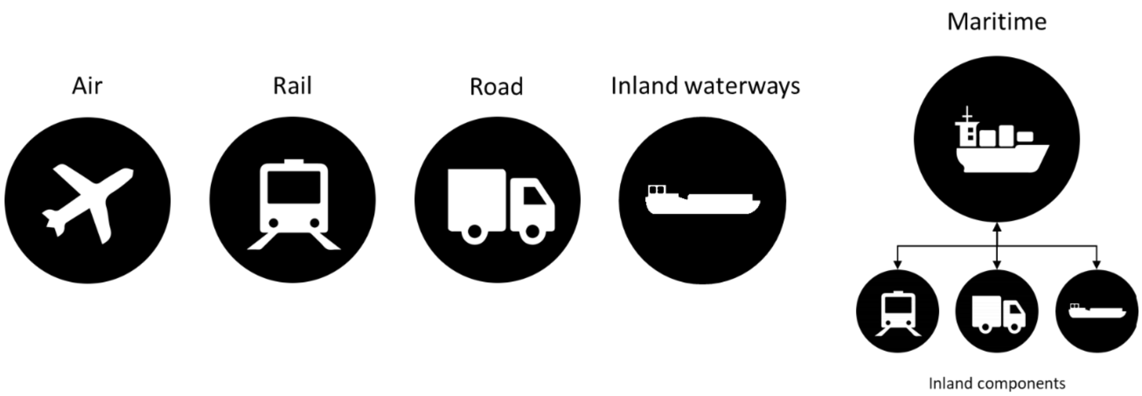
ITF Non-urban Freight Model overview

The ITF has developed and updated its freight model to estimate the impact of policy measures on freight transport under different scenarios. The first versions of the model are described in Martinez et al. (2015), ITF (2016), and ITF (2020).

The ITF freight model assesses and provides scenario forecasts for freight flows around the globe. It is a fully integrated multi-modal network model that assigns freight flows on all major transport modes (air, inland waterways, maritime, rail, road) to specific routes, modes, and network links. The maritime freight includes the access and egress inland components, and the mode choice includes rail, road or inland waterway components. Centroids, connected by network links, represent zones (countries or their administrative units) where goods are consumed or produced.

Figure 1. Transport modes distinguished by the model



Source: ITF

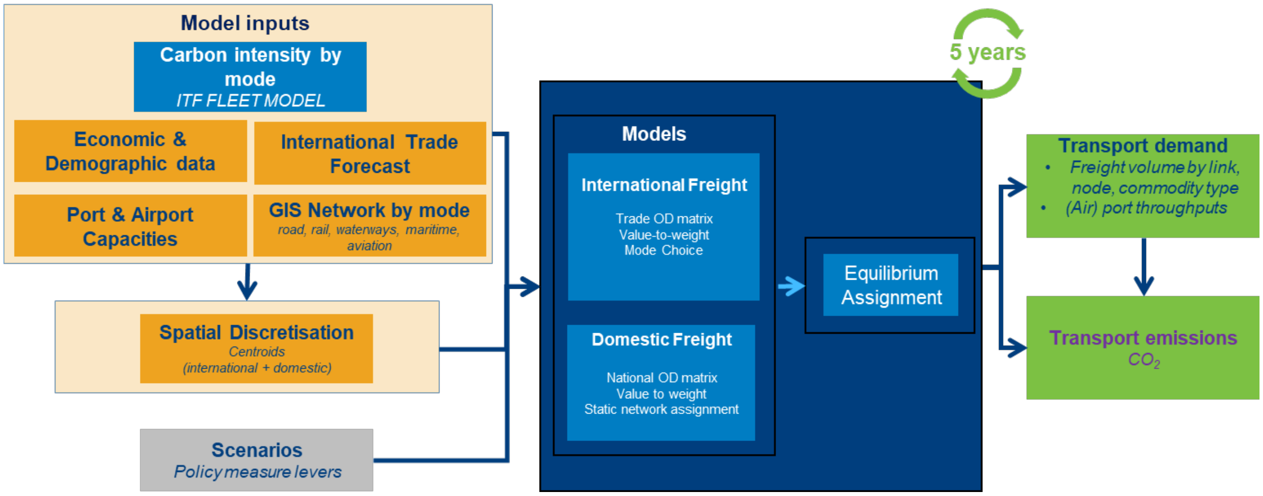
The model was developed to estimate the impact of transport and economic policy measures (e.g., the development of new infrastructure networks, the alleviation of trade barriers), technological breakthroughs or improvements (e.g., high capacity vehicles, energy transition of long-distance road freight) and environmental measures (e.g., CO_2 mitigation measures).

The most recent version of the ITF freight model integrates the (previously distinct) surface and international freight models. International and domestic freight flows are calibrated on data on national freight transport activity (in tonnes-kilometres, tkm) as reported by ITF member countries. Said data is also used to validate the route assignment of freight flows. Trade projections in value terms stem from the OECD ENV-Linkages trade model (OECD, 2021) and are converted into cargo weight (tonnes). These weight movements are then assigned to an intermodal freight network that develops over time in line with scenario settings. These define infrastructure availability, available services and related costs.

The current version of the model estimates freight transport activity for 20 commodities for all major transport modes, including sea, road, rail, air and inland waterways. The underlying network contains 8 467 centroids, where goods' consumption and production occur. Of these, 1 164 represent the origins and destinations (ODs) for international trade flows, and 7303 represent the ODs of domestic flows. Each of the 152 863 links of the network is described by several attributes. These include length, capacity, travel time (incl. border crossing times), and travel costs (per tkm).

The model framework can be found in Figure 2. Each of the components will be described in more detail in the following sections.

Figure 2: ITF Non-urban Freight model framework



Source: ITF

Model inputs

The model requires inputs of four main categories: trade forecast data; network data for different modes; economic, demographic and geographical data; and initial carbon intensity data by mode (Figure 2).

Trade forecast data originate from the OECD's ENV-Linkages Computable General Equilibrium (CGE) model. This global economic model describes how economic activities are interlinked across several macroeconomic sectors and regions. The model is built primarily on a database of national economies. An economic input-output table underpins each region, usually obtained from national statistics agencies. World trade in the ENV-Linkages model is based on a set of regional, bilateral flows. All flows are expressed in monetary terms, in constant USD, using purchasing power parities as exchange rates for national currencies. The model projects international trade flows in values for 26 regions and 20 commodities up to 2060 (J. Chateau, Fontagné, Fouré, Johansson and Olaberría, 2014).

Network data is mainly based on open GIS data for different transport modes. The ITF has consolidated and integrated various modal networks into a single routable freight network. For this purpose, networks of the different modes were interconnected by introducing transport links between centroids and using data on intermodal dwelling times. Each link in the network has several characteristics, including its length, capacity, maximum speed, cost, travel times, and border crossing time (where applicable). The costs were estimated based on the network data taking into account distance- and time-based components.

Economic and demographic data include population UN-DESA (2022) and GDP data for regions (OECD, 2022) associated with each centroid. The economic characteristics of each region also include data on the contribution of the main sectors of the economy to the GDP. The main sources for detailed regional accounts are the World Bank open-data database (https://data.worldbank.org/) for single region countries, Eurostat for European countries (https://ec.europa.eu/eurostat/web/national-accounts/regional-accounts) and national accounts for other world countries over 100 million inhabitants.

Finally, data on the emissions intensity of each mode, as well as their projected changes due to technological and logistical developments over time, come from the in-house fleet model.

Model outputs

The model provides ton-kilometres (tkm) and vehicle-kilometres (vkm) for each link and node in the freight network, disaggregated by transport mode and by commodity type. As such, values can be generated for each OD pair and for single or multi-modal routes. These, in turn, can be aggregated at different geographical scales to provide information on the following:

- Freight volumes leaving or arriving at a centroid, country, region or total and the breakdown of their destinations/origins
- The modal split of the activity by country, region, or total
- Throughput for each port, airport, or border crossing

These results can be further expanded and enhanced in combination with the ITF fleet model. The demand results above are combined with information on related CO_2 intensities and technology pathways by mode to estimate transport emissions to 2050. In the case of road and rail, these coefficients and pathways vary by region, while maritime and air values are considered uniform around the globe.

They key outputs from the combination of the freight and fleet model are then

- Transport CO_2 emissions by mode, country, and region.
- Activity and Emissions by vehicle type and distance bin. I.e., the vehicle types used for trips of different distances

These last outputs are particularly relevant as it allows us to test the viability and feasibility of new and upcoming technologies and formulate policy recommendations to increase the potential benefits.

Model components

The model estimates freight activity separately at domestic and international levels, converging at the end for the shared use of surface transport infrastructure in countries. It has five main components:

1. Spatial discretisation model
2. International freight model
3. Domestic freight model
4. Equilibrium assignment module
5. Outputs module

Once all the components are set, the model is computed sequentially, as presented in Figure 2.

The model is updated in 5-year intervals and makes scenario forecasts up to 2050, with an adapted running template for the years 2019, 2020 and 2022 to reproduce the effect of COVID on freight demand accurately. Consequently, potential future changes to the underlying freight transport network must be accounted for. These may take the form of updates to infrastructure availability, the capacity or speed on certain transport links, or transport costs that may evolve over time, given technological changes. Such potential updates are included in the model via scenarios variables that are updated in line with a 'calendar of development' of the scenario. The model user can easily change those input parameters. For example, in the case of Europe, a detailed calendar representing the TEN-T network[1] development, accounting for its attributes, has been implemented. Information on European intermodal terminals, including their expected delay times, has also been incorporated[2].

---

[1] Detailed information available at: <https://ec.europa.eu/transport/themes/infrastructure/ten-t_en>.

[2] Detailed information available at : < http://www.intermodal-terminals.eu/database >.

Detailed model component descriptions

Spatial discretisation model (centroids)

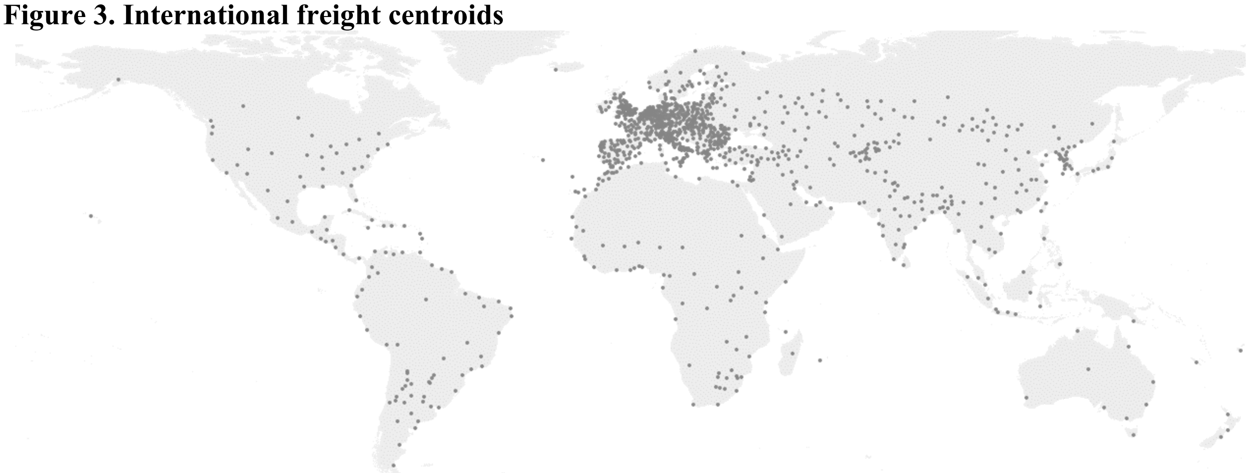
This sub-model defines two sets of centroids: international freight centroids and domestic freight centroids.

International freight centroids

International freight centroids are used to discretise regional OD trade flows into larger production/consumption centroids. The discretisation allows for a proper breakdown of the travel path used for different types of products and leads to a better representation of actual freight flows.

An adapted *set coverage* algorithm was implemented to identify centroids based on a larger set of potential centroids. These potential centroids are all global cities with a population of fewer than 300 000 people, as identified by the United Nations in 2010 (2 539 cities) (UN, 2015). The objective function minimises the number of centroids under the constraints that only one centroid can exist within a 500km radius (in the same country), while the total of the globe's land surface has to be attributed to a centroid.

Figure 3. International freight centroids



Source: ITF

This algorithm was adapted for some regions where increased spatial detail was desired in view of potential future studies to be carried out by the ITF. For the European Union, the adopted resolution level was the NUTS3 level in regions where a Functional Urban Area (FUA) is present and NUTS2 for the others (i.e., each of the NUTS3 or NUTS2 regions (where applicable) is represented by one centroid).

1 164 centroids were defined. Each centroid is named after the most representative city in the region that the centroid represents.

The influence area of each centroid is computed based on a raster world surface map. Each raster cell is assigned to a centroid based on its distance to the centroid, while cells within a country will always be assigned to a centroid within that same country. Each centroid is characterised by population and GDP indicators. Raster cells were linked to global population estimates (CIESIN - Columbia University, 2018) and raster-based information on GDP (Kummu, Taka and Guillaume, 2018) are used to estimate the population and GDP.

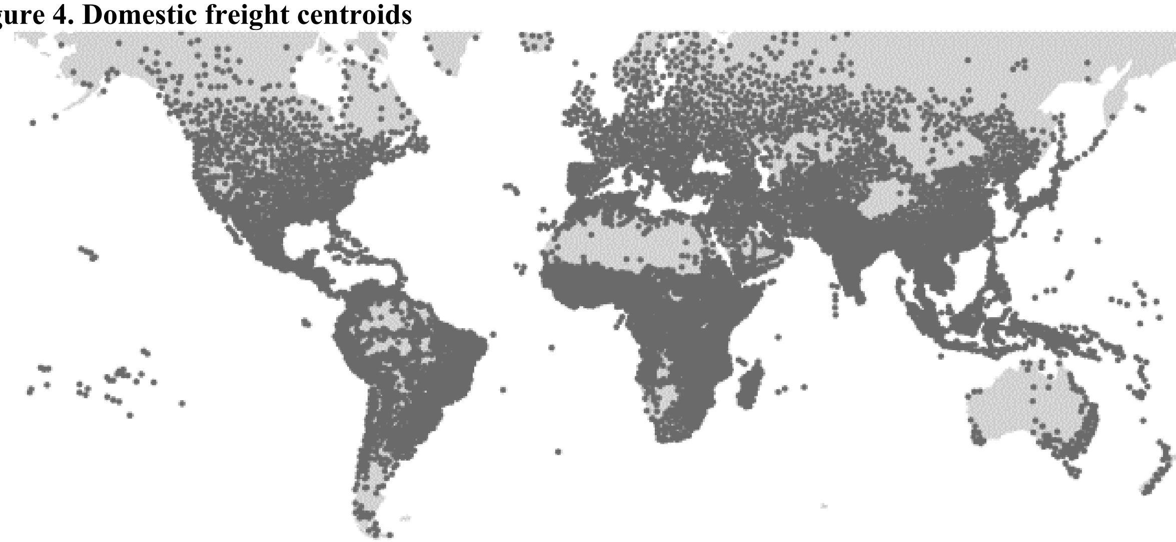
Domestic freight centroids

Domestic freight centroids define the origins and destinations of domestic freight flows. These centroids are estimated by a *set coverage* algorithm similar to the one described above. It uses raster-based GDP data (Kummu et al., 2018) to identify the most representative raster cell within a 100km radius.

The model produces a total of 7303 domestic centroids distributed as follows: North Africa (22), Central Africa (1020), South Africa (482), Commonwealth of Independent States (CIS) + Mongolia (823), South America (968), Central America and Caribbean (262), North America (845), ASEAN member countries (509), China (553), India (248), Japan and Korea (69), Oceania (249), Middle East (450), other Asian countries (70), European Union (452) and Other European countries and Turkey (145)).

As is the case with international freight centroids, the influence area of each domestic freight centroid is computed based on a raster world surface map. Population and GDP estimates are linked to each centroid while again respecting country boundaries (each raster cell is assigned to a centroid that lies in the same country as the raster cell, based on its distance to the centroid). Figure 3 provides an overview of the domestic freight centroids that have been defined in ITF's freight model.

Figure 4. Domestic freight centroids



Source: ITF

International freight model

This model includes a global intermodal network sub-model, underlying international trade projections, a weight-value conversion sub-model, and a mode share sub-model

Intermodal global network model

One of the main contributions of ITF's freight model is the consolidation and integration of different modal networks into a single freight network. Box 1 provides an overview of the data sources that were used to establish the respective transport network information in the model.

Box 1. Sources of information for global transport networks

- **Road network** information stems from the Global Roads Open Access Data Set (gROADS) (http://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1) and OpenStreetMap (www.openstreetmap.org). Only the first and second road networks are considered (i.e. motorways, main roads and truck roads).
- For the **rail network**, the model uses data from the Digital Chart of the World (DCW) (http://www.princeton.edu/~geolib/gis/dcw.html) project that is updated with data from OpenStreetMap on rail lines and rail stations as intermodal points of connection between road and rail.

- **Maritime routes** are obtained from the Global Shipping Lane Network data of Oak Ridge National Labs CTA Transportation Network Group (http://www-cta.ornl.gov/transnet/Intermodal_Network.html), which generates a routable network with actual travel times for different sea segments. This network is connected to ports based on data from the latest World Port Index Database of the National Geospatial-Intelligence Agency (http://msi.nga.mil/NGAPortal/MSI.portal).
- Commercial **air links** between international airports were integrated using data from the OpenFlights.org database on airports, commercial airlinks and airline companies (www.OpenFlights.org).
- **Inland waterways** around the world were collected from the DIVA-GIS project (https://www.diva-gis.org). Their navigability was assessed by specific information about the rivers and the sections that are navigable.
- Information on **oil or gas pipelines** was also obtained from OpenStreetMap (www.openstreetmap.org).

All the above transport networks were interconnected with road-based transport links (*connectors*) that connect the centroids to the network but also interconnect the different transport infrastructure (e.g. road-rail, road/rail-ports, etc.). In order to estimate travel times for the different types of transport infrastructure, as well as dwelling times between transport modes, the model uses average speeds based on available information by region. Border crossing times were estimated based on available datasets from TAD/OECD (http://www.oecd.org/trade/topics/trade-facilitation/).

The data sources provided in Box 1 were also used to establish transport costs for the different links. These costs encompass a distance-based and a time-based cost component. The distance-based cost component for each type of infrastructure is matched to a different unit value per region or country that takes into account infrastructure quality/performance, fuel/energy costs and labour costs in the transport sector.
The methodology for these calculations was derived from Tavasszy et al. (Tavasszy, Minderhoud, Perrin and Notteboom, 2011), where the authors establish a procedure to estimate indicators for the total costs for a link/network. The values obtained for specific countries were calibrated so to match reported mode shares by these countries. The time-based cost component reflects the value of travel time. An average aggregate value of time per hour and ton of 0.196 dollars/h.ton is derived from Tavasszy et al., 2011. Commodity-specific values of time are estimated in the mode choice model, where a distinct time-sensitiveness is obtained for each commodity type and transport type (container-based cargo, dry bulk, liquid bulk, transport equipment – RoRo and general cargo - more details are provided in Table 2).
The network model computes the free flow shortest paths between all centroids for each transport mode (if the mode is available), generating inputs used in the main econometric models (weight-value model and mode share model) presented next. These inputs are:

- The cost, travel time and distance by mode to link each pair of centroids;
- The shortest paths between the centroids for each transport mode.

Underlying international trade projections

The underlying trade projections that are used as an input to the model are disaggregated into 26 world regions. This level of resolution does not allow for estimating transport flows with precision as it does not allow a proper discretisation of the travel paths of different types of products. Therefore, the model disaggregates the regional origin–destination (OD) trade flows into the set of production/consumption centroids as defined in the spatial discretisation model. The disaggregation procedure assumes a proportionality of trade to GDP and uses raster-based GDP and population information to disaggregate trade estimates at the regional level. It matches this information for the base year (2019) if the information is available in the UN Comtrade (2022) dataset.The GDP used in the disaggregation of each commodity just considers the GDP created within the respective economic sector. This is determined as a national or regional

share (depending on data availability) of each economic sector multiplied by the estimated raster-based GDP. In the GDP of the EU, the NUTS3 or NUTS2 disaggregation was used to estimate this share.
Growth projections of centroids are based on the growth rates at the country level obtained from the OECD 2013 Economic Projections (Jean Chateau, Dellink and Lanzi, 2014), as growth rates are available at a country level only. The split of trade activity of centroids within the same country as source/destination of trade is kept constant over time.
The resulting equation for the estimation of the trade flows between centroids (OD pairs) for each type of commodity is given by

$$T_{odk}^{y} = T_{VLk}^{y} \frac{GDP_o^y \cdot S_{of(k)}}{\sum_{v=1}^{V} GDP_v^y \cdot S_{vf(k)}} \frac{GDP_d^y}{\sum_{l=1}^{L} GDP_l^y} \tag{1}$$

Where
T_{odk}^{y} = trade values from centroid *o* to centroid *d* in year *y* for commodity *k*,
T_{VLk}^{y} = trade values from origin region *V* to destination region *L* in year *y*,
$S_{of(k)}$ = share of GDP related with the same economic sector of commodity *k* in the region or country of centroid *o*,
o, *d* = origin and destination centroids,
k = commodity *k*,
y = year of analysis,
k = centroid that belongs to the origin region *V*,
l = centroid that belongs to the destination region *L*.

Weight-value model for the international trade

The conversion of value units (dollars) into weight units (tons) of cargo was formulated as a Poisson regression model. The model estimates the rate of value-to-weight conversion, using as offset variable the natural logarithm of the trade value in million dollars and a panel term representing the sensitivity of the different commodity types to transport costs. The selection of this regression method was based on the observation of the statistical distribution of the sample that fitted better a discrete statistical distribution than continuous distributions, especially for low trade connections. The model equation is given by:

$$E(y) = F \cdot exp(a + X\beta) + \varepsilon \tag{2}$$

where F is the exposition factor and X represents the systematic component of the Poisson regression model. The model was calibrated using Eurostat and ECLAC exports data[3] provided in value and weight units and using transport cost information (stemming from the network model, as discussed above). Also, geographical and cultural variables were used to estimate the model parameters: binary variables for trade agreements, land borders and for reflecting whether two countries use the same official language were introduced. Moreover, economic profile variables were included to describe the trade relationship between countries and the scale of trade intensity. These are

- The GDP percentile of the origin country ($p\%\ GDP_i$);
- The GDP percentile of the destination country ($p\%\ GDP_j$);
- The GDP per capita percentile of the origin country ($p\%\ GDP\ capita_i$);
- The GDP per capita percentile of the destination country ($p\%\ GDP\ capita_j$);
- The natural logarithm of the GDP per capita ratio between origin and destination countries ($ln \frac{GDP\ capita_i}{GDP\ capita_j}$).

[3] https://sgo-win12-we-e1.cepal.org/dcii/sigci/sigci.html

All the economic variables were defined using a relative order of countries in terms of percentiles instead of their absolute values. This is to avoid any disproportional effect in the future relation of value to weight. Any changes here are not expected to happen as it is neither assumed that products will become lighter for the majority of the commodities, especially with regards to raw materials, nor that a disruption in the market will significantly change the valuation of some commodities over others.

As a result, the values estimated by the model assume a stability of both the commodities' valuation over time and of how productivity indicators may impact them. Yet, the value-weight conversion of some energy market-related products, such as crude oil, refined oil, gas and coal, will depend strongly on the price of these commodities over time. For this reason, the value-weight conversion of these commodities has been indexed to the value forecast by IEA/OECD (IEA, 2018a) to ensure consistency in terms of the forecasted volume of trade for the next decades.

The model was estimated by keeping the minimum effect of the cost log sum positive and all commodities sensitive to costs. The minimum threshold value of 0.025 was estimated for the panel terms based on the observations in the dataset. The log sum accounts for the generalised costs, incorporating the time-based and distance-based cost terms.

Table 1 presents the calibration results for the model.

Table 1. Weight-value model calibration results

Parameter	Coefficient	p-value/ level of significance
Intercept	-13.907	0.00
Economic profile of countries		
$p\%\ GDP_{i}$	0.123	0.02
$p\%\ GDP_{j}$	-0.074	0.11
$p\%\ GDP\ capita_{i}$	-2.22	0.00
$p\%\ GDP\ capita_{j}$	1.08	0.00
$lnGDP\ capitaiGDP\ capitaj$	0.686	0.00
Economic, geographical and cultural relations between countries		
$Land\ border_{ij}$	-0.406	0.00
$Same\ language_{ij}$	0.133	0.01
$Trade\ aggreement_{ij}$	0.114	0.03
Cost commodity panel term $logsum\ cost\ dollartonne$		
Chemicals	- 0.136	0.12
Coal	- 1.679	0.00
Crude oil	- 0.395	0.00
Electronics	- 1.161	0.00
Fishing	- 0.392	0.01
Food products	- 1.324	0.00
Forestry	- 0.244	0.01
Gas	- 2.573	0.00
Iron and Steel	- 2.335	0.00
Livestock	- 0.277	0.01
Metal products	- 1.187	0.00
Non-Ferrous Metals	- 0.025	-
Non-metallic minerals	- 1.233	0.00
Other manufacturing	- 0.025	-
Other mining	- 0.025	-
Paper, pulp and print	- 0.245	0.00
Petroleum & coke	- 1.147	0.00
Rice and crops	- 0.524	0.00
Textiles	- 0.195	0.06
Transport equipment	0.025	-

(Scale)	1
Pseudo-ρ^2	0.73
Correl (y, $\hat{y}$)^2	0.92

Source: ITF

The overall model fit is high and shows the ability of the model to predict the conversion of trade values into trade volumes (in tons). The model performs well in reproducing market patterns. The trade agreement variable reveals to be a relevant explanatory factor; more expensive goods are typically transported further away. All the economic variables were found to be significant, presenting interesting relations for the weight-value ratio. Coefficients for $p\%\ GDP_i$ and $p\%\ GDP\ capita_j$ have a positive sign, indicating that larger economies tend to export larger weights/values, and wealthier destination countries tend to import larger quantities. There is quite symmetrical behaviour in terms of the size of destination markets and their wealth, showing that for less developed countries, it is more expensive to access products in the market. When there is a large difference in wealth between countries, the model predicts the import of higher-value goods to the wealthier country.

The cultural relation between countries (set as a binary value that takes the value one if the origin and destination country have a common official language and/or had a colonial relation in the past) was also found to be significant. Such country relations lead to relatively more exports of greater-value products. Conversely, countries with a land border tend to export larger quantities due to lower export costs.

Regarding the sensitivity of commodity types to transport costs, it can be seen that bulk-type commodities (liquid or solid) tend to be quite sensitive to costs. For example, textiles and other manufacturing products are less sensitive to transport costs. The value obtained for electronic components is also quite high, showing that trade volumes for electronic products are pretty sensitive to transport costs.

Mode share model for international freight

The mode share model for international freight flows (in tonnes) defines the transport mode used for trade between any OD pair of centroids. The modes include air, rail, road, waterways and maritime transport. The overall mode attributed to each trade connection represents the longest transport leg in a multi-modal trip chain. All freight is typically shipped on multi-modal chains, especially as the first and last legs are usually different from the main mode of transport. These latter domestic components of international freight movements are often unaccounted for in the literature. The ITF model does integrate these components: In the case of maritime transport, the model distinguishes one of three access modes (rail, road or waterways, while for the other non-road modes, the access mode is always assumed to be road.

The model uses a nested multinomial logit formulation, including a time commodity type panel term and a type of freight cost panel term. The mathematic formulation is given by:

$$U_{nj} = X'_{nj}\beta + Z'_{s}\alpha + \varepsilon_{nj} \tag{3}$$

where Z'_s represents characteristics of the nests, and ε follows a generalised extreme value (GEV). ε_{nj} have a joint cumulative distribution function of error terms, which is defined by

$$F\left(\varepsilon_{n1}, \varepsilon_{n2}, \dots, \varepsilon_{nJ}\right) = exp\left(-\sum_{s=1}^{S}\left(\sum_{j\epsilon B_s} e^{-\varepsilon_{nj/\lambda_s}}\right)^{\lambda_s}\right) \tag{4}$$

Where $\lambda_s$represent the nesting parameter that characterises each nest belonging to S.

The model was calibrated using export data sets from Eurostat and ECLAC, which contain information on the value, weight and mode of transport for exports from the EU and Latin America to the rest of the world. For each OD pair, we estimate the modal share in weight by commodity group. Data on travel times and distances for each mode were taken from the global network model at the centroid level. Two geographical and economic context binary variables were added: one describing if the pair of countries have a trade agreement and the other for the existence of a land border. For every OD pair, available modes were identified (e.g. land connectivity). Some commodity classes, such as coal and crude oil, cannot be shipped by air.

The dataset contained 17 427 observations, with an average weighted mode share in weight units of 19% for road, 1% for air, 79% for sea and just 1% for rail. The calibrated model has the likelihood ratio index (pseudo-rho squared) ρ^2= 0.64, showing very strong explanatory power of the mode choice. All explanatory variables are statistically significant (see **Table 2**).

Table 2. Trade value international freight mode share calibration results

Variable	Coefficient	Robust t-test	Robust p-value
Mode specific constant			
Air	-2.921	-41.50	0.00
Rail	-2.024	-40.22	0.00
Road	0.150	12.42	0.00
Lambda (nest parameter)	0.754	2.56	0.00
Sea – access by road	0.963	1.87	0.01
Sea – access by rail	0.550	2.01	0.00
Sea – access by waterways	1.050	1.65	0.02
Waterways	-0.801	1.52	0.04
Time commodity panel (1 000 hours)			
Chemicals	-0.191	-6.14	0.00
Coal	-0.002	-15.21	0.00
Crude oil	-0.153	-25.64	0.00
Electronics	-0.383	-157.44	0.00
Fishing	-0.097	-99.28	0.00
Food	-0.305	-33.33	0.00
Forestry	-0.010	-32.89	0.00
Iron and Steel	-0.014	-30.19	0.00
Livestock	-0.096	-2.65	0.00
Metal products	-0.393	-32.11	0.00
Non-ferrous metals	-0.112	-23.14	0.00
Non-metallic minerals	-0.006	-52.56	0.00
Other manufacturing	-0.177	-40.15	0.00
Other mining	0.000	0.00	-
Paper, pulp and print	-0.045	-39.6	0.00
Petroleum & coke	-0.003	-15.14	0.00
Rice and crops	-0.008	-22.11	0.00
Textiles	-0.008	-2.81	0.00
Transport equipment	-0.102	-35.18	0.00
Cost type panel term (1 million dollars)			
Container-based	0.03	-4.78	0.00
Dry bulk	0.06	-10.24	0.00
General cargo	0.02	-5.38	0.00
Liquid bulk	-0.07	-13.25	0.00
Transport equipment (Ro-Ro)	-0.02	-6.51	0.05
Geopolitical variables (trade agreement effects – TA, land border – LB)			
TA (rail and road)	1.33	4.47	0.00
LB rail	0.978	28.11	0.00
LB road	1.33	92.99	0.00

The results show a greater relationship between the sea alternative and low-value raw materials and non-perishable products. Transport-related variables present an interesting behaviour that clearly distinguishes sea transportation from the other available options. While increases in travel time reduce the utility of transporting by sea, cost aspects ensure the attractiveness of this mode. In general, the utility of a sea trade connection will depend on the balance between cost and travel time, often defined by specific sea routes and/or possible connections. Sea routes requiring a significant detour from the direct link are less attractive. Sea routes from Europe to Asia that do not use the Suez Canal are an example of such less attractive routes.

Air cargo has a very negative independent term due to the inability to send large volumes or because there are security concerns for specific commodities (chemicals, rubber and plastic, refined oil, livestock, other metals, other minerals, coal, iron and steel, crude oil, other mining, rice and crops and gas). The absence of direct flights is also very penalising (increasing the travel time and reducing utility significantly). Road and rail present similar utility behaviours. Yet, the alternative specific constant for rail is quite negative. This indicates that (although the cost for this mode is significantly lower than the one for road) its attractiveness is relatively low due to operational requirements that entail large delays and reliability concerns. This is partly due to the large number of rail operators involved in cross-national rail shipping.

Other important elements are geopolitical variables:

- Trade agreements between countries seem to favour land-based transport, indicating a potential simplification of border crossings procedures;
- A land border between countries favours exports through road and rail. Yet, this is stronger for road as the potential rail interoperability issues are still present.

Domestic freight model

Inversely to a traditional four steps model, the modelling of domestic freight does not follow the generation, distribution and assignment sequence. As no trade estimates between the different regions and cities of any one region are available, the model departs from the total freight activity estimation and follows a gravitational model to understand how the total trade splits into an OD matrix between the domestic freight centroids.

For each country, the gravitational impedance and the distance for each available mode among the domestic freight centroids allow the estimation of an average domestic travel distance. The total domestic freight activity (in tkm) is then divided by the average distance to obtain the average freight cargo weight. This weight can then be assigned to the network following the OD matrices and the shortest path between domestic centroids for the different available modes.

The two main steps of this model are presented next.

Estimates of total surface freight activity

Total surface freight activity in ton-kilometres is estimated by country. This includes all movements by road, rail and inland waterways inside each country's borders, encompassing transport of international and domestic nature, plus urban freight transport.

A Poisson regression model was used and calibrated on sample data from 51 countries from 2010 to 2015 with 306 observations. Observations cover all major countries that correspond to more than 80% of the world's surface freight movements (in ton-kilometre). Data assessments and extensive tests showed that using a discrete statistical distribution is more suitable than using a continuous distribution (e.g. lognormal) given the wide range of values and country behaviours. The natural logarithm of industrial- and agriculture-related GDP shows a higher correlation with freight activity than GDP *per se*. Therefore, it was used as an offset (or exposition factor) in the function. More than any other factor, this guides the trend and determines the volume of transport in each country. Other variables are related to the countries' geography, transport networks, and socio-demographic and economic structure (**Table 3**). The resulting equation is given by:

$$E(y) = F \cdot exp(a + X\beta) + \varepsilon \qquad (5)$$

where F is the exposition factor and X represents the systematic component of the Poisson regression model. Model calibration results show the number of factors that favour surface freight transport volumes. These include a country's size, the existence of large ports, the facts of being landlocked or having natural resources rents and ore-metal exports as a relevant part of the GDP (>12%). Also, having a geographical location and transport infrastructure that allows for transit plays an important role. Conversely, very high GDP per capita and population densities tend to reduce activity, meaning that richer economies are less transport intensive. Likewise, countries with higher densities show less freight transport activity, as there are only shorter distances to cover.

Table 3. Total surface freight activity calibration results

Parameter	Coefficient	z - value	Significance
Intercept	-14.890	-22723.6	0.00
Country profiles			
Connectivity for transit (1 000 000 km)	1.871	796.3	0.00
Population density (1 000 inhabitants/sqm)	-1.057	-574.9	0.00
Arable land (1 000 000 sqm)	0.516	1323.1	0.00
Dummy variables			
Inland waterways in activity	0.214	522.9	0.00
Large ports (in the 90 percentile of ports by capacity)	0.191	385.4	0.00
Landlocked	0.438	640.5	0.00
Natural resources rents and ore/metal exports	0.249	668.8	0.00
Fast growing (above 5% GDP growth)	0.192	552.5	0.00
Large countries in area (>1 200 000 km^2)	0.702	1283.8	0.00
Very low GDP per capita (< 4000 USD)	0.304	358.3	0.00
Low GDP per capita (4000 – 20 000 USD)	0.364	-493.0	0.00
Very high GDP per capita (> 40 000 USD)	- 0.316	568.8	0.00
(Scale)	1		
Pseudo-ρ^2	0.94		
Adjusted ρ^2	0.99		

Note: Offset (parameter with coefficient 1) for Industrial and Agriculture related GDP. Source: ITF

All variables in the model are significant, and the pseudo-R squared has a high value of 0.94.

Data sources for freight movements include ITF's surface freight database (ITF, 2017a), Eurostat, US DOT, and other national statistical agencies. GDP composition and natural resources intensity of the economy was obtained from the World Bank database. Ports capacity comes from the data set developed for (ITF, 2016).

The *connectivity for transit traffic* is an indicator that measures the route-kilometres that can take place in each country for movements between contiguous countries or countries that share the same trade agreements, the global road network and centroids for international trade where used for this calculation.

Part of the activity estimated by this model is already allocated to the network since it comes from international trade. The global intermodal network does not include urban activity, so the total volumes of urban freight per country are accounted for, including the estimates for emissions, but no mode choice or network allocation is performed. The share of urban versus non-urban freight transport activity in each country is obtained from the IEA's MoMo database (IEA, 2018a) as default. This information is complemented with ITF country survey information for member countries.

The activity that does not correspond to urban or international trade-related movements is subjected to mode-route choice using an *all-or-nothing* assignment procedure (see next section).

Mode route choice for domestic freight

Domestic freight activity (in tkm) is estimated in alignment with international freight activity estimates and domestic freight weights (in t).

The shortest paths between all centroids within the same countries are computed for all existent surface modes (road, rail and waterways) considering their attributes (e.g. cost and travel time). A simple gravity with the following formulation is applied:

$$V_{ij} = p_i * P_i * q_j * C_j * f(c_{ij}) \tag{6}$$

In this equation, V_{ij} denotes the transported freight from zone i to zone j, while P_i and C_j are the reported production and consumption of freight in the corresponding zones multiplied by zone-specific multiplication factors s p_i and q_j.These are multiplied by function f that determines the accessibility of the destination zone based on the generalised cost between zones c_{ij}:

$$f(c_{ij}) = e^{-\beta c_{ij}} \tag{7}$$

In this function, β is a sensitivity parameter that is estimated to be 0.00045, while c_{ij} defines the impedance between centroids (i.e. the zones that they represent), taking into account travel times and costs. The model generates a distribution of origin-destination flows by mode within the same country. The resulting matrix allows estimating the average travel distance of a freight movement and converting the tkm into weight. These flows (in weight terms) are assigned to the intermodal transport network model and are there subject to potential congestion also stemming from international traffic.

Equilibrium assignment

The model uses an iterative equilibrium assignment procedure with travel time and cost updates at every iteration (5 years). This also accounts for transport infrastructure updates in line with the 'calendar of development' that provides information on how infrastructure develops over time (e.g. accounting for TEN-T networks for Europe) - in terms of availability and/or link attributes (speed and capacity). Some components of the network are also assessed in terms of capacity and resulting congestion. Port capacity and throughput are also updated every iteration, using the information on planned port capacity expansions as reported at individual porta- or in the form of regional average growth rates. Port-specific data has been obtained from maritime studies (Drewry, 2013; OCS, 2012a, 2012b, 2012c).

At every iteration, freight transport activity by mode is assigned to the shortest/least-costly path (based on minimising the generalised cost). In the case of maritime shipments, a route choice model also considers the available .alternatives for port selection and transhipment options for every OD pair. The introduction of this procedure in the overall equilibrium assignment reduces the number of iterations required to converge. For creating the routing alternatives between each pair of centroids, a shortest path algorithm is computed between ports to generate the port-to-port segment(s) – consider both direct routing or indirect routing via a transhipment port). Transhipment ports are limited to large ports (more than 1 million TEUs of container traffic capacity, assuming an increase of this threshold value of 3% per year) with more than 25% spare capacity in the previous iteration.

The route and port choice algorithms use a path size logit model, which accounts for overlaps between alternative routes and transport costs associated with each alternative. The basis of this model can be found in (Bottom et al., 1999). The model is calibrated by minimising the difference between observed and modelled port throughputs for more than 400 major ports in the world. A detailed description of the model can be found in (Halim, Kwakkel and Tavasszy, 2016) and in (Tavasszy et al., 2011). The formal definition of the cost model is

$$\boldsymbol{C_r = \sum_{p\in r} A_p + \sum_{l\in r} c_l + \alpha\left(\sum_{p\in r} T_p + \sum_{l\in r} t_l\right)} \tag{8}$$

where

C_r = unit cost of route r from origin centroid to destination centroid (USD/Twenty-equivalent unit, TEU),

p = ports used by the route,

l = links used by the route,

A_p = unit cost of transhipment at port p (USD/TEU),

c_l = unit cost of transportation over link l (USD/TEU),

T_p = time spent during transhipment at port p (days/TEU),

t_l = time spent during transportation over link l (days/TEU),

α = value of transport time (USD/day).

The following is the formal definition of the route choice model. The route probabilities are given by

$$P_r = \frac{e^{-\mu\,(C_r + \ln S_r)}}{\sum_{h=1}^{H} e^{-\mu\,(C_h + \ln S_h)}} \tag{9}$$

while the path size overlap variable S is defined as

$$S_r = \sum_{a \in LK_r} \frac{Z_a}{Z_r} \frac{1}{N_{ah}} \quad (10)$$

In Equations (8) and (9):

P_r = the choice probability of route *r*,
C_r = generalised costs of route *r*,
C_h = generalised costs of route *h* within the choice set,
CS = the choice set with multiple routes,
h = path indicator/index,
μ = logit scale parameter,
a = link in route *r*,
S_r = degree of path overlap,
Lk_r = set of links in route *r*,
Z_a = length of link *a*,
Z_r = length of route *r*,
N_{ah} = the number of times link *a* is found in alternative routes.

At every iteration, the equilibrium assignment produces an all-or-nothing assignment (subject to the travel time and costs update at each assignment iteration) of all transport alternatives simultaneously. The model runs until there is a convergence of travel costs of all alternative paths for the same OD pair. The model typically converges after 5 to 10 iterations.

Calculation of the outputs

The model provides ton-kilometres (tkm) and vehicle-kilometres (vkm) for each link and centroid in the freight network, disaggregated by transport mode and commodity type. This allows calculating the corresponding values for different origin-destination pairs and routes. These outputs can be further aggregated at country and regional levels.

CO_2 emissions are estimated for each commodity either via transport activity in tkm or vkm, depending on the mode. For road transport, CO_2 is estimated via vkm, using specific load factors of trucks for the different types of commodities. Base load factors, specific for each commodity type, were obtained from the USA Commodity Flow Survey 2017[4] and Eurostat (the European Road Freight Transport (ERFT) survey).
Load factors change over time as operational improvements in freight transport are assumed to happen. These will allow reducing empty vehicle kilometres and making better use of vehicle volumes (e.g. by better packaging). For other modes, CO_2 estimates are derived by tkm. Respective CO_2 intensities per tkm were obtained from:

- ITF fleet model (road, rail and waterways)
- IMO (maritime freight) (Smith et al., 2014),
- ICAO (air cargo) (ICAO, 2018).

[4] https://www.census.gov/programs-surveys/cfs.html

Implementing Outlook 2023 scenarios

The ITF models were designed and further updated to estimate and evaluate the impact of policy measures on transport activity and related emissions under two main scenarios: *Current Ambition* and *High Ambition*.

The *Current Ambition* scenario builds on existing policies and commitments to estimate the current pathways of transport demand and related emissions. In contrast, *High Ambition* targets more profound changes in the transport sector on demand management (generation control and sustainable modal diversion) and technological breakthrough. It was built by the ITF in 2020 for the preparation of the ITF Transport Outlook 2021 (ITF, 2021), and adjusted for the ITF Transport Outlook 2023 (ITF, 2023a) since. It is the result of an international survey on current transport policies and technology development implementation worldwide, filled by many experts in the ITF network.
Table 4 shows the measures implemented in the model with target values by 2050 aggregated in two simplified categories: Global North and Global South contexts. They include enhancement to the infrastructure, economic instruments, regulatory instruments and measures to stimulate innovation and development.

Table 4. List of measures for non-urban freight transport and their implementation in the model

Type	Policy measures	**Model**	**Global North**	**Global South**
Enhancement of Infrastructure	Electric road infrastructure	Update costs and the resulting CO2 emission per vkm for road. This affects the value-weight conversion and the modal split	**30% - 50% of TKM**	**0% - 15% of TKM**
	Consolidation centres and platform sharing	This increases load factors in all modes (more the high capacity), but also, the logistic costs increase. This impacts mode choice and the conversion of tkm to vkm and reduces the conversion of value to weight	20% improvement	10% improvement
	Carbon pricing	Adapt the cost of each mode to reflect the CO_2 cost per km. Impacts mode choice and route choice	500 to 750 dollars per tonne	300 dollars per tonne
Economic instruments	**Congestion or distance-based charges**	Road costs would update costs based on verified congestion at each road link. Impacts mode choice and route choice	6.2 cents/tonne.km	2.4 cents/tonne.km
	Fuel economy standards – for vehicles and fuel	This element may only impact the CO2 intensity of the affected modes and the conversion of vkm to CO2 emissions	ITF 'High Ambition' scenario	
Regulatory instruments	**Operation of shared assets**	The adoption of shared assets allows the increase of load factors in road-based modes. This impacts mode choice and the conversion of tkm to vkm	20% improvement	10% improvement
	Low-carbon fuels	This element may only impact the CO_2 intensity of the affected modes and the conversion of vkm to CO_2 emissions	ITF 'High Ambition' scenario	
Stimulation of innovation and development	**Platooning**	This is implemented by decreasing road costs and load factors of trucks. This impacts mode choice and the conversion of tkm to vkm	5%-20% of TKM	2%-5% of TKM
	Autonomous vehicles	This is implemented by decreasing road costs. This impacts mode choice and the conversion of tkm to vkm	5%-20% of TKM	2%-5% of TKM
	Slow-steaming and Smart-steaming	Reduce the sea CO_2 intensities per ton/km by reducing energy consumption at lower speeds and minimising wait times at ports. This impacts mode choice and route choice	33% of TKM	20% of TKM

Carbon pricing

Carbon tax, green taxes and fuel taxes are different forms of taxes that can be applied to the aviation sector and are connected with the use of fuel or the fuel-burn resulting emissions. The main difference between these different forms of taxes is whether they are applied per litre of fuel or per tonne of CO_2 emitted. It is also important to note that fuel taxes for jet fuel are already in place in many parts of the world. Currently, fuel tax measures can be applied unilaterally by a country for its domestic flights or with a bilateral agreement for international flights between two countries. The CO_2 benefits of fuel or carbon taxes come mainly from demand reduction (ITF, 2023b).

Model implementation

This measure is introduced in the model by varying the unit cost for each mode. It can be based on the additional cost per vkm or tkm (based on the estimated load factor by commodity) by mode when a carbon tax is in place. This measure affects the mode choices and route choices. The implemented carbon pricing per ton is based on the reference literature (Baranzini et al., 2017; Carbon Pricing Leadership Coalition, 2018).

Congestion or distance-based charges

Congestion pricing sets a price for road travel with the objective of reducing congestion and the time losses and adverse environmental impacts that it entails. Congestion pricing can be variable (the price is fixed at different levels during different time periods) or dynamic (the price changes in real-time according to monitored traffic levels). Congestion pricing can also apply to specific city zones (e.g. in London), roads (e.g. the cordon/ring road in Stockholm) or segments of urban highways (e.g., tolled express lanes in the US) (ITF, 2023b).

Road pricing/charging is an old instrument widely used as a scheme to fund specific infrastructure realisation: the toll has to be paid by the users of the infrastructure (which can be a motorway, bridge, tunnel, etc.). The infrastructure perimeter has to be clearly defined. In Europe, road pricing is subject to regulation and law for trucks (see the Eurovignette Directive) (ITF, 2023b).

Charges can reflect all the costs related to the infrastructure: construction, maintenance, operation, and all the externalities associated with its utilisation. Charges can vary depending on the category of vehicles: light or heavy / number of axels, Euro Norm of Emission, or some other characteristics. The charge can also vary according to the time of day/year in order to reflect congestion level (and associated externalities). For distance-based charging, there can be a per kilometre charge only or a per km charge with an additional base charge. For decarbonising transport, what is most important is to apply variation according to the emissions of the vehicles. This needs an additional system (the vehicle needs a label, like Eurovignette or Crit'air) to be put into place (ITF, 2023b).

Model implementation

This measure may be introduced by affecting the cost of road freight activity. This cost increase will affect modal split but also route choice, as the trade between distance and time spent in travel may change.

Slow and smart steaming

Slow steaming is the practice of reducing maritime vehicle speeds. By operating ships at significantly slower speeds than their maximum speed, less fuel is consumed. This results in reduced CO_2 emissions. Slow steaming has been widely adopted since 2007, mainly due to the increased fuel costs at the time. Different ship types benefit differently from slow steaming (ITF, 2023b). Besides financial benefits, regulation of ship speeds could also be used to encourage slow steaming. There is also a possibility of using fuel levies to induce slow speeding through the increases in fuel prices (OECD/ITF, 2018).

Model implementation

This measure yields significantly reduced CO_2 emissions. A speed reduction of 10% translates into an engine power reduction of 27% (Faber, Thomas Huigen and Nelissen, 2017). Lower speeds are more effective if ship design speeds of ships are also lowered (Lindstad, Asbjørnslett and Strømman, 2011). The only potential adverse effect may result from the increased travel time that will affect the transport cost of some commodities that may decide the change for faster transport alternatives (e.g., road and rail). This measure has already been tested by (Halim et al., 2016).

Electric road infrastructure

Electrification of heavy-duty vehicles is more challenging than for their lighter counterparts due to the weight of the vehicle and the distances they cover. A battery sufficient to provide the necessary power is likely to have a significant impact on the possible payload for the vehicle, negatively impacting operational efficiency. Electric road infrastructure would overcome this by providing dynamic charging to moving vehicles. Studies suggest some level of uptake by 2050, but this will vary geographically. It will largely be dependent on the political will to decarbonise the sector and the available alternatives. Investment of public funds will be required for the initial development of the network, as a minimum level of coverage would need to be achieved before operators would consider electrifying their fleets. International co-operation for cross-border routes would also be required to ensure interoperability (ITF, 2019).

Model implementation

The impact of electric roads was implemented in the model by changing road costs based on IEA assumptions for their New Policy Scenario (NPS) (IEA, 2018a), affecting modal choice. This measure leads to a 37% reduction in carbon intensity in countries where the main network is equipped with electric road infrastructure. The level and timeline of implementation are differentiated by region. All relevant assumptions are based on (Cambridge Econometrics, 2018; ITF, 2018; Kasten et al., 2016); (Kühnel et al., 2018; Schulte and Ny, 2018; Siemens, 2017).

Platooning

Platooning or platoons refers to convoys of semi-automated vehicle convoys linked via vehicle-to-vehicle communication systems and is regarded as a forerunner to autonomous trucks, as it is already in advanced testing. In an expert survey carried out by the ITF, a majority of respondents estimated the cost reduction potential of platooning at 10% or more. Truck platooning can decrease the wind drag of vehicles driving closely packed in a column and thereby increase fuel efficiency. But its benefits are more associated with the reduction of operational costs (ITF, 2019). In future, policy measures that increase the cost of operating road freight, such as distance-based charging and carbon tax, could encourage the uptake of platooning to reduce costs.

Model implementation

This measure is implemented in the model as a reduction of carbon intensity per vkm for vehicle activity in the main network of countries where this measure may be implemented. The implementation schedule of such a measure varies by region and prevalence of highways in the overall road network of the country. A proportion of vkms being operated under platooning leads to a reduction in the total CO_2 intensity. The reduction in CO_2 intensity was 14%. This assumption was derived from previous work at the ITF (ITF, 2017b).

Autonomous vehicles

Autonomous vehicles are a highly disruptive technology that could bring substantial changes in lifestyles, car ownership, travel patterns, land use, etc. Therefore, authorities and policy makers are facing the great challenge of designing standards, legislation and policies which could help to minimise risks, alleviate the negative effects and amplify the positive ones.

Authorities should provide legal clarity regarding the rights, obligations and liabilities of autonomous vehicle developers, operators, owners and insurance companies. This will include conditions under which developers can test and market the vehicles, criminal and civil liability rules and legal status for all the stakeholders, etc. (ITF 2015). On the operation side, the legislation will have to define the liability of drivers, passengers and vehicles in different situations (such as physical damage to a person or property, personal data leak or if a vehicle is used as a weapon of terror or for a crime), for an occupied and unoccupied vehicle. The insurance structure and compensation in case of an accident should also be defined.

Finally, the authorities will have to internalise the costs of driving as much as possible and stimulate individuals, companies and organisations to own and operate the vehicles in a way which would allow for reducing both direct and external societal costs, encouraging sharing rather than individual use of the vehicles (ITF, 2019).

Model implementation

This measure is implemented in the model as a cost reduction for road freight activities, resulting in potential changes to mode shares in freight transport. It is assumed the reduction of the driver costs is greater than the increases in cost stemming from the technology and the vehicle (reducing by around 45% of current values). This implementation is assumed to differ by geographical region. Carbon intensity per vkm is estimated to decrease by 14%. These assumptions were derived from (Bagloee, Tavana, Asadi and Oliver, 2016; ITF, 2015, 2017b, 2018; NRC, 2010).

Operation of shared assets

Sharing assets, i.e. information flows, transport mechanisms or stocking spaces, can promote efficiency in resource management for logistic activities. One same enterprise, or several of them, can benefit from this sharing of assets. ICTs have only facilitated asset-sharing by decreasing information costs and providing platforms where various actors can share their assets. From an environmental point of view, sharing assets can increase logistic efficiencies, for instance, by increasing the occupancy rate of vehicles. Multimodality towards less carbon-intensive modes is also a possibility. Ultimately, improvements can reduce the number of trips required to deliver products, thus reducing the number of emissions linked to logistic activities. Asset sharing can also bring additional benefits. Costs for enterprises can be reduced by increasing efficiencies, for instance, by decreasing fuel consumption. Improvements linked to asset-sharing measures will be dependent on the types of activities led by the enterprises that decide to share assets. As an illustration, it will be harder to share transport assets between one enterprise transporting food and another one transporting industrial goods because of the difference in stocking needs for these products. Governments may need to consider appropriate competition regulation to facilitate such asset sharing and may need to consider how such actions could be enabled (e.g., through digital platforms) (ITF, 2023b).

Model implementation

This measure is implemented by adapting the load factor for each commodity type in each travel mode. The reference values used for different scenarios are based on the efficiency increases introduced by the IEA MoMo model in the different scenarios (IEA-NPC and IEA-EV30@30) (IEA, 2018b).

Fuel economy standards – for vehicles and fuel

A low carbon fuel standard (LCFS) is a market-based policy mechanism aiming to reduce the life-cycle greenhouse gas (GHG) emission intensity of transportation fuels/energy vectors.

The mechanism is grounded on the definition of progressively tightened regulatory thresholds/limits for the average life-cycle (i.e. including production, distribution and use) GHG emission intensity of transport fuels/energy vectors (typically gasoline, diesel oil and jet kerosene) distributed by regulated parties (typically fuel suppliers and/or other entities that produce, import, distribute or sell transportation fuels).

Fuels with a carbon intensity that is lower than the regulated threshold generate credits; fuels with higher GHG emission intensity generate deficits. In any given year, regulated parties need to have enough credits to compensate for any deficits created by the sale of carbon-intensive fuels. Regulated entities can trade credits and use credits banked from previous years to ensure they meet the policy requirements in any given year.

Mandatory vehicle efficiency standards require newly registered vehicles to emit less tailpipe CO_2 emissions than a specified threshold value (usually specified in gCO_2/km or similar) by a certain target date. Alternatively, such standards may be expressed as fuel economy standards that require vehicles to surpass a certain fuel-efficiency value (usually provided in miles/gallon fuel or similar). A vehicle's tailpipe CO_2 emissions and fuel consumption are typically assessed in standardised laboratory vehicle test procedures (ITF, 2023b).

Model implementation

This measure is implemented in the model as a reduction of carbon intensity per vkm for the road sector, with a calendar of development by vehicle type and region in the ITF fleet model.

Low-carbon fuels

The development and availability of low or zero-carbon fuels for use in long-haul freight would be the outcome of multiple policy levers, including standards to create the need for an alternative, and likely incentives for research and development and for the uptake of alternative fuels, which may currently be more expensive than the existing fossil fuel. The adoption of low-carbon fuels would reduce the CO_2 emitted per vehicle kilometre (vkm) (ITF, 2023b).

The development of low-carbon fuels for long distances can be encouraged through regulatory policy measures such as fuel economy standards and fuel blending mandates or through reducing investment risks for research and development in alternative fuels. A number of financial measures involve the public sector assuming risks that would otherwise need to be borne by private investors. Key examples include (ITF, 2023b):

- the availability of financing from public entities at low-interest rates;
- loan guarantees, i.e., the obligation by the public sector to pay some or all the debt in the event the investor fails to pay;
- debt service reserves, i.e., deposits of cash to pay interest and principal payments in case a borrower fails to make scheduled payments;
- subordinated debt, where a public agency agrees to allow a lower priority position than senior debt holders (in case of default, senior debt holders are paid in full before other debt holders are repaid);
- the provision of grants by public agencies to investors to preserve or reduce the market interest rate of a loan;
- credit insurance products for bond financing, i.e. insurances agreeing to pay a bond in the event that a payment default occurs by the issuer; and
- Public Private Partnerships (PPPs), where the commercial risk is shared amongst private partners and the public sector.

Model implementation

This measure is introduced into the model by changing the costs for road-based transport activity based on the IEA assumptions for their New Policy Scenario (IEA-NPS) (IEA, 2018a), thereby affecting modal choice. This measure also leads to a reduction in carbon intensity. The level and timeline of adoption are differentiated by region. All these assumptions are based on (Cambridge Econometrics, 2018; ITF, 2018; Kasten et al., 2016); (Kühnel et al., 2018; Schulte and Ny, 2018; Siemens, 2017).

Consolidation centres and platform sharing

Distribution centres allow for the consolidation of shipments from multiple suppliers and thereby optimise the loading of trucks onwards from the centre, improving the efficiency of the supply chain. This results in a reduction in vehicle kilometres and kilometres of empty running. Consolidation centres can also facilitate mode shift as it favours the transport of high volumes along main corridors, and trucks are required only for the first and last legs, thus reducing the vehicle kilometres operated on road.

Policies that encourage more efficient freight transport, such as distance-based charging and carbon taxes, as well as access restrictions on trucks in cities, can encourage the use of distribution centres as they can aid operators in reducing costs.

Model implementation

This measure affects the average load factors of surface transport modes (road and rail) that connect the main regional freight centres to urban consumption centres. It will also affect the average weight of, or space used in, each truck. Moreover, the use of a common platform to organise transport and measure activity has also been reported as a very cost-effective measure that companies are increasingly using (Li and Yu, 2017). The load factor gains are mainly linked with freight for typically less consolidated manufacturing goods that operate in a peer-to-peer manner or individual logistics chains of companies (e.g. textile and electronics). Load factor gains can be reflected in the conversion of tkms to vkms for each commodity type, and the load factor gain scenarios may vary by world region and target year. Values implemented can be based on existing literature on the topic, e.g., (Ballot and Fontane, 2010; Ülkü, 2012).

References

S. A. Bagloee et al. (2016), “Autonomous vehicles: challenges, opportunities, and future implications for transportation policies,” *Journal of Modern Transportation*, Vol. 24/4, pp. 284–303, Springer Berlin Heidelberg, https://doi.org/10.1007/s40534-016-0117-3.

E. Ballot and F. Fontane. (2010), “Reducing transportation CO2 emissions through pooling of supply networks: perspectives from a case study in French retail chains,” *Production Planning & Control*, Vol. 21/6, pp. 640–650, Taylor & Francis, https://doi.org/10.1080/09537287.2010.489276.

A. Baranzini et al. (2017), “Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations,” *Wiley Interdisciplinary Reviews: Climate Change*, https://doi.org/10.1002/wcc.462.

J. Bottom et al. (1999), “Investigation of route guidance generation issues by simulation with DynaMIT,” *Transportation and Traffic Theory*, pp. 577–600.

Cambridge Econometrics. (2018), *Trucking into a Greener Future*.

Carbon Pricing Leadership Coalition. (March 2018), “What is carbon pricing?,” accessed on 28, https://www.carbonpricingleadership.org/what/.

J. Chateau et al. (2014), *Trade Patterns in the 2060 World Economy*., OECD Economics Department Working Papers, No. 1142, OECD Publishing.

Jean Chateau, R. Dellink and E. Lanzi. (2014), “An Overview of the OECD ENV-Linkages Model: Version 3,” *OECD Environment Working Papers, No. 65*, https://doi.org/10.1787/5jz2qck2b2vd-en.

CIESIN - Columbia University. (2018), “Gridded Population of the World, Version 4 (GPWv4): Population Count, Revision 11,” NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY.

Drewry. (2013), *Global Container Terminal Operators Annual Review and Forecast 2013*., *Global Container Terminal Operators Annual Review and Forecast 2013*.

J. Faber, Thomas Huigen and D. Nelissen. (2017), *Regulating speed: a short-term measure to reduce maritime GHG emissions*, CE {Delft.

R. A. Halim, J. H. Kwakkel and L. A. Tavasszy. (2016), “A scenario discovery study of the impact of uncertainties in the global container transport system on European ports,” *Futures*, https://doi.org/10.1016/j.futures.2015.09.004.

ICAO. (2018), *Annual Report of the Council 2017*.

IEA. (2018a), *World Energy Outlook 2018*., Paris, https://doi.org/https://doi.org/10.1787/weo-2018-en.

IEA. (2018b), *Global EV Outlook 2018*., Paris, https://doi.org/10.1787/9789264302365-en.

ITF. (2015), *Automated and Autonomous Driving Regulation under uncertainty*.

ITF. (2016), *Capacity to Grow*., International Transport Forum, https://doi.org/https://doi.org/https://doi.org/10.1787/5jlwvz8jlpzp-en.

ITF. (2017a), “Goods transport,” https://doi.org/https://doi.org/https://doi.org/10.1787/g2g5557d-en.

ITF. (2017b), *Managing the Transition to Driverless Road Freight Transport*., Paris.

ITF. (2018), *Towards Road Freight Decarbonisation Trends, Measures and Policies*, International Transport Forum, Paris.

ITF. (2019), *ITF Transport Outlook 2019* (ITF Transport Outlook), OECD, https://doi.org/10.1787/transp_outlook-en-2019-en.

ITF. (2020), *The ITF non-urban freight transport model - Insights and example outputs*.

ITF. (2021), *ITF Transport Outlook 2021*., Paris: OECD, https://doi.org/10.1787/16826A30-EN.

ITF. (2023a), *ITF Transport Outlook 2023*, https://doi.org/https://doi.org/https://doi.org/10.1787/b6cc9ad5-en.

ITF. (2023 b), “Catalogue of Measures,” *Decarbonising Transport Initiative*, Decarbonising Transport Initiative, https://www.itf-oecd.org/decarbonising-transport (accessed January 1, 2023).

P. Kasten et al. (2016), *Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050 Endbericht*.
S. Kühnel, F. Hacker and G. Wolf. (2018), *Oberleitungs-Lkw im Kontext weiterer Antriebs-und Energieversorgungsoptionen für den Straßengüterfernverkehr*., Berlin.
M. Kummu, M. Taka and J. H. A. Guillaume. (2018), "Gridded global datasets for Gross Domestic Product and Human Development Index over 1990-2015," *Scientific Data*, Vol. 5, https://doi.org/10.1038/sdata.2018.4.
Y. Li and Y. Yu. (2017), "The use of freight apps in road freight transport for CO2 reduction," *European Transport Research Review*, Vol. 9/3, p. 36, https://doi.org/10.1007/s12544-017-0251-y.
H. Lindstad, B. E. Asbjørnslett and A. H. Strømman. (2011), "Reductions in greenhouse gas emissions and cost by shipping at lower speeds," *Energy Policy*, Vol. 39/6, pp. 3456–3464, https://doi.org/10.1016/j.enpol.2011.03.044.
L. M. Martinez, J. Kauppila and M. Castaing. (2015), "International Freight and Related Carbon Dioxide Emissions by 2050: New Modeling Tool," *Transportation Research Record: Journal of the Transportation Research Board*, 2477, pp. 58–67, Transportation Research Board of the National Academies.
NRC. (2010), *Hidden Costs of Energy*., Washington, D.C.: National Academies Press, https://doi.org/10.17226/12794.
OCS. (2012a), *North European Containerport Markets to 2025*, Ocean Shipping Consultants, Chertsey.
OCS. (2012b), *East Asian Containerport Markets to 2025*, Ocean Shipping Consultants, Chertsey.
OCS. (2012c), *Middle East Containerport Markets to 2025*, (Ocea, Ed.), Ocean Shipping Consultants, Chertsey.
OECD. (2021), "ENV-Linkages model," *The Economic Benefits of Air Quality Improvements in Arctic Council Countries*, OECD Publishing, Paris.
OECD. (2022), *OECD Economic Outlook*., Paris: OECD Publishing, https://doi.org/http://dx.doi.org/10.1787/eco_outlook-v2016-1-en.
OECD/ITF. (2018), *Decarbonising Maritime Transport Pathways to zero-carbon shipping by 2035*.
J. Schulte and H. Ny. (2018), "Electric road systems: Strategic stepping stone on the way towards sustainable freight transport?," *Sustainability (Switzerland)*, Vol. 10/4, https://doi.org/10.3390/su10041148.
Siemens. (2017), *eHighway: Innovative electric road freight transport*.
T. W. P. Smith et al. (2014), "Third IMO Greenhouse Gas Study 2014," *International Maritime Organization (IMO)*, https://doi.org/10.1007/s10584-013-0912-3.
L. Tavasszy et al. (2011), "A strategic network choice model for global container flows: Specification, estimation and application," *Journal of Transport Geography*, https://doi.org/10.1016/j.jtrangeo.2011.05.005.
M. A. Ülkü. (2012), "Dare to care: Shipment consolidation reduces not only costs, but also environmental damage," *International Journal of Production Economics*, Vol. 139/2, pp. 438–446, https://doi.org/https://doi.org/10.1016/j.ijpe.2011.09.015.
UN. (2015), *World Population Prospects*, *United Nations* (Volume 1), United Nations, Department of Economic and Social Affairs, Population Division, https://doi.org/10.1017/CBO9781107415324.004.
UN Comtrade. (2022), "UN Comtrade | International Trade Statistics Database," *UN Comtrade*.
UN DESA. (2022), *World Population Prospects 2022*, United Nations.