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The PLANET Model: Methodological Report

PLANET 4.0

February 2020

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Abstract – PLANET is a model developed by the Belgian Federal PLANning Bureau that models the relationship between Economy and Transport. Its aim is to produce: (i) medium- and long-term projections of transport demand in Belgium, both for passenger and freight transport; (ii) simulations of the effects of transport policy measures; (iii) cost-benefit analyses of transport policy measures. This methodological report describes the main features of the PLANET model, and more specifically, the version 4.0 used for the transport outlook published in January 2019.

Jel Classification – R41, R48.

Keywords – Transport, Passenger and freight transport, Long-term transport projections, Transport policy.

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Foreword

The work presented in this publication is based on a collaboration agreement between the FPS Mobility and Transport and the Federal Planning Bureau. The collaboration focusses on the development and exploitation of statistical information, the development of long-term transport projections and the analysis of transport policies.

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Executive summary

PLANET is a model developed by the Belgian Federal PLANning Bureau that models the relationship between the Economy and Transport. Its aim is to produce:

– long-term projections of transport demand in Belgium, both for passenger and freight transport;

– simulations of the effects of transport policy measures;

– cost-benefit analyses of transport policy measures.

Long-term projections of transport demand are published every three years, in collaboration with the Federal Public Service Mobility and Transport. They give a business-as-usual scenario for transport demand in Belgium, which can be compared to alternative policy scenarios.

In this methodological report we describe extensively the version 4.0 used for the transport outlook published in January 2019. The philosophy of the model and how it translates into an operational sequence are set forth, with emphasis on the key outputs, sources used and modelling methods. This report's intent is to convey a general understanding of the aims and means, constraints and limitations related to our modelling effort. As such, it is an extensive documentation for users of the model outputs, rather than an exhaustive mathematical description of each modelling step taken.

The achievement of the long-term projection relies on several preparatory steps and a projection loop. Once definitions are made clear, the preparatory steps can be summarised as follows:

(a) the observation of the transport demand in the reference year;

(b) the identification of socio-economic drivers for the transport demand, and the observation or computation of the value of the variables representing these drivers in the reference year and in all projection years;

(c) the establishment of formal links between these drivers and the transport demand per se, by the setting up of models and their estimation or calibration.

These preparatory works allow to initiate the projection loop, where all variables and parameters take the values observed or computed for the reference year. Subsequently, for each projection year, the evolution of the driver variables and endogenously computed quantities such as costs translates into evolution of the model outputs.

Ex-post computations allow to derive results regarding emissions, congestion and marginal external costs.

Synthèse

PLANET est un modèle développé par le Bureau fédéral du PLAN qui modélise la relation entre l'Economie et le Transport. Son objectif est :

– d'élaborer une projection à long terme de la demande de transport en Belgique, tant pour le transport de personnes que pour le transport de marchandises ;
– de simuler les effets de politiques de transport ;
– de réaliser des analyses coûts-bénéfices de ces politiques de transport.

Les perspectives à long terme de la demande de transport sont publiées tous les trois ans en collaboration avec le SPF Mobilité et Transport. Elles offrent un scénario de référence de l'évolution de la demande de transport en Belgique, qui peut être confronté à des scénarios de politique alternatifs.

Ce rapport méthodologique décrit de manière détaillée la version 4.0 utilisée pour les perspectives de la demande de transport publiées en janvier 2019. La philosophie du modèle et la façon dont elle se traduit de manière opérationnelle sont exposées, en insistant sur les principaux résultats, les sources utilisées et les méthodes de modélisation. Ce rapport vise à donner une compréhension générale des objectifs, des moyens, des contraintes et des points d'attention liés à notre travail de modélisation. En tant que tel, il s'agit plutôt d'une documentation exhaustive pour les utilisateurs des résultats du modèle que d'une description mathématique détaillée de chaque étape de modélisation mise en œuvre.

L'élaboration de la projection de référence repose sur plusieurs étapes préparatoires et une boucle de projection. Une fois les définitions clarifiées, les étapes préparatoires peuvent être résumées comme suit :

(a) établissement de la demande de transport à l'année de référence ;
(b) identification des déterminants socio-économiques de la demande de transport, et observation ou estimation des variables représentant ces déterminants à l'année de référence et en projection ;
(c) établissement de liens formels entre ces déterminants et la demande de transport en tant que telle, par la mise en place de modèles et leur estimation ou leur calibration.

Ces travaux préparatoires permettent d'initier la boucle de projection où toutes les variables et tous les paramètres prennent les valeurs observées ou calculées pour l'année de référence. Ensuite, pour chaque année de projection, l'évolution des déterminants et des quantités calculées de manière endogène telles que les coûts se traduisent par une évolution des résultats du modèle par le mécanisme des modèles calibrés et la détermination des vitesses d'équilibre sur le réseau routier.

Des calculs ex post permettent d'obtenir des résultats concernant les émissions, la congestion et les coûts marginaux externes.

Synthese

PLANET is een model dat werd ontwikkeld door het Federaal PLANbureau en dat de relatie tussen de Economie en Transport modelleert. Het model heeft tot doel:

– een projectie van de transportvraag in België op lange termijn uit te werken, zowel voor het personen- als het goederenvervoer;

– de effecten van beleidsmaatregelen voor transport te simuleren;

– een kosten-batenanalyse van die beleidsmaatregelen voor transport op te stellen.

De langetermijnvooruitzichten voor de transportvraag worden om de drie jaar gepubliceerd in samenwerking met de FOD Mobiliteit en Vervoer. Ze bieden een referentiescenario voor de evolutie van de transportvraag in België, dat kan worden vergeleken met alternatieve beleidsscenario's.

Dit methodologisch rapport beschrijft op gedetailleerde wijze versie 4.0 die werd gebruikt voor de transportvooruitzichten van januari 2019. De filosofie van het model en de manier waarop het zich vertaalt in operationele resultaten worden uiteengezet, met de nadruk op de belangrijkste resultaten, de gebruikte bronnen en de modelleringsmethoden. Dit rapport beoogt een algemeen inzicht te geven in de doelstellingen, de middelen, de beperkingen en de aandachtspunten van onze modelleringswerkzaamheden. Als dusdanig is het veeleer een uitgebreide documentatie voor de gebruikers van de modelresultaten dan een gedetailleerde wiskundige beschrijving van elke uitgevoerde modelleringsstap.

De ontwikkeling van de referentieprojectie berust op verschillende voorbereidende stappen en een projectielus. Zodra de definities zijn verduidelijkt, kunnen de voorbereidende stappen als volgt worden samengevat:

(a) vaststellen van de transportvraag in het referentiejaar;

(b) identificeren van de socio-economische determinanten van de transportvraag en observatie of berekening van de variabelen die deze determinanten vertegenwoordigen in het referentiejaar en in de projectie;

(c) vaststellen van formele verbanden tussen die determinanten en de transportvraag als dusdanig, door het opzetten van modellen en de schatting of kalibratie ervan.

Deze voorbereidende werkzaamheden maken het mogelijk om de projectielus te starten waarbij alle variabelen en parameters de waargenomen of berekende waarden voor het referentiejaar aannemen. Vervolgens vertaalt de evolutie van de variabelen en de endogene berekende hoeveelheden zoals kosten zich in een evolutie van de modeloutput door de werking van de gekalibreerde modellen en de bepaling van evenwichtssnelheden op het wegennet.

De ex-post-berekeningen leveren resultaten op met betrekking tot emissies, congestie en marginale externe kosten.

1. Introduction

PLANET is a model developed by the Belgian Federal **PLAN**ning Bureau (FPB) that models the relationship between **E**conomy and **T**ransport. Its aim is to produce:

- long-term projections of transport demand in Belgium, both for passenger and freight transport;
- simulations of the effects of transport policy measures;
- cost-benefit analyses of transport policy measures.

The main strengths of PLANET lie in its long-term horizon, its coherence with other FPB medium- and long-term projections, the simultaneous modelling of passenger and freight transport, the endogenous modal and time choice, and the welfare evaluation of policies.

The long-term projections are published every three years, in collaboration with the Federal Public Service Mobility and Transport. They give a business-as-usual scenario for transport demand in Belgium, which can be compared to alternative policy scenarios[1].

This paper describes extensively the version 4.0 used for the transport outlook published in January 2019. Chapter 2 gives the scope of the model. Chapter 3 describes how the model works. The different steps that lead to the projection of transport demand in Belgium are detailed one by one, followed by a description of the projection loop itself. The paper concludes with the description of the different outputs of PLANET and the ex-post calculation possibilities offered by the model.

[1] The results of the different scenarios are discussed in accompanying reports: recently, Hoornaert, B, and A. Van Steenbergen (2019), *The cost of traffic congestion in Belgium - An estimate using the PLANET-model*, Working Paper 9-19, Federal Planning Bureau.

2. Scope of the model

2.1. Purpose of the model

The purpose of the PLANET model is to study the links between economic and socio-demographic trends and the transport demand in Belgium. As such, the desired output of PLANET is a long-term projection of transport demand on the Belgian territory, having as inputs economic and socio-demographic projections. These inputs are exogenous to the model, meaning that retroaction effect on the economy and the demography in Belgium stemming from evolution in transport characteristics (flows, costs) are not modelled and hence not considered.

Transport demand is what results directly from the economic activity and the population needs. This is the clear focus of the PLANET model. The supply of transport services and infrastructure is not at the heart of the modelling scope, and subject to broad hypotheses detailed later in this paper. In the same way, the scale of the model is of macro-economic nature and the geographic subdivisions chosen to embody origins, destinations, and transport flows are rather coarse and chosen to coincide with institutional divisions allowing the necessary data collection effort. We do not consider detailed transport networks or geographical areas that would allow to tackle typical network allocation issues. Those are left over to other modelling frameworks[2], which may interact with the PLANET model.

This macroeconomic focus is also reflected in the ways individual behaviours are considered and aggregated to obtain macro-level flows. The paradigm is mostly that of a representative agent endowed with average behaviour patterns, for a limited number of population subgroups. In that sense, we do not consider detailed aspects of transport characteristics that build up a typical individual’s choice set in a realistic setting, such as activity-based modelling, trip chaining, multimodal chains. We stick to the simpler setting of “single purpose, main mode, return trips from home” for these representative agents. These choices obviously preclude certain types of analysis but appear as the best choice when our aim is to study the macro-level linkage between economy, demography and transport, to obtain an aggregated, long-term evolution of transport demand.

The temporal focus of the modelling is on the long term rather than year-per-year evolution. This means that attention is particularly paid to trend developments (and less to cyclical movements) and to determinants that explain these long-term trends.

2 e.g. regional models such as Strategische Verkeersmodellen Vlaanderen, MuStI (modèle Multimodal Stratégique de déplacement pour Iris) for the Brussels-Capital Region.

Given these choices of approach, we can reformulate the desired output of the model as the projection of four sets of Origin-Destination (OD) matrices:

- One set of OD matrices for passengers, expressed in number of trips by motive at Belgian district[3] level, for each year of the projection period;
- One set of OD matrices for passengers, expressed in passenger-kilometres[4] on the Belgian territory; by motive, mode, travel period and type of road used where applicable, at Belgian district level, for each year of the projection period;
- One set of OD matrices for freight, expressed in tonnes, by product category, type of flow, mode and travel period at Belgian district level or foreign country, for each year of the projection period;
- One set of OD matrices for freight, expressed in tonne-kilometres[5] on the Belgian territory, by product category, type of flow, mode, travel period and type of road used where applicable, at Belgian district level or foreign country, for each year of the projection period.

Beyond this set of primary outputs, ex post computations allow to produce impact evaluations in terms of:

- direct, indirect and non-exhaust emissions of pollutants;
- speed on the Belgian road network;
- welfare (e.g. marginal external costs related to congestion and environment).

Apart from speed, which is a key endogenous variable in the model, these environmental and welfare impacts have no effect on the transport projections.

2.2. Modelling approach

The modelling approach of PLANET can be summarised as follows.

a. PLANET is inspired by the so-called "four-step" transport models

A classic four-step model consists of four main modules, performed sequentially:

- A *Trip generation module*

  Its aim is to estimate total transport demand i.e. tonnages, trips or passengers, produced and/or attracted, per geographical zone (i.e. origin and destination zones), usually using demographic and economic indicators.

- A *Trip distribution module*

  Trips/persons and tonnages demand generated above are matched between origin and destination zones. Gravity models are usually used here, wherein transport flows are primarily explained by the

[3] District levels correspond to the level 3 of the European Nomenclature of territorial units for statistics (NUTS 3), which is described in Appendix C.
[4] A passenger-km (pkm) is a kilometre travelled by a passenger/person.
[5] A tonne-kilometre (tkm) is a kilometre travelled by one tonne.

relative size of the different zones and the transport costs between them. The result is an origin-destination matrix of trips/passengers or tonnages transported between two zones.

– A *Modal and Time choice module*

  The origin-destination matrix is disaggregated by time periods and modes of transport following agent's choices based on "generalised" costs, i.e. the sum of the monetary and time costs.

– A *Traffic assignment module*

  The final step is to assign transport demand over a synthetic network (usually only a road network). In this respect, it is assumed that the traffic will be distributed between the different possible routes in such a way that an individual driver cannot make a gain by changing his route. This module integrates the crucial congestion curves that determine, for each road, the relationship between speeds and traffic flow. Congestion has an impact on time costs which contribute to determining the choices in the other modules.

PLANET is largely inspired by this philosophy but departs from it on the fourth point. PLANET does not have a Traffic assignment module. This choice is dictated by the high level of aggregation of the geographical zones defined in the model, i.e. the 43 Belgian districts. A synthetic road network consisting of 43x43 links between these districts has little meaning.

b. PLANET is based on exogenous macroeconomic and socio-demographic evolutions

Exogeneity means that we only consider the impact of economic or demographic variables on transport variables. There is no feed-back from transport to (macro)economics or demographics. Models incorporating this kind of feed-back fall in the category of general equilibrium models and are the subject of other efforts within the FPB.

c. PLANET is of macro-economic nature

PLANET is a broadly aggregated model aimed at identifying and understanding the impact of economic and demographic changes on transport demand. It does so through the consideration of representative agents and modelling of their average behaviour. This kind of approach makes sense at a coarse level of aggregation only, where the number of individual situations (or local specificities of transport networks and supply) averaged out is enough for the law of large numbers to settle in and make idiosyncrasies of individual behaviours less relevant. This macro-level modelling is in accordance with the macro-economic nature of the inputs used. Obviously, this kind of model is not suitable to address local transport issues or detailed individual behaviours, just as detailed micro-level transport models could not work from the kind of macroeconomic inputs we work from. It is hence a well understood and conscious modelling strategy, which needs to be considered when devising what question may or may not be answered based on the model and its outputs.

d. PLANET is focussed on transport demand. What about transport supply?

Transport supply, i.e. supply of transport services and infrastructure, is essentially exogenous in the model. There is however a dichotomy in the treatment of transport supply between road transports and other modes in PLANET. For all road transports, we make the hypothesis that the network is constant. Any extra usage must be absorbed by the existing infrastructure, which leads to a decrease in average speed on the road. For the railway network and inland waterways, we work from an assumption of constant service level: whatever the increase in demand, the transport characteristics remain the same (constant travel time between two given points on the network). Hence the transport supply adapts to the variation in demand without restriction. This dichotomy is not as deep as it appears at first. Indeed, the number of cars using the road infrastructure adapts freely to the demand of car travel, just as the number of train seats. And the railroad network is supposed constant in so far as stations and schedules are considered, just as the road network. The difference really lies in the assumption of an absence of congestion on the existing rail and waterways network.

e. PLANET is closely linked to CASMO

CASMO is the Belgian CAr Stock MOdel, developed by FPB (see Franckx (2019)). There is a two-way relationship between the two models. On the one hand, CASMO is based on PLANET modal choice results (i.e. kilometres travelled each year) to calculate the desired number of cars each year and distributes it among several engine types and car classes. On the other hand, the composition of car stock affects the average cost of car use, which is a determining factor of modal choices in PLANET. The combination of car stock composition and distances travelled is also used to estimate the environmental impacts of car use in PLANET (see section 4.2.2 below).

2.3. Primary outputs

The primary outputs of PLANET are the aforementioned origin-destination matrices for trips and passenger-kilometres (pkm) and tonnes or tonne-kilometres (tkm) at district level, for each year of the projection period, on the Belgian territory. These OD matrices are structured along dimensions such as mode, travel period, etc., which differ between passengers and freight.

2.3.1. Dimensions of OD matrices for passenger transport

We consider three dimensions for passenger transport: the motive for travelling, the mode of transport and the period of travel. For road transport, two extra dimensions are added: the type of road used and the geographical zones crossed.

a. Motives for travelling

Six motives are analysed:

- commuting to work;
- commuting to school: trips of children attending preschool and compulsory education;
- commuting to studies: trips of students attending higher education establishments;
- business trips: work-related trips, outside commuting and the transportation of goods (which are considered in the "freight" module). They can be part of tours (i.e. postman, salesman), trips to attend meetings outside the workplace, transit between two construction sites, etc;

- other motives depending on revenues: private trips such as shopping, leisure, etc., which depend on the revenues of the household;
- other motives not depending on revenues: private trips such as services (doctor, bank), drop off/pick someone up, family visits, walking around, which do not depend on the revenues of the household.

Due to the high heterogeneity of the motives other than commuting or business trips, "other" motives for travelling were split into two categories, according to the sensitivity of the transport demand to the households' disposable income. This is the result of a simple econometric model (negative binomial regression) based on BELDAM survey data (2010). Further details are given in the next chapter and in Appendix E.

b. Modes of transport

Several modes of transport are studied for passenger trips: car, train, bus, tram, metro, motorbike, walk and bike.

Regarding transport by car, we differentiate driving alone and carpooling. They are named respectively 'car solo' and 'carpooling' in the next chapters. The mode 'carpooling' includes all instances where more than one person travels by car and is not restricted to organised forms of carpooling. Hence for example, a parent bringing children to school by car falls into the category 'carpooling' for our modelling purposes. Note that the 'car' modes also include the use of light-duty vehicles for the purpose of passenger transport.

Metro is limited to the district of Brussels, which is by far the more important subway network in Belgium. Tram is modelled for the districts of Brussels, Ghent, Antwerp, and in the three districts of the Belgian Coast (Veurne, Ostend and Bruges). Other tram networks in Belgium are not considered given their limited scope.

In the current version of the model, walk and bike are merged due to limited data availability.

c. Periods of travel

We consider two periods of time:

- a peak period, which corresponds, on weekdays, to the time slots from 7:00 to 9:00 and from 16:00 to 19:00;
- an off-peak period, which encompasses the rest of the time, including the whole weekend.

d. Geographical zones and types of roads

In classic four-stage models, once mode choice is determined, an extensive network model is used to model choice of routes between geographical entities. In such a model a fine road network is usually represented through a multitude of interconnected links, each with its own congestion function.

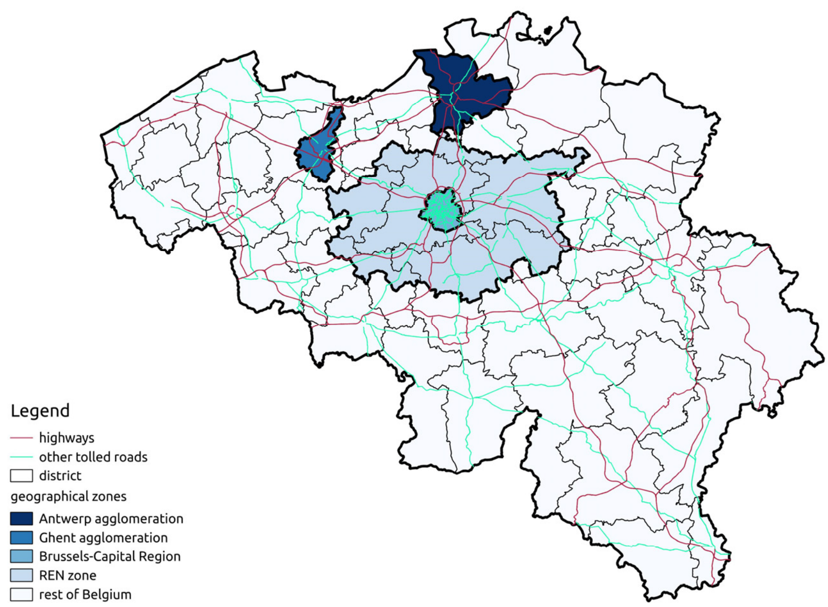
Equilibrium is defined as a Wardropian system equilibrium in which no car driver can lower his time costs by choosing another route.

For several reasons, we did not choose to model road choice in PLANET through a network model. As explained above, the most important reason is that the geographical dimension (based on NUTS3 districts) in PLANET is too coarse to serve as a basis for the rich detail that usually characterises a network model.

We instead represented the choice between a limited number of road types and geographical zones. Four geographical zones were chosen in order to represent the major congested areas in Belgium, namely Antwerp, Ghent, Brussels and the area surrounding the capital region (the zone delimiting the Regional Express Network). The remaining area is captured by a zone 'Rest of Belgium'. Within each zone, the road network is divided into three road types (highways, tolled roads other than highways, other roads), roughly chosen to correspond to the tax base of the current kilometre charge for heavy-duty vehicles[6].

Map 1 shows the existing toll roads and highways as well as the selected agglomerations on an administrative map of the country. It is worth mentioning again that no *stricto sensu* allocation of road transport flows on this network is performed within the PLANET model. Only the broad choice whether using toll roads or other roads is considered.

Map 1 Geographical zones and types of roads in PLANET



Source: FPB.

[6] Since April 1 2016, the Kilometre Charge applies for some categories of trucks (all Heavy Goods Vehicles of more than 3.5 tonnes Gross Vehicle Weight and vehicles of class N1/BC). All these trucks need to be equipped with an On Board Unit (OBU) that is constantly switched-on when they drive on public roads. This OBU will only charge the kilometres driven on paying toll roads.

2.3.2. Dimensions of OD matrices for freight transport

OD matrices for freight transport are structured along four dimensions: the type of flow, the mode of transport, the product category, and the period of travel. For road transport, two extra dimensions are also added to these four dimensions: the type of road and the geographical zone.

a. Types of flow

We consider four types of flows: national/domestic flows with origin and destination in Belgian districts, inbound flows with origin abroad and destination in a Belgian district, outbound flows with origin in a Belgian district and destination abroad, and finally transit without transhipment. The latter concerns the transport on the Belgian territory of goods whose places of origin and destination are outside the Belgian territory, without transhipment of the goods. Note that flows do not exactly coincide with the economic notions of domestic trade, imports, and exports. The definition of flows is based on the locations where the goods are loaded and unloaded, whereas the economic definition depends on change of ownership of the goods. Hence an inflow is not necessarily an import, as the corresponding goods might be reloaded on another means of transport and be part of an outflow, these goods being then only in transit from an economic point of view. A domestic flow does not necessarily relate to domestic trade, as often imported goods are unloaded (for example from a ship in a port) and reloaded on another mean of transport to be forwarded to their final destination in Belgium, this second part of the transport chain hence being a domestic flow related to an imported good.

b. Modes of transport

Goods can be carried by road, rail, inland waterways, sea or air. Road transport is split between Light-Duty Vehicles (LDV) and trucks or Heavy-Duty Vehicles (HDV). Maritime transport is mostly Short Sea Shipping (SSS) in the model. Deep Sea Shipping (DSS) and air transport are considered but not modelled in detail. The main reason is that they are not considered as a substitutable means of transport for the flows we model (i.e. flows on the Belgian territory).

c. Product categories

Goods are categorised according to their nature. Product categories correspond to the European standard goods classification for transport statistics (NST). Goods are grouped into 11 NST-based categories in PLANET (see Appendix D).

d. Periods of travel

Periods of travel are the same time slots as for passenger transport, i.e. a peak period and an off-peak period.

e. Geographical zones and types of roads

These two additional dimensions are considered for road transport only. They are the same as those described in the previous section for passengers.

3. How does PLANET work?

The achievement of the model's objective – obtaining the OD matrices described above for all projection years – relies on several preparatory steps and a projection loop. Ex post computations allow to derive results concerning congestion, emissions and external costs.

The projection of transport demand relies on three elements, that are required before the start of the projection loop:

1. The observation of the transport demand in the reference year;
2. The identification of socio-economic drivers for the transport demand, and the observation of the value of the variables representing these drivers in the reference year and in all projection years;
3. The establishment of formal links between these drivers and the transport demand per se, by the setting up of models and their estimation or calibration.

These preparatory works allow to initiate the projection loop, where all variables and parameters take the values observed or computed for the reference year. Subsequently, for each projection year, the evolution of the driver variables and endogenously computed quantities such as costs translates into the evolution of the model outputs by the working of the calibrated models.

3.1. Identification of flows of people and goods in the reference year

The basis for the whole projection, both as a calibration tool and a starting point, is the situation in the reference year. As such, this point deserves great care and attention.

OD matrices construction for the reference year relies on inputs that are not always directly observed. The setting up of a complete picture of the initial situation thus requires intermediary steps, assumptions, and models that are described below.

3.1.1. OD matrix for passenger transport in the reference year

OD matrices for passenger transport per motive, mode and period are not directly observed. They hence must be reconstructed from several sources. Moreover, the availability and nature of information varies according to the transport motive. Typically, regular transport patterns corresponding to one or another form of commuting are better documented than motives involving discretionary transport decisions. This implies that methods and steps taken differ between "commuting motives" and "other motives" *lato sensu*. The general process can be sketched as follows, for the reference year:

a. first, the number of trips between two zones, per motive, is derived from the *number of persons concerned* in each zone and their *average trip rate* as a function of socio-economic characteristics, producing OD matrices of trips per motive;
b. then, for *commuting trips*:
   - OD matrices are split between modes and periods of transport using survey data;

- they are then turned into OD matrices expressed in passenger-km using average distances by mode and motive;

c. …and for *other motives*:

- OD matrices of trips are translated into temporary OD matrices expressed in passenger-km using average distances stemming from survey results;
- these are then split by mode and period and calibrated using: survey estimation of split by period for each motive, survey estimation of the share of each non-commuting motive for each transportation mode, and the total passenger-km attributable to non-commuting motives. The latter is the residual quantity between total passenger-km statistics by mode, and total commuting passenger-km by mode obtained above in b;

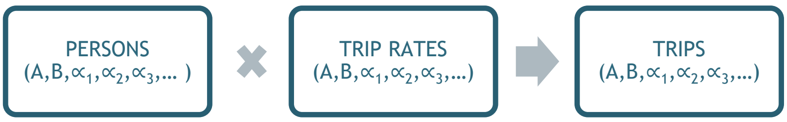
d. a last step is performed to disaggregate OD matrices of passenger-km travelled on the road between road types and geographical zones.

These computations are described in further details in the following sections.

a. Identifying the number of trips in the reference year

The number of trips is the raw expression of transport demand for passengers. It obviously depends on the number of persons present on a given territory, and on their individual need for travel, or trip rate. Direct, exhaustive observation of trips are not available to us whatever the motive. This combination of number of persons and trip rates is therefore the chosen path to obtain a picture of the raw transport demand in the reference year. This decomposition is useful not only to establish the global picture of transport demand in the reference year, but also to inform the way in which a projection of raw transport demand in the future can be obtained.

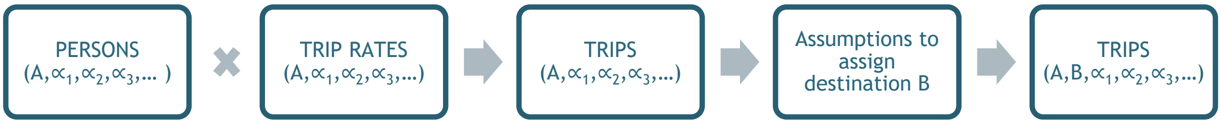
The way we combine persons and trip rates to construct trips matrices varies according to the motive studied. For commuting trips (commuting to work, to school, or to the place of higher education), we adopt the approach where first OD matrices of persons are built, and then differentiated trip rates are applied per cell of these matrices to obtain OD matrices of trips. It can be expressed as follows:



where A, B stand for Belgian districts (NUTS3) or ROW (Rest of the World)
α_1, α_2, α_3,… characteristics of the individuals (sex, age, region, etc.)

This approach allows the matching process between origins and destinations to depend on characteristics of persons, which usually are lost once trips are considered. It also allows trip rates to depend on the OD pair considered if needed. This last point will prove important for modelling behaviours such as propension to teleworking.

This approach could not be followed for the non-commuting motives, as the destination district of the persons concerned is not directly known nor unique. We thus apply differentiated trip rates directly to the number of persons from an origin district, and then distribute these trips to destinations based on strong assumptions. This can be sketched as follows:



where A, B stand for Belgian districts (NUTS3)
α_1, α_2, α_3,… characteristics of the individuals (sex, age, region, etc.)

The *number of persons* concerned for a given territory and motive of transport is readily available from administrative sources for the reference year, and in many cases, we do have at hand official projections for this number in future years. The *trip rates* on the other hand are not known exhaustively, but can be estimated based on surveys, or using expert opinion. Estimating differentiated trip rates along one or several sociologic, demographic, or geographic criteria that are available in projection years allows to project the impact on average trip rates of the composition and localisation effects in the population. It is hence useful to perform this differentiation in the reference year even though no immediate benefit can be drawn from such differentiation in the establishment of transport demand in the reference year.

The following sections deal with relevant sources, estimates, and hypotheses for each motive of passenger transport in the establishment of number of trips between two districts. As mentioned above, there is a marked difference between commuting motives (commuting to work, to school, or to the place of higher education) and other motives (business trips, other motives depending on the household's income such as leisure trips, and other motives independent of the household's income such as visiting family and friends). Commuting trips show a great deal of regularity, allowing easier inference from partial information, and benefit also from a greater coverage in usual data sources for institutional reasons. Other motives are less extensively studied, more diverse, and variable, which makes inference from limited sources difficult and imposes more restriction on the modelling possibilities.

Commuting to work

Commuting to work is a well-documented transport motive. The number of people involved by pair of origin (place of residence) and destination (place of work) districts are for most cases directly available from administrative sources, paired with several socio-demographic information such as age, sex, and work status. The national Labour Force Survey (Statbel) provides on a quarterly basis a sum of information on workers, employers where relevant, and commuting behaviour, on an individual basis. Quarterly data can be pooled to obtain sampling rates that allow good estimates of trip rates to be established, though not by pair of origin and destination districts. These surveys are therefore used to estimate trip rates differentiated by relevant socioeconomic and geographic characteristics. In the version 4.0 of the PLANET model, teleworking is implicitly taken in consideration using observed real trip rates. The explicit modelling of teleworking however is under development.

Number of persons from origin to destination

The persons relevant for this motive are *all employed or self-employed* persons either residing on the Belgian territory or working on the Belgian territory. The sources used to obtain related numbers are:

- The social security databases (ONSS, ONSSAPL) which provide for each employed individual working in Belgium, a residence district (or country if abroad), a workplace district, sex and age information;
- The healthcare system database (INAMI) which provides residence district, working country, age and sex for Belgian residents working abroad;
- The decennial micro-census (Statbel), which gives residence and working place for self-employed, by sex and age.

These sources allow to collate origin-destination matrices of number of persons by age, sex, and status (self-employed or employed) for the reference year. We work from the principle that these sources are exhaustive. Hence all other sources used regarding number of persons will be calibrated to match these figures in the reference year.

Trip rates

Trip rates for commuting to work are estimated based on Labour Force Surveys. The survey covers all working age residents in Belgium, hence all employees and self-employed residing in Belgium. Trip rates for residents abroad working in Belgium are taken as the average trip rate of workers with the same age and sex characteristics for the district of the working place.

The survey sample rate is not large enough to estimate valid trip rates for all pairs of origin and destination districts. Hence, we have studied the possible combination of characteristics to determine a segmentation of the population allowing to maximise the information obtained from the survey without making inference based on under-sampled population segments. Trip rates are thus estimated by sex, three age classes, work status (employed/self-employed) and region of residence. Districts being a subdivision of regions in Belgium, this segmentation is compatible with the design of the OD matrices for persons described above.

Commuting to school

Commuting to school is also a well-documented motive, which presents a high degree of regularity for attendants of compulsory education, that is until the age of eighteen. The situation is different for higher education, where information sources are scarce and incomplete, and transportation schemes and schedules more variable. This led us to distinguish within the motive “education” two submotives: “commuting to school” related to compulsory education, and “commuting to studies” related to all other educational purposes.

Number of persons from origin to destination

Administrative databases at the level of the district exist to produce exhaustive OD matrices of pupils for the reference year. They are collated by the Flemish authority (Onderwijs.vlaanderen.be) and French speaking authority (ETNIC) responsible for statistics on education in Belgium. Though not compulsory, pre-schooling from the age of three is included in these matrices as it concerns most of the children in this age class in Belgium. These statistics are taken as exhaustive.

Trip rates

Some survey-based data exist to estimate trip rates. However, given the compulsory nature of the education considered here, it appears logical to use a fixed trip rate based on five return trips per week, and corrected for the number of holidays to obtain average trip rates for an average day of the year. This trip rate is constant for all origin, destination, age and sex, at 3.65 one-way trips per week.

Commuting to studies

Number of persons from origin to destination

For the number of persons commuting to their study location, we only have exhaustive data for the Flemish community. For those attending a Flemish higher education institution, origin and destination districts are known, by age and sex using the official education statistics database (Onderwijs.vlaanderen.be). For the French speaking community, several partial sources can be drawn upon, mostly the education statistics (ETNIC) and the reports from the "Conférence des recteurs" in which the number of persons by higher education institution, and sometimes residence district, can be found. To obtain a full OD matrix, we use rebalancing methods (IPFP[7]). These methods allow to compute a matrix with pre-set margins (sums over rows, and sums over columns) that is as similar as possible to a seed (or reference) matrix. The computed rebalanced matrix retains as much as possible of the structure of the seed matrix, and its margins are equal to the pre-set margins. For the origin district the margins are based on the official population figures and share of students per age class computed on census data (Statbel: Micro-Census 2011); for the destination district they are based on the total higher education enrolment figures by district. To initiate the rebalancing process, we use a matrix containing all available information: when either origin or destination only is known (e.g. non-university higher education in Wallonia), origin and destination are assumed to be the same. Note that for students residing outside their official registration place, in a student residence (*kot*), we chose to keep the official residence place as the reference place of origin, but adapt the trip rate (see below). This choice stems from the fact that the distance between official residence and student residence is usually much larger than the distance between student residence and study place, and thus more relevant for our modelling objectives. The share of students residing outside their official registration place for the eleven districts with major tertiary education institutions is estimated using the Labour Force Survey.

7 Iteratively Proportional Fitting Procedure, also known as RAS.

Trip rates

The trip rates for attendees of higher education are estimated using the Labour Force Survey. They are taken as the average trip rates for the purpose of commuting to study for people aged nineteen or more[8], by region of residence. Sampling rates do not allow more refined segmentation for trip rates differentiation. For students residing outside their official registration place (*kot*), we adapt the trip rate on the hypothesis that the journey between official residence and student residence is made once a week outside holidays periods. The computed trip rate is thus 0.71 one-way trip per week for these students.

Business

As opposed to the commuting motives, administrative databases where business trips are registered are not available. We hence rely on the administrative employment data for the place of origin (working place) and use information from the BELDAM survey to distribute among destination districts business trips originating in each district.

Number of persons from origin district

The population of reference for business trips is the total of professionally occupied persons in each district. The localisation criterium is that of the working place, as we go from the simplifying hypothesis that business trips originate from the workplace. These numbers are available from the same sources used for the "commuting to work" motive, where we use the working place information only, and segment only according to the work status (employed or self-employed) as information on trip rate is scarce.

Trip rates

The average number of business trips per worker is estimated using the BELDAM survey, more specifically the diary log of trips that respondents must fill in for a particular day. This entails a very low sample rate for the population studied here. Therefore, trip rates can only be segmented according to the status (employed or self-employed). We obtain estimated trip rates of 0.1 trip per day for employees, and 0.18 trip for self-employed.

Trip destination

Given the scarcity of information, we only distinguish intra and inter-district trips based on the answers to the survey. The share of intra-district trips is estimated to be 67.3% at the national level. For inter-district trips, the trips destination is by hypothesis attributed to the districts adjacent to the origin district with equal proportions, with a slight twist for the district of Nivelles, considered to be adjacent to Brussels[9]. This allows us to produce two district-by-district OD matrices: one for employees making business trips and one for self-employed.

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8 The threshold age of nineteen years is chosen to accommodate for the fact that students between 18 and 19 can often still be part of the secondary education system, and thus not display travelling behaviours typical of the tertiary education attendees.

9 This exception makes sense given the institutional specificities of Belgium.

Other motives depending on revenues and Other motives not depending on revenues

For these two motives, only the way the trip rates are estimated differs. The number of persons is identical as well as the way destination districts are attributed.

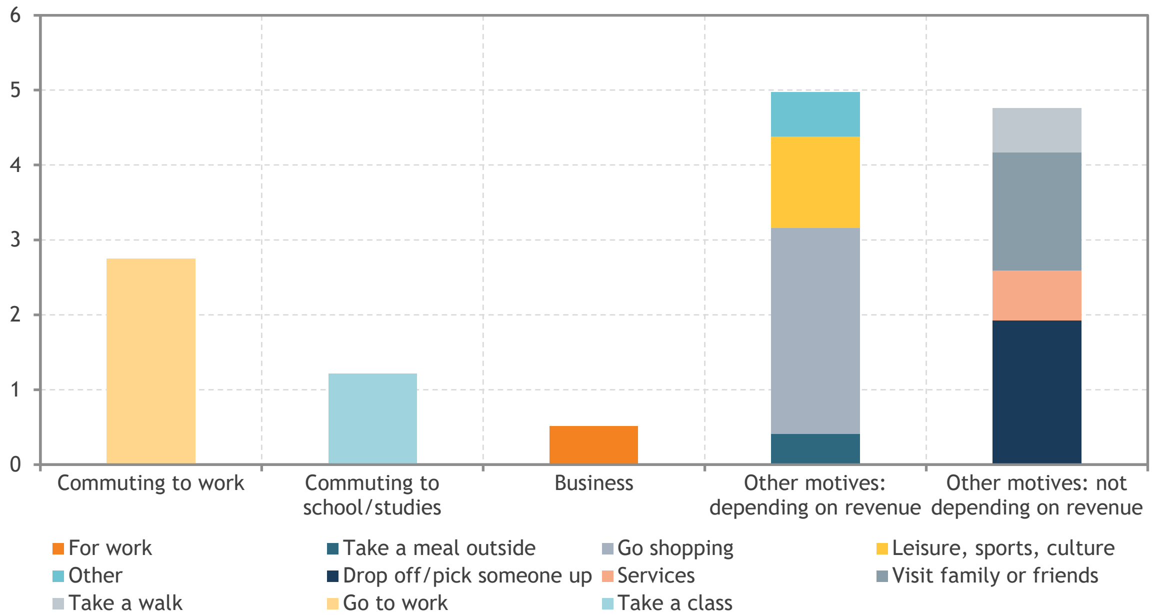
Number of persons from origin district

The number of persons in the district of origin of the trip is simply the population above three years of age[10] whose place of residence is in this district, taken from official population registers.

Trip rates

Trip rates for other motives are generalised from the BELDAM sample to the whole population using an econometric model based on the BELDAM logbook data and census data. Personal and household characteristics such as sex, age, household size, urbanisation level, education and income are used to predict average trip rates. Submotives identified as "other motives" in the survey are pooled based on the significance of the income variable in the trip rate estimates. Two groups of other motives are formed, one for which the household disposable income has a positive effect on trip rate, and another for which no significant effect is estimated. Variables and models involved are presented in more details in section 3.2.1.c and Appendix E.

Graph 1 Distribution of trips by motive in the BELDAM survey
Millions of trips a day



Sources: BELDAM survey 2010 and FPB calculations.

10 Children less than three years old are supposed never to travel without another person and therefore not taken into account.

Trip destination

Just as for business trips, the destination district of persons making trips for other motives is not known and is thus attributed among the origin district and adjacent districts according to parameters estimated via the BELDAM survey. In this case, the sampling rate is enough to estimate a share of inter-district trips for persons in each origin district[11]. These inter-district trips are then spread over adjacent districts with equal shares, in the same way as for business trips.

Trip rates estimated for each motive in the reference year are presented in Table 4 p.42.

b. Construction of OD matrices for commuting motives, expressed in passenger-kilometres, by motive, mode and travel period

Once OD trip matrices per motive are obtained for the reference year, survey information is again used to perform a modal and time split, which results in OD matrices of number of trips by motive, mode and time period. This can be done only for commuting trips as the scarce information coming from BELDAM survey does not actually allow us to estimate OD matrices of trips by mode for other motives. For these, the distinction by mode and period of transport is made at the level of passenger-kilometres, by difference (see subsection c).

Splitting OD matrices of commuting trips between modes and periods of transport

The modal split is estimated per motive using the Labour Force Survey. Six different situations regarding origin and destination locations are considered, providing six categories of OD pairs, as the survey sample size does not allow to estimate modal splits by OD pairs for all pairs of districts. A specific average modal split is estimated for any given OD pair by averaging over all pairs in the same category and Region defined as follows (see Map 2):

For a given pair O_xD_x, the modal split is computed as:

(1) **Intra-district** (O_x=D_x): the modal split for the O_xD_x pair is the average modal split for all pairs O_yD_y with O_y=D_y in the same Region as O_x;

(2) **Commuting to Brussels** (D_x = Brussels): the modal split for the O_xD_x pair is the average modal split for all pairs O_yD_y with D_y = Brussels and O_y in the same region as O_x;

(3) **Adjacent district** (O_x adjacent to D_x): the modal split of the O_xD_x pair is the average modal split over all pairs O_yD_y with O_y adjacent to D_y, O_y in the same region as O_x and D_y in the same region as D_x;

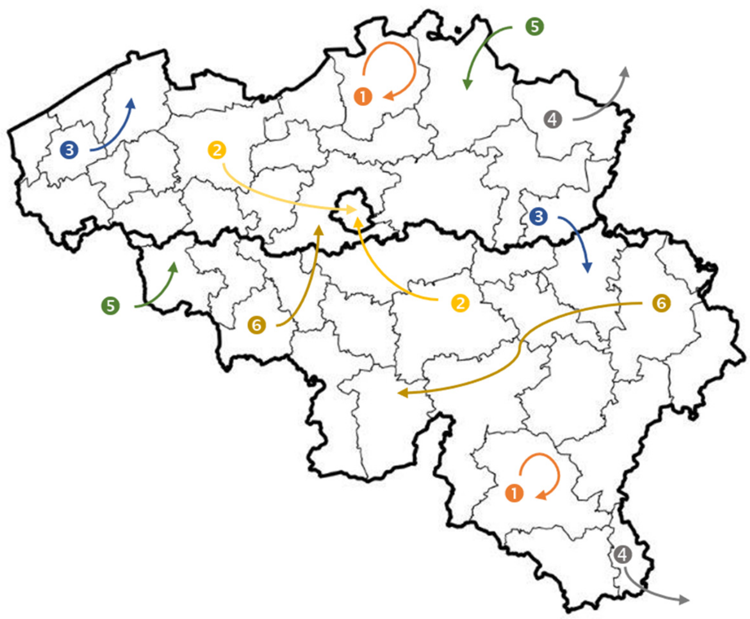
(4) **Outbound international** (D_x is abroad): the modal split of the O_xD_x pair is the average modal split over all pairs O_yD_y with D_y abroad where O_y is in the same region as O_x;

(5) **Inbound international** (O_x is abroad): the modal split of the O_xD_x pair is the average modal split over all pairs O_yD_y with O_y abroad where D_y is in the same region as D_x;

[11] The sample of BELDAM is not representative enough for a few districts, for which the average of neighbouring districts has been used for the share of inter-district trips.

(6) **Other**: the modal split of the O_xD_x pair is the average modal split over all pairs O_yD_y not belonging to one of the five preceding cases where D_y is in the same region as D_{x3} and O_y is in the same region as O_x.

Map 2 Trip classification for modal split of 'commuting to work'



Source: FPB.

For the motive "commuting to school", the Labour Force Survey only covers children aged 15 and more. We hence complete the information using the BELDAM survey. This survey provides modal splits for children commuting to school in two situations: when the school is in the same district as the place of residence, or when the school is in an adjacent district. Other situations are too few to allow a modal split estimation and taken out of the analysis. These two sources are combined using population statistics by district and age to produce average modal splits for this motive.

The information in the Socio-Economic Survey of 2001 (SES 2001), a kind of census, is used to devise peak vs. off-peak trips split for each commuting motive and mode of transport[12]. We end up with OD matrices of number of trips by motive, mode and period, for the commuting motives.

[12] Starting in 2017, the Labour Force Survey registers departure times for commuting trips. This will in the future allow us to update this information.

Box 1 Conversion from car driver/passenger to car solo/carpooling

The data available in the Labour Force Survey and the BELDAM survey mostly distinguish between the use of car as a driver and the use of car as a passenger. It is however unsatisfactory, when a model for modal choice must be set up, to think of travelling by car as a passenger as a mode that can be chosen among other alternatives. The real choice is not so much between being behind the steering wheel or not, but rather whether to use a car alone or collectively. This distinction makes more sense also when one comes to think of political measures that could be adopted (carpooling lanes, or car parks). In our case, it hence appears that the most sensible distinction is rather between driving a car alone and travelling by car collectively. For convenience we refer to these two modes as ‘car solo’ and ‘carpooling’, although we do not have a specific institutional arrangement in mind for carpooling.

To correctly model the collective use of car as a mode of transport, one needs to estimate the crucial parameter of the occupation rate. The average number of persons sharing a car will determine key elements such as the monetary costs for travellers and the number of vehicles on the road for a given level of transport demand by collective car. We therefore need to translate data available in the dichotomy driver/passenger to occupancy rates for collectively shared cars (car solo has by definition an occupancy rate of one).

We derive occupancy rates by motive under the restrictive hypothesis that the sharing of one car only happens between persons with the same motive of transport. This is a misrepresentation of the multitude of possible situations, but only an activity-based model of transport would benefit from a more precise arrangement in this regard.

We use the BELDAM survey logbook to obtain an estimate of the average number of persons onboard when a car is used collectively for each of the six motives. We also use BELDAM to compute the shares of car solo and carpooling in the total trips by car, except for the motives “commuting to school” where we suppose that all kids are passengers and thus use pooled cars, and “commuting to work”. In this last case, we take advantage of the much larger sample size of the Labour Force Survey, and use the reported share of drivers and passengers, which combined with the average number of persons in a shared car allows us to compute the shares of car solo and carpooling with some more precision. When combining solo and shared cars to obtain an average occupancy rate, we obtain figures in the same range as those obtained using road accidents statistics (Vias institute).

Estimated occupancy rates are presented in Table 1 below.

Transform commuting trips into passenger-km from distances by mode

By associating an average distance to OD matrices of commuting trips, we can by multiplication obtain OD matrices of passenger-km. Distances for these commuting motives are primarily taken from the SES 2001, where we can compute average distances for district-to-district trips by mode and commuting motive. We use in parallel a Geographic Information System (GIS) to compute average district-to-district distances also and based on this information complete the district-to-district matrices of distances where data are missing (because too few trips are reported in the SES 2001) or correct obviously erroneous data.

c. Construction of OD matrices for other motives, expressed in passenger-kilometres, by motive, mode and travel period

Unlike commuting motives, survey data do not allow us to split OD trip matrices between modes and periods for other motives. The BELDAM survey is not sufficiently sampled to allow all time and modal crossings to be reliable. Other sources and separate estimates based on BELDAM are used to perform this modal and time split at the level of *passenger-km*.

The approach followed differs therefore from that described for commuting motives. First OD matrices of trips are transformed into passenger-km and then split between modes and periods.

Transform trips into passenger-km from distances by motive

A preliminary number of passenger-km between two districts is calculated from the origin-destination matrices of trips previously elaborated, and distances estimated from the BELDAM survey. For sampling reasons, these distances are estimated for all modes of transport combined but broken down by region, non-commuting motives and differentiated whether the trip is intra-district or not. This preliminary number will be calibrated in a following step.

Splitting OD matrices of passenger-km between modes and periods of transport

As mentioned, the BELDAM survey alone does not allow us to split OD matrices between modes and periods. Additional sources are needed.

Using administrative and survey data, we have reconstructed matrices of passenger-km travelled, by mode and period for commuting motives. The number of persons involved, trip rates, and distances involved are observed or estimated based on observations.

On the other hand, we can collate rather exhaustive statistics of total observed distances travelled by mode, from traffic count data and public transportation companies reports.

The missing quantity to bridge the gap between these two sets of information is the number of passenger-kilometres travelled for “other” motives. As the sources to estimate this element per mode from trips and distance data are by far the weakest in quantity and quality, we choose to use the difference between total distances observed, and total distances reconstructed for commuting motives, as a total distance for other motives. This is done at regional level and can be expressed as follows:

$$\begin{aligned}&\mathrm{PKM(other\ motives, region, mode) = TOTAL\ PKM(region, mode)}\\&\quad\mathrm{- PKM(work, region, mode) - PKM(school, region, mode) - PKM(studies, region, mode)} \qquad (1)\end{aligned}$$

Several observed distances are expressed in vehicle-kilometres[13]. We hence make use of average number of occupants per vehicle to translate these into passenger-kilometres. Average numbers of persons per vehicle are derived from several sources: BELDAM and OVG[14] surveys, road accidents statistics (Vias

13 A vehicle-kilometre (vkm) is a kilometre travelled by a vehicle.

14 Onderzoek VerplaatsingsGedrag.

institute), and public transport company reports. Table 1 below presents average occupancy rates at national scale.

Table 1 Occupancy rates by motive, period and mode
Average number of persons per vehicle

	Commuting to work	Commuting to school	Commuting to studies	Business	Other motives: depending on revenues	Other motives: not depending on revenues
Peak						
Car solo	1.0		1.0	1.0	1.0	1.0
Carpooling	2.6	3.3	2.5	2.7	2.7	2.8
Motorcycle	1.0	1.0	1.0	1.0	1.0	1.0
Bus	32.5	32.5	32.5	32.5	32.5	32.5
Tram	80.4	80.4	80.4	80.4	80.4	80.4
Metro	217.2	217.2	217.2	217.2	217.2	217.2
Off-peak						
Car solo	1.0		1.0	1.0	1.0	1.0
Carpooling	2.6	3.3	2.5	2.7	2.7	2.8
Motorcycle	1.0	1.0	1.0	1.0	1.0	1.0
Bus	14.6	14.7	14.7	14.7	14.7	14.7
Tram	41.2	41.2	41.2	41.2	41.2	41.2
Metro	109.4	109.4	109.4	109.4	109.4	109.4

Source: PLANET v.4.0.

The total number of passenger-km travelled for “other” motives obtained as a residual for each mode is split between the three non-commuting motives based on BELDAM data, independently used for this purpose at national level. They provide, for each mode, the distribution of passenger-km between the three “other motives”, namely business, other motives depending on household’s income and other motives not depending on household’s income.

“Modal” distribution keys are then calculated on this basis and applied to the OD matrices of passenger-km constructed above as the product of the OD trip matrices by the distances, for each of the three other motives. These keys consider specificities of the district, such as tram or metro transport systems, available in certain districts only.

The distinction between peak and off-peak periods is performed in a next step, based on BELDAM data. It is estimated at national level for each crossing mode/non-commuting motive. This distribution is applied uniformly to all pairs of districts.

OD matrices are then calibrated to remain consistent with the total number of passenger-km for other motives, calculated as the difference between total number of pkm from statistics and the pkm travelled for commuting motives.

Additional corrections are made for the use of light-duty vehicles as a mode of passenger transport for business motives (typically, professional usage of LDV that does not entail freight transport, such as moving personnel or tools to workplaces). The number of LDVs originating in each district is known, see 3.1.2.a. These LDVs are supposed to follow the same patterns as cars regarding OD distribution, time period as well as type of road distributions, and occupancy rates.

We obtain this way district-to-district OD matrices of passenger-km by motive, mode, and period for the reference year. This for all combinations of motives (6), modes (8) and periods (2).

d. Allocating passenger-km travelled by road to road types and geographical zones

A last step must be performed to disaggregate OD matrices of pkm travelled by road between road types and geographical zones in the reference year. The methodology applied is described in detail in Box 2 below.

Box 2 Allocation of road flows to the road types and geographical zones

For reasons exposed in section 2.3.1.d, there is no real allocation on a road network in PLANET. Users of the road network however are presented with the choice of three types of road, which cross five geographical zones defined to single out congestion sensitive areas in the country.

We address here the issue of allocation of road traffic recorded in the reference year to these three road types and five geographical zones.

As developed in sections 3.1.1 and 3.1.2, the use of road transport in the reference year is observed directly or indirectly in the form of district-to-district OD matrices. We do not have direct information over the road types travelled on, in which proportion, nor over the volume of traffic in the different geographical zones.

In order to distinguish between road types and zones, these district-to-district global flows have to be allocated first on a road network granular enough to provide realistic routing solutions between districts and distinguish between road types and zones. In some sense, a true "fourth step" of a four-step model has to be performed for the reference year, however based on origin-destination data at a high level of geographic aggregation. Once district-to-district flows are allocated on such a network, we can measure the proportion of the flow on each type of road and in each geographical zone, to obtain a disaggregation of our OD matrices along these dimensions.

The procedure followed to achieve this aim is common to passenger transport and freight transport with however a specific attention to international flows for freight transport. In what follows, we describe a unified methodology for both passengers and freight.

(1) We first define the detailed network on which to allocate the district-to-district flows. For flows on the Belgian territory, we start from a routable road network built on OpenStreetMap data and add, for each of the road segments, the following attributes:

- the district in which the road segment is located;
- the geographical zone in which the road segment is located (see Map 1);
- the "type of road" of the segment according to the PLANET classification (Highway, Tolled road other than highway, Other);
- the average speed of a car along this segment;
- the average speed of a heavy-duty vehicle along this segment;
- the average speed of a light-duty vehicle along this segment.

We need to define two networks with these attributes, as the average speed will differ between peak and off-peak hours.

To evaluate these speed attributes, we obtained data related to Belgium from MOW, the Flemish Public Service for Mobility and Public Works. Flows and speed levels on all segments for six different periods of the day were provided by MOW for our analysis. As these six periods essentially relate to peak-hours (in particular, no data were obtained for night hours and weekends), we built an estimated seventh version for off-peak hours where the official speed limit was used to approximate free flow conditions. For this last version, the traffic flows were obtained by scaling the flows from MOW related to mid-day traffic, using existing traffic counts to compute scaling factors. Finally, the peak and off-peak speed attributes were obtained by computing averages of the relevant speed attributes provided by MOW weighted by the associated flows.

The network abroad was provided by the ETISplus* project. The only network attributes are car and HDV speeds. We are not interested in type of routes abroad, and geographical zones are defined for Belgium only. However, the part of an international trip abroad has to be modelled since the place of border crossing influences the share of this trip happening on the Belgian territory.

(2) We then assign the reference year OD flows to this network. Our OD flows being obtained at a high geographic aggregation level, the traffic between districts is by default assigned to the network in the nodes closest to the centroid of the districts of origin and destination. Centroids are weighted according to the population. Since the centroid of the district of Halle-Vilvoorde is situated outside its boundaries, this district was broken down into smaller geographical areas. Origins or destinations abroad are known on a coarser scale even (NUTS2) and their centroids are not weighted by the population.

For national transport, the assignment uses the Dijkstra algorithm to find the shortest paths (in fact fastest path, since speed attributes were used) between the OD pairs. For international transport, because of the different levels of detail between the Belgian and the foreign road networks, the assignment process was split into two stages. In the first stage the fastest paths from the Belgian zones to all border crossings were calculated. In the second stage, the fastest paths from these border crossings to the foreign zones are calculated. The overall fastest path is the path with the ‘fastest’ combination of a Belgian and a foreign segment with common border crossing.

This assignment is performed six times, once for each crossing of the type of vehicle (car, LDV, HDV) and period of travel (peak/off-peak) categories. Only the speed levels per segment differ in each case.

(3) We finally compute the share of each type of road and zone in these assigned flows. For each OD pair, period of travel (peak/off-peak), and type of vehicle (car, LDV, HDV), we have obtained a fastest path on a network containing information on the type of road used for each segment (Highway, Tolled road other than highway, Other) and the geographical zone hosting each segment (four congestions sensitive zones and the rest of Belgium). We hence only need to compute the shares of each type of road and geographical zone in the total length of this path to obtain the final allocation keys for the reference year flows to our categories.

(*) ETISplus is a “European Transport policy Information System, combining data, analytical modelling with maps (GIS), and a single online interface for accessing the data” (source: ISIS, Innovation for sustainability).

3.1.2. OD matrix for freight transport in the reference year

OD matrices for freight transport are expressed in tonnes and tonne-kilometres. As opposed to passenger transport, OD matrices by product in tonnes and tonne-kilometres in the reference year are already compiled for most modes of transport and made available by Statbel and EUROSTAT. We still need to add OD matrices by product in tonnes for rail transport and light-duty vehicles, and then produce tonne-kilometres, split by period and, where applicable, by type of road.

a. OD matrices in tonnes, by product, mode and type of flow

For heavy-duty road transport

EUROSTAT provides an OD matrix in terms of tonnes and tonne-km at NUTS3-level for the reference year for all NST07 products. This source directly suits our needs.

For rail transport

The OD matrices are based on data on tonnes and tonne-km by product provided by two major Belgian rail operators. These matrices are geographically very detailed: the place of loading/unloading is known at the level of the station itself. For each Belgian and foreign station, a NUTS3 code has been assigned. The data at our disposal, while not exhaustive, cover most of the domestic freight transport by rail for the reference year. This is however not the case for international transport. In order to take inbound and outbound international transport by other operators into account, these international flows were scaled up based on the EUROSTAT database[15]. For instance, if the flow to Austria based on data from the two operators, is smaller than reported by Austria, then this flow is scaled up to fit the EUROSTAT numbers (international transport by reporting country and (un)loading country). For transit without transhipment no other data sources were found that would allow the same treatment, and our initial estimate is kept as is.

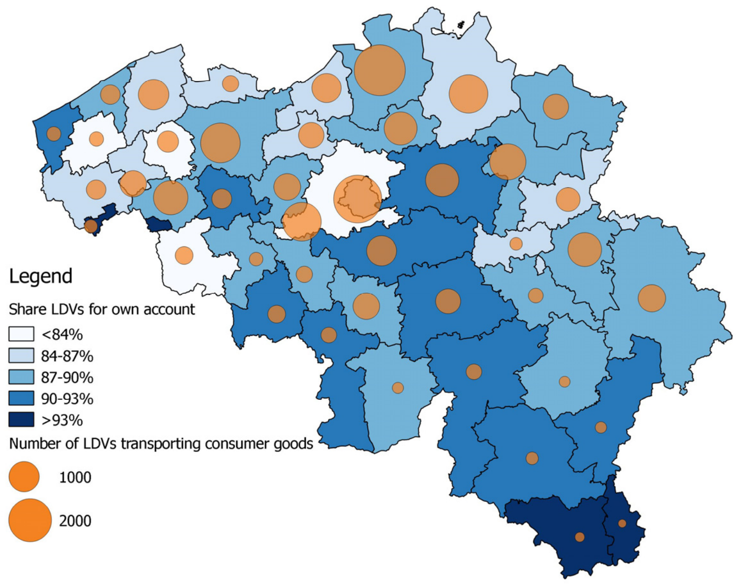
For light-duty road transport

The setting up of OD matrices for LDV transport draws upon several sources of information. By combining data from the 'Direction pour l'Immatriculation des Véhicules' (DIV), the ONSS and the 'Value Added Tax' (VAT) administration, we are able to distribute all LDVs registered by companies across districts and industries:

- The primary source is the stock of LDVs in Belgium, from the DIV. We restrict ourselves to vehicles registered by companies.
- This primary dataset specifies a geographical location for the company. Unfortunately, this location refers to the corporate headquarters. Data from the ONSS about employees allow us to redistribute LDVs across the districts where each company has operational entities, pro rata the number of employees.
- The VAT register provides for each company the industry it belongs to in the NACE classification.
- We therefore have a dataset of all LDVs registered by companies, distributed by district of operation and industry.

[15] The EUROSTAT database is not detailed by product. The scaling up is therefore performed in the same way for all product categories on the basis of global volumes.

Map 3 Geographic distribution of the LDV fleet
Number of LDV for freight transport by district



Sources: FPS Mobility and Transport, FPB calculations.

The Input/Output (IO) team from the FPB provides another VAT dataset that specifies the kind of goods and services each industry produces (per CPA[16] product code). The CPA codes enable us to classify the goods according to the NST07 classification.

The vehicles are then considered based on their typical use: service vehicles, transport of goods for own account and transport of goods for third parties. Only the last two are considered to perform goods transport and retained. Service vehicles are considered to perform transport of persons only and are taken into account in another part of PLANET, see 3.1.1.c.

We do not dispose of direct observations for the typical use of vehicles, and make thus the following assumptions:

- LDVs registered by companies from the transport services sector are assumed to perform goods transport for third account. We associate this service with the transport of good categories NST15 and NST19. NST15 (mail and parcels) clearly relates to transport for third parties whereas NST19 (Unidentifiable goods) is supposed to mostly consist of transport for third parties[17].
- LDVs registered by companies in the consumer goods production sector are assumed to perform goods transport for own account. They are associated with all other NST categories.
- All other LDVs[18] are assumed to be service vehicles.

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16 European statistical classification of products by activity.
17 In the model, goods categories are less detailed (see Appendix D). The categories NST15 and NST19 both belong to our aggregate NST42.
18 Essentially those registered by companies in the service sector except transport, and companies in the industrial sector not producing consumer goods.

The FPS Mobility and Transport provided data on the yearly kilometres driven by LDVs, split by industry. Kilometres driven by LDVs registered by companies from the transport industry, performing professional goods transport, are clearly higher than those driven by LDVs performing transport for own account. Several European sources impute this to higher average trip lengths. French survey data (SOeS, 2011) report 72 km for transport of goods for own account and 104 km for professional goods transport[19]. Combining these average trip lengths with the yearly kilometres and our distribution by district and type of goods, we can estimate the annual average number of trips per origin and type of goods.

Average load per good category is estimated combining two sources of information. A UK study on 'Company owned vans' (Dft, 2005) provides detailed information by product type transported, allowing us to compute an average load by product type as the ratio of tonne-km to vehicle-km. We thus use the UK data to obtain a distribution of loads by product and calibrate this distribution to obtain an average load overall of 380 kg per trip. The average tonnes loaded per NST goods type obtained are as illustrated in Table 2.

Table 2 Average load per goods category
Tonnes loaded per trip

Code NST	Category description	Load
01	Products of agriculture, hunting and forestry; fish and other fishing products	300 kg
04	Food products, beverages and tobacco	450 kg
05	Textiles and textile products; leather and leather products	250 kg
06	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter and recorded media	250 kg
07	Coke and refined petroleum products	375 kg
08	Chemicals, chemical products, and man-made fibers; rubber and plastic products; nuclear fuel	325 kg
09	Other non metallic mineral products	225 kg
10	Basic metals; fabricated metal products, except machinery and equipment	275 kg
11	Machinery and equipment n.e.c.; office machinery and computers; electrical machinery and apparatus n.e.c.; radio, television and communication equipment and apparatus; medical, precision and optical instruments; watches and clocks	250 kg
12	Transport equipment	325 kg
13	Furniture; other manufactured goods n.e.c.	250 kg
14	Secondary raw materials; municipal wastes and other wastes	250 kg
15	Mail, parcels	250 kg
17	Goods moved in the course of household and office removals; baggage and articles accompanying travellers; motor vehicles being moved for repair; other non market goods n.e.c.	375 kg
19	Unidentifiable goods	450 kg

Source: FPB calculations.
n.e.c.: not elsewhere classified.

We do not dispose of direct information over the destination of LDVs for any given district of origin. We therefore apply the following heuristics to devise an estimated OD matrix:

– Since the average trip length is 72 km (own account) or 104 km (third account), we can for each district of origin determine the districts of destination within this range for a return trip. The trip destinations by LDVs are limited to administrative units that are at a distance of at most half of these trip lengths from the district of origin. Map 4 shows as an illustration the possible districts

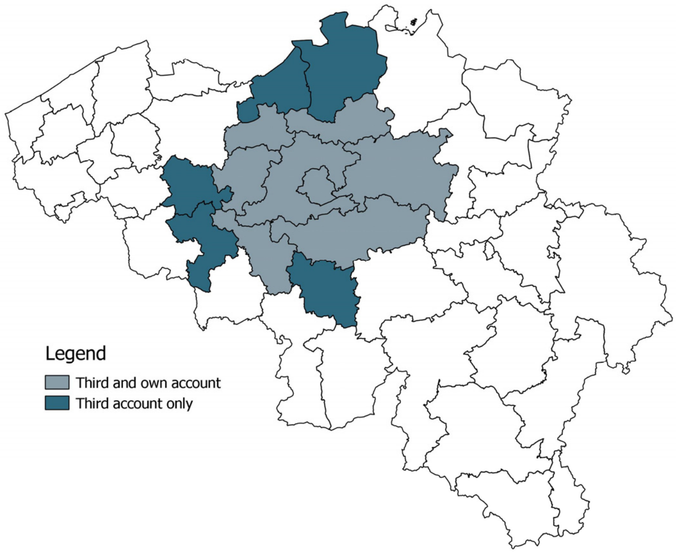
[19] These distances include the return trip.

of arrival for the LDVs coming from Brussels for third parties (NST15 and NST19) and for their own account (the other NST goods categories).

– The weights of each possible destination district for a given origin district are then determined using the HDVs' origin-destination matrix for lack of any other source.

– As a final step we aggregate the OD matrices for detailed NST products into OD matrices for our NST categories (see Appendix D).

Map 4 Destination districts within range for a LDV transport with Brussels as origin



Source: PLANET v4.0.

These steps lead us to set up a full-fledged OD matrix of tonnes transported by LDVs by NST product type in the reference year.

Inland navigation

Statbel provides an origin-destination matrix of tonnes at port level (LOCODE[20]). The Belgian LOCODES were coupled to a NUTS3 code. Since the LOCODES contain a reference to the country, coupling foreign harbours to a country was straightforward.

Short Sea Shipping

Statbel also provides an origin-destination matrix of tonnes at port level for maritime transport. The same procedure as for inland navigation is applied.

[20] United Nations Code for Trade and Transport Locations.

b. OD matrices in tonne-km, by product, mode and type of flow

Some OD matrices, such as HDV and rail matrices, are available in tonne-km, by product, mode and type of flow directly from the sources used. The other are obtained by multiplying the OD matrices in tonnes by the distance per OD pair and mode, as explained below.

Light-Duty Vehicles

In the current state of the model we assume that trips by LDVs are return trips and that the load is transported over half of the trip length. The same average trip length (*tl*) is applied to all OD pairs in function of the detailed product type:

- The half trip length *tl/2* is 52 km for product types NST15 and NST19;
- The half trip length *tl/2* is 36 km for all other product types.

A unique average distance per OD pair is computed by averaging this half trip length *tl/2* over all products using tonnes as weights:

$$dist(o,d) = \frac{\sum_{p\in\{NST1,NST2,\ldots NST20\}}\left(tons_p(o,d)\cdot\frac{tl(p)}{2}\right)}{\sum_{p\in\{NST1,NST2,\ldots NST20\}}\left(tons_p(o,d)\right)} \quad (2)$$

The OD matrix of tkm is then obtained for each product type by multiplying the OD matrix of tonnes for this product type by the average distance matrix *dist(o,d)*.

Inland navigation

Since the datasets from Statbel only apply to the trips on the Belgian territory, total distances for international trips (and for national transport between Belgian ports over the Westerschelde) had to be calculated. The ETISplus project provides the network of inland waterways. As to Belgian origins or destinations, the traffic is fed onto the network in the node closest to centroid of the municipality of the LOCODE. In the case of origins or destinations abroad, the traffic is fed in the node closest to centroid of the NUTS2 zone. The shortest path and its distance between the origin and the destination are obtained using the Dijkstra algorithm.

The OD matrix of tkm is obtained by multiplying the OD matrix of tonnes by these distances.

Short Sea Shipping

Statbel provides data on port-to-port distances. For missing OD couples, we use information from the internet: portworld.com, sea-distances.org,… The OD matrix of tkm is obtained by multiplying the OD matrix of tonnes by this matrix of distances.

c. Disaggregation by period and type of road for road transport

Period

The disaggregation by period is determined based on the diurnal traffic intensity measured on Flemish highways in 2014 provided by MOW.

Type of road and geographical zones

The repartition of the road traffic by type of road and geographical zone for the reference year proceeds using the same approach as for passenger transport. This methodology is described in Box 2 above.

3.2. Explanatory variables and models for the components of OD matrices (trips, persons, tonnes, costs)

The objective of the model, projecting OD matrices, can be achieved in several ways. One may primarily make the distinction between more statistical approaches on the one hand, and more structural approaches on the other hand. Statistical approaches would rely on the availability of a historic series of observed OD matrices of transport flows to make statistical projection based on stochastic processes techniques. Statistical properties of the observed series are in this case used to predict future evolutions. Structural approaches on the other hand try to identify links between OD matrices of transport flows and the fundamental drivers of this demand for transport. The projection of OD matrices is then made by applying these links to projected series of these drivers. In practice any structural approach will to some extent rely on statistical methods for the projections, so that this distinction is not as clear cut as we briefly expose here.

In our case, though in theory feasible, the statistical approach appears difficult to follow due to the costs of setting up a long enough historical series of OD matrices of transport flows. The sections above illustrated the difficulty of obtaining "observed" OD matrices for one reference year. Repeating these efforts systematically for a number of past years large enough to be relevant for the assessment of long-term evolutions of transport demand does not seem reasonable in our context. Moreover, statistical approaches, by being strictly based on past observed variations, do not seem to provide a suitable case for long-term projection, and should rather be considered for short-term applications.

We hence elect to follow a more structural approach, which consists in identifying relevant drivers for the evolution of transport demand, and an adequate mathematical representation of the link between these drivers and the OD matrices of transport flows. Obviously, at a certain level, the projection of these drivers will at least in part rely on a statistical approach. But the overall spirit of our model is hence on the structural side of the aforementioned dichotomy.

The present section is devoted to the description of these drivers of demand and of the linkage models used to relate drivers and OD matrices. In the context of a projection model, we work from the perspective of changes in demand.

3.2.1. Passenger transport

Three types of effect drive the evolution of the OD matrices for passenger transport: volume, compositional and behavioural effects. The volume effect simply corresponds to the fact that an increase in population will, ceteris paribus, translate to an increase in transport demand. The composition effect relates to the fact that, if the average behaviour of the persons belonging to the different categories defined by age, sex, socio-economic status, and place of residence, do not change, but the relative proportions of these categories in the total population evolve, this change in composition of the population (and its geographical repartition), will modify the projected transport demand. For example, if elderly people tend to show a lower transport demand than younger people, population ageing in the future will translate into a lower transport demand even when behaviours are kept constant for elderly and younger people. Finally, behavioural effects cover the impact of changes in behaviour within a category of persons on the transport demand. For example, global increase in revenues may drive an increase in transport demand for a given category of persons.

To link OD matrices of number of trips with the drivers of transport demand, we work along the same decomposition as for the reference year: we first consider what drives the evolution of the number of people involved for a given district of origin, then the drivers of their average trip rate and of the distribution among destination districts. The first part (number of persons) relates to volume and composition effects in the evolution of transport demand, while the second part (trip rates and trip distribution) typically embodies the behavioural effects.

It is obviously not in the scope of this model to study demographic drivers of population changes. We also take places of residence (and hence the evolution of population by district) and location of workplaces as exogenous in our model, though this would make a legitimate part of a transport model with broader scope. Consequently, there is no need to identify drivers for these quantities, and the number of people can be obtained directly from existing socio-demographic data. These data are available to us in projection as well, and therefore qualify as a workable input for our modelling approach. Hence volume and composition effects will not be endogenously modelled in our case but taken from external projection efforts.

On the contrary, the trip rates and origin/destination matches are computed within the model. They rely on additional variables that may explain behaviours or be correlated to behavioural aspects, and on models to link the quantities of interest with these variables.

Most of the explanatory variables used are exogenous to the model. In other words, their value is independent of the transport variables computed within the model and are fully known beforehand. An important exception concerns the cost variables, and especially time costs for road transport. Average expected time costs depend on the average speed on the road network, hence on the outcomes of the model. They are endogenous. These average expected costs influence behaviour, such as demanded number of trips, or distribution of trip destinations. We devote special attention to these cost variables at the end of the section.

a. Number of persons projected

The availability of population data at the required detail level has been discussed above. To validate the direct use of these numbers of persons as input, we only need to ensure that similar data are available for future years. The use of existing projection exercises to derive the required number of persons is presented more in depth in Appendix A. We summarise below the key sources used for different populations of interest:

(1) The evolution of total number of persons residing in a given district, by age and sex, is taken without modification from the demographic projections (FPB & Statbel) for all projection years.

(2) These demographic projections, coupled with socio-economic projections obtained with the models HERMREG (FPB and al.), HERMES (FPB), and MALTESE (Conseil supérieur des Finances), and the reference year situation described above, allow to derive a projection of the number of employed or self-employed persons by sex, age, and district of residence, as well as a projection of the number of employed or self-employed by district of workplace.

(3) These demographic projections, coupled with socio-demographic projections from the MALTESE model and data from the 2011 micro-census, allow to derive a projection of the number of persons attending superior education by sex, age, and district of residence.

We summarise below the way the number of persons is projected by motive:

- *Commuting to work*. The number of persons at origin is derived from (2), as well as the number of persons at destination, for each district.
- *Commuting to school*. The number of persons at origin is derived from (1) as the number of people in age of attending the compulsory education. The number of persons at destination (that is the number of persons attending compulsory education in the destination district) in a given projection year is equal to the sum of:
  - the number of persons at destination in that district for the known situation in the reference year;
  - the absolute change evolution between the reference year and the considered projection year of the population in age of attending compulsory education (3 to 18 years) residing in that same district.

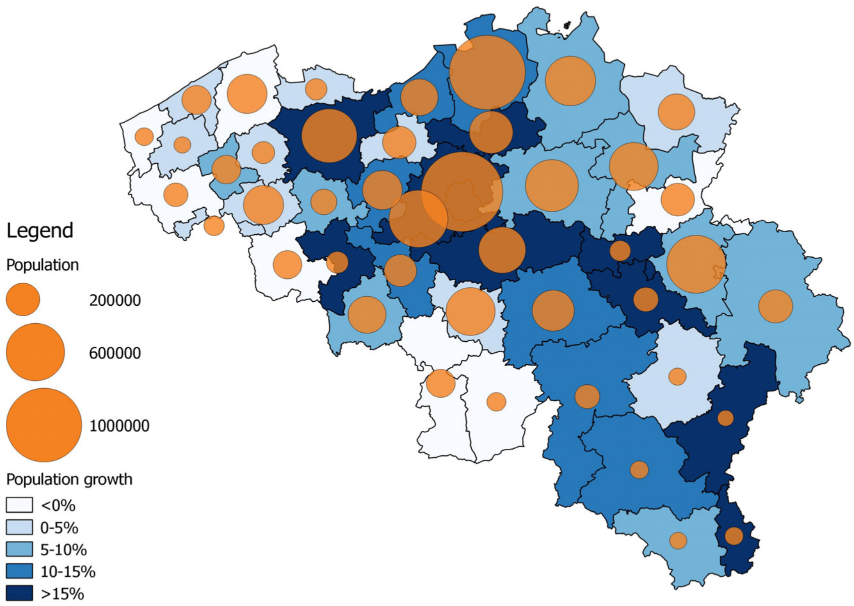
  This represents an hypothesis of local development of the educational system capacity, which is in line with current practice in Belgium : every year, the schools' capacity in a given district is increased (or decreased) by the absolute increase (or decrease) in the school-aged population in that district for that year.
- *Commuting to studies*. The number of persons at origin is derived from (3). The number of persons at destination by district is obtained for projection years by applying to the reference year situation the global rate of growth of the student population obtained from (3). Hence the relative importance of the different superior education establishments is supposed constant throughout the projection.
- *Business*. The number of persons at origin is the total number of persons with workplace in a given district, which is obtained from (2). The number of persons at destination is not explicitly projected.

– *Other motives*. The number of persons at origin is the population above 3 years of age, obtained from (1). The number of persons at destination is not explicitly projected.

We hence dispose of exogenous projections for all required numbers of persons, covering the volume and composition effects mentioned above in the evolution of the transport demand. In this first case, no additional modelling is needed.

Map 5 shows the distribution of the total population between the Belgian districts in 2015 and its projected evolution, used to project trips for other motives and commuting trips to school.

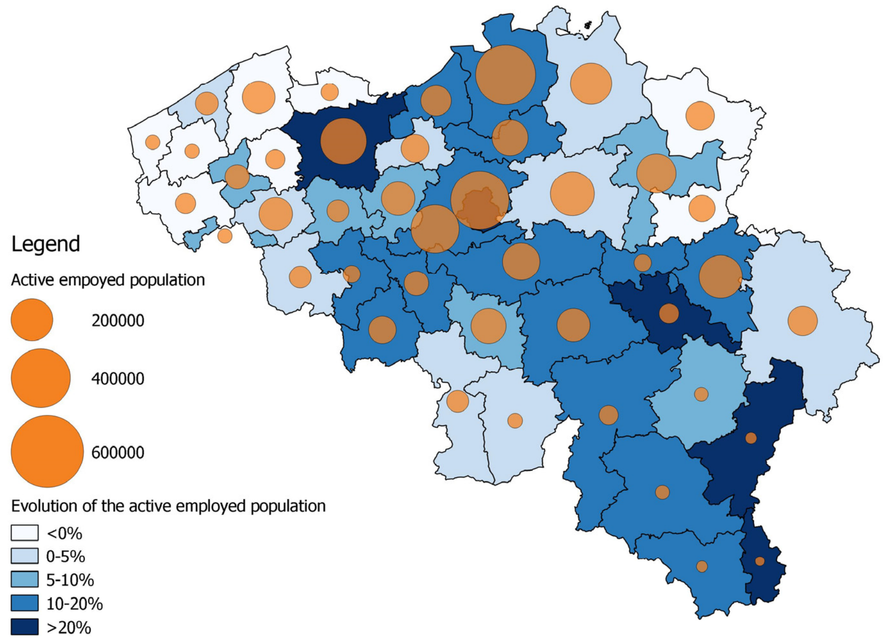
Map 5 Distribution of the Belgian population by district in 2015 and its evolution (2015-2040)



Source: Demographic projections (FPB/DG Statistics, 2017).

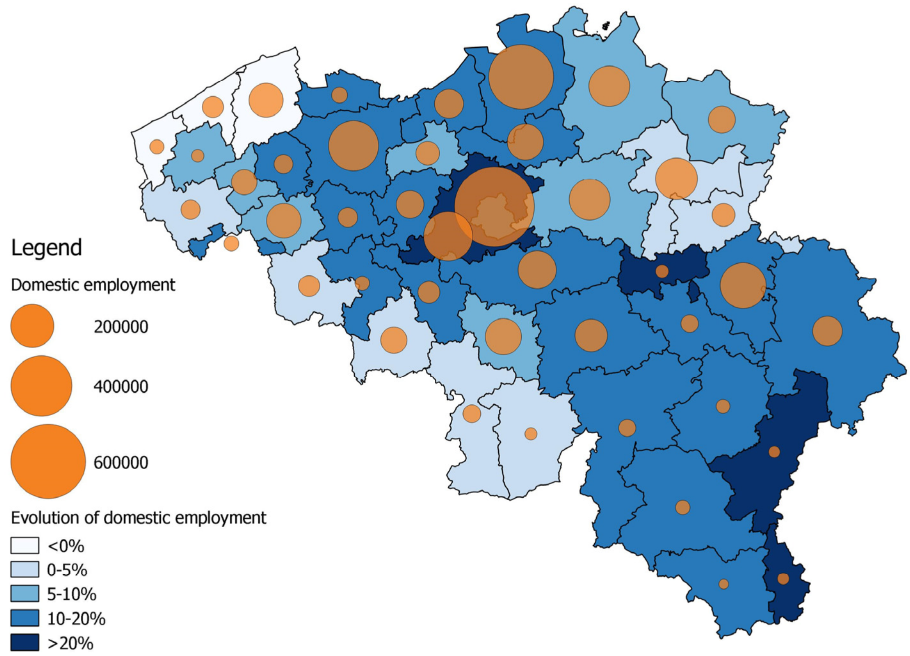
The next two maps illustrate employed and self-employed population (Map 6) and employment in Belgium (Map 7) by district, the two margins for the projected commuting trips to work.

Map 6 Employed and self-employed population in 2015 and growth (2015-2040)



Source: BFP calculation based on ICN, HERMES, MALTESE.

Map 7 Employment in 2015 and growth (2015-2040)



Source: BFP calculation based on ICN, HERMES, MALTESE.

b. Distribution of trip destinations

The destination distribution of persons originating trips in any given district is managed in a differentiated way depending on the motive of transport.

Commuting to work

For work commuting, the origin-destination matching is endogenous, and depends on work supply and work demand in all districts, and on the expected averaged generalised cost of making trips between districts. For the first two drivers of trip distribution – work supply and work demand – we have seen above that the associated variables (number of employed or self-employed persons by district, number of employed or self-employed workplace by district) are exogenous to our transport model. Generalised costs however are endogenous in the model, and the expected averaged generalised cost is taken as the averaged generalised cost observed in the reference year (or observed in the previous year for projection years) over all modes of transport, weighted by the number of pkm made with each mode.

$$aGC(o,d)_t = \frac{\sum_{mode} GC(o,d)_{mode,t-1} * nb\_pkm(o,d)_{mode,t-1}}{\sum_{mode} nb\_pkm(o,d)_{mode,t-1}} \quad (3)$$

The link between these driving factors of trip distribution (localisation of work supply and work demand, and transport costs) and the distribution of trips among possible destinations districts for each district of origin is made using gravity models. These are standard tools in the field of transport modelling. More specifically, we use two doubly constrained gravitational models to perform this origin/destination matching, one for employed and one for self-employed. Doubly constrained means that the number of persons originating trips in each district and the number of persons with destination in each district are not modelled but imposed. This data is known from exogeneous sources in our case. After consideration of several alternative specifications, we selected the following models[21] which resulted in the most favourable fits on the data for our reference year. The models are based on a power function of generalised costs. The parameters of this cost function are differentiated among four situations for the origin-destination pair, labelled by the index *k*:

- Origin and destination are in the same district (k=1);
- Origin and destination are not in the same district, but are in the same region (k=2);
- Origin and destination are not in the same region, but none is in the Brussels district (k=3);
- Origin and destination are not the in same district, and either origin or destination is in the Brussels district (k=4).

To these differentiated cost functions, a fixed barrier effect is added to flows of the third category (flows between Wallonia and Flanders). This captures institutional barriers to commuting between these regions, which are not related to transport costs. The number of persons *T(o,d)* commuting from *o* to *d* can be written as :

$$T(o,d) = A(o) \cdot B(d) \cdot f_k\big(aGC(o,d)\big) \quad (4)$$

- *A(o)*, *B(d)* are fixed effects reflecting the influence of the relative "size" of districts on the trip distribution (attraction, propulsion, and bilateral resistance). The general idea is that a district with a larger working population (resp. larger number of workplaces) will generate more commuting trips (resp. will attract more commuting trips) than a smaller district. *A(o)* and *B(d)* do not however equate

21 The model definition depends essentially on the cost function chosen.

to these numbers of persons or jobs exactly, as the number of trips between two districts is also influenced by the trip generation and attraction and the cost of travel from and to other districts around these origin and destination districts[22].

The constraints on the number of persons at origin and destination provide recursive expressions for the *A* and *B* fixed effects. The number *NR(o)* of workers with residence in a district *o* is by constraint equal to the sum of all commuters originating trips in *o*:

$$NR(o) = \sum_d T(o,d) = A(o) \cdot \sum_d \Big(B(d) \cdot f_k\big(aGC(o,d)\big)\Big) \quad (5)$$

Hence the fixed effect *A(o)* is a function of the number of workers with residence in district *o* but also of the weighted sum of all fixed effects *B* with the frictional term between *o* and *d* as weight:

$$A(o) = \frac{NR(o)}{\sum_d\Big(B(d) \cdot f_k\big(aGC(o,d)\big)\Big)} \quad (6)$$

Similarly, from the expression of the number *NW(d)* of workers with workplace in district *d* we obtain for fixed effects *B*:

$$B(d) = \frac{NW(d)}{\sum_o\Big(A(o) \cdot f_k\big(aGC(o,d)\big)\Big)} \quad (7)$$

– $f_k(x)$ is the cost function where the subscript *k* relates to the four situations listed above regarding the origin and destination districts. The retained specification of this cost function is a power function:

$$f_k(x) = exp\big(a_k + b_k \cdot ln(x)\big) \quad (8)$$

…where $a_k = 0$ if *k* is not equal to 3: this is a fixed barrier effect if OD is a flow between Flanders and Wallonia; and b_k is the friction coefficient differentiated among the four situations above. This coefficient is expected to be negative, as higher generalised costs should equate with smaller number of trips.

– An error term *e(o,d)* is added to this specification, which accounts for the fact that this way of specifying the number *T* of trips is a simplification of reality and does not exactly fit the observed values in the reference year. This allows to treat the gravity model as a statistical data generating process, and estimate parameters using statistical techniques:

$$T(o,d) = A(o) \cdot B(d) \cdot f_k\big(aGC(o,d)\big) \cdot e(o,d) \quad (9)$$

The coefficients of the cost functions and the fixed effect variables at origin and destination are estimated on the reference year data using maximum likelihood techniques, which is standard practice. The most important output here is the cost function. It represents the way in which changes in the generalised cost of transport influence trip distribution and hence the shape of the origin-destination matrices. For projection purposes, the parameters *A(o)* and *B(d)* are less relevant, as they are not directly observable exogenous quantities. As equations *(6)* and *(7)* show, they derive from numbers of persons available in projection, but with a factor that depends on all fixed effects and the cost function. It is therefore not sufficient to plug in future values for the number of persons *NW(d)* and *NR(o)* in equations *(6)* and *(7)*

22 See Anderson and van Wincoop (2001) for more details.

to obtain updated future fixed effects *A(o)* and *B(d)*. *Stricto sensu*, an iterative calibration should be performed for each projection year, taking into account the updated number of workers and workplaces per district and the updated generalised costs, to ensure that the double constraint is verified. This is however not practical. We therefore reuse the reference year's *A(o)* and *B(d)* estimated parameters to provide a starting point, update the *T* matrix using updated costs, and perform an iterative rebalancing procedure on this matrix to ensure the marginal constraints are fulfilled. We do not explicitly estimate the *A(o)*'s and *B(d)*'s for future years. Formally, the model writes:

$$ln\left(\mathbb{E}\big(T(o,d)\big)\right) = ln\big(A(o)\big) + ln\big(B(d)\big) + a_{k(o,d)} + b_{k(o,d)} \cdot ln\big(aGC(o,d)\big) \tag{10}$$

The estimates for *ln(A(o))* and *ln(B(d))* are not provided here, being of little interest. Table 3 presents the estimation results for the parameters a and b as a function of the type k of the OD pair. All estimated parameters are strongly significant. One observes that parameter absolute values is lower for self-employed than for employed workers. Generalised costs and geographic barriers appear to be a stronger deterrent to travel for employees than they are for self-employed.

Table 3 Estimation results for the commuting gravity models (standard errors in parenthesis)

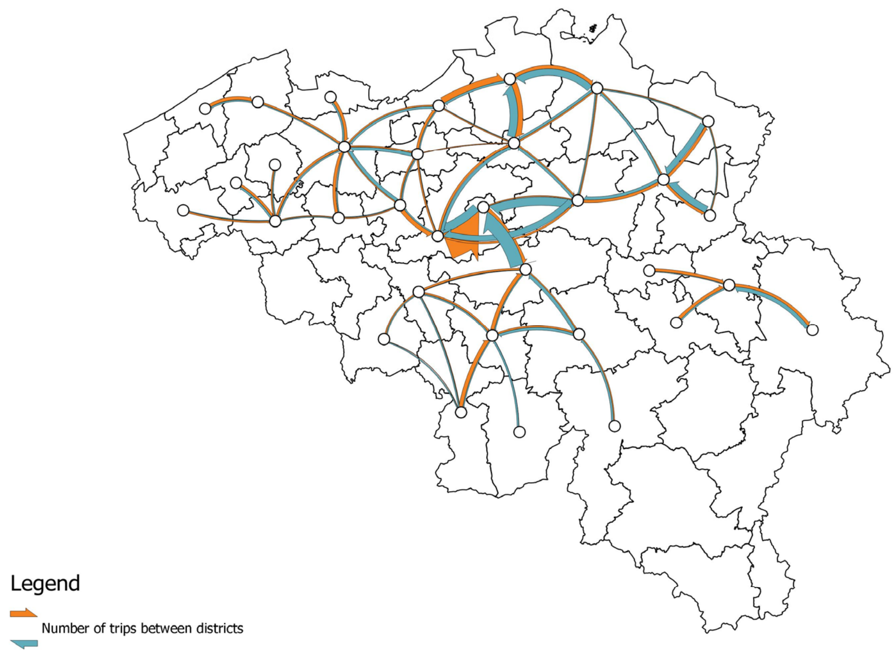
Employees			Self-employed		
Type	a_k	b_k	Type	a_k	b_k
k=1	0	-3.0 (0.07)	k=1	0	-0.9 (0.08)
k=2	0	-2.8 (0.03)	k=2	0	-2.1 (0.04)
k=3	-4.2 (0.25)	-2.2 (0.05)	k=3	-3.2 (0.30)	-1.7 (0.06)
k=4	0	-2.7 (0.07)	k=4	0	-1.9 (0.07)

Source: FPB.

The multiplicative correction factor $e(o,d) = exp\big(\varepsilon_{o,d}\big)$ is used to adjust, in the reference year, predicted values of flows for this model with observed flows. This correction factor (which represents all information not related to the relative size of origins and destinations nor to the cost of transport and which influences geographical matching between work supply and work demand) is kept constant along the projection to compute the starting point of the rebalancing procedure.

Map 8 provides an overview of the most relevant inter-district commuting flows in the reference year.

Map 8 Inter-district flows from home to the workplace in 2015



Source: PLANET v4.0.

Commuting to school, commuting to studies

Commuting to school is mostly a local phenomenon, which at our level of geographical aggregation leads to most flows being internal to the district of origin (87% of trips in 2015)[23]. The hypothesis depicted above for the evolution of the educational system capacity (increases in the district's school-age population are matched by an equivalent increase in the school offering in the district) only reinforces this characteristic. At this level of aggregation, the estimation of a gravitational model hence makes little sense. We will simply use for each projection year a rebalancing process (RAS) to adjust the flow matrix of trips observed in the reference year to the projected origin and destination margins. Therefore, no explanatory variables nor statistical models are involved in the distribution of "commuting to school" transport flows.

For the motive "commuting to studies", we do not use sophisticated modelling devices either, for several reasons. First, we do not dispose of a fully observed trips matrix in the reference year. The matrix for the reference year is a statistical construction, which does not make a sound basis for the estimation of a gravitational model. Second, the origin/destination matches of this motive are governed mostly by non-economical and non-geographical considerations. The place of superior study is constrained by many parameters outside those observed and modelled, with in the end an effect only marginal of transport-related quantities. Third and finally, the volume of trips is small (0.8% of total), which would lead to massive margins of error for a statistical modelling of the flow on a 43*43 districts matrix. We therefore elect to apply in projection years the same method as for "commuting to school": the reference year matrix is rebalanced for each projection year to match the origin and destination margins. Here again, no explanatory variables nor models are involved.

[23] Transport outlook (FPB and FPS Mobility and Transport, 2019).

Business and Other motives

For non-commuting motives, we do not explicitly model the number of persons attracted in destination districts. The available information to do so is simply too sparse. It is therefore not possible to perform a true distribution as a match between origin and destination districts. Just as was done for the reference year, we instead work from the origin district, with estimated shares of intra- and inter-district destinations, and equal spread over all adjacent districts for the inter-district trips. The little information we get from the BELDAM survey confirms that very few trips are made to non-adjacent districts.

Therefore, for non-commuting motives, the method used for the base year is repeated, but starting from the projected numbers of persons concerned in each origin district in projection years, instead of observed populations for the reference year. No explanatory variables nor models are used for trip distribution for these motives.

c. Trip rates

Trip rates are managed for each motive along a specific segmentation, depending on socio-demographic and geographic criteria (see section 3.1.1.a above on trip rates).

Two mechanisms of trip rate evolution are implemented in PLANET. The first one concerns trip rates for “other motives” only and is associated with evolutions of the aggregated socio-demographic characteristics of individuals and households in a given district. The second one concerns all motives but “commuting to school” and is associated with the evolution of average generalised costs of transport.

Evolution of trip rates for “other motives”

As mentioned in section 3.1.1.a, the observed trip rates for “other motives” from BELDAM survey’s logbook are generalised to the whole population by way of a negative binomial model. The explanatory variables considered naturally stem from the same BELDAM survey, which proves to be rich enough to provide an informative range of drivers of transport demand. After statistical selection, we remain with the following explanatory variables:

- region of residence: Brussels, Flanders, Wallonia;
- age: 0-14, 15-19, 20-34, 35-49, 50-64, 65-74, 75 and more;
- sex: male, female;
- socio-economic status (SES): inactive, student, employed, self-employed (note that the category inactive” is a residual category, which hence also includes unemployed persons. These are the historic SES categories in the PLANET model and are maintained as-is, despite the abuse of language);
- household size in number of persons;
- urbanisation index: continuous variable with values between 0 and 3 (0 = fully urban, 1 = suburbs, 2 = commuters’ zones, 3 = rural, following the typology defined in Van Hecke et al. (2009) which is in use within BELDAM). This variable takes discrete values 0, 1, 2 or 3 for individuals, but is here taken as an index. Hence only one multiplicative parameter is fitted to this variable within

the model. This amounts to make the hypothesis that behaviours evolve monotonically with the degree of urbanisation of the place of residence. This hypothesis appears valid when considering the model fit results based on the original discrete variable for urbanisation. Using the index version of the variable will allow us to make projections based on the average degree of urbanisation of a given geographical area;

– education level: continuous variable with values between 1 and 3 (1 for lower education, 2 for secondary education, and 3 for tertiary education). Just as for the degree of urbanisation, this variable is originally a discrete variable, but is used here as a continuous index, with a unique multiplicative parameter fitted;

– disposable income by consumption unit in the household (on a declarative basis): continuous variable, obtained by combining the total monthly incomes declared by the respondents and the information about the number and ages of the household members.

The results of the two model fits and parameter estimates are displayed in Appendix E.

To be considered as valid demand drivers for our modelling purposes, these variables must be available for the projection period. We can obtain these variables, or find closely related variables, from the following sources.

Trip rates are a characteristic of individuals. As such, it is the demographic projections, in their finest details available to us, that form the basis for the projection of these explanatory variables. In Appendix A we describe how demographic projection by *district of residence, age, sex and socio-economic status* are obtained. This takes care of the *sex, age,* and *socio-economic status* variables. A projection for the average level of education by age class is derived from projections of education levels by CEDEFOP[24] and a reference year situation based on the Labour Force Survey, as described in Appendix A. The geographic dimension (district of residence) is used to derive the other variables: region of residence, household size (taken as the average household size of the district available from the official demographic projections (FPB and Statbel), urbanization index (taken as the population weighted average municipal index over the district of residence, see here also Appendix A for more details).

Disposable income by consumption unit in the households is available for a projection horizon of five years at the national and regional level, as part of the outputs of HERMES and HERMREG models. We use historical data by district from the Regional Accounts (ICN), and national long-term economic projections from MALTESE, to derive a statistical projection of disposable incomes by district (see Appendix A).

We are thus able to make all necessary variables available for the projection period. Therefore, they qualify as valid drivers for the modelling of trip rate evolution for "other motives", together with the binomial negative models linking these variables and the average individual trip rates for these motives.

[24] European Centre for the Development of Vocational Training.

Impact of generalised costs on trip rates

For each motive, an overall elasticity of trip rates to the generalised costs of transport is calibrated. This elasticity summarizes the impact of the generalised cost of transport – where time costs play a major part – on individual decisions on whether to make a trip or not. We remind here that all parameters in the PLANET model are broad averages related to the macro nature of the model. Hence these elasticities are related to average propensity to make trips in the population rather than individual decisions for a given trip in a given situation.

For "commuting to school", this elasticity is considered null, as school is compulsory. We set it to zero for "commuting to studies" as well. Though no obvious reason exists to do so as opposed to "commuting to school", there is only little evidence from the literature to build upon. Given the high share of public transportation observed for this transport motive, this appears as a reasonable choice. For "commuting to work", this elasticity covers the tendency to avoid trips as generalised costs increase. It can be thought as relating to effects such as an increased recourse to home working, some eviction effects from the job market, or additional recourse to part time to compensate for increased time costs of transport. In the same vein, business trips can be avoided by making use of modern electronic communication tools, private trips avoided by using online services and shopping possibilities. We do not however explicitly model any of these phenomena. The values of these elasticities are calibrated within the global process of calibration related to modal and time choice and is described in section 3.3.3.

Table 4 illustrates the changes in the number of projected trips per person per week, resulting from these considerations.

Table 4 Evolution of the number of trips per person per week

	Number of trips per person per week (for the relevant population)		Growth
	2015	2040	2040/2015
Total	**17.7**	**17.6**	**-0.9%**
Commuting to work	8.0	7.5	-6.1%
Commuting to school	7.4	7.4	0.0%
Commuting to studies	5.4	5.4	0.4%
Business	0.8	0.7	-6.8%
Other motives depending on revenues	6.5	7.1	9.3%
Other motives not depending on revenues	6.1	5.5	-9.5%

Source: PLANET v4.0.

d. Generalised costs

Generalised costs of transport are composed of monetary and time costs, the respective importance of which depends on the modes and motives of transport considered (see Table 27 in Appendix F).

Monetary costs for passenger transport

Monetary costs for passenger transport are expressed in euro per pkm. They are estimated for car solo, carpooling, train, tram, bus, metro and motorcycle, for each of the six motives studied. Monetary costs when travelling by bike or walking are zero in the model, only time costs are therefore considered.

Monetary costs for public transport modes are based on receipts and subsidies data provided by transport companies (TEC, De Lijn, STIB, SNCB). The value added tax (VAT) is taken from the Tax Survey (FPS Finance).

For car and motorcycle, the user bears costs related to the use and the acquisition of the vehicle: purchase, insurance, maintenance, inspection, fuel (or electricity) expenses as well as different taxes (traffic tax, registration tax, excise, VAT)[25]. Several data sources are combined to estimate them (NBB, FPS Finance, Moniteur automobile, GOCA, TML,...). Car costs are differentiated according to the type of engine[26], the size of the vehicle[27] and, for fuel expenses, to the Euro emission standard[28]. A weighted average cost, all vehicles combined, is calculated from the projected car stock model (CASMO).

Fuel and electricity expenditures for car and motorcycle use consider changes in fuel and electricity prices as well as the evolution of energy efficiency of the vehicles. The evolution of fuel and electricity prices comes from the energy outlook published every three years by FPB. Changes in energy efficiency are based on the projected evolution of consumption per vehicle (VITO) and the projected car stock (CASMO).

Beside taxation on use (and on the acquisition costs for cars and motorcycles), PLANET considers the contribution of the employer in commuting costs, both for car travel (e.g. company cars) and public transport (e.g. third-party payment system). An in-depth study of commuting subsidies in Belgium is available in Laine and Van Steenbergen (2016).

Time costs for passenger transport

Time costs are also expressed in euro per pkm. They depend on the value of time and the time spent to reach the destination. More precisely, time costs for passenger transport are obtained by multiplying the different components of the transport time by a corresponding value of the time. The components of time are the time spent in the vehicle, the walking and waiting times, the time required to get to the main mode of transport (outside of walking) and the time to park his vehicle. Except for the time spent in the vehicle, the durations are assumed to be constant over the entire projection period (source: SES 2001). The time spent in the vehicle depends on the speed on the network.

Value of time

The value of time (VOT) denotes the amount an individual or business is willing to pay to save time or wants to compensate for a loss of time.

The VOT of our baseline model is shown in Table 5 for passenger transport. The values of time are expressed in euro/person/hour. Their level for the reference year is based on KiM (2013). Their evolution is estimated via an intertemporal elasticity with respect to the real GDP per capita: 0.9 for cars, 0.6 for the active modes (cycling and walking) and 0.7 for the other modes of transport studied. For road modes

25 The monetary costs of parking are not considered in the model. Only the time costs of parking are taken into account.

26 Gasoline or diesel internal combustion engine, gasoline or diesel hybrid vehicles, compressed natural gas (CNG), liquefied petroleum gas (LPG) and 100% electric.

27 Small, medium, large.

28 Due to a lack of data, the costs per vehicle, excluding fuel costs, do not vary according to the Euro standard.

(car, motorbike), the value of time also changes according to the speed on the road network during the projection. The change in GDP per capita is based on the economic and demographic outlook published by the FPB.

Table 5 Value of time for passenger transport by mode and motive for travel in 2015
euro2015/person/hour

Transport mode	Commuting	School	Business	Other motives
Foot/bike	7.6	5.9	18.6	5.9
Car, motorbike	9.0	7.3	25.6	7.3
Train	11.2	6.8	19.3	6.8
Bus-Tram-Metro	7.6	5.9	18.6	5.9

Sources: FPB calculations based on Kennisinstituut voor Mobiliteitsbeleid (2013).

Speed on the network

Speed on rail and metro networks is considered constant. Time spent in the vehicle comes from SES 2001 data.

The other modes are part of road traffic and are potentially affected by congestion to varying degrees: if the demand for road transport increases, the capacity of the network remaining constant, the speed decreases and the time spent in the vehicle increases.

Table 6 below shows the share of vehicle-km that is impacted by congestion, or contributes to it, depending on the point of view[29].

Table 6 Share of vehicle-km that contributes to congestion, by mode

Transport mode	Contribution
Car solo	100%
Carpooling	100%
Motorcycle	100%
Bus	90%
Tram	34%

Source: FPB calculations.

In-vehicle time is determined endogenously for road transport modes. This is done by means of speed-flow functions that present the relationship between speed and transport flow on the road. The latter is expressed in PCU-km[30] in order to take the contribution of each road transport mode to traffic congestion into account. By assumption, a motorcycle is assumed to be equivalent to 0.75 PCU in terms of impact on congestion. For buses and trams, the equivalence factor is 2.5.

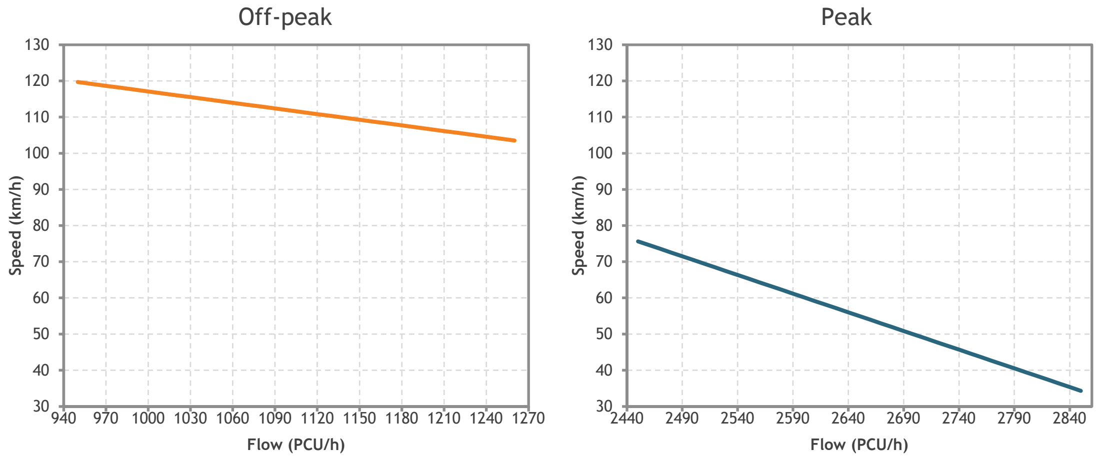
Earlier versions of PLANET incorporated a single national congestion function that replaced the modelling of the road network (see Desmet and al. (2008)). In other words, we assumed a single average speed (per period) on the road for the whole of Belgium. The model has recently been improved to include five geographical zones and three road types described above, with their own congestion function.

[29] As the Belgian saying goes: "you're not stuck in traffic, you ARE the traffic!"

[30] PCU stands for Passenger Car Unit. One PCU-km represents the equivalent of one kilometre travelled by a passenger car in terms of road flow.

Speed levels are taken from the network models developed by the Flemish and the Brussels regional administrations[31], as described in section 3.2.1.d. We also obtained from these network models a simulation that increases traffic levels by 5%, in order to capture the underlying speed-flow relationships in these models. By road/zone pair, a piecewise linear congestion function was calibrated to match the reaction of speeds to flow changes from these simulations, as illustrated in Graph 2 for highways in the REN zone. Using these congestion functions, one can infer the impact on the average speed on the road of an increase in road flow, for each road/zone pair. Table 7 below reports the speeds for cars in 2015.

Graph 2 Example of a speed-flow relation: highways in the REN zone



Source: PLANET v4.0.
The REN zone (from Regional Express Network - a major infrastructure project) is a zone around the Brussels Capital Region.
PCU = passenger car unit.

Table 7 Average speed - passenger car (2015)
km/hour

	Highways	Tolled roads other than highways	Other roads
Peak			
Brussels Capital Region		12.1	
Agglomeration REN	65.5	52.5	48.7
Agglomeration Antwerp	66.6	46.9	38.1
Agglomeration Ghent	105.3	67.5	52.0
Rest of Belgium	111.1	74.1	64.6
Off-Peak			
Brussels Capital Region		23.0	
Agglomeration REN	107.1	69.6	61.2
Agglomeration Antwerp	96.3	61.3	53.2
Agglomeration Ghent	113.6	72.7	60.3
Rest of Belgium	115.7	76.7	67.6

The REN zone (from Regional Express Network - a major infrastructure project) is a zone around the Brussels Capital Region.

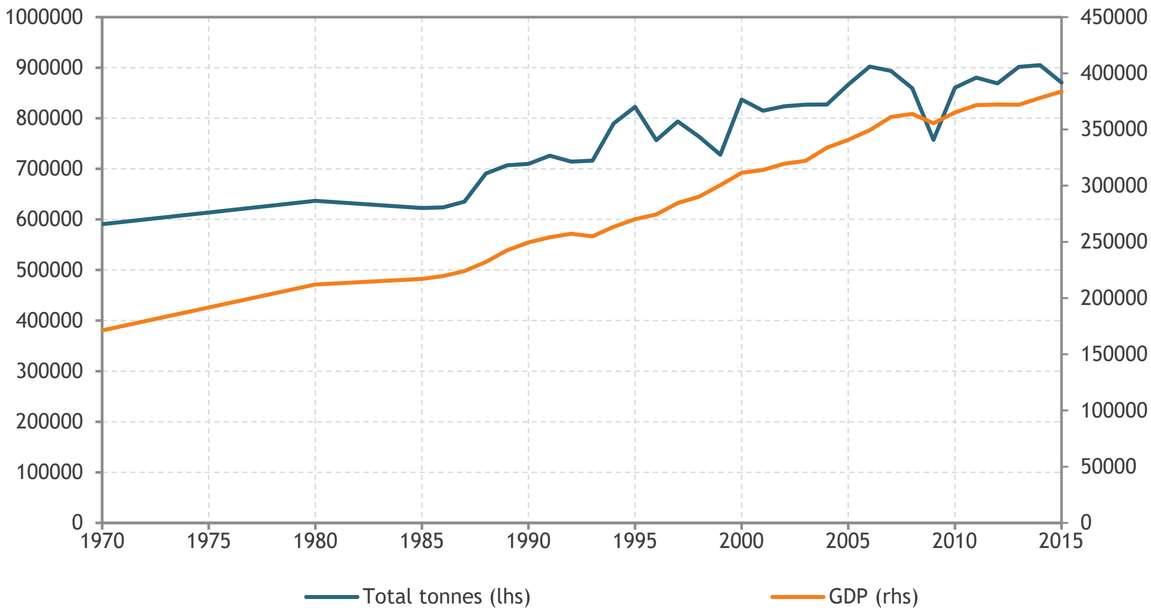
3.2.2. Freight transport

The evolution of freight transport is primarily driven by economic developments. An increase in the global volume of economic activity usually translates into a growth in demand for freight transport (see Graph 3). But as in the case of passenger transport, other effects such as composition and intensity effects play a role. For a given level of economic activity, the freight transport demand will depend on the

[31] Strategische Verkeersmodellen Vlaanderen and MuSti respectively.

nature of the activity. Some service activities such as financial services, healthcare, advanced services to production or the public sector usually impart much less freight transport demand than trade in goods activities, or industrial production activities. Hence an evolution in the composition of the economic activity will affect transport demand even for a constant total activity level. Finally within a given industry, the transport intensity evolves also with the transformations of the production processes and the position of the local companies along the value added chain: primary transformation to serve intermediary demand does not entail the same transport volumes as final product transformation for the final consumption in a given sector. These three aspects - volume, composition and intensity – must be captured by the set of drivers of transport demand that we use to project OD matrices of tonnes.

Graph 3 Evolution of total tonnes lifted and GDP between 1995 and 2015
Thousand tonnes (left) and millions of Euro 2010 (right)



Sources: ICN, Statbel, PLANET v4.0.

In terms of economic activity, the volume notion that is relevant to us is that of use and supply of goods. The basic economic indicators that we will work with are therefore output, imports, consumption and exports. These can be, to a certain extent, obtained from exogenous economic projections. They are then expressed in monetary terms and split by industry.

To correctly account for composition effects, these indicators should be translated from a by-industry classification into a by-product classification, which is usually performed using supply and use tables (SUT). The SUT available to our project also distinguish between the uses of local output and the uses of imports.

Intensity is less easily captured and its evolution more complex to forecast. We use the evolution of the share of services in the total output of each industry as a first element accounting for the evolution of this intensity. Additional elements of intensity will be taken into account through the models used to link the drivers and the tonnes transported.

Formally, the drivers of freight transport demand used in PLANET are thus per-product and per-district: output of goods, imports of goods, consumption of goods and export of goods.

The link between these drivers and tonnes transported is closely linked to the monetary value of a tonne of goods. It may seem obvious at first glance, but some aspects of data coherence loosen this link in some cases (it is especially more difficult to link domestic transported tonnes with an economic quantity, as beside locally produced goods, imports are also almost always domestically transported after transhipment). This indicator of the value of a tonne must also be projected. And tonnes lifted must be assigned to an origin and a destination to produce an OD matrix.

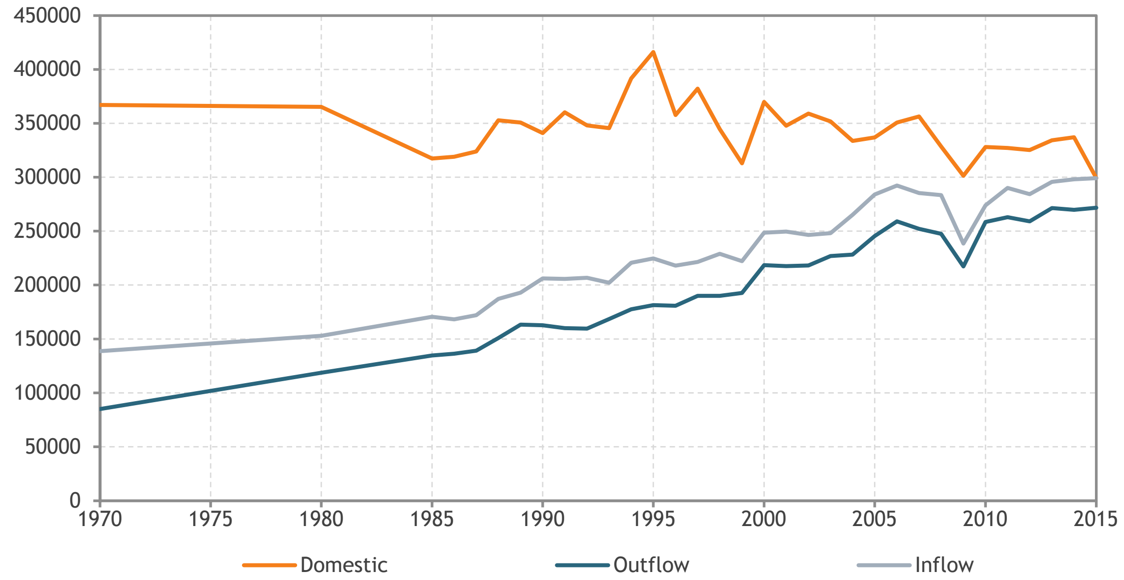
In the following paragraphs, we describe the different elements required and the chain of operations that allows the computation of these drivers. We then provide the models linking them to the total tonnes projected and the distribution of these among origins and destinations. Finally, we discuss the computation and projection of generalised costs for freight transport as a key parameter for transport choices.

a. Economic drivers of tonnes transported

The most basic expression of the volume effect on tonnes transported is observed when relating total tonnes transported and GDP. As readily visible on Graph 3 tonnes transported show a strong positive correlation with the global GDP of Belgium. The trend for these two quantities is however different. Increases in the economic activity are matched by increases in tonnes transported, but less than proportionally: the number of tonnes transported per euro of GDP decreases with the increase in GDP.

However, this relation does not hold for each type of flow, with Graph 4 showing a decline in domestic tonnes transported while inbound and outbound flows increase between 1980 and 2015. The dispersion in growth rate is even higher if one considers tonnes by product. Therefore, it is necessary, for our purpose, to obtain drivers of the freight transport demand at a sufficient level of detail, namely by type of flow, product, and district.

Graph 4 Past evolutions of tonnes lifted by type of flow, 1970-2015
Thousand tonnes



Sources: EUROSTAT, Statbel, PLANET v4.0.

We start from economic quantities available to us in projection, at least for a fraction of the total projection horizon: the outputs of the HEMREG and HERMES models provide us with value added, output, imports and exports for thirteen industries, over a medium-term projection horizon. We then perform the following operations:

– Using observed series of value added by industry and district (Regional accounts, NBB), long-term projection of national value added from the MALTESE model and employment projections by industry and district (see above), we derive projections of value added by industry and district using relative trends in productivity across districts.

– The ratio of value added to output is projected, using observed ratios on past years, and projected ratios obtained by national industry from HERMES for the first years of projection, from which trends by industry are derived.

– Value added projections are translated into output projections by industry using these projected ratios.

We therefore have projected series of output by industry and district, and national imports and exports by industry.

As a next step we use data from the supply and use tables set up by the ICN to convert this by-industry information into a by-product information. This will allow to capture composition effects in the evolution of freight transport demand. But it also will play a role in accounting for changes in transport intensity by industry. To achieve this, we use historical SUT (from 1980 onwards) to assess the general evolution of some key parameters of the production structure, namely: the share of goods production in total output, the share of goods in exports, imports, and reexports, and the share of reexports in imports. On this basis, we estimate trends for these characteristics that are used to let the production structure evolve in projection. We then proceed with the following steps:

- Using separate projected SUT for local output and imports, we obtain intermediate demand per product for Belgian output, intermediate demand per product for imports, per euro of industry output. We apply these coefficients to district's by-branch output projections to obtain district intermediate demand and output projections by product.
- National final consumption by product is projected using aggregate output projections and distributed among districts based on population figures.
- National demand for products as investment goods are projected using aggregate output and distributed among districts based on district output figures. They are then calibrated to sum to the value projected in HERMES.
- National exports by product are projected using aggregate output and distributed among districts based on district output figures. They are then calibrated to sum to the value projected in HERMES.

In doing so we obtain for each projection year a coherent set of economic indicators by product type, expressed in constant euros: for each NUTS3 district and product type, we have a *value of goods used from national output*, a *value of goods used from imports*, a *value of goods produced in the district* and a *value of this production that is exported*. We also compute the *value of imports being immediately reexported*.

These indicators have been derived using national hypothesis and production structures. They do not allow to distinguish between the use of output produced within the district and other national production. As such, they do not constitute an exact district-level summarised SUT. They do however convey useful information on the volumes and their compositions, as well as a partial intensity information stemming from the evolution of the projected SUT structure. They can thus be used as drivers for the evolution of tonnes transported in our projection. In other terms, these indicators can be used as explanatory variables, but are not valid economic accounting quantities at district level.

b. Value of a tonne

Modelling the link between OD matrices of tonnes transported by product and district, and the economic drivers defined above, also implies a translation from economic quantities in euro, to physical quantities in tonnes. This translation amounts to the computation of the value in euro of a tonne of goods for a given product. To be correct, the true value in euro of a tonne of goods in a given product category is not required for our projection, only the evolution of this value in the future, as for the reference year we have values for both the tonnes transported and the economic drivers. It is however useful to maintain this concept, as it provides a convenient basis to perform a projection.

The value of a tonne of goods is not a readily available data. For some type of goods, it is documented, or easily derived (e.g. because the value of a given volume is given and the physical density is known). For a lot of types of goods however, the typical reporting unit makes a translation into a number of tonnes a challenge. The use of national production databases (such as the PRODCOM survey) would provide crucial information but represents an effort of translation from many different measurement units into tonnes that is until now outside of our scope. We therefore work with an indicative value of the tonne (a value index of a tonne) computed by relating observed transported tonnes with economic indicators in value. This is sufficient for our purpose, as we are mostly interested in the evolution of this index which should not be interpreted as a real value of a tonne of goods.

This value index for a tonne is calibrated on the last years of data. It is differentiated by product group and by type of flow: import, export and domestic. Indeed, the share of different products in a product group varies according to the type of flow considered. Quite obviously, inbound flows are related to economic imports and outbound flows to economic exports. For domestic flows, the case is less clear-cut. Indeed, most goods imported in Belgium enter the country through a port of entry, where they are transhipped and transported toward their final destination. Hence, economic import flows also generate domestic physical flows for a majority of the tonnes transported. In the same vein, domestic production might be exported directly without transhipment, but we work under the hypothesis that this situation is not the most prevalent. We do not dispose of exact data in this regard. We thus make the generic assumption that the most relevant economic driver for the domestic flow of physical transport is the sum of domestic production and imports net of reexports.

To relate the OD matrices of tonnes by product observed in recent years with the economic counterparts computed above, by flow, we need:

- On the physical side, in the OD matrices of tonnes transported, to sum up all OD pairs originating abroad with destination in Belgium (inbound flow), all OD pairs originating in Belgium with destination abroad (outbound flow) and all OD pairs with origin and destination in Belgium (domestic flow).
- On the economic side, for the economic indicators obtained by product, to sum up all import values (related to inbound flow), all export values (related to outbound flow) and all production values to which we add the import values net of the reexported share (related to domestic flow).

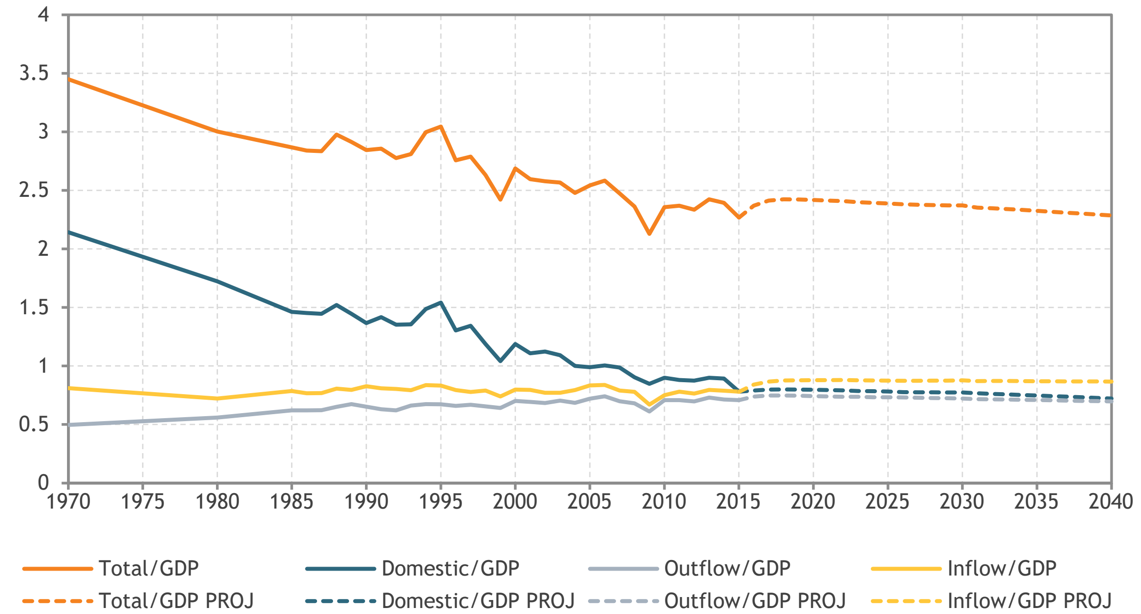
We then can approximate an aggregate value index of the tonne by product and type of flow, by taking the average ratio of economic value of the flow to total tonnes in the flow. The average is over all observation years available. We thus obtain three values per product: an average value for one inbound tonne, an average value for one outbound tonne, and an average value for one domestic tonne.

For the projection period, these average value indices of the tonne are not kept constant. They are projected to evolve in function of identified trends. These are estimated based on:

- Observed changes in value of the tonne for imports and exports by product group on the long term, based on external trade data (NBB): this is our only long-term trend source with a distinction by product type, but it does not cover domestic flows.
- Observed long-term trends in the economy-wide average value index of a tonne, computed on the long-term series of transport statistics and National Accounts for inbound, outbound and domestic flows: this is our long-term trend source for the three types of flow, but without product detail.

– Observed long-term trends in global average intensity in freight transport of the economy, as measured by the total tonnes transported divided by the GDP expressed in constant euros: this is a calibration reference, that ensures that the regular trend in decreasing transport intensity observed since 1980 at least is maintained in the future: see Graph 5.

Graph 5 Evolution of the transport intensity in Belgium in tonnes per euro of GPP
Tonnes per thousand euros of 2010



Source: PLANET v4.0.

Once projected trends for the value index of the tonne transported by product and by type of flow are available, the set of economic drivers described above can be translated into tonnes. For each district and product type, we therefore have projected series, in tonnes, for imports, export and re-exports, production, and consumption of Belgian production (final or intermediate). By construction, these series agree on average over the calibration period with the observed tonnes for the three types of flows when rearranged accordingly. To simplify the presentation of result, the series are scaled so that values for the reference year fit the observations[32].

There are two uses to these series of tonnes.

– These results allow the computation of **projected series of total tonnes transported for the three types of flow at national level**. This is an important intermediary result, as it will be used as a calibration device for projected flows of tonnes (OD matrices) obtained using gravity models.

– At the district level, these series cannot be trusted as a local supply and use table, as they were built under the hypothesis of a national production structure and a national distinction between local and imported supply. However, these series of tonnes produced, imported, exported,

32 Note that goods for product types 14 to 20 in the NST07 classification (see Appendix D) cannot be linked to a given industry's production. In some instances, because these categories concern grouped loads for which no information on the products exist, in other instances because these loads are not the result of a production or trade (for example garbage, furniture moved). These product types do not make part of the scope of the analysis and methodology presented above. They are therefore projected at the same growth rate as the sum of all other good categories in the model, by default.

reexported, and consumed, can be considered as proxies and used as **explanatory variables for the gravity models of the physical flows** described in the next section.

c. Distribution of tonnes among Origin/Destination

As in the case of commuting to the workplace for passenger transport, we make use of gravity models to perform a distribution of the flows of transport across the origin-destination matrix. There is however a major difference: in the commuting case, the number of persons originating or terminating a trip in each district was known in advance, and the gravity model was used to solve a problem with fixed margins. We then made use of so-called doubly constrained gravity models.

In the case of freight transport, the methods applied to project tonnes used and tonnes supplied in each district are not reliable enough to use these directly as constraints. This would amount to consider our proxy as a true by-district SUT, which is not defensible on scientific grounds. We therefore resort to unconstrained gravity models, where these supply and use amounts enter as explanatory variables, along with other relevant indicators, to model the matrix of transport flows.

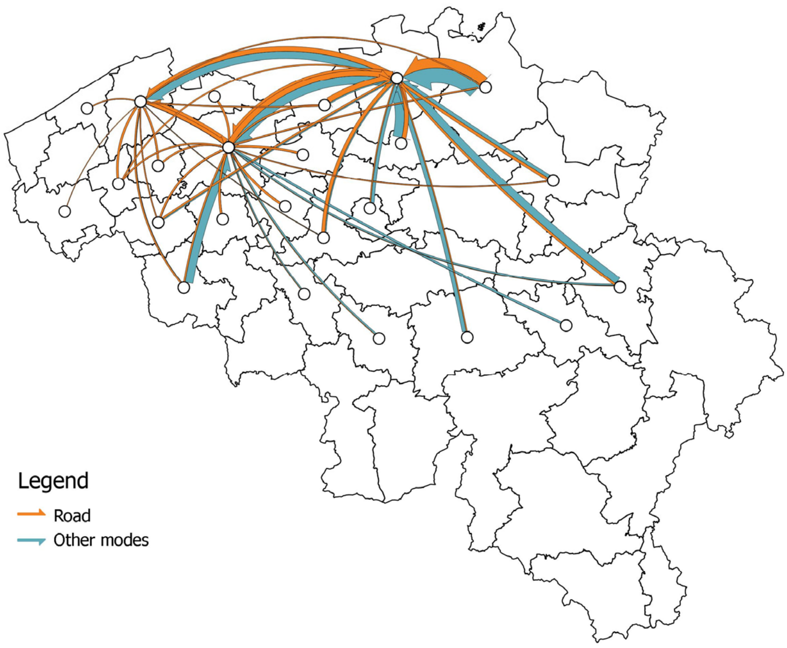
Only domestic flows are modelled using the gravity model. Inbound and outbound flows are modelled separately, since the information available on districts of origin or destination abroad is very limited (we do not make projection of goods use or supply for districts abroad). Gravity models predict flows according to the size or "mass" at the origin and destination points. These "masses" are here measured in terms of goods supply (for the origin) or use (for the destination) for a given product type. We are however free to exploit additional variables that have predictive power for the flows between origin and destination districts. We therefore chose to use indicators of the presence of a major sea[33] port in the district[34] (origin and/or destination). When the origin (resp. the destination) district has a port, the domestic flow originating (resp. terminating) in the district contains not only goods produced (resp. used) in this district of origin (resp. destination), but also imports (resp. exports) that transit via this major port and are transhipped in the district of origin (resp. destination). Map 9 and Map 10 displaying domestic flows from and towards districts of Bruges, Gent and Antwerp illustrate these large in- and outflows for major seaports, independent of these districts local production and consumption. Therefore, the relation between the indicative supply (resp. use) amount computed above and the flow of goods is different than for a district without a port, where it is expected that the supply (use) would explain most of the flow characteristics. Therefore, not only dummy variables indicating the presence of a port in the origin or destination districts are included as explanatory variables, but also an interaction term between the supply (resp. use) and the presence of a port at the origin (resp. destination). This way, supply and use terms will have two values estimated, one for districts without a port and one for districts with a port.

Another dummy variable with value 1 only when origin and destination are in the same district is included in the model. It models a local premium, in addition to notions of costs of transport, as we observe that local flows are higher than what models would predict based on masses, ports, and generalised cost of transport. There exist reasons other than (generalised) costs to favour trade with economic

[33] The inclusion of a variable flagging major airports for cargo has been tested but proved statistically not significant.
[34] This concerns the districts of Antwerp, Gent, Bruges, and Ostend.

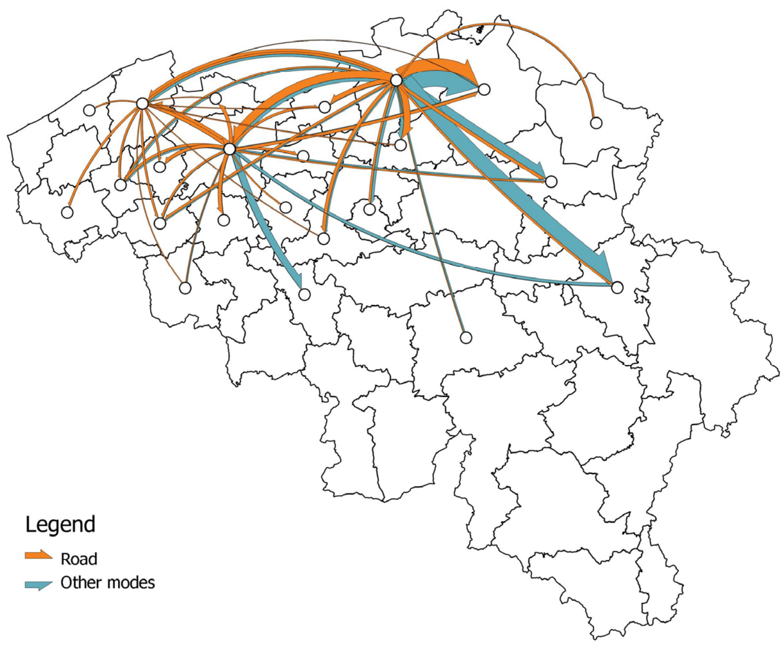
agents in the same area (for example better access to information, local knowledge,…) which must be captured in some way to correctly reproduce the observed flows. Finally, generalised costs of transport between origin and destination are taken as the average generalised costs of transport of the previous period for the projection, or the observed costs for the year of reference. They enter the gravity equation in the power form.

Map 9 Domestic flows towards the three major Belgian seaports in 2015



Source: PLANET V4.0

Map 10 Domestic flows from the three major Belgian seaports in 2015



Source: PLANET V4.0

Our gravity model thus writes as a negative binomial count model in the logarithmic form:

$$ln\left(\mathbb{E}\left(T_p(o,d)\right)\right) = \beta_{p,0} + \left(\beta_{p,1} + \beta_{p,3} \cdot Port(o)\right) \cdot ln\left(Sup_p(o)\right) + \left(\beta_{p,2} + \beta_{p,4} \cdot Port(d)\right) \cdot ln\left(Use_p(d)\right) + \beta_{p,5} \cdot Port(o) + \beta_{p,6} \cdot Port(d) + \beta_{p,7} \cdot I(o=d) + \beta_{p,8} \cdot ln\left(aGC_p(o,d)\right) + \varepsilon_{p,o,d} \quad (11)$$

…with a separate model for each product class p. The *Port(x)* variable is a dummy indicating the presence of a major seaport in district x, *Sup* and *Use* are computed supply and demand index for the district d and product p.

Table 8 Parameter description for the freight gravity model

Parameter	Description
$\beta_{p,0}$	Intercept
$\beta_{p,1}$	Supply index parameter for product p in district o
$\beta_{p,2}$	Use index parameter for product p in district d
$\beta_{p,3}$	Correction of supply index parameter when district o contains a major seaport
$\beta_{p,4}$	Correction of use index parameter when district d contains a major seaport
$\beta_{p,5}$	Correction of the intercept when district o contains a seaport
$\beta_{p,6}$	Correction of the intercept when district d contains a seaport
$\beta_{p,7}$	Correction of the intercept when the flow is intra-district (d=o)
$\beta_{p,8}$	Exponent of the generalised cost

The estimates obtained for the different product types are summarised in Table 9. All displayed parameters are significant at the 1% level. For some product types, several explanatory variables prove to bear no significant link with the tonnes flows in the OD matrix observed. There is a strong variation by product type in the results obtained, which is understandable as the available explanatory variables are limited when considering all possible factors impacting OD freight flows within Belgium. Results for the "supply and demand" variables, as well as "intra-district flow" and cost function prove consistent across product categories. The variables related to the presence of major seaports show much more variation from one product type to another.

Table 9 Estimation results for the freight gravity models

Product	$\beta_{p,0}$	$\beta_{p,1}$	$\beta_{p,2}$	$\beta_{p,3}$	$\beta_{p,4}$	$\beta_{p,5}$	$\beta_{p,6}$	$\beta_{p,7}$	$\beta_{p,8}$
NST01 (p=1)	-0.93	0.34	0.27	1.14	0.69	-7.43	-4.79	1.89	-0.08
NST02 (p=2)	1.61		0.68		-1.84	-1.84	7.39		-0.82
NST03 (p=3)	2.87	0.15	0.29			0.11	0.11	2.44	-0.58
NST04 (p=4)	-2.36	0.47	0.33	0.43	0.23	-2.86	-1.12	2.64	
NST07 (p=5)	-0.36	0.43	0.12			-3.67	0.21	2.15	-0.02
NST08 (p=6)	-1.70	0.51	0.25	0.33	0.35	-1.52	-1.14	1.95	-0.14
NST09 (p=7)	0.20	0.21	0.33	0.09		-0.45	0.67	2.49	-0.15
NST10 (p=8)	-2.74	0.51	0.63	0.20		-0.36		2.08	-0.28
NST12 (p=9)	-0.46	0.31	0.25	0.23	-1.21	-1.21	-0.61	1.73	-0.31
NSTOT (p=10)	-0.73	0.23	0.25	0.84	0.7	-5.42	-4.20	2.83	

Source: FPB.

For transit, inbound and outbound flows, in absence of sufficient information on the districts abroad to perform a similar modelling of flows, the transported tonnes for all OD pairs are supposed to grow at the same rhythm. The distribution of tonnes among origins and destination is therefore similar to that observed in the reference year, only the total volumes evolves. The overall growth rate for inbound and outbound flows is given by the preliminary result on total inbound and outbound tonnes discussed above in subsection b. For transit flow, we equate the growth rate to the growth rate of the sum of inbound and outbound flows.

d. Generalised costs

Monetary costs for freight transport

Monetary costs for freight transport are expressed in euro per tkm. They are estimated for LDV, HDV, rail, inland waterways (IWW) and short sea shipping (SSS).

For road transport, costs include expenses related to purchase, insurance, maintenance, inspection and fuel consumption as well as several taxes (traffic tax, kilometre charge,…). They are based on several data sources (NBB, FPS Finance, GOCA, TML,...). Fuel expenses include the change in fuel prices as well as the evolution of energy efficiency of the vehicles (see Table 10).

Table 10 Average consumption of fuel (diesel) and electricity for the freight transport

			2015	2025 (difference in % compared to 2015)	2040 (difference in % compared to 2015)
LDV	Diesel	l/100vkm	9.5	-4.8%	-5.4%
HDV	Diesel	l/100vkm	27.3	-0.4%	-0.9%
IWW	Diesel	l/100tkm	1.1	-0.9%	-0.9%
Rail	Diesel	l/100tkm	1.45	0.0%	0.0%
	Electricity	kWh/100tkm	3.9	0.0%	0.0%

Sources: VITO, VMM, INFRABEL and FPB calculations.

For rail, IWW and SSS, costs reflect the producer price and are based on data available in TML (2017).

Time costs for freight transport

Time costs are also expressed in euro per tkm. They are obtained by multiplying the time spent to reach the destination by the value of time.

Value of time

The VOT for freight transport are expressed in euro/tonne/hour. They come from the study of TML (2017), itself based on KiM (2013). There is no distinction according to the NST07 classification. The values in the reference year are presented in Table 11 below, as well as their evolution.

Table 11 Value of time for freight transport by mode in 2015 - national transport
euro2015/tonne/hour

	Value of time	2015	2040
HDV	7.0	+2.6%	+12.4%
LDV	130.7	+2.6%	+12.4%
Rail	2.5	+1.3%	+6.2%
IWW	0.43	+2.4%	+7.5%
SSS	0.06	+2.4%	+7.5%

Sources: TML (2017) based on KiM (2013), FPB calculations.

The evolution of the VOT is estimated by applying the evolution of the real wage cost in the transport sector to the part of the VOT related to labour: for road transport, it is assumed 50% of the VOT compared to 25% for rail, IWW and SSS. The evolution of the real wage cost in the transport sector is based on the FPB macroeconomic outlook, by sector[35].

Speed on the network

Speed levels measured for trucks and light-duty vehicles for the reference year are presented in Table 12. In projection, the rate of change of LDV and HDV speeds is assumed to be equal to the rate of change of car speed for each combination of period, zone, and type of road (see section 3.2.1.d).

35 Land transport, water transport and air transport.

Table 12 Average speed for road - freight (2015)
km/hour

	Highways	Tolled roads other than highways	Other roads
Truck			
Peak			
Brussels Capital Region		12.0	
Agglomeration REN	62.9	55.7	52.6
Agglomeration Antwerp	61.3	48.8	63.2
Agglomeration Ghent	87.4	69.5	64.5
Rest of Belgium	88.9	79.3	73.0
Off-Peak			
Brussels Capital Region	23.7	23.7	
Agglomeration REN	88.9	66.1	63.0
Agglomeration Antwerp	81.9	63.1	77.1
Agglomeration Ghent	89.7	74.2	74.8
Rest of Belgium	89.1	79.8	74.4
Light-Duty vehicles			
Peak			
Brussels Capital Region		12.1	
Agglomeration REN	62.2	57.8	52.6
Agglomeration Antwerp	59.9	49.7	60.2
Agglomeration Ghent	87.4	72.2	61.9
Rest of Belgium	86.7	77.8	65.9
Off-Peak			
Brussels Capital Region		23.5	
Agglomeration REN	87.8	66.8	62.4
Agglomeration Antwerp	79.0	64.4	72.4
Agglomeration Ghent	89.7	75.6	69.9
Rest of Belgium	89.1	78.2	67.6

The REN zone (from Regional Express Network - a major infrastructure project) is a zone around the Brussels Capital Region.

For non-road modes, the average speed is determined exogenously and is assumed to remain constant over the projection period, which implicitly means that the increase in tonne-km can be absorbed by rail and IWW infrastructures or that they will be adapted accordingly. The values are presented in Table 13. They are identical during peak and off-peak periods.

Table 13 Average speed for rail, inland navigation and short sea shipping - freight
km/hour

	Belgium	Abroad
Rail	30	55
Inland navigation	10	16
SSS		27

Source: PLANET v3.2.

3.3. Drivers and model for modal and time choice

As they express a demand for transport of persons or freight between an origin and a destination location, agents must settle for a mode of transport, a period when the transport occurs, and in case of road transport, the type of road to use. These choices depend on agents' preferences, relative costs of the alternatives, and other characteristics. The way in which we can simulate this decision process in future years depends on the available information accessible to observation in the reference year.

To follow up on the approach taken for transport demand hereabove, we seek to identify some drivers of agents' modal and time choice, and a model to link these drivers and the corresponding modal and time repartition of the transport demand. Obviously, the monetary cost of alternative modes or periods for a given transport demand, as well as the duration of the transport, will be driving the choice among alternative modes and periods. We use the notion of generalised cost throughout the model, and hence stick with it here as well. Time is monetised according to an estimated value of time, and this time cost is added to the monetary cost to obtain the generalised cost of transport for a given O/D pair, mode of transport, and period (peak or off-peak).

Other characteristics than costs weigh in the decision between alternatives. Ability to accommodate large cargo, or to perform door-to-door delivery in urban areas; ease of parking at the destination point, or accessibility to the nearest train station; these and numerous other aspects play a role in the decision process, but are not directly observed in the reference year or available as well-defined variables in projection. We have eventually to rely on the generalised cost as sole driver of the evolutions of choice between alternative modes and periods of transport. We do however observe the relative share of each mode and period in the reference year, together with their relative cost. These market shares contain valuable information on those unobserved drivers of choice, that we may exploit through appropriately structuring the information at hand. This requires resorting to the concept of substitution.

For a given motive and O/D pair, different transport modes are more or less substitutes of each other. Intuitively, walking is hardly a substitute for train for travellers from Ostend to Namur, but bicycle is a good substitute for bus for a trip within the district of Brussels, and so on. As relative prices between alternative modes change in the future, we expect to see the use of the modes becoming relatively more costly to decline in favour of good substitutes that are becoming relatively cheaper, but not so much in favour of poor substitutes even though they become cheaper also. Our aim is therefore to formalise the link between relative prices (generalised costs of transport) of modal and temporal alternatives, substitutability between alternatives, and observed market shares of these alternatives in the reference year, in such a way that we then can predict future market shares under the hypothesis that only relative prices change.

Before providing details of this approach, we discuss in the following section the structure we set up to organise modes, periods, and possibly road types, such that we always only need to compare two alternatives at a time.

3.3.1. Nested structure of alternative modes and periods of transport

Typically, mathematical modelling of choice between discrete alternatives like transport modes is done making hypothesis that may have unacceptable consequences if the framework is not correctly specified. Some of these damaging consequences can be avoided if one describes the choice set of the agents not as a structureless set of all alternatives, but rather as a nested structure where alternatives with most similar unobserved properties[36] are grouped first. Then such formed groups with most similar unobserved properties are again grouped, and so on until a final group containing all alternatives is obtained. We therefore devise nested structures for our choice sets that strive to combine, step by step, the closest (groups of) alternatives. These structures are national and identical for all motives (passengers) or products (freight). As such they represent averages, and in specific situations might appear less relevant than other possible ways to combine alternatives. This is a limitation of the macroscopic nature of the model.

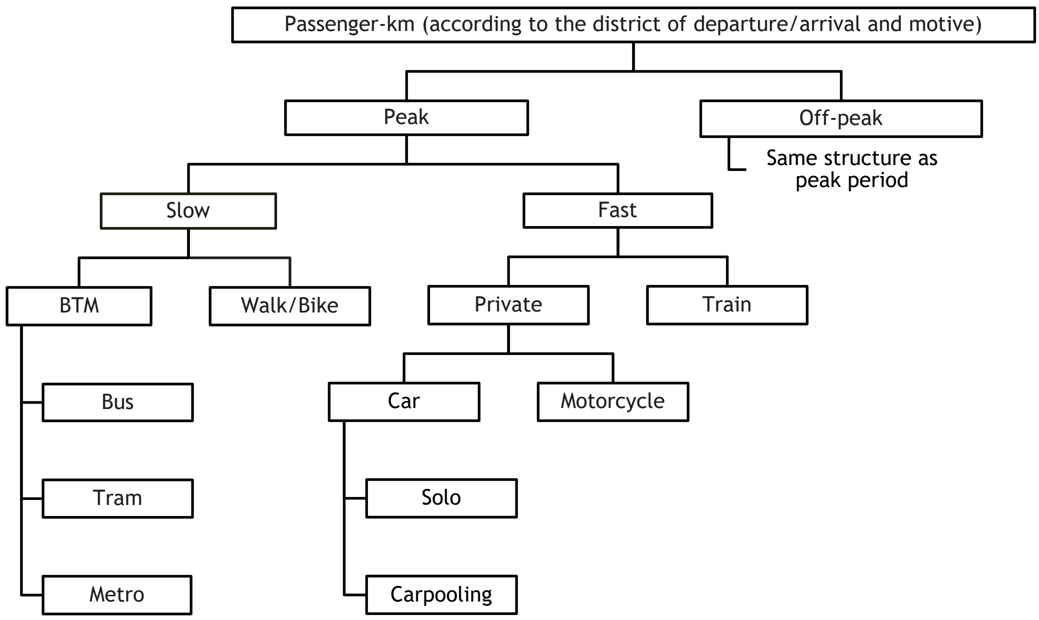
[36] Except for the measured property: generalised cost.

a. Passengers

Graph 6 presents the nesting structure selected for the modal and time choice in the case of passenger transport. The choice of type of road for transport by car does not appear on this tree. It would be located at the bottom of the tree, within each of the "car solo" and "carpooling" sets.

This structure implies that an alternative mode is considered a more relevant substitute than an alternative period of transport on average in the model.

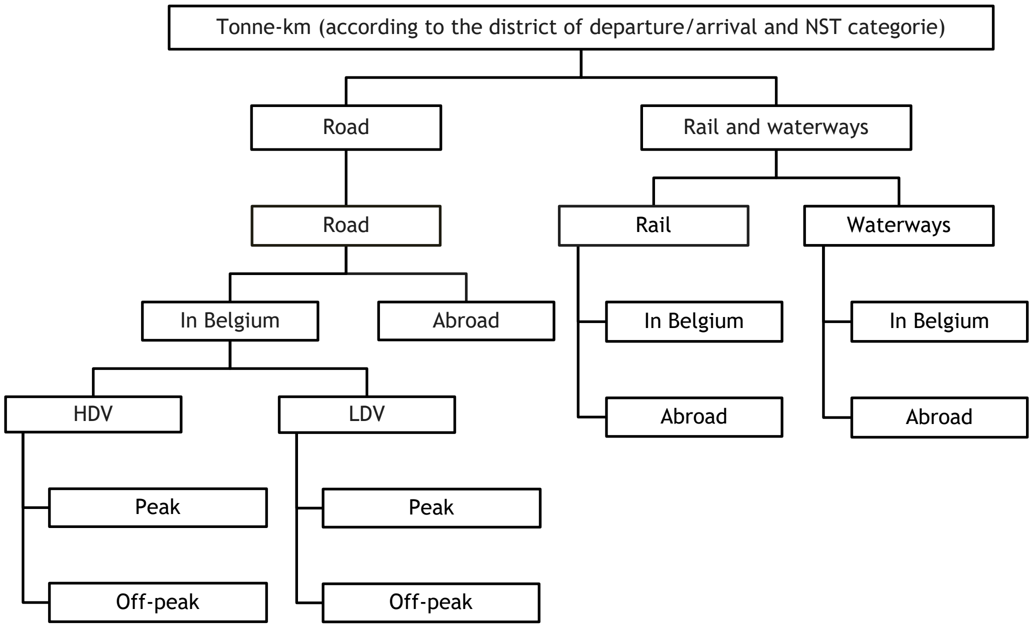
Graph 6 Modal and time choice for passenger transport: nested structure



b. Freight

As opposed to passengers, the structure chosen for freight transport makes of alternative period of travel the first choice, before a change in mode (Graph 7).

Graph 7 Modal and time choice for freight transport: nested structure



3.3.2. CES utility and derived demand and market shares

Without delving into technicalities, we briefly detour through the consumer choice theory to set up the relevant formal framework. We are looking for a formal representation of the decision process of the consumer of transport that links relative costs, substitutability, and initial market shares. There are two approaches to such a formalisation. Either one seeks to describe the behaviour of one random consumer, which will choose one alternative among several possible (discrete choice model), and derives shares of the different modes by aggregation; or one tries to describe the aggregate behaviour of a representative agent which allocates its global budget over these several alternatives (representative consumer model) to directly obtain shares by mode. We will here work from the representative agent point of view. This is not a critical choice, as it is a classical result now (see Andersen et al. 1987) that, under reasonable assumptions, both approaches deliver equivalent results (i.e. identical shares for each alternative).

Our representative agent will decide on the shares of kilometres travelled or tonnes shipped with each mode to maximise his well-being (utility) under the constraints that he faces, in our case a generalised cost budget. Note that in our case, total transport demand is fixed, and obtained from the number of trips or tonnes as described above. Hence the decision only relates to shares, not to the total amount of transport. This means that the level of the total budget is less relevant, it only provides a scale to the utility maximisation and does not affect shares.

The form of the utility function is classically chosen as a “Constant Elasticity of Substitution” (CES) function. This means that we work from the hypothesis that substitutability between modes of transport is constant, and especially does not depend on the distance travelled with each mode. Under this hypothesis, the utility function for distances q_x and q_y in two alternative modes having generalised costs respectively p_x and p_y writes:

$$U(q_x, q_x) = A \cdot \left(\alpha^{1/\sigma} \cdot q_x^{(\sigma-1)/\sigma} + (1-\alpha)^{1/\sigma} \cdot q_y^{(\sigma-1)/\sigma}\right)^{\frac{\sigma}{\sigma-1}} \quad (12)$$

With the budget constraint for a budget Y being:

$$Y \geq q_x \cdot p_x + q_y \cdot p_y \quad (13)$$

The parameter σ in the utility function is the elasticity of substitution between the two modes x and y considered in the choice. It represents the amount of change in the relative quantities consumed (km travelled) q_x/q_y given a marginal change in the relative price p_x/p_y. For sigma close to zero, the modes considered are not substitutes for each other: even for large relative price changes, there is little change in the share of each mode in the total travelled. For sigma larger than one on the other hand, even small relative price changes lead to large changes in the share of the different modes in the total, and the modes are good substitutes (or gross substitutes).

The parameter α in the utility function represents all elements other than prices and substitutability that affect the shares of the different modes, that are not explicitly modelled. One may think of it as representing dimensions of quality other than that modelled through the value of time, asymmetric prior knowledge on the alternatives, taste of the consumers of transport services,… Larger values of α correspond to a more desirable alternative x as compared to y.

We work from the hypothesis that these parameters sigma and alpha for each couple of alternatives in the trees depicted above do not change over time. We can hence calibrate the value of these parameters given the observed quantities (q_x,q_y) and costs (p_x,p_y) in the reference year and target own- and cross-price elasticities from the literature, and then use these calibrated parameters in the future to derive shares of x and y for any given evolution of costs p_x and p_y. The estimation of the elasticities of substitution parameters σ would require a large amount of data to be sufficiently reliable. Typically, those are estimated on long-time series of observed prices and quantities. Thus σ, the elasticity of substitution, will be chosen independently of the reference year data, and then α obtained through calculus. The value of σ will be chosen such that key outputs of the resulting model match with well-documented results from the literature.

Standard calculus allows to derive demand for x and y in function of all other parameters as a solution to the utility maximisation problem above:

$$q_x = Y \cdot \frac{\alpha p_x^{-\sigma}}{\alpha p_x^{1-\sigma} + (1-\alpha) p_y^{1-\sigma}} \quad (14)$$

$$q_y = Y \cdot \frac{(1-\alpha) p_y^{-\sigma}}{\alpha p_x^{1-\sigma} + (1-\alpha) p_y^{1-\sigma}} \quad (15)$$

Combining these, we can write parameter alpha as a function of all other quantities:

$$\alpha = \frac{1}{1+\frac{q_x}{q_y}\left(\frac{p_x}{p_y}\right)^{\sigma}} \quad (16)$$

As mentioned earlier, we are not interested in the total budget.

Using the demand functions obtained above, we can write the shares of mode (or time period, or road type) x or y in the total distance simply by setting Y equal to one.

Hence, using formula (*16*) with observed costs and quantities in the reference year, one can compute α. Then in projection, one can from formulas (*14*) and (*15*) retrieve shares for modes x and y given the known values of σ and α, and the projected endogenous costs p_x and p_y.

3.3.3. Calibration process

Following the discussion above, the calibration of the model involves choosing values for the elasticities of substitution σ along the nested modal and temporal alternatives and then computing the values of the corresponding α's based on observed prices and quantities in the reference year using the formulas derived in the previous section. These formulas ensure that quantities theoretically asked in the reference year following this consumer choice model would be equal to those effectively observed.

The choice of value for σ is guided by expert judgement and literature review.

For passenger transport, we strive to reproduce general own-price and cross-price elasticities between modes, as well as diversion factors that are found in the literature. We build on work by Litman (2019) and Dunkerley (2018). These meta-studies survey available work on elasticities and diversion factors estimation for modal alternatives, and provide recommended values for several modes, motives, and types of trips (urban, interurban, national). Using a pragmatic search heuristic, we vary the different substitution elasticities within acceptable ranges to try and reproduce these own- and cross-price elasticities and diversion factors.

In our calibration work, it appeared necessary to allow for a supplementary degree of freedom to ensure a correct reproduction of these stylised elasticities and diversion factors. Indeed, most surveys report "no travel" as an alternative response when intervening on price components of a given transport mode. In other words, increase in prices for a given mode not only triggers a shift to other modes, but also a decrease in total transport demand. The diversion factor provides the share of these different elements: for a given price change in one mode, how much of the decrease in the use of this specific mode is diverted to other modes and how much of this decrease is simply an overall decrease in demand.

This global decrease in demand for a given price increase cannot be modelled using elasticities of substitution only, obviously, and implies the recourse to overall price elasticities of transport demand at the top of the modal and time choice trees presented above. In practice we calibrate a global elasticity to the generalised costs for each motive of transport except "commuting to school" and "commuting to studies" (where they are set to zero). For these two motives, we assume that in a business-as-usual scenario the attendance requirements of educational institutions do not vary, and hence that trip rates remain constant in the future.

Choice between road types and geographical zones is modelled as an additional level in the CES choice tree[37]. Elasticities of substitution were chosen to capture the movements in flows resulting from selected simulations of regional models as closely as possible (see section 3.2.1.d). Crucially, the choice of nests in the choice tree needs to capture the fact that while determining routes, drivers enjoy far more flexibility in choosing between road types than between geographical areas.

As a result of our calibration process, we obtain the following elasticities and diversion factors for passenger transport (Table 14).

Table 14 Demand elasticities and diversion factors for passenger transport (passenger-km)

	Car	Train	BTM	Foot/bike	Total demand
Elasticities					
To fuel price	-0.13	0.24	0.17	0.17	-0.07
To fixed cost	-0.38	0.67	0.58	0.52	-0.21
Price of a BTM ticket	0.01	0.01	-0.30	0.11	-0.00
Price of a train ticket	0.02	-0.27	0.01	0.01	-0.00
Monetary cost of bike use	0.01	0.01	0.05	-0.52	-0.01
Diversion factors					
To fuel price		16%	9%	7%	66%
To fixed cost		15%	9%	7%	67%
Price of a BTM ticket	50%	2%		25%	22%
Price of a train ticket	82%		3%	1%	13%
Monetary cost of bike use	40%	2%	14%		44%

Source: PLANET v4.0
BTM = bus-tram-metro

For freight transport, the same procedure is used. Generalised cost elasticity at the top of the tree is introduced for transit flows only. This leads to the following results (Table 15).

Table 15 Demand elasticities for freight transport

	HDV	LDV	Rail
Elasticity to fuel cost - HDV	-0.07	0.24	0.04
Elasticity to fuel cost - LDV	0.01	-0.15	0.00
Elasticity to cost of rail transport	0.06	0.01	-0.53

Source: PLANET v4.0.

3.4. Projection of the OD matrices

In the previous sections, we described how the OD matrices for the reference year are obtained, how these matrices are linked to key drivers of transport demand, and how modal, time and road choices are modelled using substitution and price elasticities. In the present section, we describe how these elements fit together to produce a year-by-year long-term projection of the transport demand in Belgium.

The projection model is sequential. This means that the definition of the transition step from year t to year $t+1$, the situation in t being known, is sufficient to perform projections at any time horizon. It only

[37] This follows the methodology adopted in the European model TREMOVE, among other.

requires a starting point t_0 and projections of the values taken by exogenous variables for the whole period. We describe such a "one-step-ahead" projection below.

3.4.1. Initialisation of a projection step *t+1*

a. Reference generalised cost

At the beginning of year *t+1*, the reference generalised cost of transport is the average generalised cost across modes and periods recorded in year *t*. It is obtained as the pkm- and tkm-weighted averages of generalised cost of travel from an origin to a destination district, averages being taken across modes of transport, periods, and road types where applicable. This reference generalised cost will be used to compute the impact of generalised costs on trip rates for passengers, and as input to the trip and tonne distribution models (gravity models) described above.

It is needed as these steps are performed before the modal and time choice model is applied. One may interpret this as the fact that, prior to modal and time choice, agents determine their number of trips, tonnes shipped, and destinations based on the average cost observed in the previous period *t*.

b. Reference speed on the road network

The reference speeds at the beginning of projection period *t+1* are the equilibrium speeds obtained in period *t* for all types of roads and geographical zones.

c. Number of persons and tonnes

The number of persons related to transport demand by motive is a direct exogenous input, as discussed in section 3.2.1.a. We therefore have for each origin district the number of persons concerned by each motive for transport in time *t+1*. The total number of tonnes transported by type of flow is also obtained before the projection as seen in section 3.2.2. In the case of tonnes however, only the overall total by flow is known when initialising the projection step *t+1*, as the tonnes lifted by district of origin is in itself a result of the application of the gravity model.

d. Drivers of transport demand

The exogenous data at hand include the value of all transport demand driver variables identified in section 3.2 at time *t+1*. These macroeconomic and socio-demographic variables are inputs to the gravity model for freight transport:

- supply of goods used locally (i.e. goods produced and used in Belgium) in tonnes by district of supply and product type;
- demand for Belgian produced goods in tonnes by district and product type;
- presence of a major seaport by district (constant in the reference scenario);

… and to the models for passenger trip rates:

- population of each district broken down by age class, sex and socio-economic status;
- average household size in persons by district;
- urbanisation index by district;
- average education level by age class and sex, at national level;
- average disposable income by consumption unit in a household by district.

3.4.2. Generation of transport demand in *t+1*

For passenger transport, the trip rates by motive are computed according to the trip rate models and exogenous drivers:

- For the commuting motives, trip rates are initialised at their observed value for the reference year.
- For "other motives", the econometric model estimated on the reference year is used in conjunction with the updated values of the explanatory variables to predict updated trip rates for *t+1*.
- For all motives, elasticity to changes in generalised costs of transport is then applied based on the difference between the reference generalised cost introduced above, and the average generalised cost observed in the reference year. The effective trip rate *eTR* is hence obtained from the computed trip rate *TR* as :

$$eTR_{t+1} = TR_{t+1} \cdot \left(1 + CostElast \cdot \frac{RefGCost_{t+1} - GCost_{t_0}}{GCost_{t_0}}\right) \tag{17}$$

A total demand for trips is computed by multiplying number of persons in *t+1* and trip rates in *t+1* for all motives but "commuting to work". In this latter case, trip rates are applied after the trip distribution occurs.

Transport demand generation for freight happens exogenously, and is described in section 3.2.2.

3.4.3. Distribution of trips and tonnes by origin and destination in *t+1*

a. Passenger transport

Commuting to work

The gravity models $\{A, B, f_k, e\}$ described by equation (*4*) estimated on the reference year data are applied to employees and self-employed using the reference generalised cost for time *t+1* in the estimated cost function.

$$T_{t+1}(o,d) = A(o) \cdot B(d) \cdot f_k\big(aGC_{t+1}(o,d)\big) \cdot e(o,d) \tag{18}$$

This provides a starting OD matrix of persons $T_{t+1}(o,d)$, that then needs to be balanced against the margins for *t+1*. These are known from exogenous socio-demographic projections: the total number of workers residing in each district and the total number of persons employed in each district. This is performed using standard iterative rebalancing procedures. Those allow to produce an OD matrix with exact fixed margins that has the closest possible structure compared to a reference OD matrix. We thus obtain a calibrated OD matrix of persons $_{c}T_{t+1}(o,d)$.

The trip rates from the reference year per age class, sex, status and region of domicile are applied for each OD pair, as well as the impact of the increase in generalised cost, to obtain the effective number of trips per OD pair eT_{t+1} :

$$eT_{t+1}(o,d) = TR_{t_0} \cdot \left(1 + CostElast \cdot \frac{RefGCost_{t+1} - GCost_{t_0}}{GCost_{t_0}}\right) \cdot cT_{t+1}(o,d) \tag{19}$$

Other transport motives

For "other motives", the trip demand originating in each district computed for time *t+1* is distributed across the origin and neighbouring districts according to the same key as the one computed for the reference year.

For "commuting to studies", the number of students with destination in each district is computed by applying to the situation observed in the reference year the growth in total number of students relative to the reference year to each destination district. The origin and destination are matched using iterative rebalancing techniques with these margins, and the reference year OD matrix as reference.

For "commuting to school", we assumed that change in schooling offer in each district would follow the change in school-aged population of the district. Hence the number of pupils with destination in each district is the sum of the number observed in the reference year t_0 and the absolute difference in the school-aged population of this district between *t+1* and the reference year. As a consequence, the OD matrix evolution over time happens only for intra-district, or diagonal, elements. The OD matrix for *t+1* is then obtained as the OD matrix for the reference year corrected on the diagonal elements so that the row totals equate to the districts school-aged population in *t+1* taken from the exogenous population projections.

b. Freight transport

For freight transport, gravity models per product p determine the domestic flows $T_{p,t+1}$ between districts based on exogenous explanatory variables :

$$T_{p,t+1}(o,d) = \text{Exp}\left[\left(\beta_{p,1} + \beta_{p,3} \cdot Port(o)\right) \cdot ln\left(Supply_{p,t+1}(o)\right) + \left(\beta_{p,2} + \beta_{p,4} \cdot Port(d)\right) \cdot ln\left(Demand_{p,t+1}(d)\right) + \beta_{p,5} \cdot Port(o) + \beta_{p,6} \cdot Port(d) + \beta_{p,7} \cdot I(o=d) + \beta_{p,8} \cdot ln\left(aGC_{p,t+1}(o,d)\right) + \varepsilon_{p,o,d}\right] \tag{20}$$

Table 16 Parameter description for the freight gravity model

Parameter	Description
$\beta_{p,0}$	Intercept
$\beta_{p,1}$	Supply index parameter for product p in district o
$\beta_{p,2}$	Use index parameter for product p in district d
$\beta_{p,3}$	Correction of supply index parameter when district o contains a major seaport
$\beta_{p,4}$	Correction of use index parameter when district d contains a major seaport
$\beta_{p,5}$	Correction of the intercept when district o contains a seaport
$\beta_{p,6}$	Correction of the intercept when district d contains a seaport
$\beta_{p,7}$	Correction of the intercept when the flow is intra-district (d=o)
$\beta_{p,8}$	Exponent of the generalised cost

These flows are then scaled to ensure that for each product the resulting total of domestic flows is equal to the total domestic transport demand computed from macroeconomic drivers (see section 3.2.2).

For inflows and outflows, the flows in the reference year t_0 are upscaled according to the growth rate of the total outflows and inflows computed in the transport generation step based on macroeconomic drivers. To obtain transit flows for time *t+1* the reference year transit flows are upscaled according to the average growth rate of inflows and outflows.

3.4.4. Modal and time distribution by determination of an equilibrium speed in *t+1*

Having produced OD matrices of trips and tonnes for *t+1*, these need then to be split according to transport mode, period, and type of road for road transport. The modal and time choice model presented above depends on generalised costs. These are endogenous for road transport, as time costs depend on speed, which in turn depends on the total demand for road transport. The final modal and time distribution of transport demand is therefore obtained as an equilibrium, that results from the following simultaneous effects:

- Changes in speed on the road network translate into changes in time costs which influence the demand for road transport;
- Changes in demand for road transport translate into changes in road congestion which influence the speed on the road network.

An equilibrium speed has to be computed, which is the speed such that the demand for road transport corresponding to this speed entails road congestion leading to this same speed on the network. Concretely, this equilibrium speed is found as the outcome of an iterative process:

i. Initialise the tentative speed tS_k, $k=0$, as the reference speed retained from year *t;*

ii. Compute the generalised costs GC_k based on tS_k;

iii. Derive demand from road transport D_k based on GC_k using the modal and time choice model;

iv. Compute a resulting speed rS_k determined by the road congestion corresponding to demand D_k using speed-flow relationships;

v. Compare tS_k and rS_k:

– If they are equal (or close enough), we have found an equilibrium speed. End the process: the speed for $t+1$ is taken equal to tS_k.

– If they are not equal, tS_k is not an equilibrium speed. If for example $tS_k < rS_k$, the tentative speed has been set too low. For this tentative speed, time costs are high, and therefore demand low, so that congestion is low and the resulting speed rS_k is high, higher than tS_k. The situation is incoherent: we made the hypothesis that the speed was tS_k, and as a result from the model computations, we obtain that the speed is $rS_k > tS_k$. This is not an equilibrium. Thus we make a new guess by resetting the tentative speed tS_k+1 as a compromise between tS_k and rS_k (for example $tS_{k+1}=0.5\cdot(tS_k+rS_k)$), set $k=k+1$, and iterate the process from ii.

Applying all previous steps starting from $t=t_0$, one iteratively builds year by year projections for all OD matrices identified as the core output of the PLANET model in the first part of this paper. The horizon of such a projection model is freely adaptable and only limited technically by the availability of exogenous variables in projection. Of course, some hypothesis and modelling choices are related to a given time horizon, in our case twenty-five years, and the outputs for this time period are the more relevant.

4. Projection outputs and further results

The core output of the PLANET model consists in four sets of district-to-district OD matrices, organised along several dimensions:

- OD matrices of passenger trips in Belgium (by motive of transport);
- OD matrices of passenger-kilometres on the Belgian territory (by motive of transport, mode, time period, and where applicable type of road);
- OD matrices of tonnes in Belgium (by type of flow, product, mode, time period, and where applicable type of road);
- OD matrices of tonne-kilometres on the Belgian territory (by type of flow, product, mode, time period, and where applicable type of road).

In addition to these core outputs, the model produces projected series of average road speeds by road type, geographic zone and period, as well as the number of vehicle-kilometres by type of vehicle (cars, LDV, HDV, bus,...). These additional outputs are the foundation for ex post computations of indicators in the fields of congestion, emissions, and other externalities.

The set of results obtained from the model and calibration described in the preceding chapters forms the reference scenario of our transport demand projections. Using alternative hypothesis, one can simulate alternative policy scenarios with the same model. Outputs from these alternative scenarios can then be evaluated against the results of the reference scenario.

This last chapter provides examples of the different kinds of outputs PLANET can produce and their typical uses.

4.1. Core outputs

The projection outputs make a coherent set of results along several dimensions. Geographical, time, and modal dimensions share common definitions and granularity between motives of transport, passenger and freight transport, type of flows… This allows general macroscopic conclusions to be derived as well as more detailed or localised analysis to be led.

Table 17 provides an example of the first case. The evolution of broad characteristics of passenger transport is displayed, providing an overview of the evolution of global demand (number of trips) and its average geographic attributes (distance, share of trips leaving the district of origin). This type of result is well suited to the study of transport demand as a global socio-economic phenomenon. The same can be said of Table 18, in this case for freight transport. The global evolution of freight transport volumes by type of flow and mode of transport links easily to macroeconomic effects, allowing to devise the impact of economic developments on physical flows of goods and their main characteristics.

Table 17 Average trip distance, and share of inter-district trips

	Number of trips (billions per year)			Average distance (km)			Share of inter-district trips	
	2015	2040	2040/2015	2015	2040	2040/2015	2015	2040
Total	10.3	11.3	9.5%	14.6	14.6	0.3%	79.9%	79.7%
Commuting to work	1.9	2.0	4.9%	20.9	21.3	2.3%	61.8%	60.7%
Commuting to school	0.8	0.9	10.6%	7.6	7.5	-1.3%	86.9%	87.1%
Commuting to studies	0.1	0.1	11.2%	29.7	28.6	-3.8%	48.9%	50.8%
Business	0.2	0.2	4.0%	55.9	56.0	0.1%	67.3%	67.5%
Other: depending on revenues	3.8	4.6	20.7%	12.0	12.2	1.1%	83.2%	82.8%
Other: not depending on revenues	3.5	3.5	0.0%	12.8	13.0	1.3%	84.4%	84.0%

Source: PLANET v4.0.

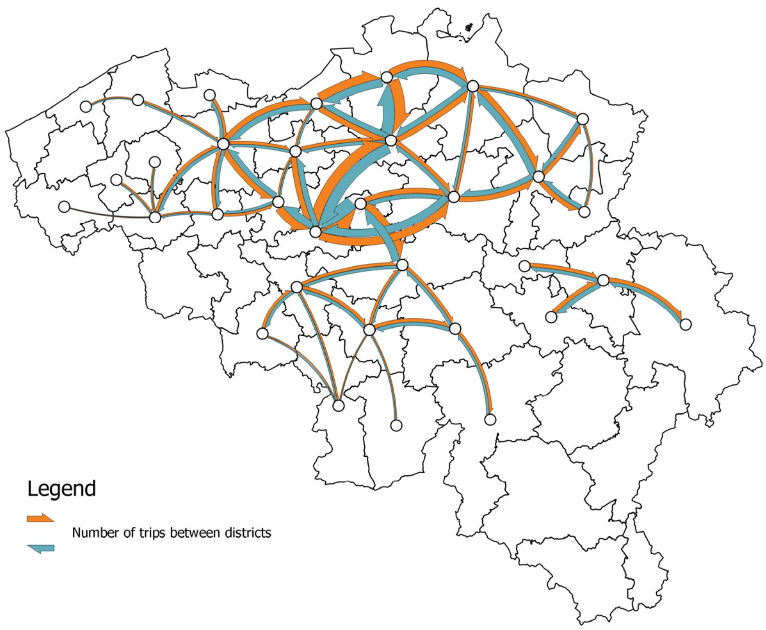
Table 18 Evolution of transported tonnes by mode of transport
Millions of tonnes

		2015		2040		Cumulative growth
Type of Flow	Mode	Tonnes	Shares	Tonnes	Shares	2040/2015
Domestic	HDV	227	79%	235	77%	3%
	LDV	9	3%	10	3%	14%
	Rail	8	3%	9	3%	11%
	Inland waterways	45	16%	50	16%	10%
Outflow	HDV	91	45%	118	44%	30%
	Rail	16	8%	23	9%	46%
	Inland waterways	51	25%	65	25%	28%
	Short Sea Shipping	44	22%	60	23%	36%
Inflow	HDV	80	36%	115	35%	44%
	Rail	14	6%	27	8%	92%
	Inland waterways	76	35%	118	36%	55%
	Short Sea Shipping	50	23%	69	21%	37%
Total (Transit incl.)	HDV	467	57%	543	52%	16%
	LDV	9	1%	10	1%	14%
	Rail	60	7%	98	9%	62%
	Inland waterways	185	23%	255	25%	38%
	Short Sea Shipping	95	12%	129	12%	36%

Source: PLANET v4.0.

At an intermediary level of detail, the full disaggregation of results by district allows the representation and analysis of the geographical spread of some key indicators of transport. Map 11 provides an example of this nature, where the evolution of long distance (inter-district) passenger flows are displayed in a visually compelling way. The main geographical areas of passenger traffic development are easily identifiable, and the geographical differences within Belgium are clearly apparent.

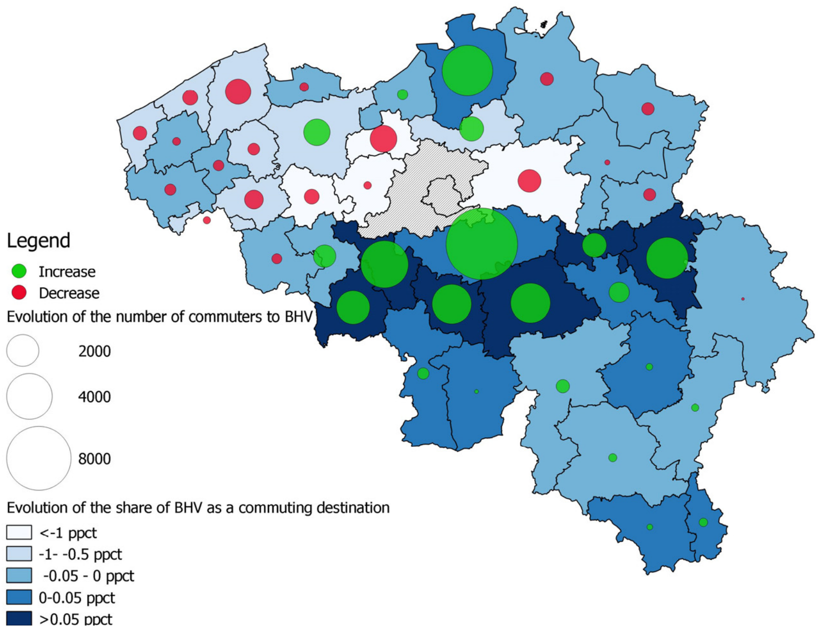
Map 11 Evolution of the 100 largest inter-district flows between 2015 and 2040, all transport motives



Source: PLANET V4.0

The full level of detail in terms of transport characteristics can also be mobilised to allow more in-depth analysis of a specific topic. Map 12 and Map 13 provide examples for passenger and freight transport respectively. The first map presents the evolution of the main work commuting flows to the broad employment centre of Brussels, detailing this evolution by district of origin both in absolute terms, and as a change in share of the overall local workforce.

Map 12 Evolution of the number of commuters to the districts of Bruxelles and Hal-Vilvorde, and of their share in the working population of the district of residence (2015-2040)

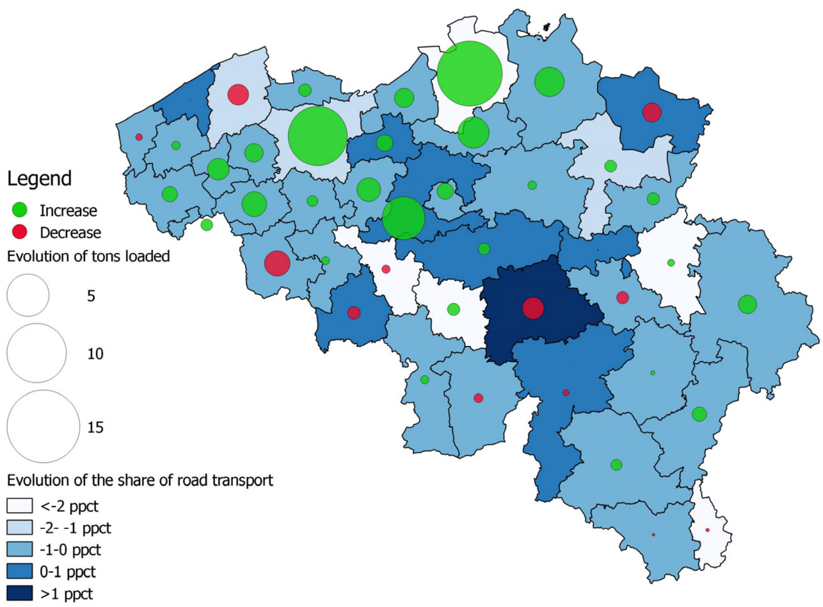


Source: PLANET V4.0.
ppct = percentage points.

The second map details the evolution of tonnes loaded per district, together with the change in share of the transport by road for these loads.

These are only few examples of the amount of information available and possible representations and level of analysis with the direct outputs of the PLANET projection.

Map 13 Evolution of domestic freight transport (2015-2040): variation in tonnes loaded in the Belgian districts (in thousands per day) and of the share of road transport (in percentage points)



Source: PLANET V4.0
ppct = percentage points.

4.2. Ex post calculations

Ex post calculations consist mainly in studying the negative impact of transport demand on emissions and road congestion, as well as computing the external costs associated with them. These are evaluated through *marginal* external cost.

Noise pollution and accidents are not covered in the current version of the model.

4.2.1. Road congestion

Road congestion can be defined as the situation when traffic is moving at speeds below the designed capacity of a roadway. It implies longer travel times and as a result increased generalised cost of transport. Under our fixed infrastructure hypothesis, an increase in demand for road transport implies congestion or increased congestion on the road network. A typical output of the model is displayed in Table 19 which presents the increase in road transport demand – in vehicle-kilometres – detailed by source of the demand (passenger or freight transport), type of road and time period.

Table 19 Distribution of vehicle-kilometres by type of transport, period and type of road

	2015		2040		Cumulative growth
	vkm	Share	vkm	Share	2040/2015
Passengers	89.6	90%	99.7	89%	11%
Peak hours	26.4	26%	28.1	25%	7%
Highways & toll roads	14.2	14%	15.3	14%	8%
Other roads	12.2	12%	12.8	11%	5%
Off-peak hours	63.2	63%	71.6	64%	13%
Highways & toll roads	34.7	35%	40.9	37%	18%
Other roads	28.5	29%	30.7	27%	7%
Freight	10.3	10%	12.3	11%	19%
Peak hours	2.7	3%	3.2	3%	18%
Highways & toll roads	2.0	2%	2.3	2%	14%
Other roads	0.7	1%	0.9	1%	30%
Off-peak hours	7.6	8%	9.1	8%	19%
Highways & toll roads	5.9	6%	6.1	5%	4%
Other roads	1.8	2%	3.0	3%	70%
Total	99.9	100%	111.9	100%	12%

Source: PLANET V4.0.

The extent of this congestion effect is determined by the speed-flow relationship for the road network considered. In our case, the outputs of PLANET allow to assess the state or evolution of congestion effects in five geographical zones, for three types of road, and two periods of time. The evolution of vehicle-km output from the core of the model translates into an evolution of speed for each element of this 30-some time and space partition. In order to accommodate the different types of vehicles and their respective impact on the road flow, the notion of PCU is used, where:

- a vehicle-km driven by a car counts for 1 PCU-km equivalent;
- a vehicle-km driven by a bike counts for 0.75 PCU-km equivalent;
- a vehicle-km driven by a LDV counts for 1.5 PCU-km equivalent;
- a vehicle-km driven by a HDV counts for 2 PCU-km equivalent;
- a vehicle-km driven by a bus or a tram counts for 2.5 PCU-km equivalent.

Using this equivalence scale, all flows computed in the model can be summed, and, using the calibrated speed-flow relationships, translated in an average speed per geographical zone and road type. Table 20 provides an example of results obtained for measures of congestion in terms of speed.

Table 20 Evolution of key average speed indicators on the road
km/hour

	2015	2040	2040/2015
Belgium, peak hours	70.4	68.5	-2.6%
Belgium, off-peak hours	80.4	78.9	-1.9%
High congestion zones, peak hours	53.6	49.4	-7.8%
High congestion zones, off-peak hours	82.3	77.5	-5.8%

Source: PLANET v4.0.
Note: / = growth rate.

4.2.2. Emissions

Both passenger transport and freight transport have negative effects on the environment. They are evaluated by considering the emissions of the different modes of transport. The emissions volume is computed as the product of transport demand and emission factors, the latter providing the emission volume per unit of transport.

Transport demand has been described extensively in previous chapters. It is taken as a direct input for all modes of transport except car transport. For the latter, the transport demand is associated with the results of the CASMO model to obtain a breakdown of the vehicle-km driven by type of engine, size and Euro standard. This breakdown coincides with the level of detail provided for the emission factors at our disposal, and thus permits a more refined estimation of the emissions related to car use.

Emission factors only appear ex post in the model. They give the emissions of a pollutant per vehicle-kilometre, tonne-kilometre or passenger-kilometre, depending on the mode of transport studied. These factors are estimated for the reference year and vary over time, based on several sources (VITO, Vlaamse Milieumaatschappij (VMM), Infrabel, STREAM studies (CE Delft)).

Three types of emissions are covered in PLANET:

– *Direct emissions*

  Direct emissions, also called "Tank-to-Wheel" emissions, emanate from the combustion of the fuels used by the means of transport. Two local pollutants are studied: nitrogen oxides (NO_x) and particulate matter ($PM_{2.5}$); as well as three greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Graph 8 displays the evolution of direct greenhouse gas emissions, by mode and source, as an example.

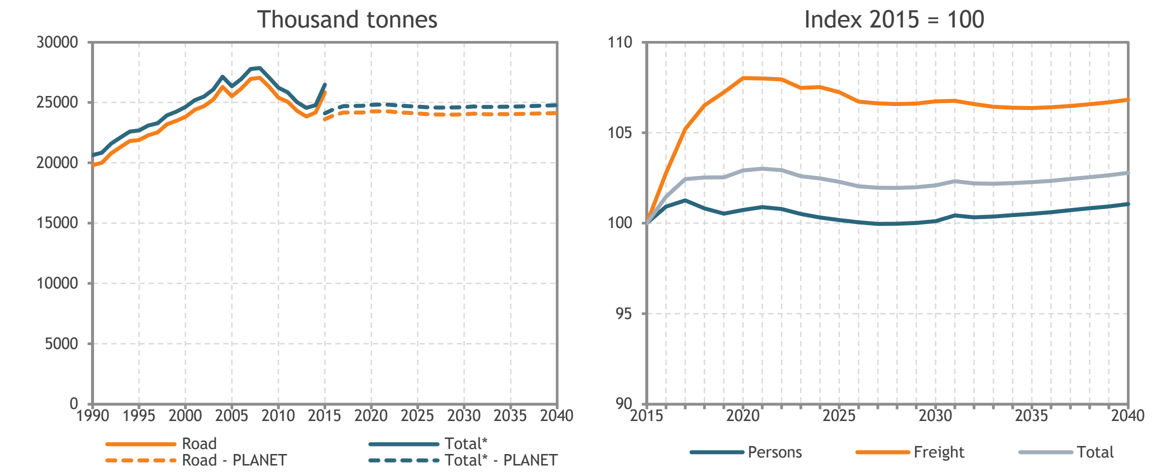
– *Indirect emissions*

  Two categories are covered here. On the one hand, the so-called "Well-to-Tank" emissions, which are released during the production and transport of (bio) fuels and during the production of electricity. And, on the other hand, emissions related to Indirect Land Use Change (ILUC), which are caused by the release of more land to produce the food crops needed to biofuel production.

– *Non-exhaust emissions*

Non-exhaust emissions come from the wear of materials such as tyres, wheels, brakes, but also the wear of road, tracks and electric cables.

Graph 8 Evolution of direct greenhouse gas emissions (road, rail, inland waterways)
In CO_2 equivalent



Sources: Transport database (FPB), PLANET v4.0.
* Total = road, railway and waterways (inland and SSS) between 1990 and 2015. Road, railway and inland waterways in projection.

4.2.3. Marginal external costs

Marginal external costs measure, in monetary terms, the damage borne by society of one extra unit of transport, which is not supported directly by the user (additional pollution, time losses for the other users,...). They are particularly relevant to determine the optimal level of taxation to internalise external costs associated with air pollution and/or congestion.

Several studies based on PLANET give practical applications of this concept to transport taxation in Belgium: fuel excise reform (Van Steenbergen (2015)), company cars (Laine and Van Steenbergen (2016a and 2017)), commuting subsidies (Laine and Van Steenbergen (2016b)), traffic taxation (Hoornaert and Van Steenbergen (2019)).

As an example, combining the effects of the road flow on road speed with values of time from section 3.2.1.d, we can calculate the resulting marginal external congestion costs. These are shown in the table below, alongside the distribution of yearly kilometres driven across time and space. Table 21 gives a feel of the concentration of congestion costs in several defined areas, at certain time periods only.

Table 21 Marginal External Congestion Costs - passenger car (2015)
Euro2015 per vkm - (% of total kilometres driven)

	Highways	Tolled roads other than highways	Other roads
Peak			
Brussels Capital Region		0.78 (1.7 %)	
Agglomeration REN	0.79 (3.6%)	0.22 (0.9%)	0.15 (3.5%)
Agglomeration Antwerp	0.42 (0.9%)	0.16 (0.2%)	0.26 (0.7%)
Agglomeration Ghent	0.12 (0.4%)	0.06 (0.1%)	0.09 (0.3%)
Rest of Belgium	0.04 (7.8%)	0.03 (3.7%)	0.03 (9.4%)
Off-Peak			
Brussels Capital Region		0.43 (3.1%)	
Agglomeration REN	0.08 (7.6%)	0.03 (1.7 %)	0.03 (6.1%)
Agglomeration Antwerp	0.16 (1.8%)	0.07 (0.3%)	0.10 (1.6%)
Agglomeration Ghent	0.04 (0.9%)	0.02 (0.1%)	0.04 (0.7%)
Rest of Belgium	0.02 (14.7%)	0.01 (8.0%)	0.02 (20.1%)

Source: Hoornaert and Van Steenbergen (2019).

4.3. Alternative scenarios

Once the reference projection is defined, one can simulate alternative scenarios and analyse the effects on the different outputs described above. A broad range of policies can be simulated. Measures can be cost related as well as not cost related. The first are mostly tax and pricing policies, but the value of time, a key factor of the model, can also be subject to change. Not cost related measures can also be introduced in PLANET, such as increasing teleworking or vehicle occupancy rates.

As an example, Table 22 shows the effects on PLANET main outputs of five policy measures. These are mainly tax measures, simulated separately:

- FIXTAX: the abolition of the current annual traffic tax in all three Belgian regions;
- COCA: the abolition of the system of company cars as it exists now;
- CONG: the introduction of kilometre charges, differentiated in space and time, for passenger cars, LDV and HDV, in peak hours;
- ROADPRICE: the introduction of kilometre charges for cars and LDV on the same tax base as currently applicable for HDV, no differentiation according to time periods;
- SUBRAIL: the increase in the operating subsidies of the SNCB corresponding to 10% of the price of a ticket.

Table 22 Examples of measures introduced in PLANET: impact on transport demand, environment, speed and welfare

	Level 2024 (reference scenario)	FIXTAX	COCA	CONG	ROADPRICE	SUBRAIL
Impact on transport demand, environment and speed (%)						
Passenger-km, cars	131.0 bn	+2.4	-3.6	-0.7	-1.3	-0.4
Passenger-km, public transports	20.2 bn	-2.5	+6.7	+1.9	+1.8	+3.7
Tonne-km, freight (road)	71.1 bn	-0.1	+0.2	-0.0	+0.1	+0.0
Speed in peak period, on highways and tolled road other than highways in agglomerations	32 km/h	-1.0	+2.5	+16.6	+2.1	+1.1
Co_2 emissions	29479 ktonnes	+2.0	-2.7	-1.0	-1.1	-0.3
NO_x emissions	48 ktonnes	+1.8	-2.7	-0.9	-1.2	-0.3
$PM_{2.5}$ emissions	4 ktonnes	+1.3	-1.8	-0.8	-0.9	+0.4
Impact on welfare (m. euro)						
Gain in time, passengers		-104.6	+217.1	+378.2	+73.2	+45.7
Gain in time, freight		-46.9	+83.6	+89.3	+58.9	+10.1
Environmental benefits		-57.7	+83.6	+29.6	+35.4	+0.2

Source: FPB (2018) based on PLANET v4.0.

5. Appendix A - Macroeconomic, demographic and socio-demographic projections

The essence of the PLANET model is to translate economic and demographic projections into an anticipated transport demand. As such, inputs for key socio-economic quantities along the timeline of the projection are of special relevance.

In order to compute differentiated trip rates for the six trip purposes, trip origin-destination matrices, as well as freight tonnes transport demand and origin-destination matrices, a series of exogenous projections must be made available to the model core. These cover:

- population by district (by age, sex, and socio-economic position);
- employment by district (by industry, and socio-economic position);
- educational provision by district (by broad level: primary, secondary, superior education);
- production of goods by district, NST product, and place of use (local or exported);
- intermediary consumption and final consumption of goods by district, NST product, and place of supply (locally produced or imported);
- share of re-exports in imported goods by district and NST product.

Additional modelling variables are also made available in projection such as:

- average education level by district, age category and sex;
- average disposable income by MCU[38], by district;
- average urbanisation index by district.

5.1. Population projections

The needed level of details regarding geographical spread and characteristics entails the combined use of several sources to obtain adequate projections. The basis for the projection is the Demographic Perspectives published jointly by the Federal Planning Bureau and Statistics Belgium (BFP & Statbel, 2017). These provide headcounts by district, age and sex for the whole projection period. The information on socio-economic position stems from economic projection exercises led within the FPB. The MALTESE model provides counts by socio-economic position at national level only. The national accounts for the base year (ICN) provide counts by district and socio-economic position. Finally, the decennial micro-census of 2011 provides share of students by sex and age classes for each NUTS2 Province. Combining these sources, we obtain by means of an iterative use of the proportional rebalancing method (RAS) year after year, projections for the population by district, sex, age and socio-economic position.

[38] Modified Consumer Unit, see chapter 5.6

5.2. Employment projections

Employment counts by district, industry, and distinction between employed and self-employed are available for the reference year in the national accounts (ICN). Extensive use of past versions of these accounts allows us to reconstruct an historical series beginning in 1986 for the employment count by district, branch and split employed/self-employed. To make these variables available in projection, we make use of the macro-sectoral models HERMES and HERMREG, which provide counts by NUTS 1 region, industry, and split employed/self-employed up to 2023, and then of the MALTESE model, which provides employed and self-employed totals at national level for the sum of all industry, over the whole projection period.

The following steps allow to obtain the desired projection:

- Using exponential smoothing methods, the shares of each industry in the total of employment are forecast from 2024 until 2040, based on the data available from 1986 to 2023. This is done separately for employed and self-employed workers. Applied to the employment total from MALTESE, these yield **national employed and self-employed counts by industry** from 2024 to 2040. These counts are already available between 1986 and 2023.
- To obtain total employment counts by district, we fit a panel regression model to a series of potential labour force by district and a series of industry mix deducted employment on the period 1986-2015.
  - The potential labour force is computed as the local district resident labour force series adjusted for commuting flows from and to other districts, as deducted from coefficients computed on the observed flows in the base year.
  - The industry-mix deducted employment is defined, per district, as the sum over all industries of the employment by industry, observed at the beginning of the series (1986) and then obtained year after year by applying common known national employment growth factors by industry (cf. supra) to all districts, until the end of the projection period.
  - A panel regression model for district total employment is fitted on the potential labour force and the industry-mix labour series for all observed districts and years (1986-2015), and then used to forecast **district total employment** between 2016 and 2040.
- Using these projections of **national employment by industry** and **total employment per district,** together with the known **reference year employment by district and industry**, we obtain by means of an iterative use of the proportional rebalancing method (RAS) year after year, projections for the employment by district, industry and split in employed/self-employed workers.

Being computed from the same sources, these population series and employment series are coherent and sum up to the same totals where relevant.

5.3. Educational provision

The educational provision by districts and education level is known for the reference year by means of statistics provided by the French and Dutch speaking communities of Belgium.

As, seen at the level of districts, basic education is a very local activity, the evolution of basic educational provision by district is assumed to follow the evolution of the basic educational demand by district. In other words, we assume that, in each district, the quantity of schooling offer increases or decreases by exactly the same amount as the total of the school-age population of the district. Under this hypothesis, future commuting flows for schooling are obtained as the matrix of commuting flows for the base year, with a diagonal adjusted so that the flows sum up by row to the school-age population of each district.

For superior education, we make the hypothesis that the superior education centres in Belgium remain as they are in number and relative size, so that the educational offer in projection by district is equal to the offer measured in the base year adjusted by the growth of national total superior educational demand.

5.4. Supply and use of goods

The demand for freight transport is derived from the need to move produced or imported goods, from their place of supply to their place of use. A first step in estimating such a demand, is to obtain detailed economic quantities related to the supply and use of goods. For PLANET, detailed information on supply and use of twelve categories of goods along the NST classification is required, with for each district information over local (produced) supply, imported supply, local use or use abroad (export). The different steps followed to obtain these are described in section 3.2.2.a.

5.5. Education level by district, age category and sex

Someone's education level is an important determinant of transport demand, as it shows a good correlation to trip rates for "other motives". As such it is used as an explanatory variable in the trip rate models. In order to do so, projections of the average education level by district must be available.

The education level is measured on the International Standard Classification of Education (ISCED) scale, and aggregated in three classes for our purposes:

- Primary education (coded 1): persons not having completed the secondary school
- Secondary education (coded 2): persons having completed the secondary school, but with no superior education
- Tertiary education (coded 3): persons having completed a curriculum in superior education

These classes are attributed values 1, 2 and 3 respectively, in order to be able to compute averages. This is a simplifying assumption, that implies that the effect of education is monotonous on the trip rates, and linear. For the reference year, the Labor Force Survey allows to estimate an education level index for six age classes[39] by sex at the national level. This index is simply the average of the attributed class of education values over the persons in a given age band and sex category.

Projections rely on the projections by CEDEFOP ("Skills Forecast") that provide for the whole of Belgium projections of the number of persons by education level, age class and sex. Aggregating these data into ISCED classes and age bands described above, one derives projections for a national education index by age class and sex. These need to be extended to our projection horizon, using trend analysis. Finally, this projection is calibrated to the observations in the reference year.

5.6. Disposable income by MCU, by district

Disposable income by (modified) consumption unit (MCU) is a key notion when the link between income and transport demand is considered. It is the disposable income by weighted individual in a household, with the first adult having a weight of 1, additional persons aged more than 13 having a weight of 0.5, and other children a weight of 0.3. Hence a household composed of two adult parents, a child aged 15 and two other children aged 12 and 8 would have a total weight of 1+0.5+0.5+0.3+0.3=2.6. The disposable income by MCU for this household would be the total disposable income of the household divided by 2.6. This notion of "weighted per capita income" is a standard in the welfare literature.

To obtain an average value of disposable income by MCU for each district in projection, one relies on demographic and household income projections. More precisely:

– The total number of MCU by district is obtained from population projections by age and household size projection, found in the Demographic Projection (BFP & Statbel, 2017);

$$MCU_t^d = \#household_t^d + 0.5 \cdot (\#(persons\ aged > 13)_t^d - \#household_t^d) + 0.3 \cdot \#(persons\ aged < 14)_t^d \quad (21)$$

– The total disposable income by district is observed from the regional accounts up to the reference year (ICN);

– Total disposable income by region is projected on a medium-term horizon in the HERMREG model.

Based on these sources, the following steps are performed:

– All disposable income quantities are expressed by MCU based on observed and projected numbers of MCU by district and region.

– Regional projection of disposable income by MCU from HERMREG are augmented up to our projection horizon. To do this, the annual growth rate of the disposable income by MCU in our final projection year (2040) is set to the long term observed average growth rate on the observations (1995-2015) for each region, and a linear interpolation of the growth rate between the last year of HERMREG projection and this final horizon is performed.

– The growth rates of the disposable income by MCU by district after the last observation in the reference year are estimated using an intra-regional convergence hypothesis : in any projection year *t* the

[39] The classes are : (0-14, 15-19, 20-34, 35-49, 50-64, 65+). The Labour Force Survey does not cover the class (0-14), but any person in this class would only have a primary education level by definition.

growth rate for a given district d is taken as the growth rate for the region R it belongs to summed with 90% of the difference between the district's and the region's growth rates for the preceding ten years period.

$$r_t^d = r_t^{R,d\in R} + 0.9 \cdot \frac{\sum_{s=t-10}^{t-1}\left(r_s^d - r_s^{R,d\in R}\right)}{10} \tag{22}$$

– Using these growth rates, disposable income by MCU in each region and district are projected starting from the observed value in the reference year.

– Using projection of MCUs, the quantities are translated into total disposable income by district and region. This allows to calibrate district-level projections so that their total matches with regional projections. This ensure consistency between our projections and HERMREG.

– These calibrated total disposable incomes by district are divided again by the number of MCU projected by district to obtain a final version of projected disposable income by MCU for each district.

5.7. Urbanisation index by district

The classification of Belgian municipalities defined by Luyten & Van Hecke (2007) provides a useful measurement of the degree of urbanisation to be linked with transport demand. Each municipality is classified into one of four categories based on characteristics measured during the 2001 census:

- Agglomeration (the more urban), that we associate with an index 0
- Suburban, that we associate with an index 1
- Alternating migration zone, that we associate with an index 2
- Rural (the least urban), that we associate with an index 3

An average urbanisation index is computed in the reference year for each district by averaging over all municipalities in the district the aforementioned urbanisation index taking municipalities' population as weights. In the baseline scenario, this urbanisation index is fixed. In future developments, municipal population projections could be taken into account to modulate the average index by district in the projection.

6. Appendix B – CASMO model

The approach to the Belgian CAr Stock MOdel (CASMO) is described extensively in Franckx (2019).

It can be summarised as follows:

- The total desired car stock is determined by the country's population and GDP per capita. The relation between these variables is based on findings from the international literature.
- For each vintage in each car class[40], the probability that a car is scrapped in the current year is estimated as a function of its age and accumulated mileage (survival model). This determines the remaining car stock.
- The desired car stock is then confronted with the remaining car stock to determine total car purchases in a given year.
- A calibrated multinomial logit model (MNL) then splits these new purchases according to the different car classes. The detailed vehicle type-size inventory is then mapped into a new inventory that is aggregated according to the EURO emission class to which the cars belong. This is fed back to the PLANET model, and, combined with an estimate of annual mileage, results in an assessment of environmental impacts.

40 Cars are grouped according to their COPERT emission class, which is determined by fuel and size. COPERT is a computer simulation programme used for the calculation of air pollutant emissions from road transport, whose technical development has been financed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change. It is used as an input in official annual national inventories (see Emissia 2018).

7. Appendix C – NUTS classification

Table 23 List of Belgian districts ("arrondissements")

NUTS 1	Code	NUTS 2	Code	NUTS 3	Code
Brussels	BE1	Brussels	BE10	District of Brussels-Capital	BE100
Flanders	BE2	Antwerp	BE21	District of Antwerp	BE211
				District of Mechelen	BE212
				District of Turnhout	BE213
		Limburg	BE22	District of Hasselt	BE221
				District of Maaseik	BE222
				District of Tongeren	BE223
		East Flanders	BE23	District of Aalst	BE231
				District of Dendermonde	BE232
				District of Eeklo	BE233
				District of Ghent	BE234
				District of Oudenaarde	BE235
				District of Sint-Niklaas	BE236
		Flemish Brabant	BE24	District of Halle-Vilvoorde	BE241
				District of Leuven	BE242
		West Flanders	BE25	District of Bruges	BE251
				District of Diksmuide	BE252
				District of Ypres	BE253
				District of Kortrijk	BE254
				District of Ostend	BE255
				District of Roeselare	BE256
				District of Tielt	BE257
				District of Veurne	BE258
Région wallonne	BE3	Walloon Brabant	BE31	District of Nivelles	BE310
		Hainaut	BE32	District of Ath	BE321
				District of Charleroi	BE322
				District of Mons	BE323
				District of Mouscron	BE324
				District of Soignies	BE325
				District of Thuin	BE326
				District of Tournai	BE327
		Liège	BE33	District of Huy	BE331
				District of Liège	BE332
				District of Waremme	BE334
				District of Verviers, municipalities of the French Community	BE335
				District of Verviers, municipalities of the German Community	BE336
		Luxembourg	BE34	District of Arlon	BE341
				District of Bastogne	BE342
				District of Marche-en-Famenne	BE343
				District of Neufchâteau	BE344
				District of Virton	BE345
		Namur	BE35	District of Dinant	BE351
				District of Namur	BE352
				District of Philippeville	BE353

Source: EUROSTAT.

8. Appendix D – Standard goods classification for transport statistics (NST)

Table 24 NST 2007 classification regrouped for use in the PLANET model

Code PLANET	Code NST 2007	Description
NST1	NST1	Products of agriculture, hunting, and forestry; fish and other fishing products
NST2	NST2	Coal and lignite; crude petroleum and natural gas
NST3	NST3	Metal ores and other mining and quarrying products; peat; uranium and thorium
NST4	NST4	Food products, beverages and tobacco
NST7	NST7	Coke and refined petroleum products
NST8	NST8	Chemicals, chemical products, and man-made fibers; rubber and plastic products; nuclear fuel
NST9	NST9	Other non metallic mineral products
NST10	NST10	Basic metals; fabricated metal products, except machinery and equipment
NST12	NST12	Transport equipment
NSTOTH	NST5	Textiles and textile products; leather and leather products
NSTOTH	NST6	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter and recorded media
NSTOTH	NST11	Machinery and equipment n.e.c.; office machinery and computers; electrical machinery and apparatus n.e.c.; radio, television and communication equipment and apparatus; medical, precision and optical instruments; watches and clocks
NSTOTH	NST13	Furniture; other manufactured goods n.e.c.
NST42	NST14	Secondary raw materials; municipal wastes and other wastes
NST42	NST15	Mail, parcels
NST42	NST16	Equipment and material utilized in the transport of goods
NST42	NST17	Goods moved in the course of household and office removals; baggage and articles accompanying travellers; motor vehicles being moved for repair; other non market goods n.e.c.
NST42	NST18	Grouped goods: a mixture of types of goods which are transported together
NST42	NST19	Unidentifiable goods: goods which for any reason cannot be identified and therefore can-not be assigned to groups 01-16
NST42	NST20	Other goods n.e.c.

n.e.c.: not elsewhere classified.

9. Appendix E – Determining the subcategories for “other motives”

Trips for motives other than commuting counted for 73% of the trips in 2015 (FPB and SPF M&T, 2019). They are very heterogenous and likely to react differently to contextual changes. They were thus split into three distinct categories, based on Beldam survey data (2010). This allows us to better identify the determinants of the evolution of this type of trips, thereby improving the quality of the associated projection, as well as the possibilities of associated analyses.

This appendix describes the way these three categories were determined and how their respective trip rates were estimated. The first category is related to business trips. The other two are related to private trips, differentiated according to the sensitivity of individual behaviour to income.

The source chosen is the BELDAM survey (2010), since it is the only source covering the entire Belgian territory and containing the information required for our use. It provides, for each respondent over 6 years old, a travel log in which all trips made during a randomly selected day are recorded. It includes the departure and arrival times, the modes of transport taken, and the distances travelled, in chronological order. The respondent can choose among several “motives” for travelling when completing his travel log:

1. Drop off/pick someone up;
2. Go home;
3. Go to work;
4. For work (if tours, number: ... trips);
5. Take a class (school, ...);
6. Eating out;
7. Shopping;
8. Services (doctor, bank, ...);
9. Visit family or friends;
10. Take a walk;
11. Leisure, sports, culture;
12. Other (specify): ....

The first step is to isolate “other motives” from commuting trips in the survey database. In order to do so the categories “go to work” and “take a class” were removed from the analysis.

The category “go home” is problematic *a priori*, as it may concern commuting trips as well as trips for other motives. Since the current modelling of PLANET does not consider travel chains, this category was removed as well. We chose instead a simplified approach with an overall “round-trip” assumption.

Each trip is associated with a return trip to home, except for trips "for work". The underlying assumption is that business trips always form a chain returning to their point of departure (tour, mission,...), the whole chain being taken under the motive "for work".

We therefore retain nine of the twelve detailed "motives" for our analysis, knowing that for eight of them (all except the motive "for work") a return trip will automatically be considered later in the modelling.

Prior to the travel log, the respondent had to provide a certain amount of information in the household questionnaire such as age, sex, home, income, etc., which makes it possible to study the link between the number of daily trips (trip rate) and the characteristics of the interviewee or his household. However, the size of the sample available in the BELDAM survey does not allow to estimate a trip rate reliably for each district and each crossing of these characteristics. We chose therefore to use econometric modelling to quantify the interactions between explanatory variables and the trip rate under the assumption that these variables, which describe personal characteristics, the household, or the place of residence or work, influence the travel behaviour of individuals. This will then allow this model to be applied to the populations of the different districts to obtain related trip rates.

On the basis of a simple econometric model (a negative binomial count model), the link between the daily trip rate and potential explanatory variables was studied for each of the nine subcategories of "other motives" identified above. It allowed us to group them into three categories in which the effects of the explanatory variables are similar:

- A first group of motives for which the trip rate varies significantly with the level of income reported for the household. This group will be called "other motives depending on revenues". It includes detailed motives 6, 7, 11 and 12;
- A second group of motives for which the trip rate does not vary significantly with the level of income reported for the household. This group will be referred to as "other motives not depending on revenues". It includes detailed motives 1, 8, 9 and 10;
- The last remaining motive, 4 "for work", is considered structurally different from the two first groups and will be kept apart under the name "business".

Graph 1 in subsection 3.1.1.a summarises the distribution of the trips between the different motives and groups of motives. It represents one-way trips only, and therefore excludes the "go home" category. It is based on the weighted trips of the BELDAM travel logs.

The following subsections provide estimates for each of the three categories.

a. Other motives depending on revenues

This first group is made up of detailed motives 6 "eating out", 7 "shopping", 11 "leisure, sports, culture" and 12 "other". For these motives, the finding of a positive dependency on household income level expressed per consumption unit (CU) makes sense. Essentially, these are motives that do not cover an existential necessity and/or involve an expense. For these, the link between trip rate and explanatory variables was estimated jointly, for the following explanatory variables:

- region of residence: discrete variable, with categories: Brussels, Flanders, Wallonia;
- age: discrete variable, with categories: 0-14, 15-19, 20-34, 35-49, 50-64, 65-74, 75 and more;
- sex: discrete variable, with categories: male, female;
- socio-economic status (SES): discrete variable, with categories: inactive, student, employed, self-employed (note that the category "inactive" is a residual category, which hence also includes active but unemployed persons. These are the historic SES categories in the PLANET model and are maintained as-is, despite the abuse of language.);
- household size in persons: ordinal variable;
- urbanisation index: continuous variable with values between 0 and 3 (0 = fully urban, 1 = suburbs, 2 = commuters' zones, 3 = rural, following the typology defined in Van Hecke et al. (2009) which is in use within BELDAM). This variable takes discrete values 0, 1, 2 or 3 for individuals, but is here taken as an index. Hence only one multiplicative parameter is fitted to this variable within the model. This amounts to make the hypothesis that behaviours evolve monotonically with the degree of urbanisation of the place of residence. This hypothesis appears valid when considering the model fit results based on the original discrete variable for urbanisation. Using the index version of the variable will allow us to make prediction based on the average degree of urbanisation of a given geographical area;
- education level: continuous variable with values between 1 and 3 (1 for lower education, 2 for secondary education, and 3 for tertiary education). Just as for the degree of urbanisation, this variable is originally a discrete variable, but is used here considered as a continuous index, with a unique multiplicative parameter fitted;
- disposable income by consumption unit in the household (on a declarative basis): continuous variable, obtained by combining the total monthly incomes declared by the respondents and the information about the number and ages of the household members.

Table 25 shows the results of the estimate. We note that for each variable selected, at least one category corresponds to a significant effect on the trip rate, except for gender and household size. They are kept in the model, knowing that they do not lead to statistical problems and that they are significant in some subcategories of motives.

Table 25 Estimation of the trip rate model, income-dependent motives

Variable	Parameter	Standard deviation	Significance
Intercept	-1.733	0.124	***
Sex = F	-0.021	0.029	
Age (15,20]	-0.334	0.076	***
Age (20,35]	-0.239	0.095	*
Age (35,50]	-0.029	0.101	
Age (50,65]	-0.083	0.103	
Age (65,75]	-0.203	0.113	.
Age (75,120]	-0.432	0.115	***
SES: inactive	0.392	0.043	***
SES: self-employed	-0.189	0.071	**
SES: student	0.233	0.083	**
Region: Flanders	0.189	0.054	***
Region: Wallonia	-0.039	0.056	
Household size	-0.018	0.013	
Education level index	0.471	0.025	***
Urbanisation index	-0.024	0.013	.
Logarithm income per CU	*0.29 (pro memo)*	*0.032*	***

Source: FPB calculations.
Significance level: *** < 0.1%; ** < 1%; * < 5%; . < 10%.

What can be deduced from Table 25 is that, for example, a man aged between 35 and 50, employed, living in Flanders, in a household of three persons, with tertiary education (index 3), in a suburban commune (index 1), will have a trip rate estimated at an average 0.79 trip (one way) per day for the other motives depending on revenues:

$$tr_{income-dependent} = \exp\big(-1.733_{(intercept)} - 0.021_{(sex)} * 0 - 0.029_{(age)} + 0_{(ses)} + 0.189_{(region)} - 0.018_{(household\ size)} * 3 + 0.471_{(education\ level)} * 3 - 0.024_{(urbanisation)} * 1\big)$$

$$= \exp(-0.238) = 0.79 \qquad (23)$$

In order to be able to apply such a model in a practical way as part of the projection, it is necessary to have the value of these explanatory variables for the projection period. The methods and sources used for this purpose are described in Appendix A.

An important element of this estimate is the impact of education level: the coefficient for the education index is significantly positive and quite high. This variable is in fact an indicator of lifestyle variation, with higher mobility measured for populations with higher education levels. This is important in projection, knowing that the expected level of education of the population will continue to rise in Belgium, especially for older age groups. This results in an increase in projected mobility via the trip rate.

Finally, the intercept of this model will be used as a calibration variable for the reference year. Knowing that the binomial negative model is logarithmic, the intercept parameter plays multiplicatively in the estimate of the trip rate, which makes it suitable for this role.

b. Other motives not depending on revenues

This group is made up of the detailed motives 1 “drop off / pick someone up”, 8 “services (doctor, bank, ...)”, 9 “visit family or friends”, 10 “take a walk”.

These motives may be considered as either a necessity (to move for services, to drop off or pick someone up), or an activity that does not involve any expense. It is therefore consistent that this group has a trip rate that does not depend significantly on the level of household income. The same explanatory variables as for the first group are considered. Table 26 gives the estimation results of the corresponding model.

Table 26 Estimation of the trip rate model, income-independent motives

Variable	Parameter	Standard deviation	Significance
Intercept	-1.786	0.146	***
Sex = F	0.090	0.033	**
Age (15,20]	-0.477	0.095	***
Age (20,35]	-0.083	0.113	
Age (35,50]	0.017	0.119	
Age (50,65]	-0.263	0.121	*
Age (65,75]	-0.352	0.132	**
Age (75,120]	-0.779	0.137	***
SES: inactive	0.348	0.048	***
SES: self-employed	-0.014	0.074	
SES: student	-0.331	0.098	***
Region: Flanders	0.076	0.014	***
Region: Wallonia	0.185	0.064	**
Household size	0.158	0.065	*
Education level index	0.347	0.015	***
Urbanisation index	0.021	0.028	

Source: FPB calculations.
Significance level: *** < 0.1%; ** < 1%; * < 5%; . < 10%.

The remarks made for income-sensitive motives also apply to the present case, in particular concerning the education index, although here the effect is less important (0.347 against 0.471). This is consistent with intuition, knowing that the categories of motives such as “leisure, sports, culture” that are part of the first group are probably the most sensitive to the level of education as a marker of lifestyle.

c. Business

This is the motive 4 “for work”. For this category, given the limited data available (around 500 entries in travel logs), only two average trip rates are estimated: one for employees and one for self-employed workers, all other characteristics combined, at national level. We estimate 0.1 trip per day per worker for employees and 0.18 for self-employed workers, significantly different from zero. It is difficult to pronounce ourselves on the probable evolution of this trip rates: opposing tendencies in terms of impact are at work in the evolution of the modes of work and consumption. For example, the development and use of new remote working technologies (i.e. teleconferencing) that will limit the number of business trips in the future, and the rise of electronic commerce which often transfers from the buyer to the seller the travel related to the purchase of the good, resulting in fewer “shopping” trips and more “professional” delivery trips. In this state and in the absence of more detailed sources, these trip rates are kept constant in projection. They are applied to the projected number of employees and self-employed persons.

10. Appendix F - Average generalised costs of transport

Table 27 Average generalised costs of passenger transport by mode and motive

	euro2015/pkm	Difference in % compared to 2015 (in real terms)		Average annual growth rate	Share of time cost in the generalised cost	
	2015	2025	2040	2015-2040	2015	2040
Commuting to work						
Peak						
Car solo	0.54	8.5%	25.5%	0.9%	42%	53%
Carpooling	0.34	11.2%	32.3%	1.1%	65%	73%
Train	0.30	9.6%	26.6%	0.9%	90%	92%
Bus	0.38	13.7%	34.3%	1.2%	97%	98%
Tram	0.71	10.6%	28.8%	1.0%	94%	95%
Metro	0.78	9.4%	26.8%	1.0%	93%	95%
Walk/bike	0.70	9.4%	26.1%	0.9%	100%	100%
Motorbike	0.74	5.5%	13.7%	0.5%	26%	34%
Off-peak						
Car solo	0.50	6.9%	22.0%	0.8%	37%	47%
Carpooling	0.30	9.2%	27.7%	1.0%	60%	68%
Train	0.28	9.4%	26.1%	0.9%	89%	91%
Bus	0.33	12.7%	32.8%	1.1%	96%	97%
Tram	0.58	10.8%	29.4%	1.0%	92%	94%
Metro	0.65	9.3%	26.4%	0.9%	92%	94%
Walk/bike	0.66	9.4%	26.0%	0.9%	100%	100%
Motorbike	0.68	4.3%	11.1%	0.4%	20%	26%
Commuting to school						
Peak						
Carpooling	0.36	11.7%	32.9%	1.1%	71%	77%
Train	0.19	9.8%	27.8%	1.0%	94%	95%
Bus	0.40	11.3%	30.2%	1.1%	95%	96%
Tram	0.52	10.7%	28.8%	1.0%	96%	97%
Metro	0.59	9.6%	27.2%	1.0%	95%	96%
Walk/bike	0.67	9.0%	25.4%	0.9%	100%	100%
Motorbike	0.70	4.1%	10.5%	0.4%	19%	25%
Off-peak						
Carpooling	0.33	10.7%	31.1%	1.1%	68%	75%
Train	0.18	10.0%	28.1%	1.0%	94%	95%
Bus	0.32	10.8%	29.5%	1.0%	94%	95%
Tram	0.43	10.9%	29.4%	1.0%	95%	96%
Metro	0.49	9.5%	26.9%	1.0%	94%	95%
Walk/bike	0.55	9.3%	26.4%	0.9%	100%	100%
Motorbike	0.67	3.5%	9.3%	0.4%	16%	22%
Commuting to studies						
Peak						
Car solo	0.49	6.2%	20.5%	0.7%	30%	40%
Carpooling	0.29	8.7%	26.7%	1.0%	52%	61%
Train	0.16	9.4%	27.6%	1.0%	92%	94%
Bus	0.28	12.4%	32.7%	1.1%	95%	97%
Tram	0.53	10.3%	28.5%	1.0%	96%	97%
Metro	0.59	9.6%	27.2%	1.0%	95%	96%
Walk/bike	0.63	9.0%	24.8%	0.9%	100%	100%
Motorbike	0.72	4.6%	11.6%	0.4%	22%	29%
Off-peak						
Car solo	0.46	4.9%	17.8%	0.7%	26%	35%
Carpooling	0.26	7.4%	24.2%	0.9%	48%	57%
Train	0.14	9.3%	27.3%	1.0%	91%	93%
Bus	0.23	11.8%	32.0%	1.1%	95%	96%
Tram	0.43	10.7%	29.3%	1.0%	95%	96%
Metro	0.49	9.5%	27.0%	1.0%	94%	95%
Walk/bike	0.60	9.1%	24.9%	0.9%	100%	100%
Motorbike	0.68	3.8%	9.9%	0.4%	17%	23%

	euro2015/pkm	Difference in % compared to 2015 (in real terms)		Average annual growth rate	Share of time cost in the generalised cost	
	2015	2025	2040	2015-2040	2015	2040
Business						
Peak						
Car solo	0.94	15.0%	40.2%	1.4%	62%	72%
Carpooling	0.61	15.4%	41.7%	1.4%	78%	84%
Train	0.59	9.2%	26.0%	0.9%	90%	92%
Bus	0.83	12.3%	32.2%	1.1%	98%	98%
Tram	1.29	11.5%	30.7%	1.1%	97%	98%
Metro	1.67	9.5%	27.1%	1.0%	94%	96%
Walk/bike	2.81	8.6%	24.1%	0.9%	100%	100%
Motorbike	1.05	8.8%	21.8%	0.8%	46%	55%
Off-peak						
Car solo	0.84	12.9%	36.0%	1.2%	57%	68%
Carpooling	0.53	13.5%	38.3%	1.3%	75%	81%
Train	0.54	9.5%	26.3%	0.9%	89%	91%
Bus	0.61	11.7%	31.8%	1.1%	97%	98%
Tram	0.99	11.9%	31.5%	1.1%	96%	97%
Metro	1.35	9.4%	26.7%	1.0%	93%	95%
Walk/bike	2.81	8.6%	24.1%	0.9%	100%	100%
Motorbike	0.98	7.7%	19.7%	0.7%	42%	51%
Other: depending on revenues						
Peak						
Car solo	0.55	6.8%	21.6%	0.8%	37%	47%
Carpooling	0.31	9.1%	27.1%	1.0%	59%	67%
Train	0.29	8.3%	23.0%	0.8%	79%	83%
Bus	0.37	10.9%	28.6%	1.0%	87%	90%
Tram	0.64	9.8%	26.5%	0.9%	85%	88%
Metro	0.82	8.0%	22.8%	0.8%	79%	83%
Walk/bike	0.89	8.6%	24.1%	0.9%	100%	100%
Motorbike	0.73	4.2%	10.9%	0.4%	23%	29%
Off-peak						
Car solo	0.52	6.0%	19.9%	0.7%	35%	44%
Carpooling	0.29	8.2%	25.6%	0.9%	56%	64%
Train	0.27	8.2%	22.7%	0.8%	78%	82%
Bus	0.29	10.1%	27.4%	1.0%	84%	87%
Tram	0.54	9.7%	26.4%	0.9%	82%	85%
Metro	0.72	7.7%	22.0%	0.8%	77%	81%
Walk/bike	0.89	8.6%	24.1%	0.9%	100%	100%
Motorbike	0.71	3.7%	10.0%	0.4%	21%	26%
Other: not depending on revenues						
Peak						
Car solo	0.54	6.9%	21.7%	0.8%	37%	47%
Carpooling	0.31	9.2%	27.5%	1.0%	60%	67%
Train	0.28	8.2%	22.9%	0.8%	79%	83%
Bus	0.36	10.7%	28.3%	1.0%	88%	90%
Tram	0.58	9.6%	26.4%	0.9%	86%	89%
Metro	0.70	8.2%	23.4%	0.8%	81%	85%
Walk/bike	0.89	8.6%	24.1%	0.9%	100%	100%
Motorbike	0.73	4.2%	10.9%	0.4%	23%	29%
Off-peak						
Car solo	0.52	6.0%	20.0%	0.7%	34%	44%
Carpooling	0.28	8.4%	25.9%	0.9%	56%	64%
Train	0.27	8.2%	22.7%	0.8%	78%	82%
Bus	0.29	10.0%	27.2%	1.0%	85%	88%
Tram	0.48	9.7%	26.5%	0.9%	83%	86%
Metro	0.60	7.9%	22.5%	0.8%	78%	82%
Walk/bike	0.89	8.6%	24.1%	0.9%	100%	100%
Motorbike	0.71	3.7%	10.0%	0.4%	20%	26%

Source: PLANET v4.0.

Table 28 Average generalised costs of freight transport for category of goods NSTOTH

	euro2015 /1000tkm	Difference in % compared to 2015 (in real terms)		Average annual growth rate	Share of time cost in the generalised cost	
	2015	2025	2040	2015-2040	2015	2040
National road transport in Belgium						
HDV – peak	168.1	11.3%	21.9%	0.8%	46%	45%
HDV – off-peak	157.8	11.8%	22.2%	0.8%	42%	42%
LDV - peak	3504.1	7.4%	17.4%	0.6%	59%	59%
LDV – off-peak	3090.0	7.2%	17.1%	0.6%	54%	54%
Rail	139.6	0.8%	3.7%	0.1%	59%	60%
IWW	48.4	2.2%	6.7%	0.3%	89%	89%

Source: PLANET v4.0.

11. Abbreviations

11.1. Organisations

CEDEFOP	Centre européen pour le développement de la formation professionnelle
DIV	Direction pour l'immatriculation des véhicules
ETNIC	Entreprise publique des technologies nouvelles de l'information et de la communication (Fédération Wallonie-Bruxelles)
FPB	Federal Planning Bureau
FPS	Federal public service
GOCA	Groupement des entreprises agrées pour le contrôle automobile et le permis de conduire
ICN	Institut des Comptes nationaux
INAMI	Institut national d'assurance maladie-invalidité
NBB	National Bank of Belgium
ONSS	Office national de sécurité sociale
ONSSAPL	Office national de sécurité sociale des administrations provinciales
SNCB	Société Nationale des Chemins de fer Belges
Statbel	Office belge de statistiques
STIB	Société des Transports Intercommunaux de Bruxelles
TEC	Transport En Commun (Wallonia)
TML	Transport & Mobility Leuven
VITO	Vlaamse instelling voor technologisch onderzoek

11.2. Other

BELDAM	BELgian DAily Mobility survey
CASMO	CAr Stock MOdel
GDP	Gross domestic product
GIS	Geographic Information System
HDV	Heavy-duty vehicle
LDV	Light-duty vehicle
NST	European standard goods classification for transport statistics
NUTS3	Level 3 of the European Nomenclature of territorial units for statistics
OVG	Onderzoek VerplaatsingsGedrag
PCU	Passenger Car Unit
pkm	Passenger-kilometre

SES	Socio-economic status
SES 2001	Socio-economic survey 2001
SSS	Short Sea Shipping
tkm	Tonne-kilometre
VAT	Value added tax
vkm	Vehicle-kilometre
VOT	Value of time

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