REDUCING CO₂ EMISSIONS DUE TO A SHIFT FROM ROAD TO CABOTAGE TRANSPORT OF CARGO IN BRAZIL

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Abstract: This work aims to evaluate the existing Brazilian National Plan for Logistics and Transport (PNLT) impact for reducing CO$_2$ emissions in the domestic cargo transport. A formal system dynamics model is built that captures the causal relationships influencing the modal shift from road to cabotage transport of cargo in Brazil. Scenarios are charted to understand the impact of PNLT policies and the implications for the transport infrastructure. The simulation shows that pressure to reduce CO$_2$ emissions is beneficial in the acceleration process of modal shift.

Keywords: Cargo transport, Modal shift, Greenhouse gases emission, System Dynamics.

1 Introduction

Problem: Significant CO$_2$ emissions in the transportation sector and political pressure to reduce emissions.

Importance: In the global agenda, transport is a great contributor (huge potential for impact). According to the International Energy Agency (IEA), the transportation sector is responsible today for about 19% of the world energy consumption and for about 23% of the CO$_2$ emissions and it projects that such participation will continue to increase in the future. The IEA concludes that, considering the actual tendencies, the energy consumption and CO$_2$ emissions in the transportation sector will globally increase approximately 50% by 2030 and more than 80% by 2050.

Challenges: High inertia from road transportation. Its high attractiveness also makes it difficult to change. On the other hand, the Intergovernmental Panel on Climate Change (IPCC) informs that in order to avoid the worst climate change impacts, the global CO$_2$ emissions should be reduced by at least 50% until 2050 in comparison with the emission level observed nowadays. In order to achieve this goal, the transportation sector will play a significant role because even with significant CO$_2$ emission reductions in other sectors, if the transportation sector fails to reduce its CO$_2$ emissions significantly until 2050, it will be very difficult to accomplish the established goal.

Contribution of this paper: This work investigates policies that have the ability to influence the modal shift from road to cabotage transport. In particular, the model explicits the comparative advantages of road and cabotage transport to capture the dynamics of the shift in transportation modes over time. Regarding specific governmental policies, we consider PNLT goals and explicitly provide a trajectory that clarifies how they can be achieved within the required time horizon. This allows capturing the effects that PNLT
policies will have on the reduction of CO\textsubscript{2} emissions after implementation and evaluating the potential reductions of CO\textsubscript{2} emissions in the transportation sector and their contribution to the PNMC objectives. Therefore, our work evaluates PNLT policies and their impact on CO\textsubscript{2} emissions in the Brazilian national transportation sector using a formal system dynamics model.

The main purpose of the model is to analyze the modal shift from road to cabotage over time, driven by the level of investment in the modes capabilities and governmental pressure to reduce CO\textsubscript{2} emissions. As a final result, we want to understand the dynamics of modal shift in cargo transport and its impact on CO\textsubscript{2} emissions. In addition, our model provides a common framework through which (i) policy makers can understand the system and perform policies analysis, (ii) other related sectors can be incorporated and modeled (Abbas and Bell, 1994).

The remaining of this document is composed as follows. The next section presents additional detail on the political context of the transport sector in Brazil and some of its challenges. Section 3 provides an overview of the concepts used in this work. Section 4 describes the formal system dynamics model and the data used. Section 5 presents the base case behavior of the model, specific scenario and policy analyses. Finally, in section 6 we provide a discussion about the possible impacts of PNLT in the reduction of CO\textsubscript{2} emissions and its contribution to the PNMC objectives, as well as some conclusions.

2 Brazilian Transportation Context

In December 2008, the Brazilian National Policies on Climate Change (PNMC) (Brazil, 2009) was presented aiming (i) to encourage the development and improvement of actions in order to mitigate the emission of Greenhouse Gases (GHG) in Brazil, (ii) to collaborate with the global effort to reduce GHG emissions, and (iii) to create internal conditions for dealing with the impacts of global climate change. The goals presented in the PNMC were expected not only to reduce the emissions of GHG, but to bring some socioeconomic benefits and some other environmental gains, such as:

- Reduce the rate of annual deforestation in the Amazon region by 80\% by 2020;
- Increase the domestic consumption of ethanol by 11\% per year over the next ten years;
- Double the area of planted forests to 11 million hectares in 2020, of which 2 million would be planted with native species;
- Replace one million old refrigerators per year in the next ten years;
- Increase the recycling of municipal solid waste by 20\% by 2015;
- Increase the electric power supply cogeneration, mainly through the use of sugar cane bagasse, to 11.4\% of total electricity supply in the country by 2030;
- Reduction of non-technical losses in electricity distribution in the rate of 1,000 GWh per year over the next ten years.

The regulatory act no. 7390 (Brazil, Act 7390/2010) related to the PNMC, signed on December 9\textsuperscript{th} 2010, estimates that Brazil will reach the year 2020 emitting at most 3.3 billion of tons (Gt) of CO\textsubscript{2} (carbon dioxide) equivalent (sum of all the GHG emissions converted to CO\textsubscript{2}) per year. However, in order to achieve the Brazilian volunteer commitment instituted in Law no. 12187 (Brazil, Law 12187/2009) from 2009, the regulatory act requires the implementation of some actions that will allow the reduction of CO\textsubscript{2} emission between 1,168 and 1,259 million of tons (Mt) per year, which indicates that Brazilian emissions should be at
most 2.1 Gt of CO₂ per year in 2020. According to the Brazilian Ministry of the Environment (MMA), the regulatory act in conjunction with other governmental actions provides a new base to the implementation of the United Nations Framework Convention on Climate Changes (UNFCCC) in Brazil.

The PNMC regulation act implies the establishment of a threshold for CO₂ emission levels, which requires the incorporation of specific goals for twelve sectors of the national economy. In order to meet these goals, each sector will need to present an action plan by the end of 2011. In 2005, according to the inventory submitted to the UNFCCC, Brazil emitted 2.19 Gt of GHG in CO₂ equivalent measures. In 2009, the emissions decreased to 1.77 Gt of CO₂ equivalent. However, according to the MCT, in order to maintain the GHG emission levels, Brazil will need to reduce the emissions in sectors such as transport, industry and agriculture, other than combating the deforestation.

In the transportation sector, the evaluation of CO₂ emissions must consider the ratio between the increase in cargo demand and the increase in Growth Domestic Product (GDP) to project a trend for the following years. Figure 1 depicts a graph which presents a ratio between those two indices provided by the European Environmental Agency (EEA). Observing the graph, it can be seen that the cargo demand, measured in tons per kilometer (tkm), has been increasing at a higher rate than the GDP.

In addition, the graphs also show that the economic growth (GDP) generates more cargo demand (tkm), which causes an increase in the CO₂ emissions. The emission levels, on the other hand, depend on the cargo transportation modes. Table 1 presents the participation of each Brazilian transportation modes in the CO₂ emission in 2006 and the transportation modes participation in the Brazilian transport matrix. Therefore, if the economic growth and the transport matrix are maintained, the CO₂ emission levels will not be reduced and the goals proposed by the Brazilian National Policies on Climate Change will not be achieved.

<table>
<thead>
<tr>
<th>Mode</th>
<th>CO₂ tons/year</th>
<th>Participation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>83,302,000</td>
<td>88.31</td>
</tr>
<tr>
<td>Air</td>
<td>6,204,000</td>
<td>6.58</td>
</tr>
<tr>
<td>Waterway</td>
<td>3,558,000</td>
<td>3.77</td>
</tr>
<tr>
<td>Railroad</td>
<td>1,260,000</td>
<td>1.34</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>93,324,000</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

Figure 1 – CO₂ emissions in the transportation sector.
Source: EEA, 2010
Table 2 – Brazilian cargo transportation matrix (Brazil, MMA).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cargo Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.4%</td>
</tr>
<tr>
<td>Pipeline</td>
<td>4.19%</td>
</tr>
<tr>
<td>Waterway</td>
<td>13.59%</td>
</tr>
<tr>
<td>Road</td>
<td>61.09%</td>
</tr>
<tr>
<td>Railroad</td>
<td>20.73%</td>
</tr>
</tbody>
</table>

Aiming to change this situation, in 2007, the Brazilian Ministry of Transport elaborated the Brazilian National Plan for Logistics and Transport (PNLT), which was developed in a partnership with the Brazilian Ministry of Defense via the Center of Excellence in Transportation Engineering. Among the main PNLT objectives, we may highlight the following:

- Elaborate the planning process in the transportation sector, based on a geo-referenced information system containing all the key data in the sector, either at the bid involving all transportation modes, or at the demand;
- Consider the costs of the entire logistics chain between the origins and destinations of transport flows;
- Change, with a better balance, the current cargo transportation matrix of the country, with more intensive and appropriate use of railroad and waterway modes, taking advantage of their energy efficiencies and productivity in moving streams of higher density and distance of transport;
- Promote environmental conservation, aiming to respect the restriction areas and control of land use, be it the issue of production of goods, be it in the deployment of infrastructure.

However, the PNLT does not include a provision aiming at reducing GHG emissions among its main goals. This reduction is expected to be achieved by changing the percentage of the cargo transportation matrix (presented in Table 2) within a 15 to 20-year time horizon. Such expected changes are presented below and summarized in Figure 2:

- Increase the participation of railroad from the current 25% to 32%;
- Increase the participation of waterway from 13% to 29%;
- Evolution of pipeline and air modes to 5% and 1%, respectively;
- Decrease the participation of the road mode from 58% to 33%.

Figure 2 – Progress of the Brazilian cargo transportation matrix (Brazil, PNLT, 2009).
Although this figure shows a desired goal, it does not detail how this can be done and the scope of this work is to provide a trajectory that helps getting it done.

On the other hand, the PNMC refers to the PNLT in the transportation sector analysis, but it does not recognize the effects that PNLT policies will have on the reduction of CO$_2$ emissions after implementation.

3 Overview of subjects

This section presents a brief summary of the emission of greenhouse gases and its relation to the transportation sector, and a literature review on the use of system dynamics to simulate transport networks.

3.1 Greenhouse Gases Emissions

The greenhouse gases (GHG) occur naturally in the atmosphere and help to sustain life on the planet, since they retain the natural heat of the sun. IPCC reported in (IPCC, 2001) that without this retention of heat the temperature on Earth would be approximately 33 degrees Celsius lower than the one experienced today, thus impeding life as we know it nowadays. The most important gases that occur naturally and are associated with this effect are water vapor (H$_2$O), carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O). Besides these, there are other greenhouse gases that do not occur naturally, being produced only syntactically; these gases are the chlorofluorocarbons (CFCs), the hydro fluorocarbon (HFC), the per fluorocarbon (PFCs) and sulfur hexafluoride (SF$_6$) (IEA, 2010).

In recent years, GHG emissions have grown at an annual rate of 3 to 4%, and CO$_2$ emission in 2007 was approximately 28.8 billion tons (Gt). Globally, the transportation sector is the second largest emitter of CO$_2$, contributing approximately with 6.5 Gt in 2007 (IEA, 2010), and this volume results mainly from burning fossil fuels derived from petroleum. Moreover, it is projected that the transportation sector will continue to have a substantial representation in the GHG emissions in the world, as illustrated in Figure 3.

Figure 3 – Projected global CO$_2$ emissions related to energy (Mt) (IEA, 2010).

Despite its great contribution to GHG emissions, the transportation sector is considered one of the most resistant to reducing greenhouse gases emissions. Some reasons
for this resistance can be considered the result of a market failure, as users of light vehicles are not made aware of the economic and environmental impacts of their actions, and the primary means of cargo transportation is the road mode.

These characteristics of the transportation sector associated with projections of increasing its contribution to GHG emissions require some government actions, if not for the reduction of GHG emissions, at least for its stabilization.

According to (Apogee, 1998), strategies to mitigate GHG emissions in the transportation sector can be grouped into three categories, which were focused on reducing travel in vehicle efficiency and fuel used.

The strategies associated with reductions in travels try to reduce GHG emissions by reducing vehicle miles per person. The reduction in fuel consumption occurs with the elimination of travel, reduction in distance traveled, or replacement of personal vehicles usage by alternative modes that use less energy.

The second category focuses on strategies for reducing GHG emissions through improved fuel consumption efficiency. Since CO₂ emissions are directly proportional to the amount of fuel consumed, improvements in fuel consumption efficiency would proportionately reduce GHG emission per kilometer. These strategies may also be performed through the use of incremental vehicle technologies, advanced technologies and operational practices. For example, it is estimated that incremental improvements in combustion and transmission using existing technologies could reduce GHG emissions by up to 20%.

The third category of strategies focus on reducing GHG emissions through the use of fuels that have low volume of carbon emissions as compared to conventional fossil fuels. All fuels have a carbon concentration which reflects the amount of CO₂ emitted per unit of energy consumed in combustion; therefore, the use of fuels with lower carbon helps reduce emissions (Yeh, Sperling, 2010). Even though the fuels with low carbon concentration offer an opportunity to reduce GHG emissions without substantially reducing the demand for transportation, they face a combination of barriers to their implementation related to infrastructure and economic issues.

If all transport technologies and fuels could be developed and implemented, they would bring GHG emissions from the transportation sector below the levels measured in 2000 by 2030. However, although the vehicles, fuels and technologies are attractive in the short term, they are insufficient to achieve the reduction targets of 80% by 2050 (McCollum and Yang, 2009).

Calculation of CO₂ emissions by the energy sector, which includes the transportation sector, can be made using two different methodologies: top-down and bottom-up (IPCC, 2006).

The top-down methodology, or reference approach, estimates CO₂ emissions taking into account only the amount of the energy consumed in the country, but not considering how the energy is consumed. Emissions are estimated from a balance involving domestic production of primary fuels, net imports of primary and secondary fuels and the internal variability of the stocks of those fuels. The advantage of top-down method over other methods is its non-dependence in detailed information regarding the use of fuel by the end user.

The bottom-up methodology, or by sector approach, identifies and quantifies the emissions of all GHG separately and takes into account not only the amount of fuel consumed, but also the type of equipment used and their respective efficiency. In this approach, emission sources are divided into stationary sources and mobile sources, and typical emission factors are developed for each source. However, these factors vary widely depending on the technology and the country it is being considered; they are developed based on sample information and the engineering knowledge each country has about the different
technologies. Therefore, one cannot generalize the emission factors, i.e. factors should be
developed in accordance with the reality of each country. Because of this greater detail, this
methodology facilitates the study of policies and projects to reduce emissions, but it is
difficult to apply because it is extremely complex to obtain data related to sources of fuel
combustion and GHG emissions.

The IPCC classifies the gases emissions in some key categories. The key categories
considered in this study are: \textit{1A3b - Fuel Combustion Activities - Transport - Road} and \textit{1A3d - Fuel Combustion Activities - Transport - Water-borne Navigation} (IPCC, 2006 Volume 1
Chapter 4 Table 4.1).

3.2 System Dynamics in Simulation of Transportation Networks

The sustainable development of an effective urban transport system is a key point in
reducing the consumption of energy resources and building an urban society that enjoys a
better quality of life. The concept of sustainable urban transport involves four aspects:
economic sustainability, environmental sustainability, social sustainability and sustainable
transport (Wang, et al., 2008). The study of the dynamic relationships between economic
development and environmental preservation can provide the scientific basis for planning the
coordinated development of (an urban) society (Duan and Yang, 2008). However, because of
the complexity and scope of transport systems, traditional simulation methods are not suitable
for its analysis. Complex systems like this have been successfully simulated and analyzed
using system dynamics that was first proposed by Forrester and later used in urban systems
modeling (Wang, et al., 2008).

Such transportation simulation systems involve many agents, with multiple feedback
loops among them; furthermore, they consider different time intervals for response among
users, developers, operators and managers. The system dynamics model not only offers a
different perspective, with a whole system approach to transport planning, but also
demonstrates to managers the importance of these feedback loops and lag responses. The
system dynamics approach also provides specialized tools that help managers understand the
underlying structures of systems and cause and effect relationships within them. Furthermore,
the approach allows for model calibration to data and generation of optimal policies
(Shepherd and Emberger, 2010).

In addition, the time-dependent aspect allows the system dynamics model to simulate
performance patterns not as a result of extrapolation of trends, but through the continuous
application of rules and relationships that modify simulated conditions and on which
subsequent understanding and decision analysis may be based (Abbas and Bell, 1994).

Moreover, the modeling process of transportation systems requires that its model
captures the consequences of investment policies since its main aim is to aid policy-makers in
reaching an optimum design policy with plausible solutions to a lot of transportation
problems (Abbas and Bell, 1994).

Some proposed system dynamics models played an important role in helping the
evaluation of policies in order to reduce emissions. One is the TREMOVE (EEA, 2011),
which was designed to evaluate the effect of different transport policies on emissions of
pollutants from European countries.

Another model designed to support policy decisions about transport and its impact
GLADYSTE (Global Scale System for Dynamic Simulation Model Transport Emissions) that
extends the coverage of TREMOVE to the globe (Purwanto et al., 2010). In this model, the
CO$_2$ emissions in cargo transportation is mainly determined by the quantity shipped, the
transport mode used and the power consumption characteristics of each mode. Because these
components interact, environmental impact can be changed through policies that expand the
network of each mode (Wang et al., 2010).
In GLADYSTE model, the transportation system and environmental impacts are simulated through four modules that are interconnected. The first module refers to the demand for motorized transport, taking into account the supply-demand balance. The second module considers the outputs of the first one, generating the fleet needed to meet the demand. In the environmental module, fuel consumption and pollutant emissions are calculated from the fleet, and the average speed of each transport mode to meet the demand. Finally, the module of the impacts calculates the costs of externalities, taxes and subsidies. (Purwanto et al., 2010).

System dynamics was also used in a study conducted on behalf of the Community of European Railway and Infrastructure Companies (Doll et al, 2008) to analyze the impact of transport on CO\textsubscript{2} emissions, which simulates the environmental impact caused by a partial shift of the railway demand to road. The model simulates the reference transport demand in four different segments of market and the final output of the model consists of the CO\textsubscript{2} emissions in various scenarios.

4 Model Description

The main purpose of the model is to analyze the modal shift from road to cabotage over time, driven by the level of investment in the modes capabilities and governmental pressure to reduce CO\textsubscript{2} emissions. As a final result, we want to understand the dynamics of modal shift in cargo transport and their impact on CO\textsubscript{2} emissions.

A modal shift occurs when one transportation mode has a comparative advantage in a similar market over another. Comparative advantages can take various forms, such as costs, capacity, time, flexibility or reliability. Depending on what is being transported, the importance of each of these factors varies. In this work, the most important factor for the achievement of modal shift is directly related to the capability of each transportation mode; the assumption is appropriate since, in the long term, this may cause the greatest impact within the premises of the study.

Figure 4 illustrates the model diagram developed to study the impacts of modal shift over the CO\textsubscript{2} emissions.

Figure 4 – System Dynamics model diagram.
The diagram can be divided in 4 parts:
- Transport Capacity
- Transport Demand
- Modal Shift
- CO₂ emissions

The following figures show each of these four parts. All the equations units, inputs and outputs are detailed in Annex A.

**Transport Capacity**

Figure 5 shows the increase in Road and Cabotage, relating the modal shift, increasing demand and investment to increase transport capacity.

![Figure 5 – Road and Cabotage Transport Capacity.](image)

Main equations:

Road Transp Capacity = Change in Road Capacity - Road Transp Capacity Erosion  
Cabotage Transp Capac = Change Cabotage Capacity - Cabotage Transp Capac Erosion  

Cabotage Transport Demand = Mode Shift Road x Cabotage * Total Transport Demand  
Road Transport Demand = (1-Mode Shift Road x Cabotage) * Total Transport Demand

Table:

Table 3 shows Transport Saturation and Pressure to improve capacity. Obtaining this value function is difficult; an approximation to the values from the table is a representation of empirical observations of professionals in the area.
Table 3 – Transport Saturation and Pressure to improve capacity.

<table>
<thead>
<tr>
<th>Transport Saturation</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
<th>&gt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure to improve capacity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01</td>
<td>0.04</td>
<td>0.1</td>
<td>0.25</td>
<td>0.54</td>
<td>1</td>
<td>1.8</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

**Transport Demand**

Figure 6 shows the increase of Transport Demand in function of economic growth.

![Figure 6 – Transport Demand.](image)

Main equations:

\[
\text{Change In Total Transport Demand} = \text{Total Transport Demand} \times \text{Growth Rate} \quad (5)
\]

\[
\text{Total Transport Demand} = \text{Integ} \left( \text{Change In Total Transport Demand} \right) \quad (6)
\]

**Modal Shift**

Figure 7 shows the change in the modal according to the government policies and differences in competitiveness. The curve value study was based on the study of Yoshizaki et al. (2007).

![Figure 7 – Modal Shift.](image)
Main equation:

\[
\text{Mode Shift Road x Cabotage} = \int \left[ \text{"Comparative advantages between modals (cost and capacity)"} + \text{Government Policies to Mode Shift Road x Cabotage} \right]
\]

(7)

Tables:

Table 4 lists the government policies with the pressure to reduce CO\(_2\) emissions. These values are assumptions adopted for the study, because it is currently difficult to predict those parameters.

<table>
<thead>
<tr>
<th>Pressure to reduce CO(_2)</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Policies</td>
<td>0</td>
<td>0</td>
<td>0.001</td>
<td>0.002</td>
<td>0.004</td>
<td>0.006</td>
<td>0.01</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 shows the ratio of the difference between the use of modals and generating competitive advantages. Obtaining the curve value study was based on the study of Yoshizaki et al. (2007) and Costa et al, 2009.

<table>
<thead>
<tr>
<th>Difference between modals</th>
<th>0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative advantages</td>
<td>0</td>
<td>0.0415</td>
<td>0.078</td>
<td>0.11</td>
<td>0.137</td>
<td>0.19</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Yoshizaki et al. (2007) and Costa et al, 2009 (adapted).

**GHG emissions**

Figure 8 Totals CO\(_2\) emissions based on the modal emissions (road and cabotage).
Main equations:

\[ \text{CO}_2 \text{ Emissions} = \text{Integ} (\text{Cabotage Transp CO}_2 \text{ Emissions} + \text{Road Transp CO}_2 \text{ Emissions}) \] (8)

\[ \text{Road Transp CO}_2 \text{ Emissions} = \text{Road Transp Demand} \times \text{Road Transp CO}_2 \text{ Emissions Rate} \] (9)

\[ \text{Cabotage Transp CO}_2 \text{ Emissions} = \text{Cabotage Transp Demand} \times \text{Cabotage Transp CO}_2 \text{ Emissions Rate} \] (10)

Table:

Table 6 lists the CO\textsubscript{2} emissions with the pressure to reduce CO\textsubscript{2} emissions. These values are assumptions adopted for the study, because those parameters are currently difficult to predict.

<table>
<thead>
<tr>
<th>CO\textsubscript{2} Emissions (Gt)</th>
<th>0</th>
<th>500</th>
<th>1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure to reduce CO\textsubscript{2}</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Obs: Based on the worst case, existing and growing pressure to understand the implications on PNLT and the transport infrastructure in Brazil.

Cargo Transportation in Brazil

One of the greatest challenges of this work was to obtain a representative set of data of cargo transportation in Brazil. Although the Brazilian governmental regulatory agencies regulate the transport activities in Brazil, such as the National Land Transport (ANTT) and the National Waterway Transport (ANTAQ), they do not have a centralized database with a matrix with origin and destination of national transport. Even the Ministry of Transport does not have a centralized database that serves as a source for determining the required variables values. Therefore, the development of this work is based on information obtained from professional private companies operating in road and cabotage modes.

The full list of model variables is presented in Annex A as well as their initial values used in this work.

4.1 Demand Estimation

The estimated demand used in this work was based on data obtained from PNLT and from the enterprise Log-In Logística Intermodal (Log-in, 2010) that operates in the cabotage transport in Brazil. In 2009, this company hired a consultancy to assess the potential of cargo that would shift from the road transportation mode to the cabotage mode. According to this study, in 2009 93 million tons of cargo were handled per month. Excluding bulk handling, intra-state transportation and the states not competitive for the maritime mode, a potential of 2.5 million tons of cargo per month was estimated for movement by cabotage (Figure 9).

Considering an average weight of 16.5 tons per container, the market potential of cabotage was estimated at 2.5 million ÷ 16.5 = 151,000 TEUs (Twenty-Foot Equivalent Unit). The estimated volume achieved by this mode in 2009, estimated at 24,000 TEUs per month, so the total potential market that year was 151,000 + 24,000 = 175,000 TEUs per month. The results of this study are summarized in Figure 9.
In the same study, the potential market for cabotage by 2018 was projected considering a linear growth of Brazilian GDP of about 3% per year as from 2010. Figure 10 illustrates the estimated market growth of cabotage transportation mode resultant from this study.

\[
D_C = 0.27 D_T
\]

where, \(D_C\) is the demand for cabotage and \(D_T\) is the total demand for transportation

The total demand for transportation has a relationship with the level of economic activity of a country, and one of the indicators used to estimate the growth in demand is related to the Gross Domestic Product (GDP), as shown in Figure 1. Thus, in order to determine the demand trend curve, the current TKU (ton per kilometer) should be obtained and its growth estimated in function of the GDP growth. The PNLT considered for
calculating the GDP by region and a matrix of origin and destination obtained by simulation as there are no official data. This method of demand generation is not used in this work and macro values are considered here for the whole country and not per region. Therefore, the transport mode production participation values from 2006 are adopted in this work, as shown in Table 7 (CNT, 2009).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Million (TKU)</th>
<th>Participation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>485,625</td>
<td>61.1</td>
</tr>
<tr>
<td>Railroad</td>
<td>164,809</td>
<td>20.7</td>
</tr>
<tr>
<td>Waterway</td>
<td>108,000</td>
<td>13.6</td>
</tr>
<tr>
<td>Pipeline</td>
<td>33,300</td>
<td>4.2</td>
</tr>
<tr>
<td>Air</td>
<td>3,169</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>794,903</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

The PNLT considers the planning horizon from 2005 to 2025; therefore, the total annual demand should be estimated for the same period. In order to perform such estimation, a value of 1.5 was considered. This value was obtained with long-experience logistics professionals working in the cabotage transport mode.

The projection of demand is presented in Table 8. The demand for road and waterway are calculated according to the PNLT transport matrix presented in Table 2 without considering the pressure for modal shift. In turn, the demand for cabotage is calculated using the 0.27 factor presented in Equation 11.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TOTAL DEMAND TKU</th>
<th>TKU % Grow Rate</th>
<th>% Road PNLT</th>
<th>Road TKU</th>
<th>% Cabotage PNLT</th>
<th>Cabotage TKU</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>719,910</td>
<td>6.8%</td>
<td>79.0%</td>
<td>568,729</td>
<td>21.0%</td>
<td>151,181</td>
</tr>
<tr>
<td>2011</td>
<td>768,864</td>
<td>6.8%</td>
<td>77.3%</td>
<td>594,075</td>
<td>22.7%</td>
<td>174,788</td>
</tr>
<tr>
<td>2012</td>
<td>821,147</td>
<td>6.8%</td>
<td>75.5%</td>
<td>620,239</td>
<td>24.5%</td>
<td>200,907</td>
</tr>
<tr>
<td>2013</td>
<td>876,985</td>
<td>6.8%</td>
<td>73.8%</td>
<td>647,215</td>
<td>26.2%</td>
<td>229,770</td>
</tr>
<tr>
<td>2014</td>
<td>936,620</td>
<td>6.8%</td>
<td>72.1%</td>
<td>674,990</td>
<td>27.9%</td>
<td>261,629</td>
</tr>
<tr>
<td>2015</td>
<td>1,000,310</td>
<td>6.8%</td>
<td>70.3%</td>
<td>703,551</td>
<td>29.7%</td>
<td>296,759</td>
</tr>
<tr>
<td>2016</td>
<td>1,068,331</td>
<td>6.8%</td>
<td>68.6%</td>
<td>732,875</td>
<td>31.4%</td>
<td>335,456</td>
</tr>
<tr>
<td>2017</td>
<td>1,140,977</td>
<td>6.8%</td>
<td>66.9%</td>
<td>762,933</td>
<td>33.1%</td>
<td>378,044</td>
</tr>
<tr>
<td>2018</td>
<td>1,218,564</td>
<td>6.8%</td>
<td>65.1%</td>
<td>793,691</td>
<td>34.9%</td>
<td>424,873</td>
</tr>
<tr>
<td>2019</td>
<td>1,301,426</td>
<td>6.8%</td>
<td>63.4%</td>
<td>825,104</td>
<td>36.6%</td>
<td>476,322</td>
</tr>
<tr>
<td>2020</td>
<td>1,389,923</td>
<td>6.8%</td>
<td>61.7%</td>
<td>857,119</td>
<td>38.3%</td>
<td>532,804</td>
</tr>
<tr>
<td>2021</td>
<td>1,484,438</td>
<td>6.8%</td>
<td>59.9%</td>
<td>889,673</td>
<td>40.1%</td>
<td>594,765</td>
</tr>
<tr>
<td>2022</td>
<td>1,585,380</td>
<td>6.8%</td>
<td>58.2%</td>
<td>922,691</td>
<td>41.8%</td>
<td>662,689</td>
</tr>
<tr>
<td>2023</td>
<td>1,693,185</td>
<td>6.8%</td>
<td>56.5%</td>
<td>956,085</td>
<td>43.5%</td>
<td>737,100</td>
</tr>
<tr>
<td>2024</td>
<td>1,808,322</td>
<td>6.8%</td>
<td>54.7%</td>
<td>989,755</td>
<td>45.3%</td>
<td>818,567</td>
</tr>
<tr>
<td>2025</td>
<td>1,931,288</td>
<td>6.8%</td>
<td>53.0%</td>
<td>1,023,583</td>
<td>47.0%</td>
<td>907,705</td>
</tr>
</tbody>
</table>

This method of calculating demands results in a very high percentage of participation of cabotage mode in waterway in the early years. In the absence of more detailed data for
validation of the values obtained, this work disregards the first 5 years of the table and uses only the values from 2010.

4.2 Capabilities Estimation

The estimated capacity of each transportation mode considers that the current demand is being met by a utilization factor, which was estimated by the Alliance Company logistics professionals as being 0.8. Table 9 shows the estimated capacities of each transportation mode at the beginning of the planning horizon.

<table>
<thead>
<tr>
<th>Year</th>
<th>Road</th>
<th>Cabotage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>710,911</td>
<td>188,976</td>
</tr>
</tbody>
</table>

The capacity of each transportation mode has some dynamic characteristics of loss and replacement that affect the available capacity to meet the demand. Analyzing these characteristics with logistics professionals, a relationship between growth and investment was identified on roads and vehicles for the road transportation and on vessels and ports for the cabotage transportation. On the other hand, the capacities are decreasing with the obsolescence of the vehicles on road transportation and vessels on cabotage.

Considering only the information provided by the PNLT, a government investment of R$ 74,194 million in the road mode and R$ 25,162 million is required in the cabotage mode (ports only) in order to increase the capacity of those transportation modes.

Fleet obsolescence rates are difficult to estimate since they must consider the average age of the vehicles fleet on road transportation and their participation in meeting the demand of this transportation mode. The same applies to the fleet of vessels in the cabotage mode. Since these relationships cannot be derived due to lack of available data, the obsolescence rate used in this work was 1% per year for the two transportation modes.

Table 10 shows the values of cost and obsolescence for each transportation mode.

<table>
<thead>
<tr>
<th></th>
<th>Road</th>
<th>Cabotage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for replacement</td>
<td>0,1213</td>
<td>0,0297</td>
</tr>
<tr>
<td>Rate of obsolescence</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

4.3 CO₂ Emissions

The GHG emitted from each key category (1A3b – Road transportation and 1A3d – Water-borne Navigation) is considered separately in this work. Carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) are emitted from both road and cabotage transportation modes. The key category analysis is performed for each of these gases separately because the methods, emission factors and related uncertainties differ for each gas.

After the calculation of each gas emissions, their values are converted to CO₂ equivalent, which is the emissions measurement standard, by multiplying the quantities calculated by the conversion factors for each gas (CO₂ = 1, CH₄ = 23 and N₂O = 296) (U.S. Department of Energy, 2009) and summing them up as depicted in Equation (12).

\[
CO₂eq = CO₂ + (23 \times CH₄) + (296 \times N₂O)
\]  (12)
Based on the equation of CO$_2$ eq. Figure 11 below shows CO$_2$ per kg emissions in each modal for every 1,000 tku transported.

![CO$_2$ emissions by transport mode](image)

Figure 11 – CO$_2$ emissions by transport mode). Brazil, Ministry of Transportation (2009)

### 4.4 Scenarios

The model has been built with the VENSIM software based on the approach of System Dynamics Modeling. The model simulates the transport demand in one market segment, specifically the transport of general cargo, via road transportation and coastal shipping (cabotage).

The model was used to simulate five different scenarios the variable values of which are defined in Table 11. The first scenario provides a pessimistic case (worst case), where no modal shift is expected. Scenarios 2 and 3 represent moderate cases, while scenarios 4 and 5 are considered optimistic cases. The parameters that will be changed in all the scenarios are the level of investment in the capacity of road transport and cabotage and the presence or absence of pressure to reduce CO$_2$.

The scenarios were created considering the possibility of covering the limits of the events that may occur. The pessimistic scenario would represent the worst case, in which the change of modal PNLT proposal would not occur; the moderate scenarios represent the modal shift at a rate as proposed in PNLT optimistic scenarios and evaluate a condition in which the modal shift is more pronounced.

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Road Investments</th>
<th>Cabotage Investments</th>
<th>Pressure to reduce CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pessimistic</td>
<td>x 1.5</td>
<td>x 0.5</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>x 1.0</td>
<td>x 1.0</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>Moderate CO$_2$</td>
<td>x 1.0</td>
<td>x 1.0</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>Optimistic</td>
<td>x 1.0</td>
<td>x 1.5</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>Optimistic CO$_2$</td>
<td>x 1.0</td>
<td>x 1.5</td>
<td>yes</td>
</tr>
</tbody>
</table>
As far as other parameters are concerned:
- Initial time: 2010;
- Final time: 2025.
- Time step: 0.03125 years.

5 Main results

The results of the system dynamics model are available in several dimensions:
- Modal shift: showing the transition and maturation of the change of modal.
- Comparative advantages.
- CO$_2$ emissions: shows the evolution of CO$_2$ emissions.

A significant result for analysis is the rate of change of modal. Figure 12 shows the behavior of this variable. This graph represents the modal share of cabotage in the total demand, as a consequence of model assumptions, the share of road transportation is provided by the complementary value of the percentage. We may note in the scenarios Moderate CO$_2$ and CO$_2$ Optimist that the presence of pressure to reduce CO$_2$ has a significant impact on the final value of participation of modes, besides providing a stronger growth in the last decade of the simulation. This difference in the last decade can be better understood with the values of comparative advantages.

![Cabotage share graph](image)

Figure 12 – Scenarios modal shift (cabotage share).

Comparative advantages are shown in Figure 13. This figure shows the synthesized form of the competitive advantage of modal cabotage on the roads; this advantage is represented by the fraction of the annual migration of a modal to another. In the pessimistic scenario, where there is no change of modal, one can see that the advantage of modal cabotage is not representative. In the Moderate and Optimistic scenario, we see a creation of an early lead and maintained that advantage over time. It is worth noting that the maintenance of competitive advantage over time did not cause a more representative modal shift than changes in CO$_2$ and Optimistic scenarios Moderate CO$_2$. This dynamic is shown in Figure 13.
Figure 13 – Comparatives advantages between road and cabotage.

Figure 14 presents the scenarios Optimistic, Optimistic CO₂ Optimistic advantages and Advantage CO₂. In the graph, it is apparent that the competitive advantage of Optimistic scenario (green) the modal share of coasters does not remain. By contrast, CO₂ Optimistic scenario there is an increased modal share of cabotage even with the decline of competitive advantage; this is due to the presence of the factor of pressure to reduce CO₂ emissions.

Initially, a strong level of inertia makes the modal shift a slow and sometimes difficult to perceive process. Only a few users will experiment with modal shift, often as part of a publicly subsidized initiative (government providing the initial funding to develop infrastructures). Inertia implies that the modal shift is often much less significant than expected, leading to a situation of underperformance. The reasons behind the inertia are linked to accumulated investments and assets in the prior mode and terminals.

This observation is interesting because what we see in Moderate and Optimistic scenario is a process of maturation inertia and modal migration, despite this attempt to stabilize over the years, which slows the modal shift. With the presence of pressure to reduce CO₂, CO₂ scenarios Moderate and Optimistic CO₂ process of modal shift has a faster maturation.

Maturation occurs when the full potential of the modal is reached and a new equilibrium in modal share is reached, so their respective comparative advantages are of lesser variance.
Regarding CO₂ emissions, as in Figure 15 below, the Pessimistic Scenario (1) presents a worse than the other scenarios (13%) as compared to the Optimistic CO₂ scenario. The other scenarios show that the main factor in the reduction of CO₂ emissions is to invest in cabotage.

6 Conclusions

The objective was to evaluate the impacts of the implementation of the Brazilian National Plan for Logistics and Transport (PNLT) in the CO₂ emissions from transportation of domestic cargo in Brazil. To do so, a model based on system dynamics was used that allowed the analysis of the causal processes that occur in a modal shift in the matrix. Five
scenarios were simulated that showed that the inertia for the maturation of the modal shift is long, which is actually observed in practice. These delay factors corroborate that this modal shift will occur is always beneficial. In the model, the impact of the implementation of a pressure to reduce CO\textsubscript{2} emissions in the simulation showed that this parameter is beneficial in the acceleration process of modal shift. This highlights the importance of public power as a motivator of the implementation of practices that do less damage to the environment.

References


Doll, C.. Fiorello, D; Pastori, E; Reynaud, C.; Klaus, P.; Lückmann, P.; Hesse, K.; Kochsieck, J.Long-Term Climate Impacts of the In-roduction of Mega-Trucks Study to the Community of European Railways and Infrastructure Companies (CER), Brussels. Fraunhofer ISI (study co-ordinator, Karlsruhe) TRT (Milan), NESTEAR (Gentilly), Fraunhofer-ATL (Nuremberg), Fraunhofer-IML (Dortmund). Karlsruhe, July 2008.


### ANNEX A – Description of the System Dynamics model

<table>
<thead>
<tr>
<th>Nº</th>
<th>Name</th>
<th>Unit</th>
<th>Input (n°) and [Unit]</th>
<th>Equation</th>
<th>Output (n°) and [Unit]</th>
<th>Initial Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Change in Road Capacity</td>
<td>TKU/ (Year*Year)</td>
<td>▪ (9) Government Investments in Road Transport Capacity [Money/Year]</td>
<td>(Government Investments in Road Transport Capacity*Pressure to Improve Road Capacity)/Road Transport Capacity Investment Rate</td>
<td>▪ (2) Road Transport Capacity [TKU/Year]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (7) Pressure to Improve Road Capacity [Dmnl]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (8) Road Transport Capacity Investment Rate [Money/(TKU/Year)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Road Transport Capacity</td>
<td>TKU/ Year</td>
<td>▪ (1) Change in Road Capacity [TKU/(Year*Year)]</td>
<td>Change in Road Capacity-Road Transport Capacity Erosion</td>
<td>▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]</td>
<td>710911</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (6) Road Transport Saturation [Dmnl]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Road Transport Capacity Erosion</td>
<td>TKU/ (Year*Year)</td>
<td>▪ (2) Road Transport Capacity [TKU/Year]</td>
<td></td>
<td>▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (4) Road Capacity Erosion Rate [1/Year]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Road Transport Capacity Erosion Rate</td>
<td>1/Year</td>
<td></td>
<td></td>
<td>▪ (3) Road Transport Capacity Erosion [TKU/(Year*Year)]</td>
<td>0.01</td>
</tr>
<tr>
<td>5</td>
<td>Road Transport Demand</td>
<td>TKU/Year</td>
<td>▪ (29) Mode Shift Road x Cabotage [Dmnl]</td>
<td>(1-Mode Shift Road x Cabotage)*TOTAL TRANSPORT DEMAND</td>
<td>▪ (6) Road Transport Saturation [Dmnl]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (34) TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Road Transport Saturation</td>
<td>Dmnl</td>
<td>▪ (5) Road Transport Demand [TKU/Year]</td>
<td>Road Transport Demand/Road Transport Capacity</td>
<td>▪ (7) Pressure to Improve Road Capacity [Dmnl]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (2) Road Transport Capacity [TKU/Year]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Pressure to Improve Road Transport Capacity</td>
<td>Dmnl</td>
<td>▪ (6) Road Transport Saturation [Dmnl]</td>
<td>2.9*Road Transport Saturation^4.73</td>
<td>▪ (1) Change in Road Capacity [TKU/(Year*Year)]</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Road Transport Capacity Investment Rate</td>
<td>Money/(TKU/Year)</td>
<td></td>
<td></td>
<td>▪ (1) Change in Road Capacity [TKU/(Year*Year)]</td>
<td>0.121255</td>
</tr>
<tr>
<td></td>
<td>Government Investments in Road Transport Capacity</td>
<td>Money/Year</td>
<td>▪ (10) Initial Investment in Road Transport Capacity [Money/Year]</td>
<td>Initial Investment in Road Transport Capacity*Cumulative Growth</td>
<td>▪ (1) Change in Road Capacity [TKU/(Year*Year)]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>▪ (35) Cumulative Growth [Dmnl]</td>
<td></td>
<td></td>
<td></td>
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<td>Unit</td>
<td>Input (nº) and [Unit]</td>
<td>Equation</td>
<td>Output (nº) and [Unit]</td>
<td>Initial Value</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------</td>
<td>-----------------------</td>
<td>----------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>10</td>
<td>Initial Investment in Road Transport Capacity</td>
<td>Money/ Year</td>
<td></td>
<td></td>
<td>(9) Government Investments in Road Transport Capacity [Money/Year]</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Change in Cabotage Capacity</td>
<td>TKU/ (Year* Year)</td>
<td>• (19) Government Investments in Cabotage Transport Capacity [Money/Year]</td>
<td>(Government Investments in Cabotage Transport Capacity*Pressure to Improve Cabotage Capacity)/Cabotage Transport Capacity Investment Rate [Money/(TKU/Year)]</td>
<td>(12) Cabotage Transport Capacity [TKU/Year]</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Cabotage Transport Capacity</td>
<td>TKU/ Year</td>
<td>• (11) Change in Cabotage Capacity [TKU/(Year*Year)]</td>
<td>Change in Cabotage Capacity-Cabotage Transport Capacity Erosion</td>
<td>(13) Cabotage Transport Capacity Erosion [TKU/(Year*Year)]</td>
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</tr>
<tr>
<td>13</td>
<td>Cabotage Transport Capacity Erosion</td>
<td>TKU/ (Year* Year)</td>
<td>• (12) Cabotage Transport Capacity [TKU/Year]</td>
<td>Cabotage Transport Capacity*Cabotage Transport Capacity Erosion Rate</td>
<td>(16) Cabotage Transport Saturation [Dmnl]</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Cabotage Transport Capacity Erosion Rate</td>
<td>1/Year</td>
<td>• (29) Mode Shift Roadx Cabotage [Dmnl]</td>
<td>(Mode Shift Roadx Cabotage)*TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td>(13) Cabotage Transport Capacity Erosion [TKU/(Year*Year)]</td>
<td>0.01</td>
</tr>
<tr>
<td>15</td>
<td>Cabotage Transport Demand</td>
<td>TKU/Year</td>
<td>• (34) TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td>(Mode Shift Roadx Cabotage)*TOTAL TRANSPORT DEMAND</td>
<td>(16) Cabotage Transport Saturation [Dmnl]</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Cabotage Transport Saturation</td>
<td>Dmnl</td>
<td>• (15) Cabotage Transport Demand [TKU/Year]</td>
<td>Cabotage Transport Demand/Cabotage Transport Capacity</td>
<td>(17) Pressure to Improve Cabotage Capacity [Dmnl]</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Pressure to Improve Cabotage Transport Capacity</td>
<td>Dmnl</td>
<td>• (16) Cabotage Transport Saturation [Dmnl]</td>
<td>2.9*Cabotage Transport Saturation^4.73</td>
<td>(11) Change in Cabotage Capacity [TKU/(Year*Year)]</td>
<td></td>
</tr>
<tr>
<td>№</td>
<td>Name</td>
<td>Unit</td>
<td>Input (n°) and [Unit]</td>
<td>Equation</td>
<td>Output (n°) and [Unit]</td>
<td>Initial Value</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>18</td>
<td>Cabotage Transport Capacity Investment Rate</td>
<td>Money/(TKU/Year)</td>
<td>• (20) Initial Investment in Cabotage Transport Capacity [Money/Year]</td>
<td>Initial Investment in Cabotage Transport Capacity*Cumulative Growth</td>
<td>• (11) Change in Cabotage Capacity [TKU/(Year*Year)]</td>
<td></td>
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<tr>
<td>19</td>
<td>Government Investments in Cabotage Transport Capacity</td>
<td>Money/Year</td>
<td>• (20) Initial Investment in Cabotage Transport Capacity [Money/Year]</td>
<td></td>
<td>• (11) Change in Cabotage Capacity [TKU/(Year*Year)]</td>
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</tr>
<tr>
<td>21</td>
<td>CO2 Emissions</td>
<td>Ton</td>
<td>• (26) Cabotage Transport CO2 Emissions [ton]</td>
<td>Integ (Cabotage Transport CO2 Emissions+Road Transport CO2 Emissions)</td>
<td>• (24) Pressure to Reduce CO2 Emissions [1/Year]</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>Road Transport CO2 Emissions</td>
<td>ton/Year</td>
<td>• (5) Road Transport Demand [TKU/Year]</td>
<td>Road Transport Demand*Road Transportation CO2 Emissions Rate</td>
<td>• (21) CO2 Emissions [ton]</td>
<td></td>
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<tr>
<td>23</td>
<td>Road Transportation CO2 Emissions Rate</td>
<td>ton/TKU</td>
<td>• (21) CO2 Emissions [ton]</td>
<td></td>
<td>• (28) Government Policies to Change Mode Shift Road x Cabotage [1/Year]</td>
<td>0.6</td>
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<tr>
<td>24</td>
<td>Pressure to Reduce CO2 Emissions</td>
<td>1/Year</td>
<td>• (21) CO2 Emissions [ton]</td>
<td></td>
<td>• (28) Government Policies to Change Mode Shift Road x Cabotage [1/Year]</td>
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<tr>
<td>25</td>
<td>CO2 Emissions Factor</td>
<td>1/(ton*Year)</td>
<td>• (21) CO2 Emissions Factor[1/(ton*Year)]</td>
<td></td>
<td>• (28) Government Policies to Change Mode Shift Road x Cabotage [1/Year]</td>
<td>1 (or 0)</td>
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<tr>
<td>26</td>
<td>Cabotage Transport CO2 Emissions</td>
<td>ton/Year</td>
<td>• (15) Cabotage Transport Demand [TKU/Year]</td>
<td>Cabotage Transport Demand*Cabotage Transportation CO2 Emissions Rate</td>
<td>• (21) CO2 Emissions [ton]</td>
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<tr>
<td>27</td>
<td>Cabotage Transportation CO2 Emissions Rate</td>
<td>ton/TKU</td>
<td>• (15) Cabotage Transport Demand [TKU/Year]</td>
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<td>• (21) CO2 Emissions [ton]</td>
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<tr>
<td>28</td>
<td>Government Policies to Change Mode Shift Road x Cabotage</td>
<td>1/Year</td>
<td>• (24) Pressure to Reduce CO2 Emissions [1/Year]</td>
<td>0.02*Pressure to Reduce CO2 Emissions^1.8671</td>
<td>• (29) Mode Shift Cabotage x Cabotage [Dmnl]</td>
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<tr>
<td>Nº</td>
<td>Name</td>
<td>Unit</td>
<td>Input (nº) and [Unit]</td>
<td>Equation</td>
<td>Output (nº) and [Unit]</td>
<td>Initial Value</td>
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<tr>
<td>29</td>
<td>Mode Shift Road x Cabotage</td>
<td>Dmnl</td>
<td>• (30) Comparative advantages between modals (cost and capacity) [1/Year]</td>
<td>Integ (&quot;Comparative advantages between modals (cost and capacity)&quot;)+Government Policies to Mode Shift Road x Cabotage</td>
<td>• (5) Road Transport Demand [TKU/Year]</td>
<td>0.21</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• (28) Government Policies to Mode Shift Road x Cabotage [1/Year]</td>
<td></td>
<td>• (15) Cabotage Transport Demand [TKU/Year]</td>
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<tr>
<td>30</td>
<td>&quot;Comparative advantages between modals (cost and capacity) &quot;</td>
<td>1/Year</td>
<td>• (6) Road Transport Saturation [Dmnl]</td>
<td>(-0.2377*(Road Transport Saturation-Cabotage Transport Saturation)^2+0.4377*(Road Transport Saturation -Cabotage Transport Saturation)/Time to Promove Modal Shift</td>
<td></td>
<td>0.21</td>
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<td>31</td>
<td>Time to Promove Modal Shift</td>
<td>Year</td>
<td>• (31) Time to Promove Modal Shift [Year]</td>
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<tr>
<td>32</td>
<td>Change in TOTAL TRANSPORT DEMAND</td>
<td>TKU/ (Year*Year)</td>
<td>• (32) Change in TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td></td>
<td>• (5) Road Transport Demand [TKU/Year]</td>
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<td>• (33) TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td>TOTAL TRANSPORT DEMAND*Grow Rate</td>
<td>• (15) Cabotage Transport Demand [TKU/Year]</td>
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<tr>
<td>33</td>
<td>TOTAL TRANSPORT DEMAND</td>
<td>TKU/Year</td>
<td>• (32) Change in TOTAL TRANSPORT DEMAND [TKU/Year]</td>
<td>Integ (Change in TOTAL TRANSPORT DEMAND)</td>
<td>• (5) Road Transport Demand [TKU/Year]</td>
<td>719910</td>
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<td></td>
<td>• (33) TOTAL TRANSPORT DEMAND [TKU/Year]</td>
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<tr>
<td>34</td>
<td>Change in Cumulative Growth</td>
<td>1/Year</td>
<td>• (35) Cumulative Growth</td>
<td>Cumulative Growth*Grow Rate</td>
<td>• (35) Cumulative Growth</td>
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<td>35</td>
<td>Cumulative Growth</td>
<td>Dmnl</td>
<td>• (34) Change in Cumulative Growth [1/Year]</td>
<td>Change in Cumulative Growth</td>
<td>• (34) Change in Cumulative Growth [1/Year]</td>
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<tr>
<td>36</td>
<td>Grow Rate</td>
<td>1/Year</td>
<td>• (36) Grow Rate</td>
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<td>0.068</td>
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