Economic Impact of Road Transport Development for Aquitaine for the Period 2007-2013 Subject to Regional Climate Plan Constraints

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This work was sponsored by the French Agency for Environment and Energy Management (ADEME) and Aquitaine regional council.

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Abstract

The region of Aquitaine has implemented a climate plan to reduce its greenhouse gas emissions by 10% during 2007-2013. Road transport must contribute to 24% of GHG emissions reductions. However, a large number of road infrastructure projects will be implemented during this period in order to keep up with traffic increases. The aim of this paper is to assess the economic contribution of road transport development and its impact on greenhouse gas emissions. We estimate opportunity costs so as to assess economic sacrifices necessary to offset the growth in emissions from road transport. We then compute net economic contribution of transport development by incorporating opportunity costs.

Keywords: Input-output analysis, minimum disruption approach, eco-environmental impact, opportunity cost, road transport, greenhouse gas emissions.

JEL :C76, H54, H76, Q52, Q54, R11, R53, R58
In conjunction with efforts at the national level, the Aquitaine region implemented a climate plan in March 2007. This plan is ambitious, because the target is to reduce by 10% greenhouse gas emissions (GHG) by 2013. Such a commitment presupposes specific actions. The climate plan is composed of 48 measures with a budget of 100 million Euros for the period 2007-2013.

In this context, any project increasing significantly GHG emissions must be offset against GHG reductions from other sectors of the regional economy.

We will consider the effects of road transport development programs in Aquitaine for the base period. Transport strongly contributes to GHG emissions. It represents some 30% plus of regional GHG emissions (CITEPA, 2007). According to the CITEPA (2007), between 1990 and 2005, regional GHG emissions fell by 1119 ktCO₂eq (- 4.65%) while GHG emissions from road transport increased by 591 ktCO₂eq (+8.92%). However, this is all the more worrying as, according to the climate plan, transport sectors must in fact make a contribution of 24% to GHG emissions reduction.

An examination of the regional road transport program reveals plans for a large number of highway projects, which would generate extra GHG emissions during both infrastructure construction and the period of road use. Each infrastructure construction project both generates wealth and spurs job creation, but it also causes environmental cost. In cost-benefit analyses, carbon cost is taken into account using tutelary values. To assess regional impact in accordance with climate plan targets, it is important to compute both economic contribution and opportunity cost. This leads us to ask the question: what consumption levels must be renounced in order to maintain the desired trajectory of GHG emissions reduction?

We are here located within a regional framework. Public authorities compare benefits in terms of services rendered with investment costs to assess cost of realization of infrastructure construction. This induces them to calculate the rate of return for the project. In this paper, we are interested both in economic and environmental (GHG emissions) impact of both road infrastructure construction and road use (road traffic).

Infrastructure construction projects contribute in a clear manner to the regional economy. It can be assumed that investment funds from outside the region would not have been injected into the regional economy if the projects had not been implemented. Regional monies can be directed into other sectors with quite significant wealth creation resulting. Therefore, we must take into account in the analysis only funds generated from outside the region when assessing projects’ economic contribution, whereas we must take total funding and investment into account, wherever it may come from, when assessing GHG emissions.

If an increase in GHG emissions occurs in the road transport sector, the only possibility for meeting climate plan targets lies in reducing final consumption in other sectors. Thus a trade-off must be made between creation of added value and jobs stemming from road projects and loss of added value and jobs resulting from a fall in final consumption to offset extra emissions from road transport use.

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3 Climate plan measures comprise ecological district development, renewable energy development, support for social housing with high-energy performance, promotion of energy independency for farms, and loans at reduced rates of interest to help households to invest in green improvements. The project of rail motorway (fast transport of trucks loaded on flat wagons), experimented with in 2008 by the RFF, the Réseau Ferré de France, is also incorporated.

4 See instructions from transport ministers of March 25, 2004

5 We outline in the appendix a simple and stylized model linking GDP and GHG emissions with transport and other economic sectors consumption as principal variables. These two variables induce GHG emissions and the sum of GHG emissions must be lower or equal to climate plan targets.
In the first section of this paper, we will briefly describe the input-output model as constructed for the Aquitaine region. We will point out the importance of such an exercise, but also its limitations.

In the second section, we will describe data used to estimate costs of road transport and road traffic.

In the third section, we will attempt to assess both economic and environmental impacts of road transport development by calculating GHG emissions as well as economic contributions.

In the final section, we will estimate the opportunity cost of road transport development. This will be compared against economic contribution.

1. The Input-Output model

The model we have constructed is a model based on the input-output table (IOT). The IOT outlines economic flows between different branches of an economy. It indicates both the origin and the destination of the goods and services of each branch. As the INSEE does not provide IOT’s at the regional level, we constructed one ourselves for the Aquitaine region for 2001. Furthermore, we constructed an environmental and energy balance sheet in order that energy and environmental data be consistent with economic data according to IOT classifications. Energy and environmental data were provided by the CITEPA.

Input-output (IO) analysis is advantageous as a tool for studying environment-economic connections with a high degree of sectoral detail. It incorporates into the analysis economic interactions by including complex sectoral interrelationships. Thus, we can evaluate both economic and environmental outcomes of a project by taking into account both direct and indirect effects.

An increase in final demand within a sector will directly raise output and emissions within that sector (a direct impact). Therefore, this sector, in order to increase its output, must increase its inputs. As a result, sectors which supply these inputs must raise at the same time their output and their emissions (first-round impact). As the output of these sectors increases, their input must rise also. Thus, sectors supplying these inputs must increase at the same time their output and their emissions (second-round impact), and so on. Direct and indirect effects are taken into account by the Leontief inverse matrix. Certain elements of a Leontief inverse matrix indicate the amount of direct and indirect production necessary to satisfy one unit of final demand. By integrating indicators such as energy intensity and emissions coefficients, we determine the amount of GHG emissions necessary to satisfy one euro of final demand.

This approach imposes onto the model a set of strong assumptions:
- Fixed technology, i.e. the share of different inputs remains unchanged (fixed technical coefficients).
- Constant return of scale: to double production, all inputs must also double, without exception.
- Linearity: labour intensity, energy intensity and emissions coefficients are stable.

This model is explained in more detail in Appendix 1.

After describing briefly the model, we will present data pertaining to road transport in the Aquitaine region.
2. Road Transport Projects for 2007-2013

We are interested only in projects involving construction of new infrastructure or significant increase in the capacity of existing infrastructures. We distinguish the information collected from the construction of infrastructure from that concerning road traffic increases.

Data on road infrastructure construction

Socio-economic studies conducted by local public authorities provide data on investment costs of road construction. Investment costs include construction costs, land acquisition costs and research costs. Based on discussion with the contracting authority, we can assume that construction costs and research costs account respectively for about 75% and 10% of the investment costs. The costs are expressed in euros as of 2001, because the IOT amounts are calculated for 2001. We selected four road projects: conversion of a two-lane road into a three-lane road within the western section of the Bordeaux ring road, construction of the highway between Langon and Pau (A65), conversion of a main road (RN10) into a highway (A63) in the département of Landes, and conversion of a two-lane road into a three-lane road along a highway in the Basque Country (A63).

We will also be interested in project financing, and more precisely where these funds come from. Economic impacts of the projects will not be the same depending on where funds come from. If monies come from the regional area itself, we will assume that they have no regional economic impact. If the project in question had not been undertaken, the funds would have been directed into other sectors, with quite a similar economic impact.

If funds come from the State or the contractor, these funds would not have been assigned to the region if the project had not taken place. Thus, only these funds produce any regional economic impact.

- Conversion of a two-lane road into a three-lane road within the western part of the Bordeaux ring road

We are concerned here only with the first phase of conversion of the two-lane road into a three-lane road. The second phase will be constructed after the base period of the climate plan. Investment cost, expressed exclusive of taxes, is estimated at €108 M\textsubscript{2000}, or €111.9 M\textsubscript{2001}. Research costs and construction costs are estimated respectively at €11 M\textsubscript{2001} and €84 M\textsubscript{2001}.

The financing of this project is under discussion. Local public authorities will indicate the amount of funds they intend to allocate when the PDMI (Programme de développement et de modernisation d’itinéraire) is implemented. This share will probably lie between 1/3 and 100% of total costs. We will assume the share of the State’s contribution will be 50% and that the rest will be covered by local authorities/government.

- Construction of A65

The construction of the A65 is set to be finished for October 2010. Investment costs are estimated at €1043 M\textsubscript{2004}, or €981 M\textsubscript{2001}. Research costs and construction costs are estimated respectively at €98 M\textsubscript{2001} and €738 M\textsubscript{2001}.

The A65 will be financed in its entirety by the contractor A’LIENOR. This project is set to be financed at a rate of 20% from the capital of A’LIENOR’s two sponsors (Eiffage and Sanef) and 80% from bank loans. Thus, this project will receive no public subsidies. We assume therefore that the monies for this project are to come in their entirety from outside the region.
- **Conversion of a main road (RN10) into a highway (A63) in the département of Landes**

According to the socio-economic analysis conducted, two phases are to be distinguished. The first phase is to be finished for 2009. This corresponds to the finalization of the installation of highway standards, the construction of two segments of approximately 15 km of the two-lane roads and construction of parking offering 1200 spaces for heavy goods vehicles (HGV). The second phase is slated to be finished for 2020. This second phase will not be taken into account in our model because it goes well beyond the study period. The investment costs are estimated for the first phase at €253 M\textsubscript{2006}, or €230 M\textsubscript{2001}. Research and construction costs are estimated respectively at €23 M\textsubscript{2001} and €173 M\textsubscript{2001}.

This project is to be tendered for contractor bids soon. Nevertheless, we have no access to any information regarding the name of the future contractor and the origin of funds to be invested. We assume that financing will be undertaken in its entirety by the contractor and that investment funds would come from outside the region.

- **Conversion of two-lane road into three-lane road on highway in the Basque Country (A63).**

Conversion of the two-lane road into a three-lane road along a highway in the Basque Country began in spring 2008 and is set to finish before 2016. However, socio-economic studies pertaining to this project have not been published. We were able only to obtain information on project costs. This is set at €520 M. We assume that these costs include research, construction and land acquisition costs. Research costs and building costs are estimated respectively at €52 M and €390 M.

This conversion of a two-lane road into a three-lane road in the Basque Country will be financed in its entirety by the ASF\textsuperscript{6}. We assume that investment monies will come in their entirety from outside the region.

Data on costs can be viewed in the table below.

### Table 1: Costs of the different road transport projects (In M€)

<table>
<thead>
<tr>
<th></th>
<th>ring road of Bordeaux</th>
<th>A63 Basque country</th>
<th>A63 Landes</th>
<th>A65</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>construction costs</td>
<td>84</td>
<td>390</td>
<td>173</td>
<td>736</td>
<td>1 362</td>
</tr>
<tr>
<td>research costs</td>
<td>11</td>
<td>52</td>
<td>23</td>
<td>96</td>
<td>184</td>
</tr>
<tr>
<td>land acquisition costs</td>
<td>17</td>
<td>78</td>
<td>36</td>
<td>147</td>
<td>275</td>
</tr>
<tr>
<td>TOTAL</td>
<td>112</td>
<td>520</td>
<td>230</td>
<td>981</td>
<td>1 843</td>
</tr>
</tbody>
</table>

Data on the origins of funds can be viewed in the table below.

### Table 2: Origins of funds for the financing of road transport projects

<table>
<thead>
<tr>
<th></th>
<th>Origins of funds (en M€)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>region</td>
<td>outside</td>
</tr>
<tr>
<td>ring road of Bordeaux</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>A63 Basque country</td>
<td>-</td>
<td>520</td>
</tr>
<tr>
<td>A63 Landes</td>
<td>-</td>
<td>230</td>
</tr>
<tr>
<td>A65</td>
<td>-</td>
<td>981</td>
</tr>
<tr>
<td>TOTAL</td>
<td>56</td>
<td>1 787</td>
</tr>
</tbody>
</table>

\textsuperscript{6} ASF : Autoroute du sud de la France
Having indicated the costs of the different projects and the origins of funds, we will turn now to the road traffic data.

**Data Pertaining to Road Traffic**

It is necessary to ascertain variations in road traffic due to these projects and to consider their economic and environmental impacts. The research institute for the North-South Corridor has been able to produce estimate variations of road traffic for the Aquitaine region in the north-south direction. We will use these data. It is advisable to apply due caution. However, as it is assumed that traffic will increase independently of infrastructure construction. Road infrastructure will be constructed only as a means to increase traffic flow-through. Although it is doubtful that the re-fitting that is envisaged will have such relief effects only, we will hold to that assumption in this study. We take into account here both the impact of the expected variation in traffic rate and the construction of the infrastructure itself.

Two hypotheses were put forth in regard to estimation of variations in passenger car and HGV traffic rates: a high hypothesis and a low hypothesis. In regard to passenger car traffic, this will grow on average at 4.9% per year for the high hypothesis and 2.5% per year for the low hypothesis. In terms of HGV traffic, this will increase 2.36% per year for the high hypothesis against 1.55% per year for the low hypothesis.

It is possible using this information to estimate both economic and environmental impacts of the development of road transport for Aquitaine region.

### 3. Economic and Environmental Impacts of Road Transport

We will discriminate between impact from the construction of road infrastructure and impact from road traffic per se, treating each separately. Following this, we will attempt to provide a synthesis of the data.

**Economic and environmental impact of construction of road infrastructure**

Research and construction costs will both feed the final demand for construction and R&D. The model that we have constructed makes it possible to determine both economic and environmental impact.

Table 3 below depicts the impact of different road projects according to economic indicators (final demand, employment, importation and added values) and environmental indicators (energy consumption and greenhouse gases).
Table 3: Economic and environmental impacts of construction of road infrastructure

<table>
<thead>
<tr>
<th></th>
<th>Economic Impact</th>
<th>Environmental Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Final demand</td>
<td>labour</td>
</tr>
<tr>
<td>ring road of Bordeaux</td>
<td>48</td>
<td>430</td>
</tr>
<tr>
<td>A63 Basque country</td>
<td>442</td>
<td>3,972</td>
</tr>
<tr>
<td>A63 Landes</td>
<td>196</td>
<td>1,750</td>
</tr>
<tr>
<td>A65</td>
<td>334</td>
<td>7,497</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,519</td>
<td>13,665</td>
</tr>
</tbody>
</table>

These projects are expected to create €781 M of added value. To build these roads, the region will have to import €707 M of goods and services, and 2,276 workers per annum\(^7\) would also be needed. In terms of environmental impact, these projects would be expected to increase energy consumption by 34 ktones. 80% of energy consumption is expected to come from liquid fuels. GHG emissions from these projects are forecast to be 129 ktCO2eq.

After estimating both economic and environmental impacts of construction of road transport infrastructure, we will estimate this impact along the same two parameters for road traffic.

**Economic and environmental impact of increase in road traffic rates**

We assume that the increase in final consumption from fuel, road transport industries and exportation of road transport industries is identical to the increase in passenger car traffic. We assume also that the increase of final consumption and exportation of goods transport is proportional to the rise in volume transported.

Results for the low hypothesis can be viewed in the table below.

Table 4: Economic and environmental impacts of road traffic increase (low hypothesis)

<table>
<thead>
<tr>
<th></th>
<th>Economic Impact</th>
<th>Environmental Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Final demand</td>
<td>labour</td>
</tr>
<tr>
<td>passenger transports</td>
<td>323</td>
<td>918</td>
</tr>
<tr>
<td>goods transports</td>
<td>151</td>
<td>1383</td>
</tr>
<tr>
<td>TOTAL</td>
<td>480</td>
<td>2301</td>
</tr>
</tbody>
</table>

Final demand is forecast to increase by €480 M. This would create an increase of €123 M of added value, an increase of imports of €341 M, and a demand for 2,301 workers for this period, or 384 workers per year. Energy consumption and GHG emissions will increase respectively by 224 ktones and 706 ktCO2eq.

Results for the high hypothesis can be viewed in the table below.

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\(^7\) It is important to note that the workers needed to construct road infrastructure are temporary workers. These disappear again when construction is finished.
Table 5: Economic and environmental impacts of road traffic increase (high hypothesis)

<table>
<thead>
<tr>
<th>Economic and environmental impact</th>
<th>Final demand (M€)</th>
<th>Labour (workers)</th>
<th>Importation (M€)</th>
<th>Added value (M€)</th>
<th>Energy consumption (ktOE)</th>
<th>GHG emissions (ktCO2eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>passenger transports</td>
<td>685</td>
<td>1910</td>
<td>569</td>
<td>111</td>
<td>420</td>
<td>1327</td>
</tr>
<tr>
<td>goods transports</td>
<td>235</td>
<td>2148</td>
<td>136</td>
<td>109</td>
<td>34</td>
<td>107</td>
</tr>
<tr>
<td>TOTAL</td>
<td>923</td>
<td>4058</td>
<td>675</td>
<td>222</td>
<td>454</td>
<td>1434</td>
</tr>
</tbody>
</table>

Final demand is forecast to increase by €920 M. This would create a growth of added value of €220 M, an increase in imports of €675 M, and a demand for 4 058 workers for this period, or 676 workers per year. Energy consumption and GHG emissions will increase respectively by 454 ktoe and 1 434 ktCO2eq.

The following summarizes the impact results laid out in tabular form above.

Economic and environmental impact of increase in road traffic

Economic and environmental impacts of an increase in road traffic are the sum of economic and environmental impacts of road infrastructure construction and of increase in road traffic.

Table 6 shows results for the low hypothesis.

Table 6: Economic and environmental impact of road transport development (low hypothesis)

<table>
<thead>
<tr>
<th>Economic and environmental impact</th>
<th>Final demand (M€)</th>
<th>Labour (workers)</th>
<th>Importation (M€)</th>
<th>Added value (M€)</th>
<th>Energy consumption (ktOE)</th>
<th>GHG emissions (ktCO2eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>construction of road infrastructure</td>
<td>1 519</td>
<td>13 665</td>
<td>707</td>
<td>751</td>
<td>34</td>
<td>129</td>
</tr>
<tr>
<td>increase of road traffic</td>
<td>450</td>
<td>2 301</td>
<td>341</td>
<td>123</td>
<td>224</td>
<td>706</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1 999</td>
<td>15 957</td>
<td>1 048</td>
<td>804</td>
<td>258</td>
<td>835</td>
</tr>
</tbody>
</table>

Added value and importations will increase respectively by €904 M and €1 048 M with 15 957 workers needed for this period (or 2 660 workers per year). Energy consumption and GHG emissions will rise respectively by 258 ktoe and 835 ktCO2eq.

Results for the high hypothesis can be viewed in Table 7.

Table 7: Economic and environmental impact of road transport increase (high hypothesis)

<table>
<thead>
<tr>
<th>Economic and environmental impact</th>
<th>Final demand (M€)</th>
<th>Labour (workers)</th>
<th>Importation (M€)</th>
<th>Added value (M€)</th>
<th>Energy consumption (ktOE)</th>
<th>GHG emissions (ktCO2eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>construction of road infrastructure</td>
<td>1 519</td>
<td>13 665</td>
<td>707</td>
<td>751</td>
<td>34</td>
<td>129</td>
</tr>
<tr>
<td>increase of road traffic</td>
<td>920</td>
<td>4 055</td>
<td>675</td>
<td>220</td>
<td>464</td>
<td>1 434</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2 439</td>
<td>17 714</td>
<td>1 382</td>
<td>1 001</td>
<td>488</td>
<td>1 563</td>
</tr>
</tbody>
</table>

Added value and importations will increase respectively by €1 001 M and €1 382 M with 17 714 workers needed for this period (or 2 660 workers per year). Energy consumption and GHG emissions will rise respectively by 488 ktoe and 1 563 ktCO2eq.
Regional economic contribution of road development could be calculated by an increase of worker or added value. But it is important to take into account also negative impact on the environment due to GHG emissions. To ascertain whether the development of road transport is in accordance with a GHG emissions reduction policy, we must calculate its opportunity cost.

### 4. Calculation of opportunity costs

Opportunity cost is defined as economic sacrifice undergone to offset extra emissions from the development of road transport. We use a minimum disruption approach (Proops et al., 1993) to calculate this cost. This is an optimization technique. It calculates the lowest variation of final demand to reach a GHG emissions reduction target. The aim here is to ascertain the minimum economic restructuring required to offset extra emissions from road transport. The model gives us final demand, added value and workers that must be sacrificed to offset extra emissions.

Following this it is useful to compare the economic contribution of development of road transport with its opportunity cost.

If this difference is positive, the economic contribution will be higher than costs to offset extra emissions. Development of road transport may operate in accordance with a GHG emissions reduction policy. However, if the difference is negative, economic contribution will be lower than costs to offset extra emissions. Development of road transport will not be able to operate in accordance with GHG emissions reduction policy.

We will compare the economic contribution of road transport development with its opportunity cost for both the high and for the low hypothesis.

Results for the low hypothesis can be viewed in Table 8.

<table>
<thead>
<tr>
<th>Table 8: Net economic contribution (low hypothesis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>economic contribution</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
<tr>
<td>final demand (M€)</td>
</tr>
<tr>
<td>added value (M€)</td>
</tr>
<tr>
<td>employment (workers)</td>
</tr>
</tbody>
</table>

For the low hypothesis, results are somewhat unclear. Road transport development has positive aspects for final demand and added value but negative aspects for employment.

Table 9 shows the net economic contribution for road transport development for the high hypothesis.
Table 8: Net economic contribution (high hypothesis)

<table>
<thead>
<tr>
<th></th>
<th>economic contribution (€)</th>
<th>opportunity costs (€)</th>
<th>net economic contribution (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>final demand (final)</td>
<td>2,439</td>
<td>3,692</td>
<td>1,153</td>
</tr>
<tr>
<td>added value (MV)</td>
<td>1,001</td>
<td>1,469</td>
<td>468</td>
</tr>
<tr>
<td>employment (workers)</td>
<td>17,714</td>
<td>33,001</td>
<td>16,287</td>
</tr>
</tbody>
</table>

Results show clearly that road transport development cannot operate normally in accordance with a GHG emissions reduction policy. Values for economic contribution are negative for final demand, added value and employment.

As a result of having conducted this study, we were able to calculate opportunity cost for each kilogram of CO₂ emitted. Opportunity cost is €2.3/kgCO₂eq for final demand, €0.94/kgCO₂eq for added value and 21 workers/kgCO₂eq for employment.

We conclude that road transport development for the period 2007-2013 will not run in compliance with GHG emissions reduction policy. Road transport infrastructure might be implemented successfully if road transport traffic, particularly for passenger traffic, is controlled. Otherwise, both economic and social advantages risk not being realized.
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APPENDIX 1: Detailed description of Input-Output model

Figure 1: Input-output analysis
Final demand (Y) comprises of:
- Final consumption (FC)
- Gross capital formation (GCF) is the sum of gross fixed capital formation (demand for capital goods) and changes in inventory
- Exportation (X)

\[ Y = FC + GCF + X (1) \]

Goods and services intended to meet final demand may be produced either within the region (final demand of local origin for goods and services (Y\text{d})) or imported (final demand of outside origin for goods and services (Y\text{m})). We assume here that the share of imported final consumption, gross capital formation and exportation of outside and local origin is fixed. Let respectively \( m_{i}^{FC} \), \( m_{i}^{GCF} \), \( m_{i}^{X} \) be the share of imported final consumption, gross capital formation and exportation.

Domestic local variations in final consumption, gross capital formation and exportation are calculated respectively:

\[
\Delta FC^d = (1 - m_{i}^{FC}) \Delta FC \quad (2) \quad \Delta FC^m = m_{i}^{FC} \cdot \Delta FC \quad (3)
\]

\[
\Delta GCF^d = (1 - m_{i}^{GCF}) \Delta GCF \quad (4) \quad \Delta GCF^m = m_{i}^{GCF} \cdot \Delta GCF \quad (5)
\]

\[
\Delta X^d = (1 - m_{i}^{X}) \Delta X \quad (6) \quad \Delta X^m = m_{i}^{X} \cdot \Delta X \quad (7)
\]

We can then calculate variation of domestic local final demand implementing equations (2), (4) and (6):

\[
\Delta Y^d_i = (1 - m_{i}^{FC}) \Delta FC_i + (1 - m_{i}^{GCF}) \Delta GCF_i + (1 - m_{i}^{X}) \Delta X_i \quad (8)
\]

We can also calculate variation of imported goods and services needed to satisfy final demand using equations (3), (5) and (7)

\[
\Delta Y^m_i = m_{i}^{FC} \cdot \Delta FC_i + m_{i}^{GCF} \Delta GCF_i + m_{i}^{X} \Delta X_i \quad (9)
\]

A change in final demand will modify domestic production through an Inverse Leontief matrix.

Let \( A_R \) be the regional technical coefficients. These are defined as the amount of regional input \( i \) required to produce one unit of regional gross output \( j \). Let I be the identity matrix and P the production vector. Regional output is found by multiplying an inverse Leontief matrix by a final demand vector for domestic goods and services.

\[
\Delta P = (I - A_R)^{-1} \Delta Y^d \quad (10)
\]

A variation in production will induce a change in added value (\( \Delta V \)). We assume that the amount of added value per unit of production will be the same because of the assumption of fixed technology.

\[
\Delta V_j = v_j \cdot \Delta P \quad (11)
\]
A variation in production will induce also a change in employment \((\Delta N)\) by assuming workers needed per unit of production (employment intensity) is fixed.

\[
\Delta N = n_i \Delta P_i \tag{12}
\]

To satisfy this production, intermediary inputs \((\Delta CI^m)\) will change also.

\[
\Delta CI^m = \sum_j m_{ij} \Delta P_j \tag{13}
\]

We can thus ascertain total variations in importation from final demand changes. Total variation in importation is the sum of imported input change (13) and change in final demand for imported goods and services (9).

\[
\Delta M_i = \Delta CI^m + \Delta Y^m \tag{14}
\]

A change in final demand will induce also changes in fossil fuel demand and GHG emissions of both households and companies. Production variation will modify both demands for fossil fuel \(f\) produced by sector \(i\) \((\Delta C^p_{if})\) and GHG emissions by assuming energy intensity (energy consumption needed to produce one unit of output) and GHG emissions coefficients (GHG emissions per unit of fossil fuel burnt \(e\) and GHG emissions per unit of output \(m\)) are fixed.

\[
\Delta C^p_{if} = c_{if} \Delta P_i \tag{15}
\]

\[
\Delta E^e_i = \sum_f e_{if} \Delta C^p_{if} + m_i \Delta P \tag{16}
\]

A variation in final demand will change final demand for fossil fuel \(f\) produced by sector \(i\) \((\Delta C^v_{if})\), whether it comes from the region or from outside, and change also GHG emissions by assuming the price of fossil fuel, and emissions coefficients are fixed. Let \(P_{if}^d\) and \(P_{if}^m\) be respectively domestically and imported inverse price of fossil fuel \(f\) produced by the sector \(i\).

\[
\Delta C^v_{if} = P_{if}^d \Delta FC^d_i + P_{if}^m \Delta FC^m_i \tag{17}
\]

\[
\Delta E^e_i = e_{if} \Delta C_i \tag{18}
\]

It is possible to ascertain thus total variation in fossil fuel consumption and GHG emissions from a change in final demand.

Total variation in fossil fuel consumption is the sum of variations in energy consumption from production (15) and variations in energy consumption from households (17)

\[
\Delta C_{if} = \Delta C^p_{if} + \Delta C^v_{if} \tag{19}
\]
Total variation of GHG emissions is the sum of variation of GHG emissions from production (16) and GHG emissions from households (18).

\[
\Delta E_i = \Delta E_i^p + \Delta E_i^y \tag{20}
\]
APPENDIX 2: Theoretical approach of net economic contribution of road transport development

We will first define the concept of arbitrage before then explaining net economic contribution of road transport development.

2.1. Arbitrage concept

GHG emissions are emitted by:
- transport sector: \( E_1 \)
- other economic sectors: \( E_2 \)

We must distinguish two types of consumption:
- consumption \( T \) responsible for emissions from transport sector: \( T = T(E_1) \)
- consumption \( C \) responsible for emissions from other economic sectors: \( C = C(E_2) \)

We assume that emissions are proportional to consumption. \( T'(E_1) > 0 \) et \( C'(E_2) > 0 \).

In our model, the gross domestic product (GDP) varies in accordance with consumption of transport sectors and other economic sectors.

\[
GDP = GDP\left[T\left(E_1\right), C\left(E_2\right)\right] \quad (21)
\]

The planner maximizes regional output subject to GHG emissions \( E \).

\[
\begin{align*}
\text{Max} & \quad GDP\left[T\left(E_1\right), C\left(E_2\right)\right] \\
\text{s.t} & \quad E_1 + E_2 = E
\end{align*}
\]

(22)

This program will be solved by using Lagrangian \( L \).

\[
L = GDP\left[T\left(E_1\right), C\left(E_2\right)\right] + \lambda \left(E - E_1 - E_2\right) \quad (23)
\]

First order conditions for a maximum are found by differentiating (23)

\[
\begin{align*}
\frac{\partial L}{\partial E_1} &= \frac{\partial GDP\left[T\left(E_1\right), C\left(E_2\right)\right]}{\partial T\left(E_1\right)} \cdot \frac{\partial T\left(E_1\right)}{\partial E_1} - \lambda = 0 \\
\frac{\partial L}{\partial E_2} &= \frac{\partial GDP\left[T\left(E_1\right), C\left(E_2\right)\right]}{\partial C\left(E_2\right)} \cdot \frac{\partial C\left(E_2\right)}{\partial E_2} - \lambda = 0
\end{align*}
\]

(24)

Producing the following result:
Equation (25) must be interpreted in the following way. To maintain the amount of GDP, an increase in emissions $E_1$ must be offset by a decrease in emission $E_2$. Thus arbitrage must be effected between these two types of emissions.

This problem can be represented graphically as presented below:

![Figure 2: Arbitrage of emissions arbitrary between road transport sectors and other economics sectors](image)

The line representing GDP represents all combinations of emissions from transport sectors ($E_1$) and other economic sectors ($E_2$) that induce the same amount of regional GDP. GDP is represented by a line because of an assumption of linearity in the input-output analysis. The line $D_1$ represents all combinations of emissions ($E_1$, $E_2$) that induce the same amount of total emission (emission constraint line). The optimization program aims to find an optimal combination of consumption for different economic sectors so as to maximize output subject to emissions constraints.

This results in emissions for transport sector $E_1$ as well as emissions for other economic sectors $E_2$, and so determines consumption for transport $T_{1}^{l}$ as well as consumption for other economic sectors $C_{2}^{l}$. It is represented by the point A in the graph above.

We assume an increase in consumption for transport. This leads to an increase of emissions from transport sectors from $E_1^1$ to $E_1^2$. To retain the same level of GDP, we must decrease emissions from other sectors from $E_2^1$ to $E_2^2$, and so decrease consumption from...
other economic sectors. This is represented by point C. The graph above represents the arbitrage to be carried out between emissions from transport sectors and other economic sectors in order to maintain level of GDP.

We will next explain net economic contribution of road transport development.

2.2. Concept of net economic contribution of a project

We will distinguish net positive economic contribution from net negative economic contribution.

The graph below describes a net positive economic contribution of road transport development.

![Figure 3: Case of Net positive economic contribution case](image)

At the beginning of the period, the region has a GDP level of GDP$_1$ with an emissions constraint represented by the line D$_1$.

The optimization calculation gives emissions from the transport sector and other economic sectors respectively equal to E$_1^2$ and E$_1^1$. The development of road transport will induce an increase in total production from GDP$_0$ to GDP$_1$ with an accompanying increase in emissions constraint (from D$_1$ to D'$_1$). Emissions from road transport thus will rise from E$_1^1$ to E$_1^2$. This rise in production (depicted in our graph by the passage from point A to point B) measures the economic contribution of the project. This equals GDP$_1$ - GDP$_0$. 
To offset extra emissions from road transport, emissions from other economic sectors must be reduced from $E_1^i$ to $E_1^o$ with $|E_1^i - E_1^o| = |E_1^2 - E_2^2|$. This entails a decrease in consumption for other economic sectors. The new amount of regional production is the intersection between the new emission constraint line $D_2$ and the line parallel to GDP permitting offset of extra emissions from road transport. In our example, regional production is equal to GDP$_2$. Point C is the new economic equilibrium. This offsetting will reduce regional production of GDP$_1$- GDP$_2$; this is the opportunity cost of road transport development. It represents the necessary level of wealth needed to be sacrificed to offset extra emissions from road transport.

In this case, GDP$_2$ > GDP$_0$. Net contribution of road transport development is positive: GDP$_2$-GDP$_0$> 0. Economic contribution of the projects is greater than its opportunity cost. Thus, road transport development will have a net positive economic impact.

Let us study a case of negative economic contribution.

![Figure 4: Case of net negative economic contribution](image)

The explanation of economic contribution of the project and its opportunity costs remains unchanged. However, in our case here, opportunity cost (GDP$_1$ – GDP$_2$) is higher than economic contribution (GDP$_1$ – GDP$_0$). Thus, net economic contribution of road transport development is negative (GDP$_2$ – GDP$_0$ <0). Wealth creation from road transport development is lower than the necessary sacrifices to offset extra emissions.