Anticipation of the access to the aggregate resource by breaking present schemes in the long term

Mario-Luis Rodriguez Chavez

Ecole doctorale n° 398 : Géosciences et Ressources Naturelles

Doctorat ParisTech

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Mario-Luis RODRIGUEZ CHAVEZ

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Directeur de thèse : **Jacques SCHLEIFER**

Jury

Peter MOSER, Professeur, Montanuniversität Leoben, Autriche	Rapporteur
Bert DE VRIES, Professeur, Universiteit Utrecht, Pays-Bas	Rapporteur
Isabelle CADORET, Professeur, Université de Rennes 1, France	Examinateur
Patrick LEBRET, Docteur, BRGM, Orléans, France	Examinateur
Arnaud COLSON, Ingénieur, UNICEM, Paris, France	Examinateur
Jacques SCHLEIFER, Docteur, MINES-ParisTech, Fontainebleau, France	Examinateur

T H E S E

MINES ParisTech
Centre de Géosciences
35, Rue Saint Honoré, 77305 Fontainebleau CEDEX

To Laura

Abstract

The classic belief that construction minerals are available in virtually infinite quantities has been shattered in many European countries by the rising difficulties in gaining access to the resource. A growing demand in construction aggregates has to cope with growing social, political and environmental constraints. The fact that the aggregates market is mainly regulated by mechanisms on the scale of the local surroundings of a consumption centre makes macroeconomic predictions difficult.

Based on the French-Austrian research project ANTAG (*Anticipation of the access to the aggregate resource by breaking present schemes in the long term*), a key issue of the research work was the conception and building process of a macroeconomic top-down model representing the French aggregates market. It shows an approach of modelling macroeconomic mechanisms in order to simulate long-term scenarios and anticipate the effect of breaking actions. The model calibration of the baseline case is performed using the principle of System Dynamics. The submodels reflect the dynamics of demand, accessibility, production, transport and impacts upon the environment, and their interaction.

A supply-and-demand equilibrium for each macro-region had to be found for the competitive supply end, which has been achieved by introducing an innovative macroeconomic competition modelling approach. The production of each supply source follows from a mechanism which allocates parts of the whole market overcapacity to them. The monitoring of the overcapacity of the primary sources and the dynamics of niche markets and their interaction with the competitive market are important features of this work. Missing time series data has been reconstructed making strong hypotheses, so that the authorized reserves, the extraction capacity and the actual production of a supply source of a region could be linked to each other via feedback loops.

Since the average transport distances from the quarries to the consumption centres are permanently increasing, they are mainly responsible for the CO_2 emissions within the construction minerals market. Modelling each mode of transportation allows comparative impact analyses of CO_2, transport flows, land-use and energy consumption on the basis of scenario simulations.

Seven selected breaking scenarios are presented and their simulation results are compared to the base case. An economic slowdown will reduce civil engineering activities and consequently the impacts upon the environment. A substitution of aggregates and new technology and a reduction of demand would have the same effect. A significant increase of recycling capacity will result in a reduction of crushed rock and alluvial deposits production as well as impacts due to smaller transport distances. A move away from road transport towards alternative transport modes results in a poor CO_2 reduction, since the secondary road transport now contributes to a larger extent and the waterway distances increase faster. A further scenario focuses on foreign aggregates penetrating the French market on a large scale and their transport. Local resources are being preserved at the cost of significantly higher transport flows. A shortfall of alluvial deposits due to a lack of social acceptability will result in a shortage of construction minerals. This lack of capacity can be balanced with an increase in hard rock capacity.

For the scenarios model feature extensions and implementations of secondary feedback mechanisms such as the transport capacity saturations or effects on the market equilibrium due to a new big player of the alternative modes were required. Uncertainty analysis using Monte Carlo method was performed for the base case and crucial submodel extensions.

Acknowledgements

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A FINITE AND INDISPENSABLE RESOURCE

1. Introduction

1.1 State of affairs and challenges in the aggregates market

Construction minerals are the second most exploited resource in France forming the basis of every infrastructure in the country. France consumes about 400 million tonnes of aggregates per year. The general trend of aggregates production in Metropolitan France in the last 30 years shows a clear increase in demand. The production history curve is cyclic, increasing by 0.8% on average per year (Figure 1). 93% of the current demand in aggregates is sourced locally and 95% of the aggregates are transported by road. The demand is satisfied by multiple types of supply sources, either of local origin or from abroad.

Producers, consumers, public authorities and society as a whole are currently confronted with a situation where future demand has to be satisfied under growing social, political and environmental constraints as well as rising difficulties in access. It is important to ask, therefore, how will the extraction profiles of the different supply sources evolve? And which transport modes will be used?

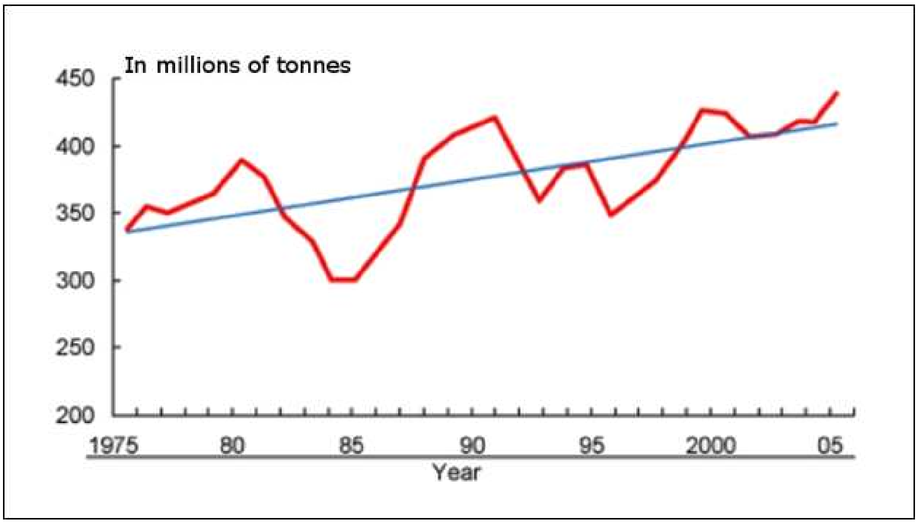

Figure 1: Consumption of construction aggregates in France (UNICEM data basis)

The characteristics considered specific for the aggregates market will be discussed as follows.

1.2 The supply end

The supply sources of aggregates are divided into different groups. Hard or crushed rock is extracted from quarries using explosives. In the last ten years crushed rock accounted for over 50% of national production. Alluvial deposits, unconsolidated or soft rock, are the second most exploited aggregate resource. They are extracted from streambeds and are usually of a better quality. Soft rock extraction has been continuously decreasing in the last years due to the fact that social acceptability has become a more and more important issue.

Marine aggregates and recycled material are regarded as secondary resources. Both together contribute to less than 10% of national demand. Marine aggregates which are extracted offshore resemble alluvial deposits in their nature, but since they are further away from most of the consumption centres, they are only used in particular regions of France today. Recycled minerals from building construction and public works are an alternative to classic mineral extraction, but their capacities seem limited at the moment.

Imports from abroad are marginal, at the moment, but constantly increasing. In 2004 the national imports have exceeded the exports for the first time. Considering the fact that the demand is growing we have to ask how the production profiles could evolve in the next 30 years. Where are the limitations?

1.3 Social acceptability

Local aggregates extraction has important social impacts. Social acceptability is a determining factor in terms of reserves provision. This socio-political phenomenon is a result of stakeholders' strategy, psychology and public debate. Aggregates, unlike other natural resources, are normally not exploited from underground mines, but from open-cast quarries. The most famous acronym in this respect is the so called NIMBY-effect (Not-In-My-BackYard) which expresses the attitude of people that there is a need for aggregates whilst simultaneously expressing the attitude of the same people against extraction from their own environment.

Campbell and Roberts (2003) reported in their case study of Michigan that people do not like industrial activity near their homes no matter how economically important they may be. There are several ongoing cases of conflicts, for example, even in places where aggregates production is a key minerals industry accounting for 70% of direct employment. This opposition is due to negative externalities, especially of hard rock quarry extraction (Willis and Garrod, 1999). It is clear that social acceptability plays a key role in the aggregates market, but where exactly does it intervene and to what extent? Social acceptability is obviously different for cases of crushed and soft rock. The fact that this parameter and its evolution are difficult to measure made its handling a major challenge throughout this study.

1.4 Particular transport conditions

The construction aggregates market is a local market characterised by a short average transport distance. This is due to the low value-to-weight ratio of aggregates, which means that transport costs contribute a large amount to the overall costs. Global predictions are tricky because aggregates are usually available on a regional basis. Restrictive environmental policies make access to the resource close to consumption centres difficult. Furthermore, urbanisation and depletion of reserves near consumption areas result in increasing haul distances from the quarry to the consumption centre. 95% of the current aggregates are transported by road, and only 5% by rail and waterway. This makes road transport responsible for the bulk of CO2 emissions. A study covering the costs of relocating sand and gravel mines has been carried out by Jaeger (2006).

1.5 Price inelasticity

One surprising conclusion may be the fact that the demand of aggregates is not price-elastic (Nötstaller, 2003) with the exception of road construction and maintenance (Willis and Garrod, 1999). The reason for this could be that the low price of aggregates only contributes a few percent to the total of civil engineering costs. Another reason could be the need for great masses of aggregates combined with the difficulty of substitution.

2. ANTAG - a strategic project

2.1 Aims and consortium

The thesis is based on the French-Austrian research project ANTAG (Anticipation of the access to the aggregate resource by breaking present schemes in the long-term; original title: “Anticipation de l’accès à la ressource granulats par rupture des schémas actuels à long terme”), which aims, first of all, at building a model representing the main mechanisms and principles which affect the access to aggregates in a realistic way. The model, once built, must allow simulating long-term evolutions of key economic and environmental parameters in the French aggregates market (Rodriguez Chavez et al., 2010a) over the next 30 years according to scenarios.

Issues currently discussed in the aggregates industry involve favouring alternative transport modes, in order to decrease road transport, which is the most pollutive transport mode; preserving of local resources by importing large quantities from abroad and/or increasing recycling capacities; repercussions on the shortfall of soft rock reserves and taking actions in order to balance the missing capacities. In this manner, the model must be flexible enough to allow the integration of new principles and mechanisms which could occur in the aggregates market. Its applications should not be limited to the current functioning of the aggregates industry and its mechanisms.

Environmental decision support systems have been built and applied in the past for different domains (Preface Environmental decision support systems, 2007) but not for the construction aggregates industry. The ANTAG-project targets the development of a System Dynamics model, which reflects the dynamics and interaction of demand, access, production, transport and allows an estimation of the future impact upon the environment on a national scale.

In this project, the actors in the French consortium are organised in a similar manner as described by Refsgaard et al. (2007). The organisations and their functions are:

– The Scientific Partner - Ecole Nationale Supérieure des Mines de Paris / ARMINES;

- The Industry Partner - Union Nationale des Industries de Carrières et Matériaux de Construction (UNICEM);
- The Public Authority Partner - Bureau de Recherches Géologiques et Minières (BRGM);
- The International Partner - Montanuniversität Leoben - University of Leoben (MUL), also working on an equivalent project in Austria with two partners:
  - ◊ Wirtschaftskammer Niederösterreich (Austrian Federal Economic Chamber);
  - ◊ Wirtschaftsministerium (Austrian Ministry of Economics).

2.2 Breaking away from current practice

The strategy of the project is to reform the traditional approach, which treats the French aggregates market on the scale of its hundred départements. The aim is to offer a macroeconomic approach, which considers the aggregates market globally. The *Schéma Départemental des carrières* (SDC) includes:

- an inventory of resources;
- the demand of construction minerals of each département;
- a transport mode analysis;
- an investigation of the impacts of existing quarries;
- an inventory of environmental data;
- an examination of targets aiming at reducing impacts upon the environment due to extraction and at favouring the rational use of construction material;
- an examination of targets for quarry rehabilitation after exploration.

The SDC covers the national economic interest, the demand of construction minerals of a département and of the neighbouring départements, protection of the environment, production sites and sensitive areas, and the need for balanced land management while promoting efficient use of natural resources.

Neither a geological nor a geographical inventory of resources will be considered within the ANTAG-project. The aim is to anticipate the macroeconomic effects of a trigger (a “breaking action”), such the increase of alternative transport, on the aggregates market by simulating long-term evolutions of consumption, supply and transport and their impact upon the environment provoked by a trigger. The project follows the approach: model – apply – convince. An economic model representing the state of affairs is calibrated using historical data by the consortium of partners. The model is then applied by simulating different scenarios in order to study the repercussions upon the model. Finally the model and its applications are presented to external organisations in order to convince them of the long-term benefits the model and its applications can offer in the future.

PART II

A MACROECONOMIC MODEL FOR AGGREGATES

3. Model specifications

3.1 Introduction

The characteristics of the construction aggregates market show that predictions in this domain are a complex task. In order to build a decision support system tool, first choices regarding the model conception have to be made. The consortium of the ANTAG-project had to decide on a geographic subdivision of the French territory depending on the national inhomogeneities in production and consumption behaviour. Another decision which will be discussed concerns the general structure of the model for the access to aggregates. Furthermore the modelling principle and why it had been chosen will be explained. Those first choices will be explained in the following chapters.

3.2 Treating inhomogeneities

Since the ANTAG-project follows a macroeconomic approach, the first idea would be to treat France as one block. Building one single model for the whole French territory, however, would neglect geographical inhomogeneities in its consumption and production behaviour, geographical split of reserves and consequently in its transport flow pattern.
In order to take into account those inhomogeneities a national subdivision is necessary. So the next step was to consider the market at a scale of the hundred French départements, the départements being the administrative units in France. This would have lead to the construction of one hundred models. Each model’s consumption, production and transport pattern would have had to be treated individually. The national consolidation of one hundred models would have been a tricky task, since at such a small scale, some regions might be importing 100% of their demand and others might be exporting 100% of their local production.

The Schéma Directeur d'Aménagement et de Gestion des Eaux (outline for the organization of the development and management of water resources) proposes a division into six distinctive macro-zones (Figure 2). The 100 départements are consolidated into:

- Adour-Garonne;
- Artois-Picardie;
- Rhône-Méditerranée;
- Loire-Bretagne;
- Seine-Normandie;
- Rhin-Meuse.

The advantages are, on one hand, the fact that the division corresponds to a large extent to the consumption basins initially envisaged, and, on the other hand, the fact that it offers a good split between the supply sources, mainly for the soft rock reserves being in the hydrographical basins. Furthermore the model has to be applied to six regions. The sum of inter-regional flows in 2005 at this macro-scale is at about 10 million tonnes, which is less than 2,5% of the national consumption.

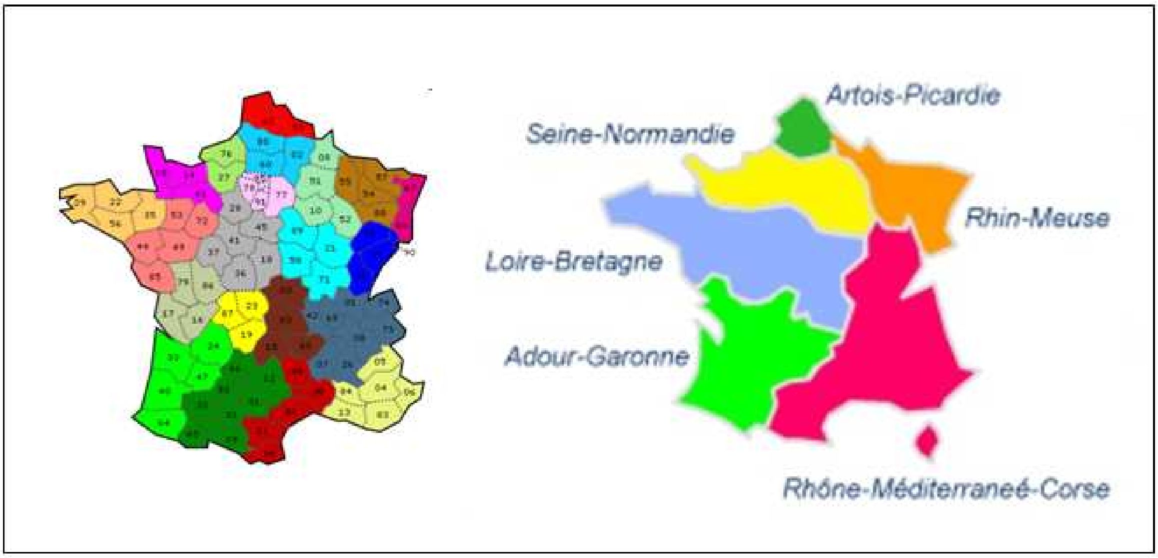

Figure 2: France divided into six regions

Adour-Garonne, for instance, is an autonomous region. The consumption of the whole region is produced within this zone. Loire-Bretagne exports construction aggregates to Seine-Normandie. Artois-Picardie is a transit region and a victim of the “domino-effect”. The region imports construction minerals from Belgium and exports to the region of Seine-Normandie. Seine-Normandie itself is a big consumer compared to its local production. Rhin-Meuse is a big exporter to foreign countries compared to its consumption. Rhône-Méditerranée connects the Rhône to the Mediterranean Sea and can be served to a large extent by waterway.

The next step now is the construction of a general model outline and its application to each of the six macro-regions, each of them having a different behaviour and being defined by region-specific data. The subsequent consolidation of all the regions has to confirm that the sum of the transport flows into all zones equals the sum of the transport flows out of all zones. The difficulties in the construction of the model are obvious. The transfer of a microeconomic local market to a macroeconomic global scale will require optimistic hypotheses.

3.3 Model structure

The model is divided into submodels. This makes it easier to understand its structure. The submodels' general structure is identical for each of the six regions in the base case model. The only exception is the market submodel, which varies from region to region due to differences in the production profiles of the supply sources and consequently in the market balance. The submodels are defined as:

- Consumption
- Market
- Production hard rock
- Production unconsolidated rock
- Multimodal transport split
- Road transport
- Alternative transport
- Energy
- Impacts upon the environment

A simplified scheme linking the main submodels is presented below (Figure 3). The consumption submodel computes a local demand in aggregates for each year. The first decision made during its conception was to divide the local demand of a region into two separate sectors: buildings and public works. The demand for each of the branches is driven by the input variables gross domestic product and population. The demand does not alter as a function of price, and the price has therefore been neglected in the consumption submodel. On the other hand the demand is mitigated by the substitution of aggregates by other material, and new technology reducing the quantity of aggregates needed in order to satisfy the same demand. The local demand is defined as the sum of the demand for buildings and public works. The total demand of a region is then defined as the sum of the local demand and the demand from other regions and abroad.

In the market submodel the total demand is satisfied by different supply sources. The submodels treating the two primary supply sources, hard rock and unconsolidated rock, basically function in the same way, but need to be separated for obvious reasons (different market development, different social acceptability, etc.). The secondary sources are handled in the market submodel.

The two production submodels are governed by mechanisms which allow the treatment of the following components:

– Production of the respective supply source;
– The corresponding production capacity;
– The stock of authorised reserves at a given point in time;
– The new authorisations each year (which depend on the social acceptability of the respective supply sources);
– Average production costs per tonne for the respective supply source (depending on the energy consumption).

No data could be gathered for the accessible reserves, which are potential production volumes in regions where no authorisations have been given out, yet (and from which a certain volume of aggregates would have been transferred to the stock of authorised reserves).

The transport submodel focuses on how aggregates are transported from the production sites to the consumption centres. The three modes of transportation (road, rail and waterway) are modelled separately. Each one is considered specific in terms of:

- Average transport distance;
- Transport volume;
- Transport flow (tonne-kilometres);
- Average transport costs per tonne kilometre for each of the modes;

The impacts upon the environment caused by production and transport volumes are gathered in the environmental-impacts submodel. The environmental impacts submodel stores the following parameters for the whole region:

- Energy consumed for all supply sources [l];
- Electricity consumed for all supply sources [kWh];
- Tonne-kilometres for all transport modes (transport flows);
- CO2 emissions for all supply sources and transport modes;
- Land-use [ha];
- Explosives used for hard rock production [t].

In order to perform a full analysis of these environmental parameters, the production of each supply source and the transport split must be determined on a macro-scale for each of the six regions. Comparative impact analyses on the basis of scenario simulations, however, require macroeconomic mechanisms, which adapt according to the scenario.

The main model structure of the constructed base case scenario, which represents the “business as usual” projected until 2037 (which corresponds to 30 years since the beginning of the ANTAG-project), is shown in Figure (3).

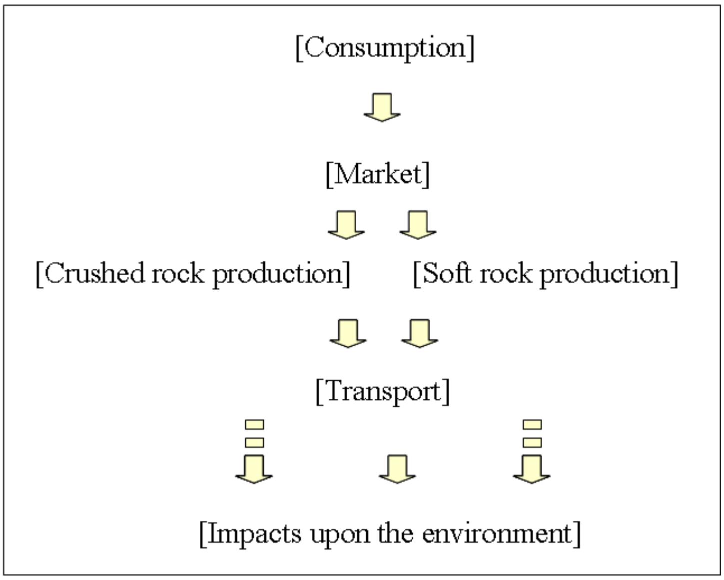

Figure 3: Linking the main submodels

This chain does not look like a classic supply chain known in standard economics. At the time of the basic conception of the model, feedback relationships to a submodel further upstream of the chain were not defined and other potential ones were not yet identified. Since in the current base case models, feedback relations already exist between the market- and the production submodels, this structure is not to be understood as a strict computational chain but rather as a logical sequence of submodels.

3.4 Modelling principle

It made sense to assume from the beginning of the study that, in principle, there are feedback relationships and interactions between variables from different submodels within each time step. A variable Y can be a function of X and Y might also influence X through a chain of cause and effect. However, it was not clear in the beginning where, how and under which circumstances these feedback relations might occur. It was clear, though, that it would make sense to introduce feedback at some point in the model and that there must be a possibility of doing so also at a later point in time. The modelling approach must thus allow the introduction of feedback not only in the early but also at the later stages of the model construction.

Judged from a long-term perspective, managing resources and environmental issues showed unexpected side-effects due to underestimation of the importance of feedback effects (Pahl-Wostl, 2007). The introduction of System Dynamics software (U.S. Department of Energy's, 1997) made sense, since it is specially designed to take feedback relationships into account. Even if some feedback loops, expected from the early stages of base case model construction, proved to be unrealistic throughout the study (as, for instance, the price effect on demand) System Dynamics has been kept as the modelling approach. The possibility of introducing (newly discovered) feedback relations at any stage of the model extension, as in scenario construction or refinement was crucial for this study.

Different System Dynamics packages have been used in related problems (van Vuuren et al., 1999; Salini and Karsky, 2003). The ANTAG-models have been built with the use of Vensim® Professional 5.4c. This icon-based programming language allows the introduction of endogenous variables. Therefore it uses stock-and-flow-structures. Stocks are defined by an initial level and are altered by possible flows into the stock and/or optional flows out of the stock. Stocks and flows can influence other variables and can also be a function of other variables and constants. Figure (4) shows a simplified excerpt of one of the submodels with a specific example of a stock-and-flow-structure in Vensim layout. System Dynamics computes the values of variables incrementally from one point in time to the next. The results are obtained in the form of time series.

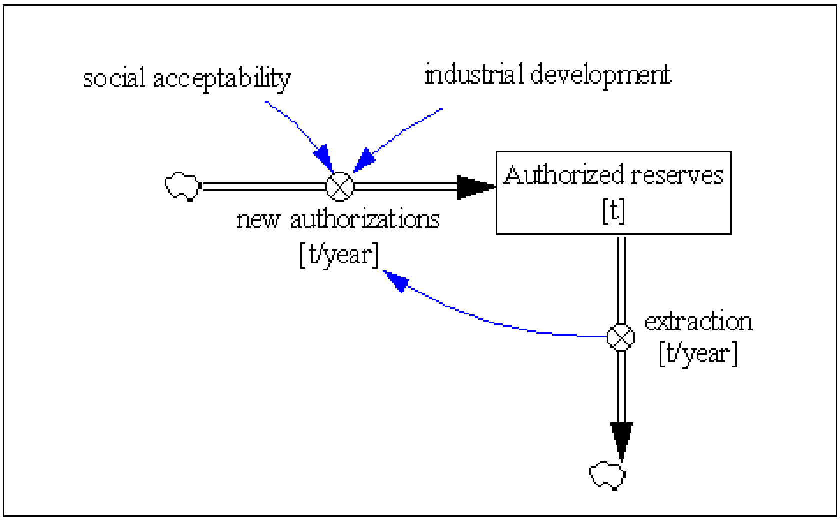

Figure 4: Stock-and-flow structure (excerpt of an ANTAG submodel)

In each time step the stock of authorised reserves is calculated as show in Equation (1).

$$Ra_{t+1} = Ra_t - e_t + a_t \quad (1)$$

Where

Ra_{t+1} ...	the level of authorised reserves in year t+1
Ra_t ...	the level of authorised reserves in year t
e_t ...	the aggregates extraction in year t (= production $\bullet$ waste factor)
a_t ...	the new authorisations in year t

The stock of authorised reserves is a quantity of reserves ready for extraction. Every time step the level is decreased by a flow of extraction (flow out) and increased by a flow of new authorisations (flow in). A simple feedback loop is introduced for the relationship between extraction and new authorisations: the new authorisations depend, among two other constant factors, on the extraction. Every feedback loop requires at least one stock.

In the ANTAG-models one time step has been defined to be a year. Due to data availability (see chapter 4.6) the starting time of the simulation will be 1995. Thus an initial value will have to be defined for each of the stocks in the model for the year 1995.
A difficult part in the use of System Dynamics is the identification of stocks and flows. The challenge is the transfer from causal relations between variables to stock-and-flock structures as shown in Figure (4).

4. Model calibration

4.1 Demand of a macro-region

4.1.1 Conception of the consumption submodel

The consumption submodel is aimed at computing the local demand per region. A separate handling and computation of the two sectors buildings and public works was necessary from the beginning due to the difficulty to directly linking the population to local demand. The demand is calculated for each of the branches before their tonnages are summed up (Figure 5). The main reason is that there is no constant ratio of tonnes consumed per inhabitant. This ratio is not only geographically dependent upon the zones but it also varies over time. Different modelling approaches have been proposed for the local demand of construction aggregates. An approach based on population projections has been performed by Jaeger (2006).

Before transferring the concept to stock-and-flow structures, we will first focus on the simple causal relations of this submodel. In the ANTAG-model the classic macroeconomic driver used is the gross domestic product per capita for each region. It drives both the demand of buildings and public works whereas both are mitigated by exogenous forces, one being the substitution and technology decreasing the demand in new aggregates, the other one being a demand-decreasing function at equal GDP for public works (Figure 5). This is not feedback within this submodel.

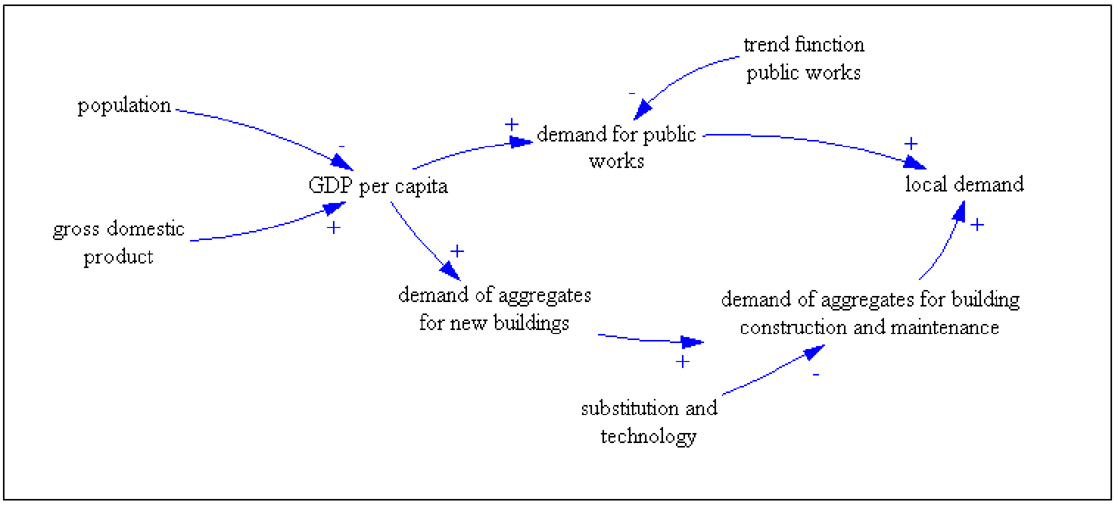

Figure 5: Causal relations for the consumption submodel

The population and the gross domestic product of each region have been modelled separately by expressing them as two different stocks. Even if the gross domestic product follows a flow concept, it has been decided to model it as a stock of which the value can easily be altered by a flow. The levels of the stocks are increased year by year by a flow each one describing their net increase. In order to introduce economic cycles the Time-function, which is automatically generated by Vensim, has been applied to the net increase of the gross domestic product. We can assume that the economic situation of country or a region will determine its construction activity, so introducing economic cycles in the model seems crucial, if we want to link GDP to the demand of aggregates.

$$Population_{t+1} = Population_{t} + NetIncreasePopulation_{t} \tag{2}$$

$$NetIncreasePopulation_{t} = \frac{CoeffPop}{Population_{t}} \tag{3}$$

Where

$Population_{t+1} \ldots$ population in year t+1

$Population_{t} \ldots$ population in year t

$CoeffPop \ldots$ calibrated constant

$$\mathrm{GDP}_{t+1} = GDP_{t} + NetIncreaseGDP_{t} \tag{4}$$

$$NetIncreaseGDP_{t} = GDP_{t} \bullet GrowthRate_{GDP} \bullet \{A + B \bullet \cos[(C + D \bullet Time) \bullet 2\pi]\} \tag{5}$$

Where

$A, B, C, D \ldots$ calibrated constants

$Time \ldots$ Vensim time function, starting with t=0 at the beginning of simulation

The demand of construction aggregates is related to the change in building [m^2/y] and the demand for public works [t/y]. We assume in the model that these two are related in a simple way to the change in GDP per capita. Initial attempts to relate GDP per capita to expenditures in the pubic works sector [€/year] and then convert the amount of euros into a demand of tonnes, failed due to a lack of data. Therefore, the demand of public works [t/year] is directly computed on the basis of GDP per capita.
The gross domestic product computes. In the buildings sector an impact delay of the gross domestic product per capita has been observed.

$$Buildings\left[\frac{m^2}{y}\right]_{t+1} = E \bullet GDPperCapita\left(\frac{€}{cap}\right)_t + F \qquad (6)$$

Where

E, F … calibrated constants

A peak in year t in the GDP per capita, for instance, will have a qualitative influence on the profile of the demand for buildings construction in year t+1. The fact that for this sector consumption data was available in square metres of new buildings per year and in tonnes of building construction and maintenance per year allowed a separate calibration of the substitution of aggregates by other materials and new technology for building construction. The meaning of this function is twofold:

- The use of a substituting material decreasing the number of tonnes used for a square metre of building construction;
- The technological progress enabling a more efficient use of aggregates for the same number of square metres.

The substitution is considered a stock [m^2/t] of which the level is increased by a net flow at a constant growth rate (usually around 0,5% in the ANTAG-model).

$$Subst\,\&\,Tech_{t+1} = Subst\,\&\,Tech_t + NetIncreaseSubst\,\&\,Tech_t \qquad (7)$$

$$NetIncreaseSubst\ \&\ Tech_t = Subst\ \&\ Tech_t \bullet GrowthRate_{Subst\&Tech} \tag{8}$$

The reciprocal K [t/m²] has to have an asymptotic shape since substitution has a natural limit. This factor has been decreasing in the last 10 years but, however, can never become zero. By multiplying K [t/m²] by the demand of new buildings [m²/year], we obtain the demand of building construction and maintenance in [t/year].

Concerning the branch of public works an equivalent function named “trend function for public works” reducing the demand at equal wealth has been implemented. The function describes, in principle, a trend of dematerialisation equivalent to the energy intensity described by De Vries et al. (1999).

$$DemandPublicWorks\left[\frac{T}{y}\right]_t = TrendFunctionPublicWorks\left[\frac{\frac{T}{y}}{\frac{€}{cap}}\right]_t \bullet \ldots$$
$$\ldots \bullet GDPperCapita\left[\frac{€}{cap}\right]_t - G \tag{9}$$

Where

G ... calibrated constant

$$TrendFunctionPublicWorks = \frac{H}{I + Time} \tag{10}$$

Where

H, I ... calibrated constants

No separate handling of the effective demand of civil engineering constructive works and the substitution by materials disposable on site was available. Figure (6) shows the stock- and flow structure for the consumption submodel. The consumption submodel can also be found in Vensim layout in Appendix A.

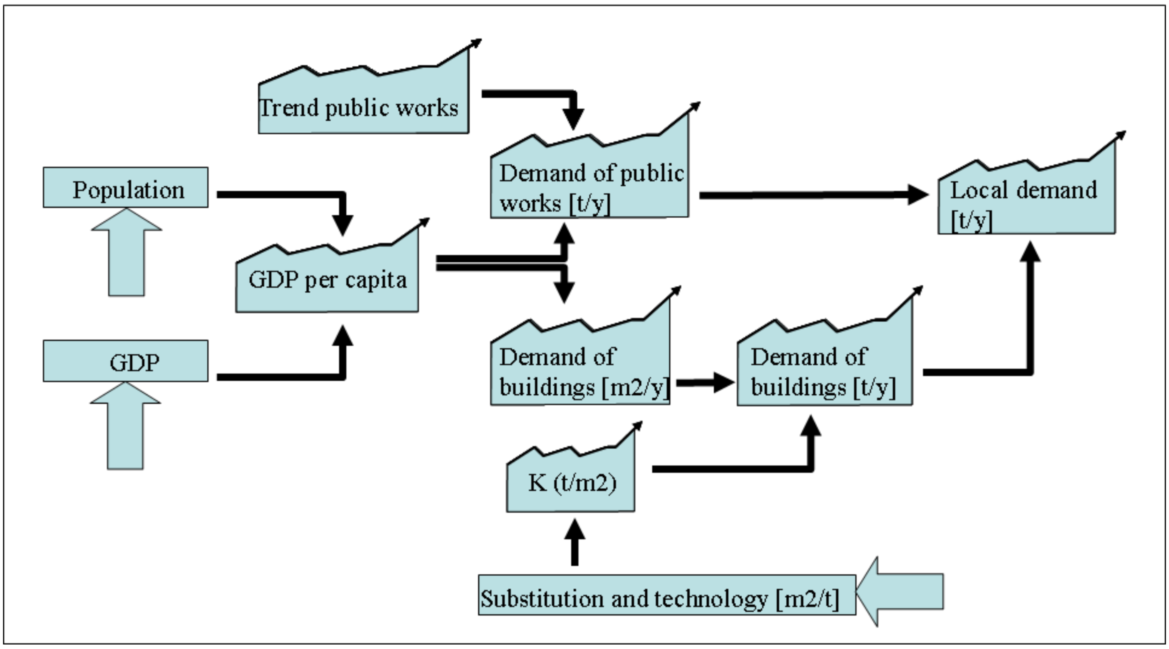

Figure 6: Consumption submodel scheme

4.1.2 Method of data reconstruction

For the two consumption sectors the square metres of new buildings and tonnes of building construction and maintenance per year and of annual turnover in euros for public works were known. For the latter one only six points were available which made a calibration impossible. The approach followed was thus to rebuild the primary data of demand of public works in tonnes. Since data series existed for the local demand in tonnes and the demand of building construction in tonnes for each of the six regions, the demand of public works has been estimated by subtraction. The calibration has then been performed using the gross domestic product per capita as a driver based on that created data series. However the calibration quality for the public works sector and furthermore of the local demand was not satisfactory. A different method of the reconstruction of public works data was required.

This time the data series of the demand of public works in tonnes per year is built half on the basis of simulation output values. The square metres of new building have been simulated based on the GDP per capita evolution. By applying the equally calibrated factor of substitution and technology, we obtain the demand of building construction and maintenance in tonnes per year. This simulated demand of one of the two branches is now subtracted from the local demand data series. By this means an alternative series of

historic consumption of public works in tonnes has been built. As in the previous attempt, the demand in public works is simulated as a function of the GDP per capita. By applying the trend function a better agreement of historic data and simulation output can be found.
The calibration of a System Dynamics model, as shown in this chapter, is ambiguous. There are multiple ways in which data can be reproduced. The demand of aggregates is a non-observable quantity similar to the energy demand reported by De Vries et al. (1999). It is implicit in the production data of the different supply sources and the building construction in square metres, the hypothesis being that the market is in equilibrium and that there is no shortage in aggregates.

4.2 Calibration of a macroeconomic competitive market equilibrium

4.2.1 Introduction

The challenge in handling locally produced primary sources occurs as a result of fact that there is a need for constraints in terms of production as a response to demand. These constraints will be the stock of producible reserves (authorised reserves) and the maximum possible extraction (capacity). In terms of data for the supply end only data for production/extraction for all supply sources and new authorisations for local supply sources were available. No data for reserves or capacities were available. The estimation of data concerning the capacity of installations on site is difficult on a micro-scale. On a macroeconomic scale the data gathering is even more unpromising.
Which data was available for each part of the calibration will be explained in the respective section. The calibration of the supply end part of the model facing the current data situation was a major challenge of this research work. A comprehensive summary of the data situation faced in the ANTAG-project will be given at the end of the calibration section (chapter 4.6).

4.2.2 *Early attempts to calibrate a market balance under strong simplifications*

Adding the local demand to the demand from other regions within France and from abroad to the local demand, results in the total demand which has to be raised by the multiple supply sources of the respective region. The first assumption considers that extraction will always be near the capacity that can be extracted due to installations.

$$Ra_{t+1} = Ra_t - c_t + a_t \tag{11}$$

Where

Ra_{t+1} ...	the level of authorised reserves in year t+1
Ra_t ...	the level of authorised reserves in year t
c_t ...	the extraction capacity in year t
a_t ...	the new authorisations in year t

The new authorisations are driven by the gradual variation of the total demand from one year to the other. The four supply sources hard and soft rock, recycling and marine aggregates produce their capacities, and the imports from other regions balance the difference of the sum of the all capacities and the total demand. The results of the simulation compared to the production data series showed that this mechanism fails in following the most important trends. This is due to the fact that the two primary sources hard and soft rock are so different, that the overall market trend cannot be used as a driver for new authorisations of the primary sources.

The most cogent reason, however, why this approach was not used, is the fact that it lacks a real form of competition. The competitiveness of all the sectors (except the imports from other regions) is 100%, since they all produce their whole capacity. Every sector will satisfy its capacity according to a given hierarchy. The remaining imports from other regions act like a balancer in case the demand has not been covered, which may make sense in the zone Adour-Garonne because the quantity imported is negligible. In Artois-Picardie, however the imports from abroad and other regions make up to 30% of the total demand, which would make it illogical to let the imports act as a compensator.

4.2.3 Competition among actors

If the total demand of a region is inferior to the sum of all its sources' capacities, at least one of the actors will not be able to produce all of its capacity. This competition assumes that we are not confronted with a shortage of aggregates (known as Hubbert Peak in the oil industry) and that the market is in equilibrium which means that demand equals consumption. In classic economics market competition would normally be solved by intersecting the supply and the demand functions at the market clearing price. Since the demand of aggregates is not price elastic (Nötstaller, 2003), it cannot be used as a criterion for competition. The reason might be that the low price of aggregates only contributes a few percent to the total civil engineering costs. Another reason could be the need for great masses of aggregates together with the difficulties in substitution.

In order to explain the principle of a market equilibrium among the actors on the supply end on a macroeconomic scale (the demand coming from the consumption submodel and being given at this point in time), we will imagine a poker table of players taking turns in giving away parts of their potential production into a common pot (Figure 7). How much of the potential production will be given away by each actor, in other words, the difference between capacity and extraction of each source, will depend on his competitiveness relative to the other actors.

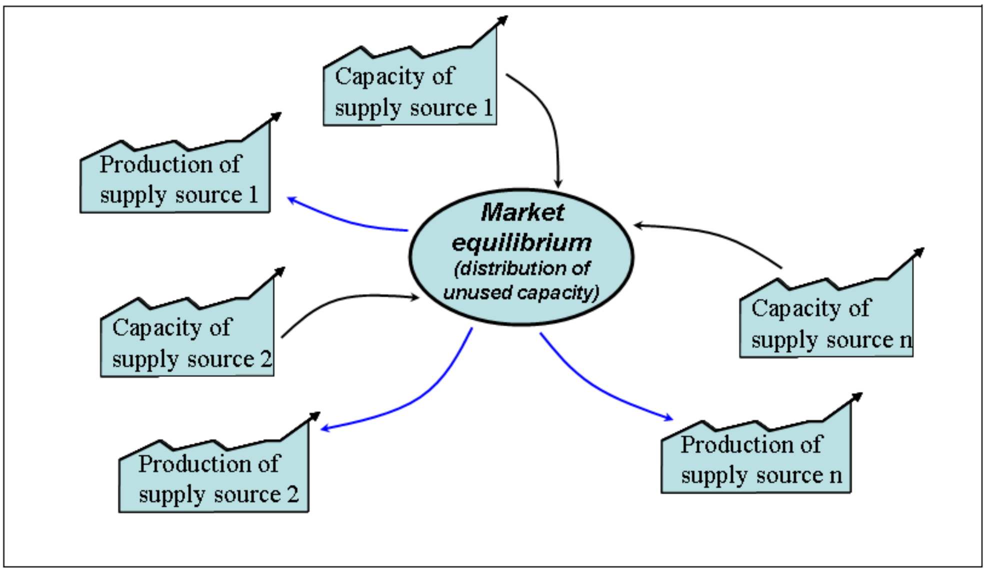

Figure 7: Market competition

The distribution of the whole market overcapacity on each of the sources is evaluated iteratively by introducing turns (Figure 8). In turn 16, for instance, hard rock loses 7 units. Once the overcapacity to be distributed reaches 0 (or a value closer to 0 than the one resulting from the next turn played), the process is stopped. Since the same number of turns might be necessary to distribute the overcapacity in more than one year (for instance 11 turns for year 1995 and 2005) errors can occur.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005			
DEMAND	55 420	49 193	50 439	49 816	52 930	56 666	59 779	61 025	61 647	60 402	62 270		1 unit =	
∑capacities	60 141	60 593	60 963	61 314	61 820	62 317	62 957	63 764	64 393	64 929	65 513		100 000 tonnes	
units demand	554	492	504	498	529	567	598	610	616	604	623			
units ∑capacities	601	606	610	613	618	623	630	638	644	649	655	lost	supply	turn
demand-capacity	***-47***	***-114***	***-105***	***-115***	***-89***	***-57***	***-32***	***-27***	***-27***	***-45***	***-32***	units	source	played
	-44	-111	-102	-112	-86	-54	-29	-24	-24	-42	-29	3	imports	1
	-41	-108	-99	-109	-83	-51	-26	-21	-21	-39	-26	3	imports	2
	-37	-104	-95	-105	-79	-47	-22	-17	-17	-35	-22	4	hard rock	3
	-33	-100	-91	-101	-75	-43	-18	-13	-13	-31	-18	4	soft rock	4
	-29	-96	-87	-97	-71	-39	-14	-9	-9	-27	-14	4	hard rock	5
	-25	-92	-83	-93	-67	-35	-10	-5	-5	-23	-10	4	soft rock	6
	-22	-89	-80	-90	-64	-32	-7	-2	-2	-20	-7	3	hard rock	7
	-19	-86	-77	-87	-61	-29	***-4***	***1***	***1***	-17	-4	3	soft rock	8
	-11	-78	-69	-79	-53	-21				-9	***4***	8	hard rock	9
	-3	-70	-61	-71	-45	-13				***-1***		8	hard rock	10
	15	-52	-43	-53	-27	***5***						18	soft rock	11
		-34	-25	-35	-9							18	hard rock	12
		-25	-16	-26	***0***							9	soft rock	13
		-17	-8	-18								8	hard rock	14
		-9	***0***	-10								8	soft rock	15
		-2		***-3***								7	hard rock	16

Error for the distribution of 57 units of overcapacity

Figure 8: Iterative distribution of overcapacity

The exercise will then result in a relationship between the number of turns played and the potential production lost compared to capacity for each of the sources. The total quantity which has to be distributed corresponds to the number of turns played, which in turn corresponds to the distribution of the lost quantity of each sector. The number of lost units of an actor at a certain turn and the calibrated sequence in which the actors lose in their potential production must apply in each year (Rodriguez Chavez et al., 2010b). Figure (9) shows the lost units of potential production for the participating sources and the played turn. If the overcapacity is high, as in year 1998 in the example in Figure (10), 16 turns (or rounds) are played (Figure 9), if it is low, as in year 2003, only 3 two are played. In year 2003 there is no need for playing more than 3 turns, since the whole overcapacity is already distributed over the supply sources at round 3.

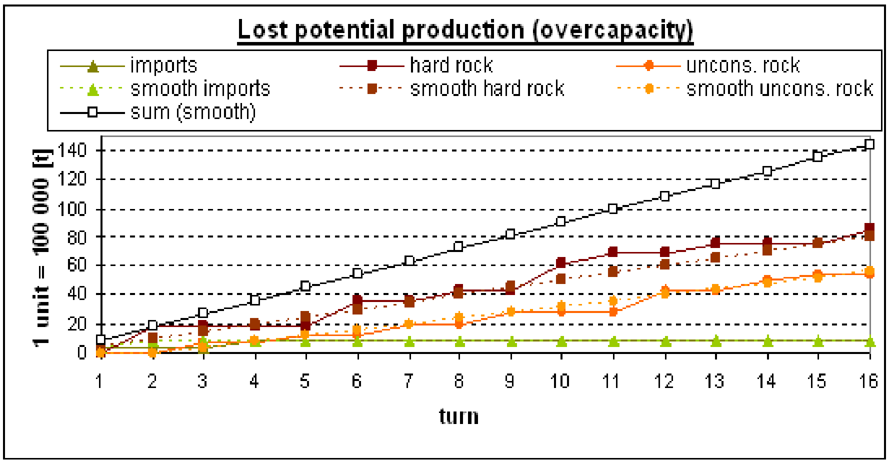

Figure 9: Turns as a function of overcapacity for the region Adour-Garonne

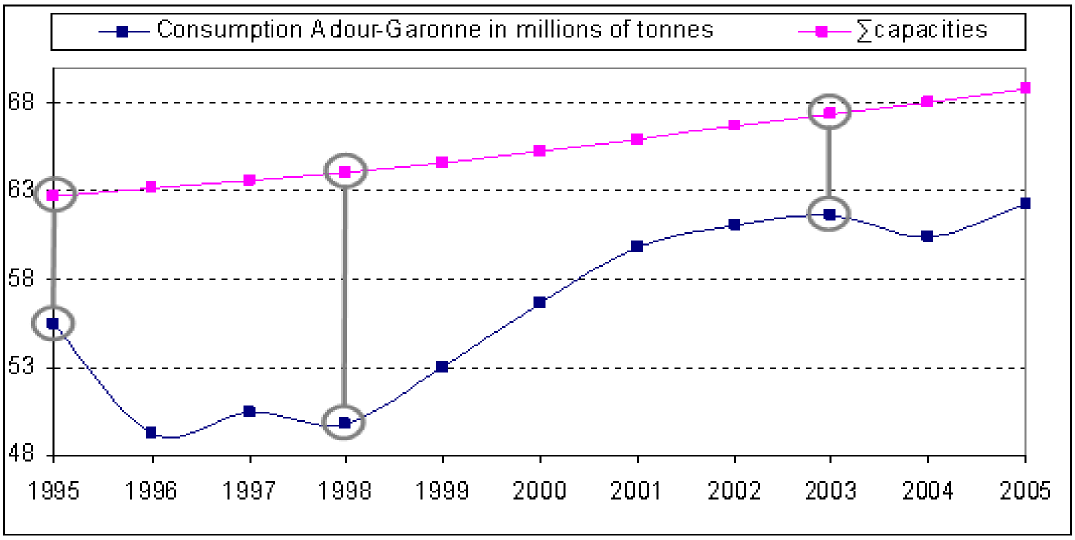

Figure 10: Consumption and sum of capacities of Adour-Garonne

The resulting relationships have been replaced by linear functions, so that controlling the relative competitiveness becomes simpler. The steeper its slope is, the less competitive the supply source. Thus, the competition curves of the niche markets, producing at their capacity, will lie at the turn-axis. A scenario aiming at an increase of capacity of a niche market, for instance, could consider changing slopes, dependent on the new capacity launched on the market.

Figure (11) shows the causal relations corresponding to the market competition in Figure (9). Note that only 3 actors take part in this competition example (recycling, marine production and imports from abroad are defined as niche markets). How the niche players have been treated will be discussed in section 4.3).

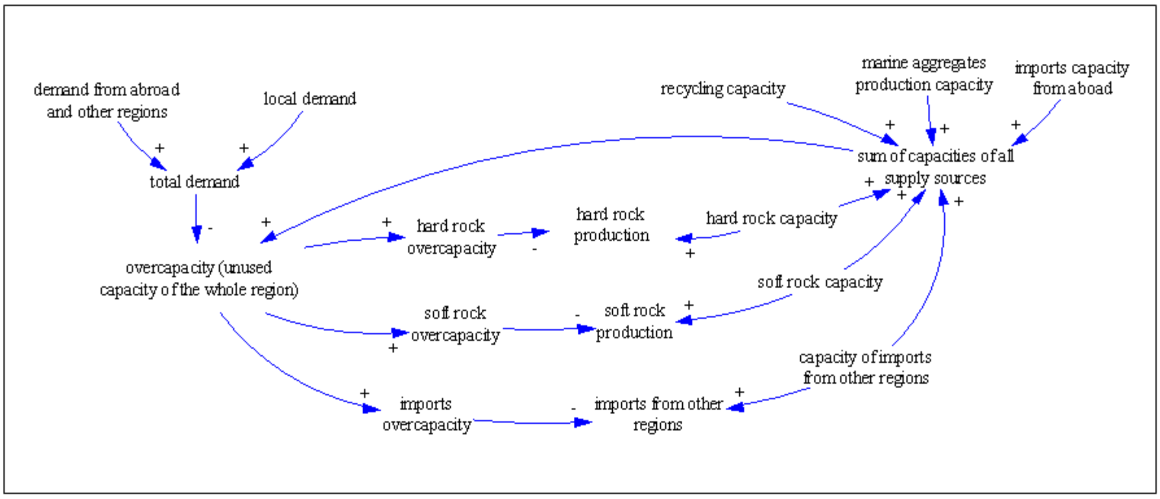

Figure 11: Causal relations for the market submodel for the region Adour-Garonne

4.2.4 Functioning during a simulation run and beyond the calibration period

The sequence in which actors lose their potential production, in other words their relative competitiveness, is calibrated on the basis of each source's production data. However, how many turns will be effectively played in a certain year is obviously dependent on the total overcapacity of a region. If it is low in a given year, only a few turns might be played, whereas in a year with a high overcapacity a couple of turns might be added, so the whole unused quantity can be distributed. The mechanism's advantage is that it instantly distributes the overcapacity over all the supply sources once the total demand and the total market capacity of a region are known.

4.2.5 Causal relations between reserves, capacity and production

In order to find and understand the parameters that are crucial for the described mechanism, causal relations between the reserves, the capacity and the production have been elaborated. Also, it will help us to understand which data is necessary in order to transfer the causal relations into stock-and-flow structures. The description follows the causal loop diagram shown in Figure (12).

An increase in demand of a region will naturally cause a decrease in overcapacity, when subtracted from the sum of the capacities. A decreasing overcapacity of the region, ceteris paribus, causes a decrease in overcapacity of the supply sources (in this example hard rock). This will cause, ceteris paribus, an increase the hard rock production, which will cause an increase in new authorisations (if we assume that the more aggregates we produce, the more new authorisations we will get in order to maintain a high level of authorised reserves). A higher level in hard rock reserves causes an increase in hard rock capacity. We assume that these two are related to each other in a very simple way. A higher hard rock capacity will cause an increase in the overall capacity of the region which will then cause an increase in overcapacity. This loop is thus a negative or balancing loop.

The small loop indicated in Figure (12) is also balancing. A decrease in hard rock reserves will cause a decrease in hard rock capacity. Consequently, the hard rock production is increased, ceteris paribus. An increase in hard rock production will cause a decrease in hard rock reserves, since the tonnage extracted is not available for production anymore.

The two negative feedback loops already seem to give away at this stage that the model is stable.

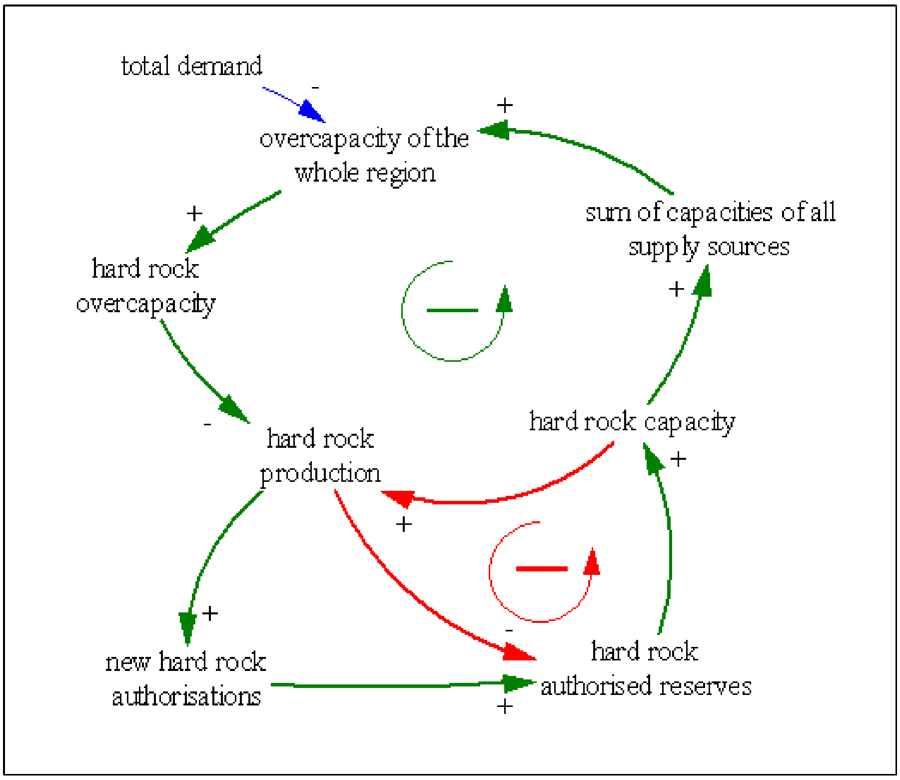

Figure 12: Causal loop diagram for the reserves-capacity-production interaction (balancing)

However, one reinforcing feedback loop is traced within this causal loop diagram (Figure 13). A decrease in overall overcapacity causes a decrease in hard rock overcapacity, which, ceteris paribus, causes an increase in hard rock production. An increase in hard rock production causes a decrease in authorised reserves, which in turn causes a decrease in capacity. This causes, ceteris paribus, a decrease in the sum of capacities of the whole region. Consequently, the overall overcapacity decreases, as at the beginning of the loop.
Balancing feedback loops generally stabilise the system whereas reinforcing or positive feedback loops generally destabilise them or can even make systems explode.

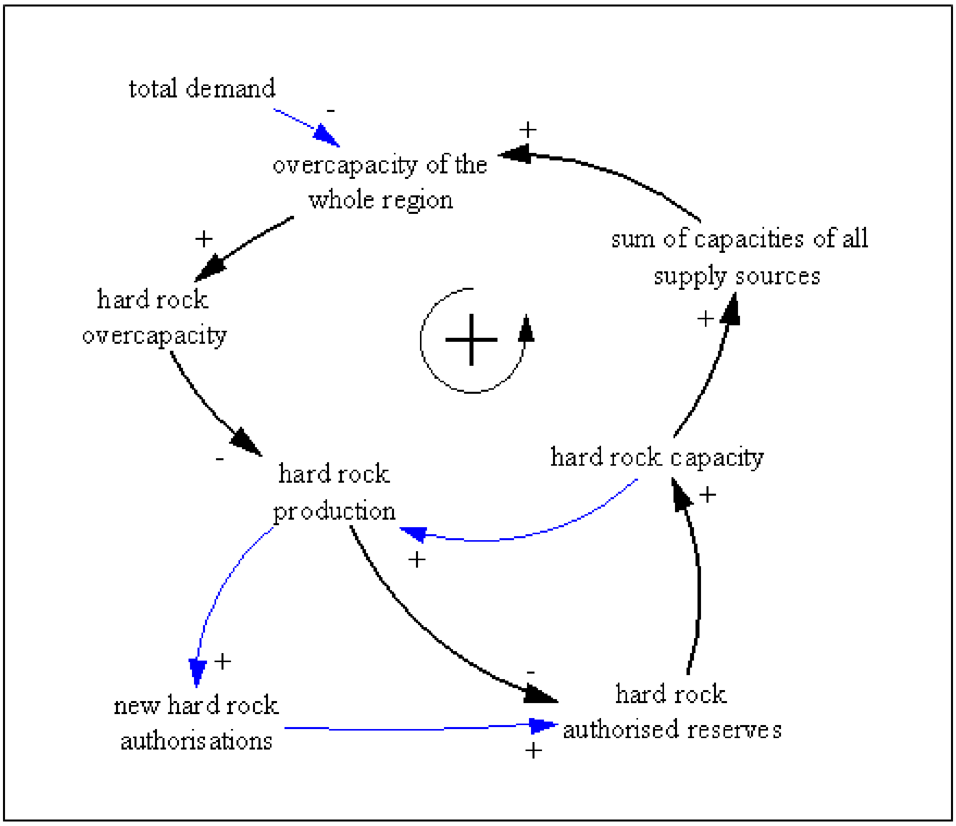

Figure 13: Causal loop diagram for the reserves-capacity-production interaction (reinforcing)

4.2.6 Data reconstruction of capacity and authorised reserves

The market balance mechanism and the causal relations described require the modelling of capacity. However, no data was available for the capacities of hard rock, unconsolidated rock or imports on a regional basis. Similar studies have confronted the same problem

(Giljum et al., 2008), whereas in our case the authorised reserves are indispensible. They have to be introduced, since they are a crucial constraining factor for production in the access to the resource.

Each quarry has a limited duration of authorisation and a maximum allowed extraction each year. By summing up the authorised tonnage of all quarries, we obtain a stock of reserves producible at a certain point in time. We decided to express this physical stock of authorised reserves for a huge number of quarries as a stock in System Dynamics.

Available data allowed estimating only one data point for each of the two primary supply sources per region. This has been done by assuming that the authorised reserves of a quarry in 2005 equal the extraction in 2005 times the rest of the duration (number of remaining years) of its authorisation (Equation 12).

$$Ra_{2005} = \sum e_{2005} \bullet N_{REMAINING} \qquad (12)$$

Where

Ra_{2005} … stock of authorised reserves in year 2005

e_{2005} … extraction in year 2005

$N_{REMAINING}$ … number of remaining years of authorisation

Having estimated a value for the authorised reserves of 2005, the next step was the reconstruction of what the initial value could have looked like. An initial value is required in order to allow the stock-and-flow structure starting to compute its incremental time series. Since production data were available back to the year 1982, an estimation of the stock of authorised reserves of the year 1982 was possible making a couple of hypotheses:

First, the capacity of the year 2005, $c*_{2005}$, was defined as the maximum extraction which occurred between the years 2000 and 2005. This hypothesis makes sense, since we can assume that an actor will not instantly reduce his capacity significantly from one year to the other, even if his capacity is not fully saturated. This would apply to the soft rock branch, since it is a declining sector. The same was applied for the growing hard rock branch. If in one year the production is higher than in the year before, the capacity itself has not necessarily been increased in that same year. The capacity adjusts to the market in the mid- or long-term, but not instantly. Thus this judging from a five-year perspective makes sense, especially from a macroeconomic point of view, where production capacities are difficult to estimate. Note that this capacity is only an auxiliary variable.

$$c^*_{2005} = e_{MAX\ (2000-2005)} \tag{13}$$

By dividing the estimated stock of authorised reserves of the year 2005 [tonnes] by the auxiliary variable c^*_{2005} [tonnes/year], we obtain a number of years of lifetime, N^*.

$$N^* = \frac{Ra_{2005}}{c^*_{2005}} \tag{14}$$

By assuming that the evolution of the capacity of a supply source follows the evolution of the extraction (which is known back to the year 1982), we can compute the capacity of 1982 (Equation 13). This assumption might seem contradictory to the one stated in Equation (11), since we compute the capacity values year by year, and since the extraction values can vary significantly, the capacities also would. However, we are interested in what the initial capacity value (1982 in our case) could have looked like, the capacity values in between not being used in the model. Those will be reconstructed using a different assumption.

$$\frac{c^*_{t+1}}{c^*_t} = \frac{e_{t+1}}{e_t} \tag{15}$$

By multiplying the capacity of 1982 for each local supply source, hard and soft rock, by the previously defined auxiliary variable, the constant lifetime N^*, we obtain the authorised reserves in the year 1982.

$$Ra_{1982} = c^*_{1982} \bullet N^* \tag{16}$$

Knowing the two boundary values in 1982 and 2005, we can now start rebuilding the missing time series data. The incremental computation of the stock of authorised reserves from one time step to the next (Equation 17) in the model looks as follows:

$$Ra_{t+1} = Ra_t - e_t + a_t \tag{17}$$

Where

Ra_{t+1}...	the level of authorised reserves in year t+1
Ra_t …	the level of authorised reserves in year t
e_t …	the aggregates extraction in year t
a_t …	the new authorisations in year t

This allows the derivation of the capacity in each year. An approach known in the oil industry presumes that there is a reserves/maximum extraction ratio N, which constrains the extraction of the reserves since the reserves cannot be exploited below it (Nail, 1992) (Equation 18). The number of years of maximum potential extraction, N, is kept constant over time. Note that the remaining duration of authorisation is for each quarry a purely administrative figure. By summing up the authorised reserves of a macro-region they become a macroeconomic stock with an average lifetime. We thus lose the notion of authorisation.

$$\frac{\mathrm{Ra}_t}{\mathrm{N}} = \mathrm{c}_t \tag{18}$$

Where

Ra_t …	stock of authorised reserves in year t
N …	lifetime of the authorise reserves
c_t …	extraction capacity in year t (as computed by the model)

The lifetime N is usually close to the auxiliary variable $N*$. The difference between the two might be a fraction of a year, meaning smaller than 1 (= one year of lifetime).
The extraction is derived from the capacity by distributing the overcapacity by the market balance mechanism. The derived capacity must allow the market balance mechanism to

result in robust extraction profiles. Whatever the value of N is, it must allow the stock of authorised reserves to hit the estimated value of 2005 (starting at Ra_{1982}).

The last element missing in the stock-and-flow structure (Equation 17) are the new authorisations.

4.2.7 Integration of social acceptability, industrial development, new authorisations

The lifetime of reserves is different for crushed and unconsolidated rock. By assuming that it is a constant number of years, we neglect the fact that the years left can become small enough to justify new authorised reserves in the magnitude of, for instance, twice the total demand per year. If N remains high, only negligible quantities may be authorised. How big the variations from one year to the other can be is shown by the UNICEM data series in Figure (14). By assuming a fixed number of years of lifetime in the model, we obtain a smooth curve for the new authorisations.

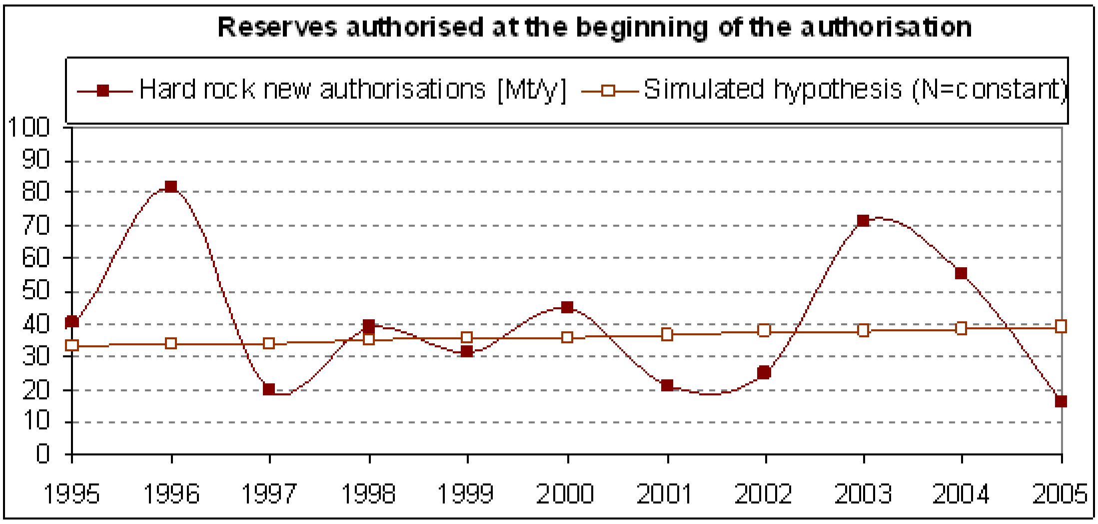

Figure 14: Authorisations of hard rock reserves (UNICEM data basis) and simulation results assuming a fixed N

The extraction, e_t ($\leq$ capacity, c_t), resulting at each time step from the market submodel, is the driving factor in the renewal of authorised reserves as shown in Equation (17). We assume that in the aggregates industry companies invest in new capacities once new authorisations are given out.

$$a_t = e_{t-1} \bullet \left(\frac{e_t}{e_{t-1}} \bullet SA \bullet d \right) \quad (19)$$

Where

a_t …	new authorisations in year t
e_t …	extraction in year t
e_{t-1} …	extraction in year t-1
SA …	social acceptability
d …	factor of industrial development

Equation (19) states that there is a will to renew the quantity exploited the year before, e_{t-1}. The gradual increase of extraction e_t / e_{t-1} represents the market trend of the source.

The social acceptability is, as described in chapter 1.3, a complex phenomenon. We assume that it has decreased within the calibration period between 1995 and 2005, but we are not able to measure the progression. Furthermore it seems that the social acceptability for alluvial deposits (soft rock sites) is declining faster than for hard rock. What would be a useful way to integrate this soft parameter in the model in order to leave the possibility open to alter this parameter as a trigger action for a scenario, for instance? This variable had to be quantified. It was decided that the factor of social acceptability, SA, is kept constant at its maximum level of 100% for hard and soft rock in the calibration period. By doing so we assume that there is an acceptance to renew the total quantity extracted which is being subtracted from the stock of authorised reserves. However, the social acceptability is not the only parameter determining new authorisations.

The factor d represents the industrial development of a primary supply source. As the lifetime N, the value of the constant d must allow the curve of authorised reserves to hit the estimated data point for 2005 (typically 1,15 for hard rock being a developing sector, and around 0,95 for soft rock being a declining sector). If the industrial development, d, was kept constant at 1 in the calibration period (which is the case for the social acceptability) the stock of authorised reserves would stay constant, since the new authorisations would equal extraction (Equation 17). Hence the value of d solely determines the production history in the model. The corresponding stock-and-flow structure is presented in Figure (15).

The derived capacity must allow the market competition mechanism to result in robust extraction profiles. A calibration in terms of simulation-to-data-fit was only possible on the basis of the supply sources' extraction, since this was the only data available.

If the product of social acceptability and industrial development is smaller than 1, a certain percentage of the extracted volume is not being renewed which consequently causes a decrease of authorised reserves and hence the capacity. On the other hand, if it is greater than 1, the capacity is increased the following year. An increase in capacity expresses a player's anticipation of being more competitive than the others. If a player feels that he is not going to be able to allocate his production, he will not increase his capacity. The real competitiveness, on the other hand, is given by the market competition imposing how much of the capacity will be effectively produced.

A problem in analysing historical production data series is the fact that it is impossible to distinguish between social acceptability and the industrial development. The production profile is the result of a complex set of mechanisms. We know that if the curve profile of a source increases in a certain year, their product, in terms of the ANTAG-model, must have been greater than 1 (which we assume is the case for hard rock), and if it decreases, their product is smaller than 1 (which we assume is the case for soft rock).

Figure (15) also shows clearly that the force decreasing the stock of authorised reserves, in fact, is the result of the market equilibrium. The same force also drives the new authorisations, which also influence the stock of reserves and consequently the capacity sent to the market equilibrium module.

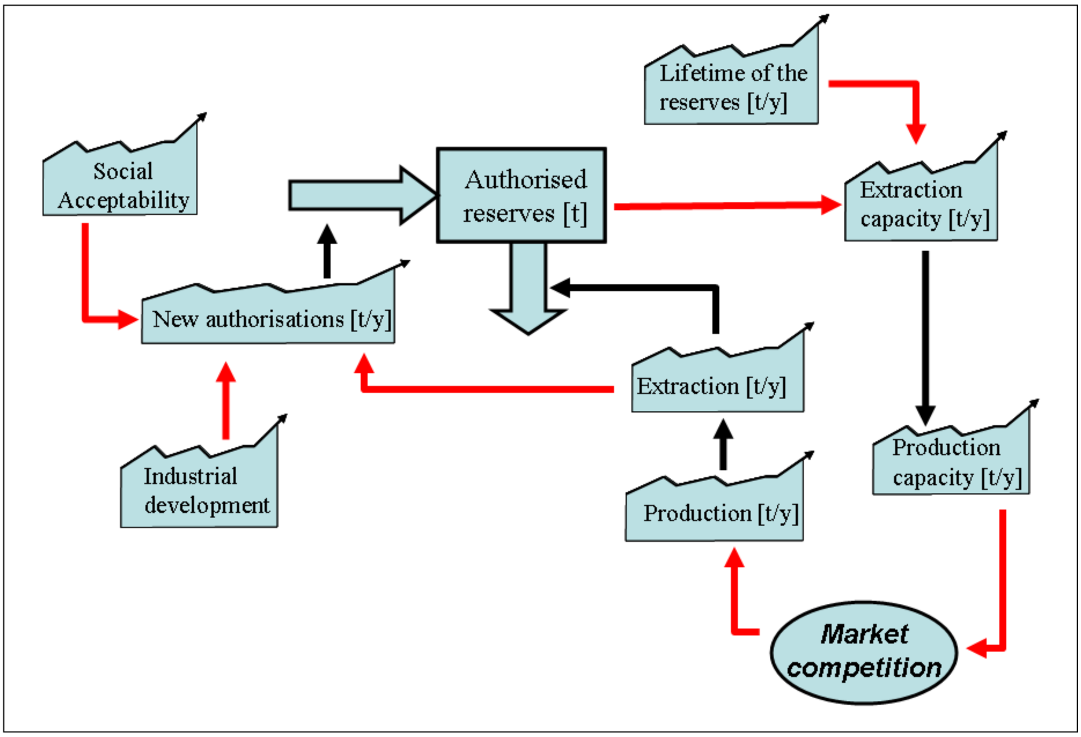

Figure 15: Stock-and-flow structure for the supply end of a primary source interacting with the market competition mechanism

4.3 Characteristics and dynamics of niche markets

4.3.1 Questions posed and choices

Marine aggregates and recycled material are regarded as niches, which produce lower quantities than the primary resources at their capacity. The data points provided by UNICEM shown in Figure (16) make us wonder what the progression of the curve could look like in the following years. The most important questions addressed while working on the data analysis with the consortium of the ANTAG-project were the following:

– What do the increasing data points represent? Is it the penetration of the recycled minerals into an existing aggregates market, in which case the actual recycled minerals would equal the capacity? Or is it rather the result of a significant capacity increase in the market which will lead to an increase in production as a logical consequence? In the latter case is the capacity significantly higher than the actual recycled minerals?

- Will the curve constantly increase or will the curve face a maximum capacity limit beyond which it cannot grow any further?
- If not, what is the capacity recycling limit for each region?

Their behaviour is represented as increasing stocks obeying S-curves. The stocks represent an increasing capacity penetrating the market, the growth dynamics being low in the beginning and showing an accelerating effect after a couple of years. In the end the recycled construction materials and the offshore production of marine aggregates will tend to move towards a maximum capacity limit. A similar approach has been used for the waste concrete recycling target setting by Hsiao et al. (2002). The limit for the recycling capacity has been fixed at 15% of the value of the local production of the year 2005, which obviously depends on the region. In an earlier version of the model, the actual recycling capacity was defined as a growing percentage of the local demand of a region. This would imply that the recycling capacity fluctuates if the local demand does. By assuming a recycling capacity which can only grow and not decrease up to a certain limit, we obtain more stable results from the market balance mechanism. Note that the niche actors practically take their capacities out of the whole market capacity. Thus they leave the remaining overcapacity to be distributed mainly among the primary supply sources within the market competition.

Furthermore the geographically specific values of 15% of the local production seem to be realistic recycling capacities for a base case assumption for each of the regions, according to UNICEM.

The graph shows the assumed progression of the recycled material curve together with the available data points for the zone Adour-Garonne (Figure 16). Marine aggregates capacity limits for the concerned regions have been estimated based on production of the *Institut français de recherche pour l'exploitation de la mer* (IFREMER).

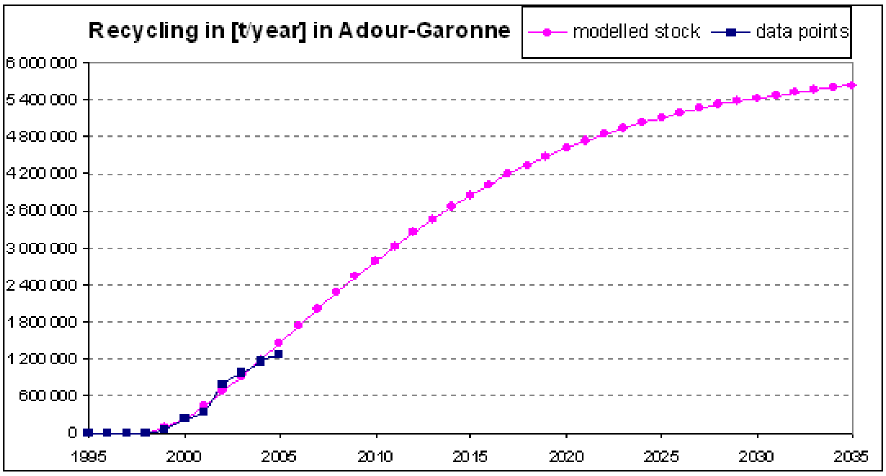

Figure 16: Recycling capacity data points by UNICEM and forecast for Adour-Garonne

4.3.2 *Mathematical modelling of the penetration of niche markets*

Equations (20) – (22) define the asymptotic function (which corresponds to the capacity limit) and show that the value of the asymptote A has to be formulated implicitly in order to be included in the flow equation. In this way the stock can be given a growth limit. Mathematically, two solutions exist for α, whereas only one suitable for the flow equation. l in the flow equation is adjusted according to the data points of the respective supply source. The latter coefficient determines the growth rate.

$$CapN_{t+1} = CapN_t + NetIncCap_{t->t+1} \qquad (20)$$

$$NetIncCap_t = l \bullet t \bullet \exp(-\alpha \bullet t) \qquad (21)$$

$$A = l \bullet \frac{\exp(-\alpha)}{[1-\exp(-\alpha)]^2} \qquad (22)$$

Where

$CapN_t$ …	the level of a niche player's capacity in year t
$CapN_{t+1}$ …	the level of a niche player's capacity in year t+1
$NetIncCap_t$ …	net increase of the capacity level in year t

A …	asymptote
l, α …	constants
t …	time

4.3.3 *Niches markets data treatment*

Peaks in the curve profile of public works made for difficulties in the modelling work. The fundamental observation made during profile analysis was the fact that the peak in the profile of aggregates consumption of public works actually corresponds to the peak in recycling capacity (Figure 17). This leads to the approach of cutting the peak in the recycling profile in order to build a profile representing “normal” conditions (step 1). The difference in tonnage of the raw and the new profile is being subtracted from the raw public works data curve (step 2). This allows one to, on the one hand, model the demand of aggregates for public works, whilst, on the other hand, apply the S-curve to the recycling capacity progression using existing principles already mentioned. The regions affected are the two smallest Artois-Picardie and Rhin-Meuse. Model validation by running it without certain exogenous events has been described as a way of validation. (De Vries et al., 1999).

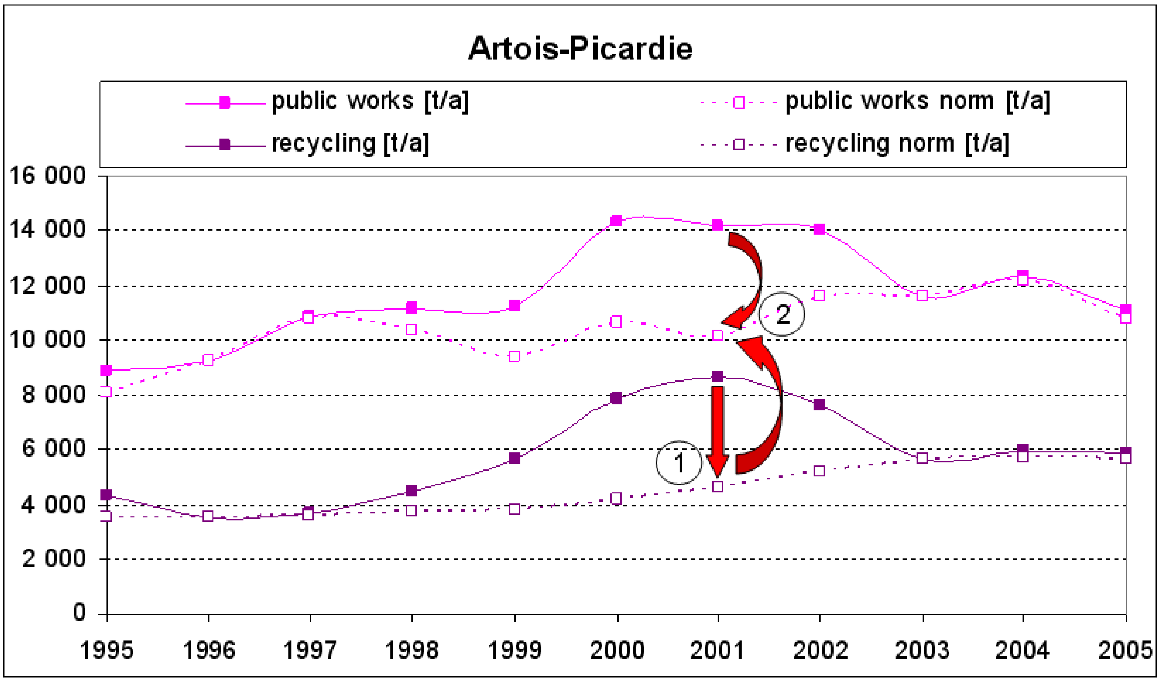

Figure 17: Public works and recycling capacity raw data treatment

4.4 Transport distance modelling

4.4.1 Phenomena in aggregates transport

We will now focus on the parameters influencing the transport distance evolution. There are different reasons why the transport distance from the production site to the consumption centre can alter. The localisation of the production sites is a result of the transport costs and the availability. The haul distances are the result of an optimisation and correspond to an optimum. If conditions change they will tend to move to another optimum (Figure 18). If the production capacity of a site is saturated, the part of the demand previously supplied by this site will now be shifted to other production sites either those with existing overcapacities or new ones, which both will make the distance increase. Quarries do not produce infinite volumes of aggregates. Once a quarry is depleted and closed the next one supplying the same consumption centre will more likely be located further away as a result of urbanisation. If a reservoir was closer to the consumption centre, it would probably have already been exploited. This rule does obviously not apply to each of the huge number of quarries in France since new consumption centres can appear close to production sites. However, the model being macroeconomic and top-down required a solution on a global scale. Transport flow problems have been addressed in the past by using cellular automata based spatially explicit models (Wahle et al., 2001). Cellular automata are specifically designed for the modelling of the dynamics of spatial distributions (Moustakas et al. 2006). Being grid-based discrete time models obeying rules describing how the occupancy of the grid cells changes from one step to the next, cellular automata usually assume that that the contents of each cell depend only on its contents and the contents of the adjoining cells in the previous time step. Using such grids in modelling the aggregates transport flow would particularly make sense on a microeconomic scale. In the ANTAG-project, however, we not consider geographical and geological inventories of resources nor microeconomic transport paths. The study focuses on macroeconomic parameters like mean transport distance, transported tonnage and tonne-kilometres of each of the six macro-regions.

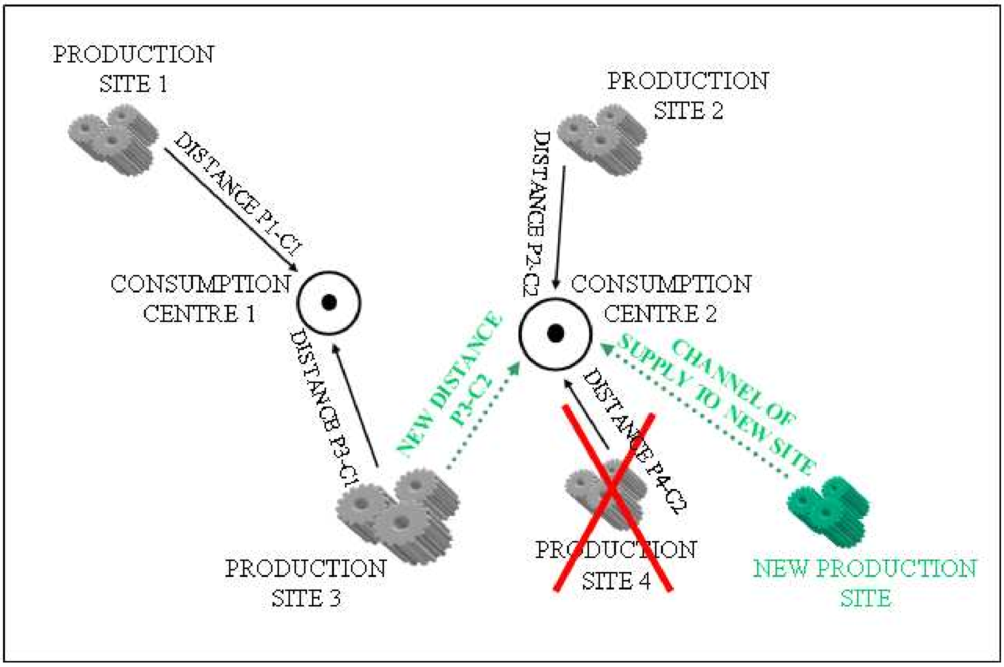

Figure 18: Change of relative localisation of consumption centres and production sites

4.4.2 Approach and choices made and in the modelling process

The first choice in the modelling approach was the use of stocks for the average values of haul distance for each of the transport modes. Each time new reserves are authorised, the stock level for the road transport distance grows with the flow of authorised reserves for the same year (Figure 19). Furthermore, the current split of road-alternative transport modes has an influence on the level of the stock. The higher the percentage of road transportation, the faster its distance will grow. However, the split between the transport modes is kept constant at all times in the base case. The marginal distance is initially kept between 350 and 500 metres per 100 million tonnes of new authorisations depending on the regions. This means that this value is calibrated for the initial split factor of road-alternative transport modes for each region. Once the split factor changes, the marginal distance alters as well.

The initial value of marginal road distance, $mDist_{ROAD}(initial)$, (350-500 metres / 100 million tonnes depending on the region) has been calibrated on the basis of the road transport costs, which is known in the period 1995-2005. Knowing the costs per tonne-kilometre in 2005 (0,12 €/tkm of road) and that 30% thereof are energy-related, makes it possible to calculated back the effective change of transport distance year by year. An increase in absolute fuel costs can only be related to either an increase in transport distance or an increase in gasoline price - and the latter one is known.

$$netIncreaseDist_{ROAD\,t}\left[\frac{km}{y}\right] = \mathrm{mDist}_{\mathrm{ROAD}}\left[\frac{\mathrm{km}}{100\mathrm{Mt}}\right]_t \bullet \ldots$$
$$\ldots \bullet newAuthorisations(hard + soft)\left[\frac{t}{y}\right]_t \qquad (23)$$

Where the marginal road distance is defined as:

$$\mathrm{mDist}_{\mathrm{ROAD}}\left[\frac{\mathrm{km}}{100\mathrm{Mt}}\right]_t = \mathrm{mDist}_{\mathrm{ROAD}}(\mathrm{initial}) \bullet \mathrm{X}_{\mathrm{R\text{-}A}\,t} * \mathrm{J} \qquad (24)$$

Where

$\mathrm{X}_{\mathrm{R\text{-}A}\,t}$ … split factor between road and alternative transport modes in year t

J … dimensionless constant calibrated in such a way that its product with $\mathrm{X}_{\mathrm{R\text{-}A}\,t}$ results in 1 in year 0

Note that the net increase in road distance can strongly exceed the range of 350-500 metres depending on the amount of new authorisations. How the road distance changes over time will depend on the region and mostly on the scenario performed.

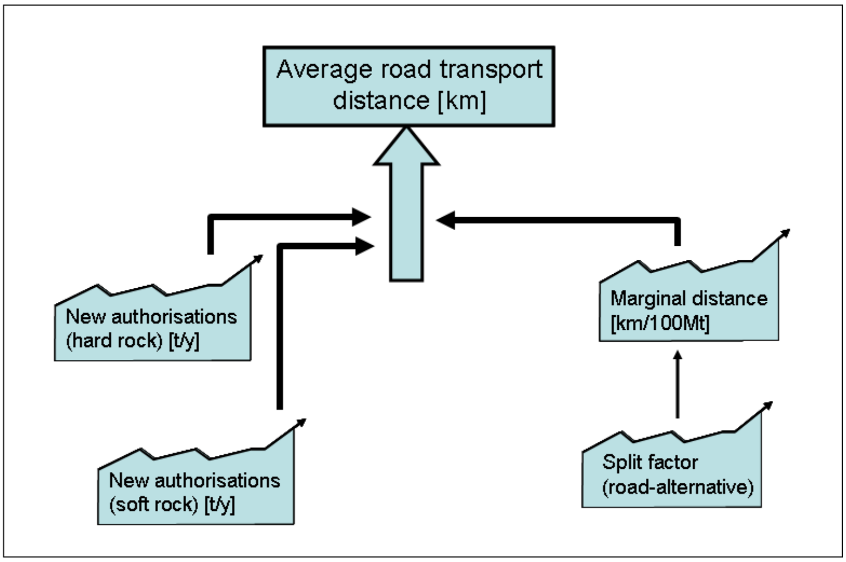

Figure 19: Road transport distance model layout

The transport distance of the recycled aggregates is assumed constant since recycling will always take place close to consumption centres. The average haul distance for rail and waterway increases with increasing freight conveyed by the respective transport mode. The driving factor is the tonnage difference of two subsequent years (Figure 20). Equation (25) applies to either rail or waterway.

$$netIncreaseDist_t\left[\frac{km}{y}\right] = \mathrm{mDist}\left[\frac{\mathrm{km}}{\mathrm{t}}\right] \bullet \left(F_t - F_{t-1}\right)\left[\frac{t}{y}\right] \qquad (25)$$

Where

$F_t - F_{t-1}\ldots$ difference of freight conveyed by the respective transport mode from year t-1 to year t

$\mathrm{mDist}\left[\frac{\mathrm{km}}{\mathrm{t}}\right]\ldots$ marginal transport distance kept constant at 1 kilometre per 1 million tonnes for each of the alternative transport modes

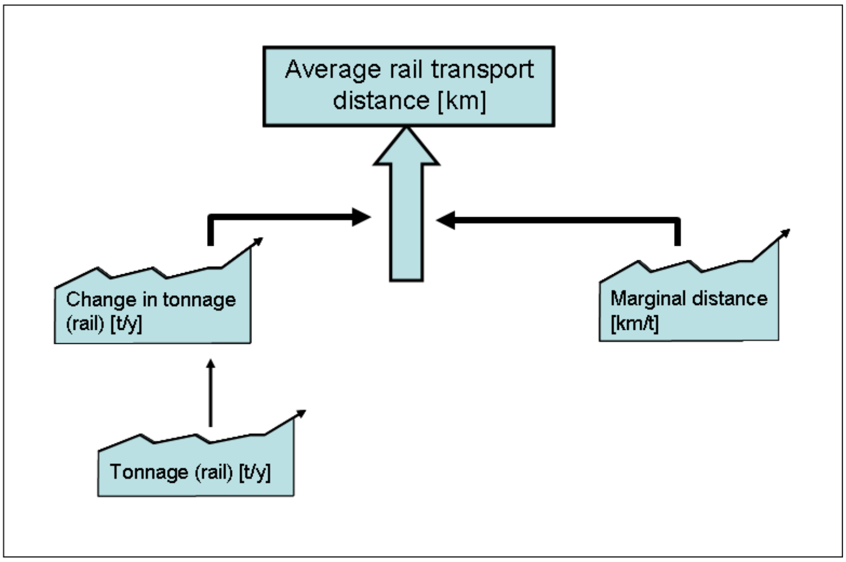

Figure 20: Rail transport distance model layout (identical for waterway)

In 75% of cases freight transported by secondary modes will not reach their final delivery destination. Thus, a secondary road transport has been introduced at a constant average distance.

4.5 Computing cost development on a macro-economic scale

4.5.1 Difficulties in handling production costs

The production costs can be divided into the following components:

$$C_P = C_L + P_G + P_E + T_P + C_F \tag{26}$$

Where

$C_P \ldots$	production cost per tonne produced [€/t]
$C_L \ldots$	land fee [€/t]
$P_G \ldots$	price of gasoline [€/t], data for calculation available in [€/l] and [l/t]
$P_E \ldots$	electricity price [€/t], data for calculation available in [€/kWh] and [kWh/t]
$T_P \ldots$	generalised pollution tax (*TGAP - taxe générale sur les activités polluantes*), (0,1 €/t introduced in 1999 ; 0,2 €/t in 2009)
$C_F \ldots$	fixed costs [€/t]

Production costs per tonne were available for hard and soft rock for all the six regions for the year 2005 only (Table 1). Furthermore indices of the price per tonne at departure from the quarry from 1995 to 2005 were available for hard and soft rock (but only on a national basis and not per region).

In an early first attempt it was assumed that the price per tonne at departure from the quarry will vary proportionally to the production costs per tonne, since the transport costs do not have to be considered. This hypothesis also implies that macroeconomically the profit margin of companies' increases proportionally as the production costs increase. This allows one to calibrate a cost profile exogenously. This profile could have been extrapolated for the baseline case scenario. However, no decomposition of the different factors is possible. Furthermore only one overall cost profile can be computed without any regional distinction.

In Euros per tonne	Hard rock production costs in 2005	Soft rock production costs in 2005
Adour-Garonne	5,58	7,38
Artois-Picardie	7,03	6,35
Rhône-Méditerranée	6,98	8,13
Loire-Bretagne	6,08	7,58
Seine-Normandie	6,41	8,65
Rhin-Meuse	5,51	6,97

Table 1: Hard and soft rock production costs in 2005

The second assumption uses a cost structure which was also only available for the year 2005 (Figure 21). The idea now is to calculate an initial split using the same cost structure for all of the regions and the production costs per region in 2005. The next step is to find historical indices of the variable cost components for the calibration period 1995-2005 (the fixed costs kept are constant at all times). The maximum deviation of the simulations for the six regions from the curve resulting from the first approach is less than 10%.

In fact, we observe that the second approach results in curves which all grow more slowly than the price indices (1% per year on average). This could lead to the conclusion that on the fixed cost sector changes within its cost structure in this 10-year period are also likely. According to economic theory, fixed costs can become variable costs in the long-term.

There are many factors that could influence fixed costs. First of all the aggregates industry is facing more and more concentration. The number of minerals producing companies has decreased over the last decade. In 1998 France had 1800 companies whereas in 2007 only 1660 and in 2008 there were 1620 companies on the construction aggregates market. The national consumption as well as the annual turnover is increasing. The average size of a quarry is more likely to increase due to the fact that the average spacing between quarries tends to become bigger. Effects like economies of scale are quite likely to influence fixed costs to a certain extent. In the ANTAG-model this effect is implicitly taken into account: a capacity increase reflects the anticipation of being more competitive and this affects the market balance in the market submodel.

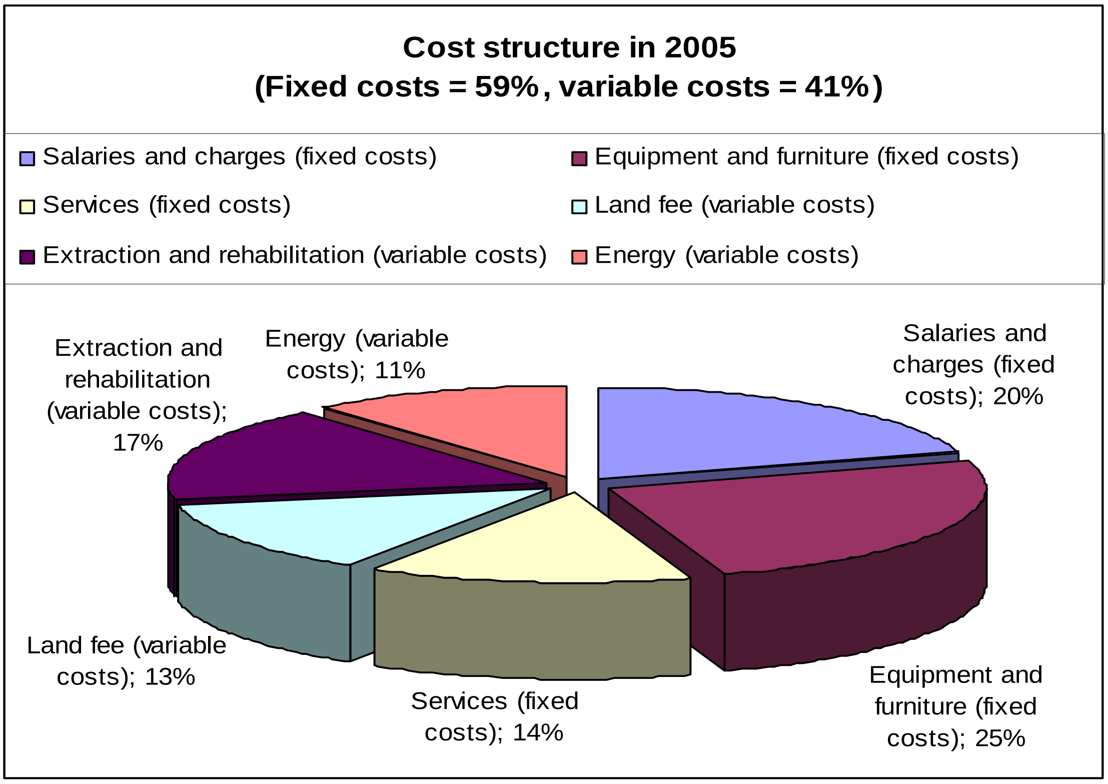

Figure 21: Cost structure for hard and soft rock in 2005

4.5.2 Transport costs

The transport costs per tonne-kilometre are estimated as 0,12 € per tonne-kilometre for road transport, 0,05 € per tonne-kilometre for railway and 0,03 € per tonne-kilometre for waterway transport on average. The cost estimation is consequently based on the calculation of average transport distances of the respective mode. This would presume that all the costs are fixed and the final transport costs only depend on haul distance in a certain year.

$$C_T = D \bullet C_M \qquad (27)$$

Where

C_T … transport cost per tonne [€/t]

D … average transport distance [km]

C_M … marginal transport costs [€/tkm]

For road transport, however, a further decomposition was possible. In 2005 the variable costs accounted for 45% whereas we know that 30% are energy-related costs. Since we know the gasoline price and the average gasoline consumption (40 litres for a charged truck + 27 litres for an empty truck for the way back with 25 tonnes carrying capacity per 100 kilometres), the energy-related costs are identifiable. The marginal transport costs are then composed of energy-related costs and other costs (where other costs are not necessarily fixed costs, but costs where no data for further composition was available, like maintenance, for instance).

$$C_M = C_{M,E} + C_{M,O} \qquad (28)$$

Where

$C_M \ldots$ marginal transport costs [€/tkm]

$C_{M,E} \ldots$ energy-related marginal transport costs [€/tkm]

$C_{M,O} \ldots$ other marginal transport costs [€/tkm]

The energy-related marginal transport costs are computed on the basis of the gasoline price and the average marginal consumption per tonne-kilometres. (The latter one in our case is: 0,0268 [l/tkm] = (40 litres +27 litres) / (25 tonnes $\bullet$ 100 kilometres))

$$C_{M,E} = P_G \bullet G_M \qquad (29)$$

Where

$P_G \ldots$ gasoline price [€/l]

$G_M \ldots$ average marginal consumption [l/tkm]

No data for the energy-related costs was available for rail and waterway transport. Consequently the marginal transport costs could not be decomposed any further and remain constant, since the changing gasoline price could not be taken into account.

4.6 Data summary and hypotheses for a base case model calibration

Time series in the period 1995-2005 of aggregates consumption in [m²/year] of new buildings (and in [tonnes/year] for building construction and maintenance) and in [t/year] for public works for each of the six zones could be traced back using data sets of the *Union Nationale des Industries de Carrières et Matériaux de Construction* (UNICEM). Another way of reconstituting data for national demand of construction aggregates caused by data problems has been presented by Hsiao et al. (2001).

Data for the gross domestic product and the population for each of the regions was used in order to model the driving force of local demand. Production time series for the primary supply sources including waste production for primary resources were available in the period 1982-2005. Data for the secondary sources were available for the calibration period. No data was available either for production capacities or for authorised reserves of the primary supply sources. The fact that demand is not price-elastic required another competitive criterion for a supply-and-demand equilibrium other than the market clearing price. However, the introduced macroeconomic competition mechanism presumes that the capacities and the authorised reserves are known. Thus, the missing capacity time series data has been rebuilt by making optimistic assumptions. One data point for the stock of authorised reserves for hard and soft rock could be estimated.

The quantification of social acceptability was necessary since controlling this factor must be possible in order to make the model flexible for scenarios. Since the measuring of social acceptability is difficult, the factor is kept constant for the calibration period at its maximum level (100%). The factor of industrial development of each of the two primary supply sources was calibrated using long-term trends of the hard and unconsolidated rock extraction history since could be traced back to 1982.

The unitary energy consumption in kilowatt-hours and litres of diesel oil per tonne produced were available in the UNICEM data basis for all supply sources. The coefficients allowing a subsequent conversion of production-related energy consumed to the emitted CO2 depending on the energy source were selected after consulting different sources (Schlaeppi and Challandes, 2001; http://eic.climate.org/; http://www.greenhealth.org.uk/; http://www.uic.com.au/; http://www.acdis.uiuc.edu/;

http://www.ambafrance-gr.org/; ADEME, 2006) and the *Bureau de Recherches Géologiques et Minières* (BRGM). The split of the modes of transportation including their average transport distances were available for the year 2005. Coefficients in CO2 per tonne-kilometres for all the transport modes (and additionally litres of diesel oil per tonne-kilometres for road transport) were available. Furthermore coefficients in tonnes per hectare allowed the computation of land use for each of the zones.

Waste factors for hard and soft rock were available (between 1,15 and 1,2 for hard rock, depending on its fraction of limestone and volcanic rock, and 1,05 for soft rock), which allowed the conversion from extraction to effective production.

Production costs for the primary supply sources and transport costs for the three modes were available in 2005. Knowing the unitary energy consumption for production and road transport, and land fee and generalised pollution tax for aggregates production allowed us to estimate a cost structure by splitting up the costs into their components.

4.7 Robustness of mechanisms and calibration quality

During model calibration a selected subset of model parameters (simulated results) are matched with historic proxy data. A selected subset of calibration parameters and constants are systematically varied in such a way that the simulated results reproduce available historic proxy data as closely as possible. Uncertainties in modelling often occur due to a lack of data (van Ruijven et al., 2010). Ten years of time series data (with the exception of local production where data could be traced back to 1982) is a rather short period for a System Dynamics model calibration, since the power of such models consists in long-term simulations. An exact adjustment of the simulation output to data points results in implausible curve profiles over 30 years. This is due to the fact that both GDP and the population showed above average growth rates in each of the regions in the period 1995-2005. Since those two are the drivers of the model, a strict calibration on the basis of the values available result in an abnormally high demand estimation (830 million tonnes in 2035 which would mean the double of today’s national demand).

Historic data for GDP and population before 1995 (start of the calibration period) and predictions beyond 2005 (end of the calibration period) were available only on a national basis by the *Institut national de la statistique et des études économiques* (http://www.insee.fr/). In order to obtain a more realistic figure of national consumption in 2035 (around 550 million tonnes as a compromise of the ANTAG-consortium) the national GDP and population evolutions have been normalised and applied to each of the regions. The drivers now, having their region-specific absolute values, grow exogenously at the average national rate based on historic data and available predictions. The calibration results shown in this section are thus based on plausible long term behaviour rather than potentially unrealistic short term trends.

Calibration therefore can also be understood as compromise between the existing (or reconstructed) data series and what certain key variables could look like in the next 30 years. For all the input and output parameters in the different submodels the calibration error could be kept to less than 10% for the six regions.

Figures (22) - (24) show the modelled inputs of the consumption submodel's exogenous drivers and substitution for the region Seine-Normandie.

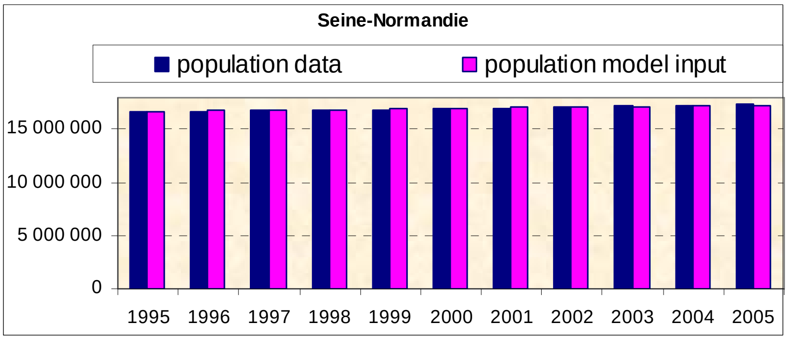

Figure 22: Model input and data for the population of Seine-Normandie

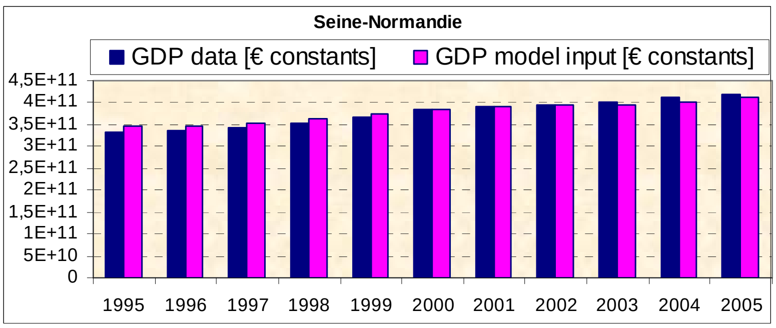

Figure 23: Model input and data for the regional gross domestic product of Seine-Normandie

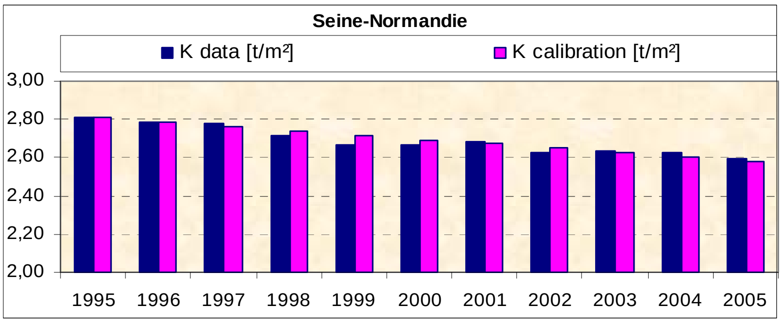

Figure 24: Model input and data for the substitution coefficient K of Seine-Normandie

Figures (25) - (27) show the calibration results of the consumption submodel for the region Seine-Normandie

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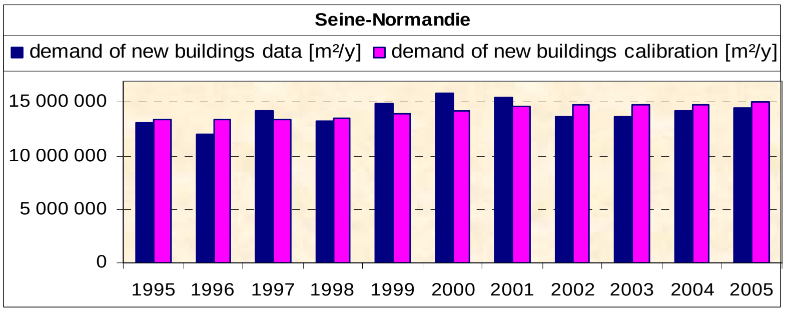


Figure 25: Calibration results for the demand of new buildings of Seine-Normandie

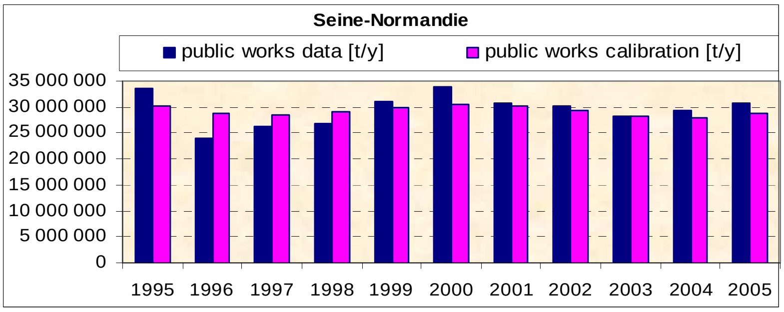


Figure 26: Calibration results for the demand of public works of Seine-Normandie

The computation of the total demand is based entirely on the modelled drivers, population and gross domestic product, and the modelled substitution. The simulation error has been found to be acceptable.

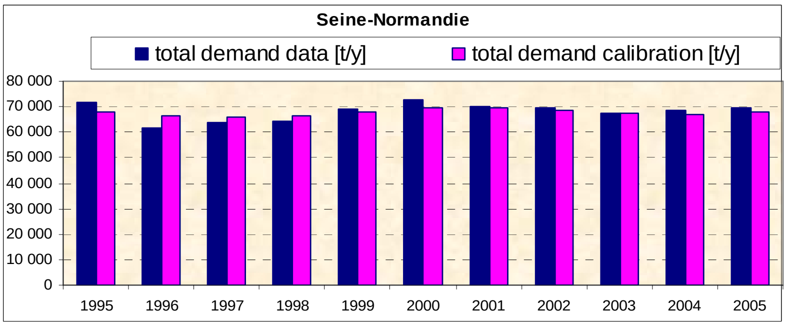


Figure 27: Calibration results for the total demand of Seine-Normandie

The following graphs (Figure 28 - 32) show the results of the calibration of the supply end for the region Seine-Normandie. The simulated production and import time series are the results of the mechanism computing the market competition. As shown in chapter 4.2 the production and the thereof dependent new authorisations determine the stock of authorised reserves from which the capacities are derived and sent to the market balance module. The reconstructed capacities from which the actual production is derived are also marked.

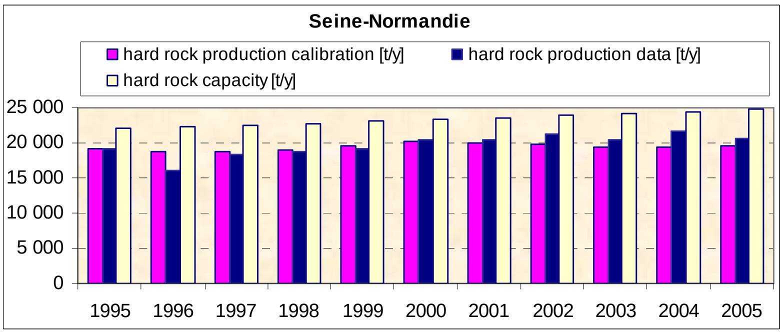


Figure 28: Calibration results for the hard rock production of Seine-Normandie

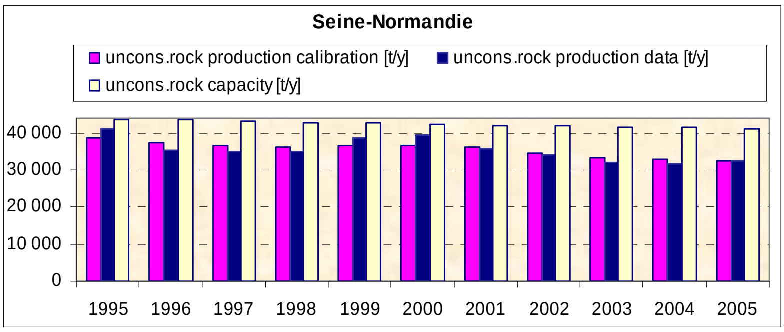


Figure 29: Calibration results for the unconsolidated rock production of Seine-Normandie

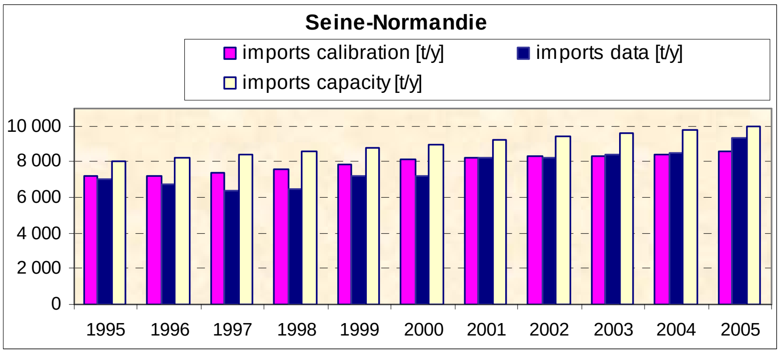


Figure 30: Calibration results for the imports from other regions of Seine-Normandie

Note that for the niche markets different starting points have been chosen for the S-curve.

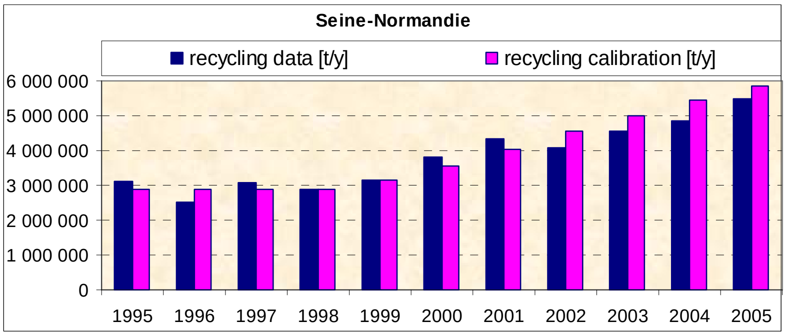


Figure 31: Calibration results for recycling of Seine-Normandie

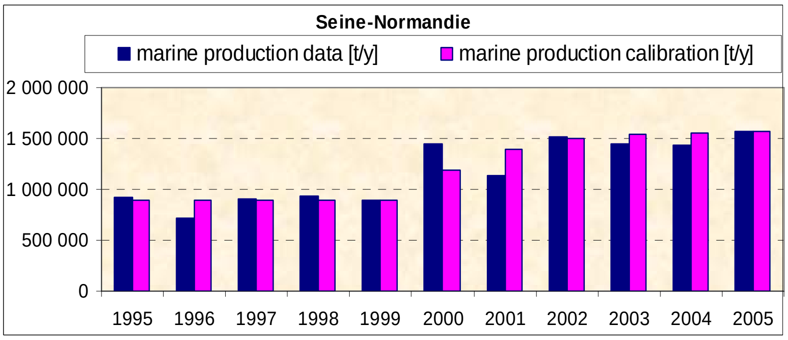


Figure 32: Calibration results for marine aggregates production of Seine-Normandie

Table 2 compares the estimated authorised reserves which were only available in 2005 and the simulation results of the reserves of the same year. After 10 time steps of simulation (10 years) the model showed marginal deviations.

In tonnes	Hard rock authorised reserves in 2005		Soft rock authorised reserves in 2005	
	Reconstructed	Simulation output	Reconstructed	Simulation output
Adour-Garonne	464096000	471050624	318833000	318578144
Artois-Picardie	265553000	251534112	57196000	57299368
Rhône-Méditerranée	918636000	894271808	447054000	463240576
Loire-Bretagne	1943066000	1896585856	284204000	284473632
Seine-Normandie	429843000	425671072	298994000	298281920
Rhin-Meuse	125276000	123790840	356287000	353576576

Table 2: Comparison of authorised reserves data and simulation output in 2005

5. Base case simulation and uncertainty analysis

5.1 The baseline scenario

The model has been calibrated on the basis of data, which was available in a certain period. The mechanisms found during the building process were adjusted so the model output could be close enough to the data time series available as described in chapter 4.7. In order to evaluate what the defined mechanisms would result in beyond the calibration period, the baseline scenario (or base case) was expanded upon. It projects the "business as usual" functioning of the model to the whole simulation period. This includes the calibration period from 1995 to 2005 and from 2006 to 2037. The predictive simulation of the model's parameters can be considered as an extrapolation of the current mechanisms. The base case represents an evolution which could be observed if nothing else changed and everything observed in the calibration period stayed the same. It is thus not meant to be a prediction of what is going to happen inevitably.

The base case serves as a simulated data set used for comparative analysis of all of the further developed breaking scenarios. In this manner a qualitative (increase or reduction) and a quantitative (how much) comparison can be drawn between the simulated model variables in different scenarios.

The characteristics predominant in the calibration period have been maintained. Those are among others:

- A regular increase of the gross domestic product (GDP growth rate constant for each of the six zones);
- A regular acceleration of substitution of aggregates by other materials and new technology for building construction;
- A regular reduction of the demand for public works at equal GDP (trend function);
- Industrial development stays constant (always superior to 1 in the case of hard rock and below 1 in the case of soft rock);
- Social acceptability stays at 100% for both primary supply sources;
- Road transport stays greater than 90% of the total transport in each of the regions.

Keeping the drivers' growth rate at the values of the calibration period, results in 550 million tonnes of national consumption in 2035. This value was obtained as a compromise between the partners of the ANTAG-project. A perfect calibration of macroeconomic drivers resulted in unrealistically high values in 2035 due to comparatively high population and GDP growth in the calibration period, as described in chapter 4.7. Particular caution is required when calibrating a long-term model using data series of a 10-year period. The model calibration and the setup of the base case simulation are, in this particular situation, unusually dependent upon each other.

The local supply sources still dominate the market while the niche markets have reached their maximum capacity limit. Since the factors of industrial development and social acceptability have not changed, the unused capacity is kept at a reasonable level and thus can absorb the demand fluctuations. The base case has been developed for each of the six regions. The full base case model in Vensim layout can be found in Appendix A.

5.2 Computation of the impacts upon the environment

The environmental impacts and externalities are driven by the access to the aggregate resource and consequently they result from the market equilibrium study in the market- and production submodels carried out in the ANTAG-project. They are also driven by the transport dynamics and, as we will see in the scenario assessment in chapters 7 and 8, their feedback mechanisms. The impacts are then computed by simply applying the respective coefficients to the tonnage produced and the tonne-kilometres transported. Of course the coefficients could alter in a separate transport scenario by considering, for instance, an increase in the carrying capacity of trucks.

Since the average transport distances from the quarries to the consumption centres are permanently increasing, they are mainly responsible for the CO2 emissions within the construction minerals market. Modelling each mode of transportation will allow comparative impact analyses of CO2, transport flows, land-use and energy consumption on the basis of scenario simulations. The CO2 emissions are a very representative key indicator for the overall impact, since CO2 is generated at the production and transport stage of the model no matter what type of source and what type of transport mode. The impacts upon the environment outside France, however, are not considered.

5.3 Sensitivity analysis

5.3.1 Principles and simulation setup

In the base case scenario sensitivity testing was performed in the period 2010 – 2035. Since 10 years of times series is a rather short period for the calibration of a System Dynamics model, which focuses on long-term trends, we cannot assume that the exact values of the driving coefficients, which have been calibrated on the basis of this period, are known. If we knew the exact values of all parameters, sensitivity testing would make no sense.

Sensitivity analysis was performed using the Monte Carlo method. The Vensim® package used allows multiple-parameters testing within one simulation. This is crucial since we are facing multiple uncertainties and the outputs of different modules can interact among each other to a large extent. Each parameter requires the assignment of a minimum and maximum value along with a random distribution over which to vary them in order to see their impact upon the model behaviour. It has been considered that any number between the minimum and maximum values is equally likely to occur. Consequently, the Random Uniform Distribution has been chosen in this study as the kind of probability distribution from which values are drawn for each parameter. Monte Carlo sensitivity then works by sampling a set of numbers from the defined boundary domains. Once the distribution for each parameter is sampled, the resulting values are used in a simulation run. The number of simulations has been set at 200, which means that the sampling process is repeated 200 times.

5.3.2 Parameters selection and testing

The consumption submodel is the driving force for the whole ANTAG-model. It computes the local demand for a region at the end of the chain, which is the driving parameter for everything downstream of it. Market competition will adjust to a specific demand of a year, the distribution of overcapacity among the supply sources will depend upon, and so will the transport volumes and the environmental impacts, which are proportionally related to the production and transport volumes. Understanding to which parameters the demand is sensitive is crucial since it drives all the subsequent submodels and determines the output of the model more than any other parameter.

The four parameters of interest in the consumption submodel are the constants determining the growth of the gross domestic product, the population, the substitution and the new technology for building construction, as well as the decelerating force for aggregates consumption of public works (Figure 33). Those are tested parallel starting in 2010.

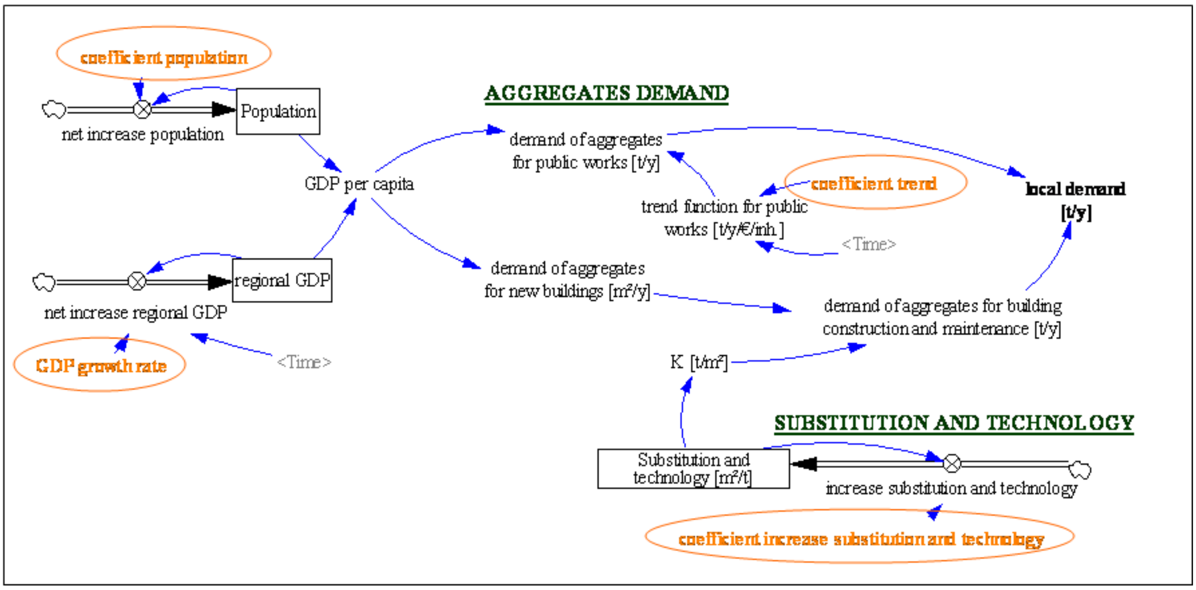


Figure 33: The four testing points for the demand uncertainty analysis (Vensim layout)

Testing all four parameters symmetrically illustrates that the local demand showed the highest sensitivity to the regional GDP growth rate. The GDP growth rate, however, is more likely to decrease significantly rather than increase in the long term, and, in this regard, remains the most uncertain factor. It made thus sense to test the GDP growth rate asymmetrically between 1% and 1,6% (in a region where 1.6% is the actual value in the model) and the other 3 parameters symmetrically by ±5%. This showed huge variations (Figure 34). The outer bounds of uncertainty (100%) show that the maximum value of approximately 150 million tonnes is much closer to the base case value (red curve) at the end of the simulation than the minimum value of approximately 115 million tonnes. The same is true for the CO_2 emissions shown in Figure (35).

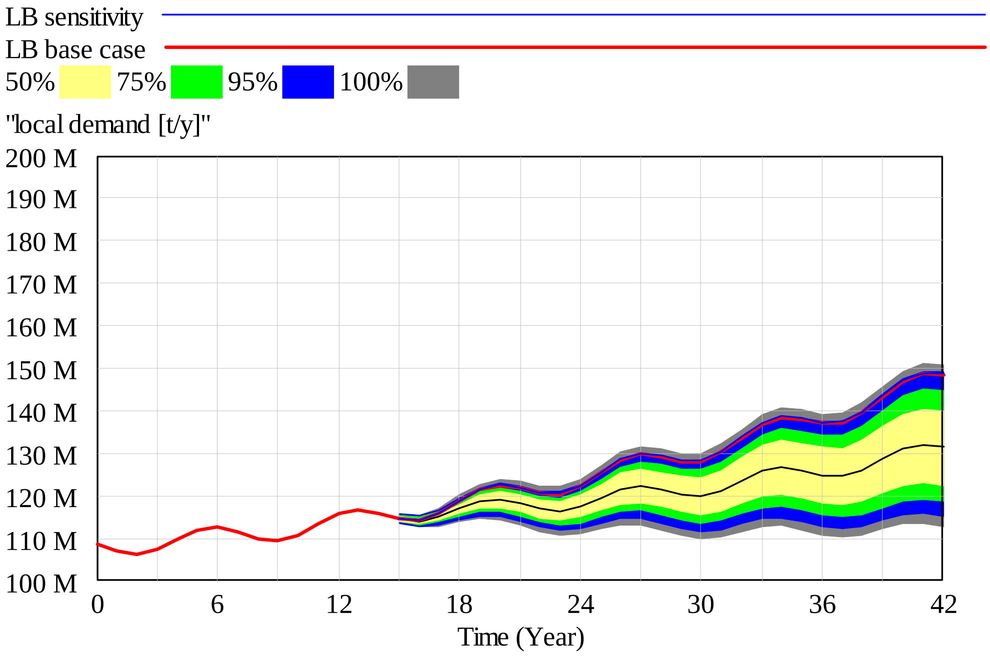


Figure 34: Local demand uncertainty for Loire-Bretagne (sensitivity tested to local demand input parameters) - starting time 1995

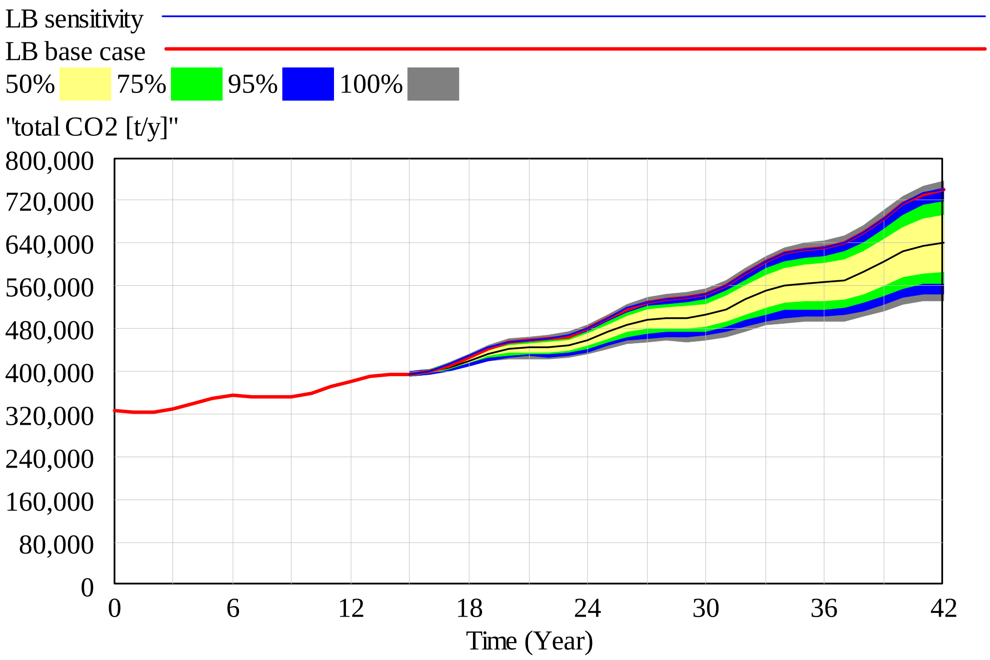


Figure 35: Total CO2 uncertainty for Loire-Bretagne (sensitivity tested to local demand input parameters) - starting time 1995

A Monte Carlo sensitivity test of the recycling capacity limit could lead to the assumption that the model output will vary more or less significantly in road transport flow and in

CO2 due to transport. The reason for this expectation is the fact that recycled construction material is exclusively transported by road. However, testing the recycling capacity by ±15% (Figure 36) showed no significant effect on the model output (Figure 37-38). Note that the CO2 emissions in Figure (38) refer to road and secondary road transport as well as road transport of recycled construction material.

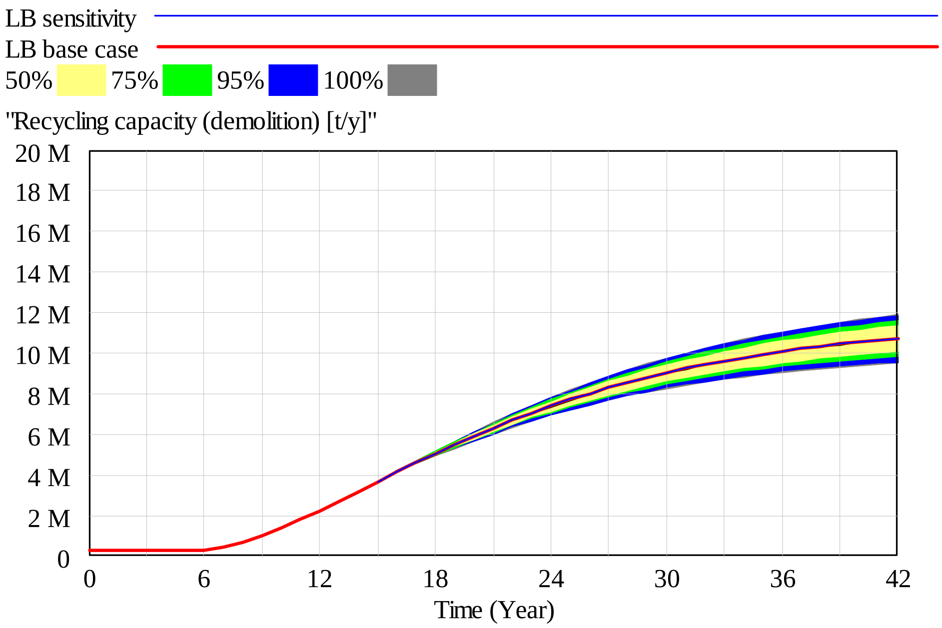


Figure 36: Recycling capacity uncertainty for Loire-Bretagne (sensitivity tested to recycling capacity limit) - starting time 1995

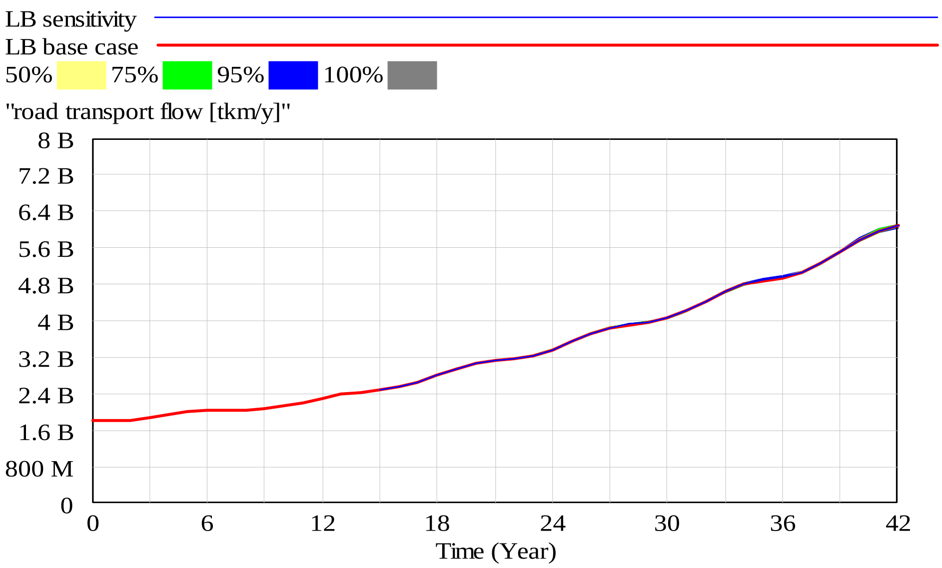


Figure 37: Road transport flow uncertainty for Loire-Bretagne (sensitivity tested to recycling capacity limit) - starting time 1995

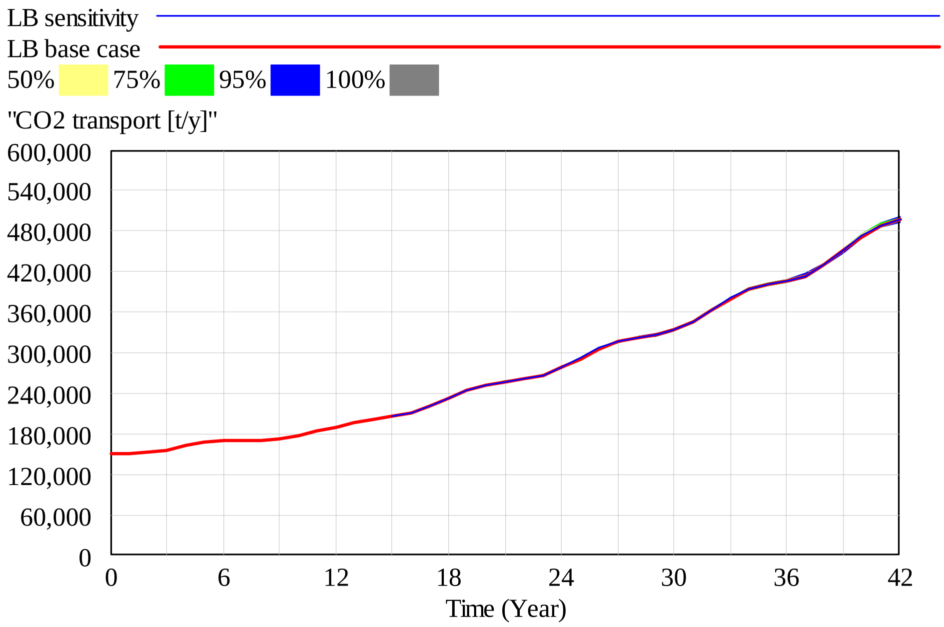


Figure 38: Transport -related CO_2 uncertainty for Loire-Bretagne (sensitivity tested to recycling capacity limit) - starting time 1995

Further uncertainty analyses included the waste factor and the factor of industrial development. However, the model output did not show any particular sensitivity to those parameters.

5.4 Model consolidation

5.4.1 Calibration region per region

The model conception and calibration has always been carried out in reference of one region. This was possible because the data was available per region for the calibration of ANTAG-models. The starting point was the region Adour-Garonne, an autonomous region producing nearly its whole entire demand. Furthermore all the supply sources including marine aggregates production interact with the market, which is not the case in all of the regions. Adour-Garonne was therefore a good starting point to conduct the first data review and curve profile analysis to study how each of the supply sources developed.
Once calibration results for Adour-Garonne were satisfactory, the model was transferred to the region Artois-Picardie. This region is different since import from abroad and other

regions within France make up 30%. Also Artois-Picardie is very small compared to Adour-Garonne since it only consists of 3 départements. Obviously the curves of competition differ from one region to the other.

In two of the six regions (Seine-Normandie, Rhin-Meuse) alluvial deposits production is higher than hard rock production. Consequently, they are likely to have more unused capacity than the hard rock sector, which changes the market balance. Measures taken due to different circumstances regarding the niche markets have been described in chapter 4.3.3. The consolidation should verify two things:

- The sum of the imports from other zones within France must equal the sum of exports to other zones within France (∑flow into all zones = ∑flow out of all zones). The sum of transport flows must equal zero;
- The simulation output must give realistic results in the long-term on a national basis. The development of the French aggregates market must have certain credibility. The latter one can be checked upon by consulting other estimations and forecasts at least for the base case and some other scenarios.

The consolidation of all the six zones is most important whenever all the six regions are affected. It does not necessarily make sense when testing a region-specific scenario, for instance. The consolidation for the calibration period and furthermore for the base case simulation is especially important.

5.4.2 Results of the base case consolidation

The base case projection of the national consumption (Figure 39) shows realistic output values. The consumption is at almost 550 million tonnes in 2035, which corresponds to an 0,8% annual average increase observed in the last 30 years (1975-2005). The capacity increases in the same way, always guaranteeing a certain buffer. The unused capacity reaches a maximum of 20,7% when put in relation to national consumption. The profiles reflect “business as usual”.

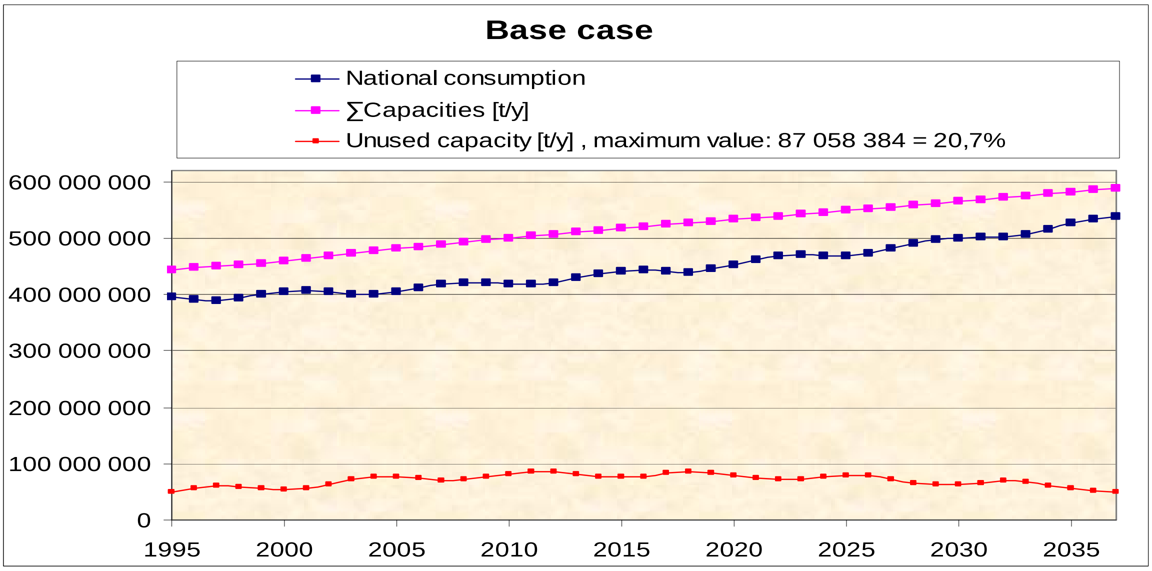


Figure 39: Base case consolidation: consumption and capacity

Figure (40) shows the profile curves of the five supply sources. Obviously the imports from other zones within France disappear when consolidating on a national basis. They are treated in Figure (41). The hard rock sector is expected to develop its production while the soft rock production is slowly decreasing. The recycling sector increases nationally in the same manner as on a regional basis by obeying S-curves, its capacity limit being 48 million tonnes. Marine production and the imports from abroad contribute marginally to the overall aggregates mix.

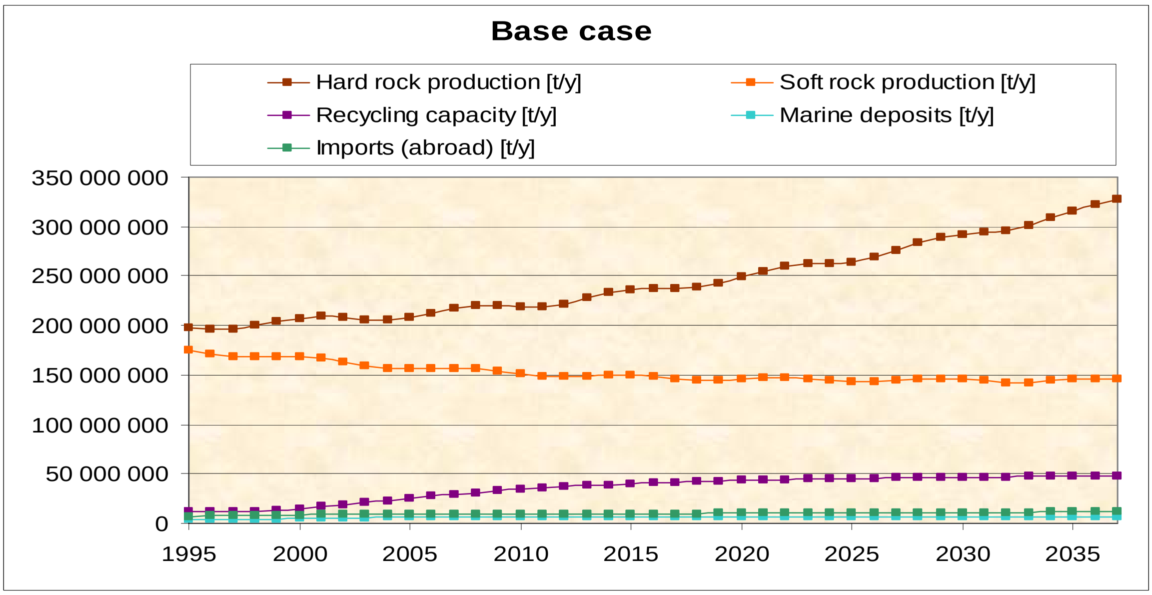


Figure 40: Base case consolidation: supply sources

The sum of the imports from other regions within France and the export to other regions within France should equal zero. Exports are easy to control since they are represented by exogenous stock-and-flow-structures. The imports, on the other hand, are a result of the market equilibrium, which means that, on a regional basis, they directly depend on the total demand and on all the other players on the market. The region which has the most impact on the flow balance is Seine-Normandie, as can be seen from Figure (42). The difference of imports and exports stays small with errors inferior to 1 million tonne.

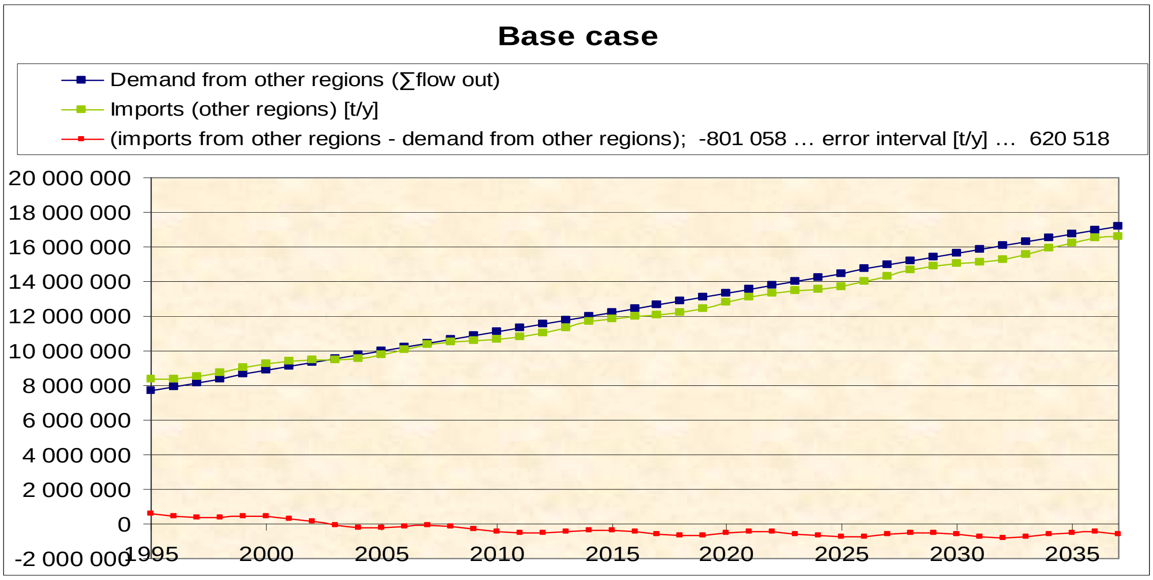


Figure 41: Base case consolidation: flow balance

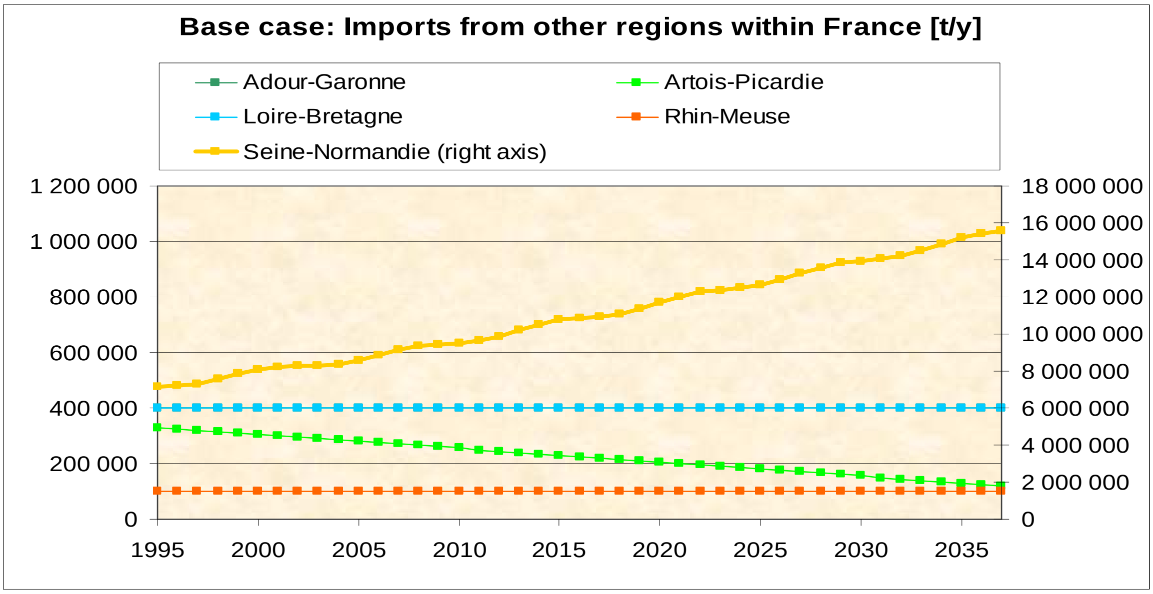


Figure 42: Base case consolidation: imports from other regions

Figure (43) shows the main impacts upon the environment.

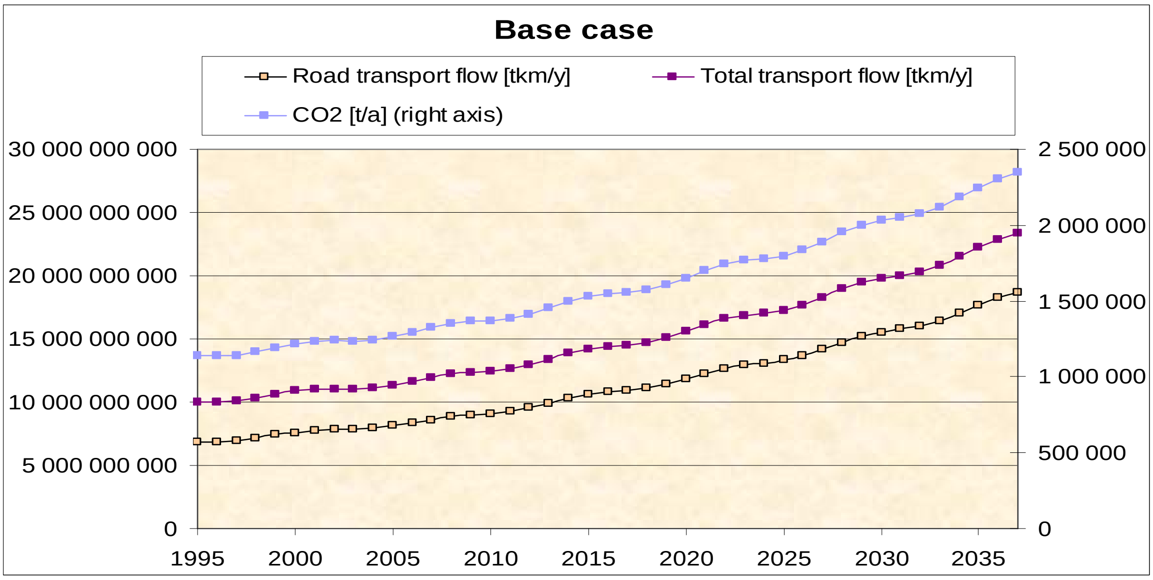


Figure 43: Base case consolidation: impacts

6. Summary and closing remarks

This macroeconomic System Dynamics model is aimed at representing the French aggregates supply and transport market and estimating environmental impacts on a national scale. The goal is to estimate the big trends in the construction minerals market for each of the six macro-regions. The building and calibration process of the System Dynamics was a key issue of the French-Austrian research project ANTAG. The aggregates market characterized by a short average transport distance is governed by the micro-economics of local surroundings. The transfer of microeconomic mechanisms to a macroeconomic scale was the most complex task throughout the model conception. In order approach this task, causal loop diagrams have been build before transferring them into stock-and flow structures. This difficulty was present at nearly all stages of the process and was a particularly influential factor in the estimating the future consumption, finding the market balance and transport modelling:

- The fact that the total demand of a region is only divided into only two sectors, which are driven by the gross domestic product per capita surely is debatable. Furthermore the GDP growth rate is the biggest uncertainty in the model according to Monte Carlo sensitivity testing;
- The market submodel, which focuses on the competitive supply end of the French aggregates market determines an equilibrium among the supply sources. The transfer of a local market to macroeconomic competition has been achieved by defining different supply sources and assigning a production potential (capacity) to them. The production of each supply source follows from a mechanism, which allocates parts of the whole market overcapacity to them. The mechanism is stable unless the gap between the capacities of equally scaled sources (e.g. crushed rock and alluvial deposits) becomes too large – in which case the “loss” of potential production (unused capacity) imposed by the market balance mechanisms would exceed the production capacity of the smaller producer. The market equilibrium mechanism is always calibrated for a certain scale and only robust within this scale;
- The penetration of niche markets happens, in particular for recycled aggregates, on a very local basis, since the haul distances are small and not expected to increase significantly. This is due to the fact that recycling happens close to even in

consumption centres. Profiles obeying S-curves have been chosen to describe the way they introduce their capacity to the market;

- In modelling the transport distance growth, the difficulties in the transfer from a micro- to a macroeconomic scale becomes even clearer. There are numerous routes of transport among the large number of quarries and consumption centres. The distances constantly change due to various reasons. An effective way to model the combination of those effects was to make the average haul distance for road increase as a result of reservoir depletion near consumption centres and urbanisation, forcing new quarries to be authorised in locations further apart.

The integration of the macroeconomic mechanisms into the model was performed on the basis of two constraining factors in the model calibration:

- First, the data, which was either available for a 10-year period, which is relatively short for comparable studies, or could only be estimated for one point in time;
- Second, future estimation other than those resulting from the ANTAG-model, which gave suggestions concerning the plausibility of the model.

The challenge was building a baseline case scenario and finding an agreement between these two constraints. Following a strict calibration of available data (and one is tempted to do so if there is not so many), results in unrealistic values in the long-term. Focusing on the available long-term predictions will, on the other hand, cause the quality of the calibration to worsen. The calibration error is kept at less than 10%.

Missing data has been reconstructed for the consumption of the public works branch, the authorised reserves and the production capacities of hard and soft rock. In this manner the authorised reserves, the extraction capacity and the actual production of a supply source of a region could be linked to each other via feedback loops.

The consolidation on a national basis by integrating the model output of the six regions confirms a realistic inter-regional communication: the sum of aggregates exported to other regions within France roughly equals the sum of aggregates imported to other regions within France.

PART III

SCENARIOS – BREAKING ACTIONS AND FEEDBACK

7. Model feature extensions and add-ons

7.1 Introduction

In this chapter secondary feedback relations and additional modelling techniques will be explained. They need to be introduced in order to take into account secondary mechanisms involved in certain scenarios. Model extensions had to be made for different submodels, since they can concern either

– the market equilibrium;
– the supply end;
– the transport;
– or a combination of them.

This chapter is a preliminary step for the understanding of scenarios since the technical aspects are explained in detail. Which one of the mechanisms discussed in the following chapters is applied in a certain scenario will be explained during the scenario discussion itself.

7.2 Monitoring overcapacity

Overcapacity (or unused capacity) can have two possible origins. If the capacity is estimated too high compared to the demand, unused capacity will result from the market balance mechanism. The same thing happens if the demand decreases while the capacity follows the original trend. An overcapacity that is too large is unlikely since actors would never accept plenty of unused capacity in the long-term. They will rather adapt to the situation with which they are confronted. Hence the model requires a mechanism that monitors the new authorisations year by year.
The causal loop diagram in Figure (44) highlights the implemented new relations compared to the base model’s causal loop diagram (Figures 12 and 13). Two new feedback loops can be observed. Whereas for the most part, they look the same (both balancing and their repercussions are similar), in the first loop an increase in overcapacity

and, consequently, in hard rock overcapacity, causes a decrease in new hard rock authorisations. On the other hand, in the second loop an increase in hard rock overcapacity also causes a decrease in industrial development, which also causes a decrease in new hard rock authorisations. In both cases decreasing hard rock authorisations cause a decrease in hard rock reserves, consequently in hard rock capacity and in the sum of capacities. This results, ceteris paribus, in a fall of overcapacity, which is the opposite effect when compared to the beginning of the loop.

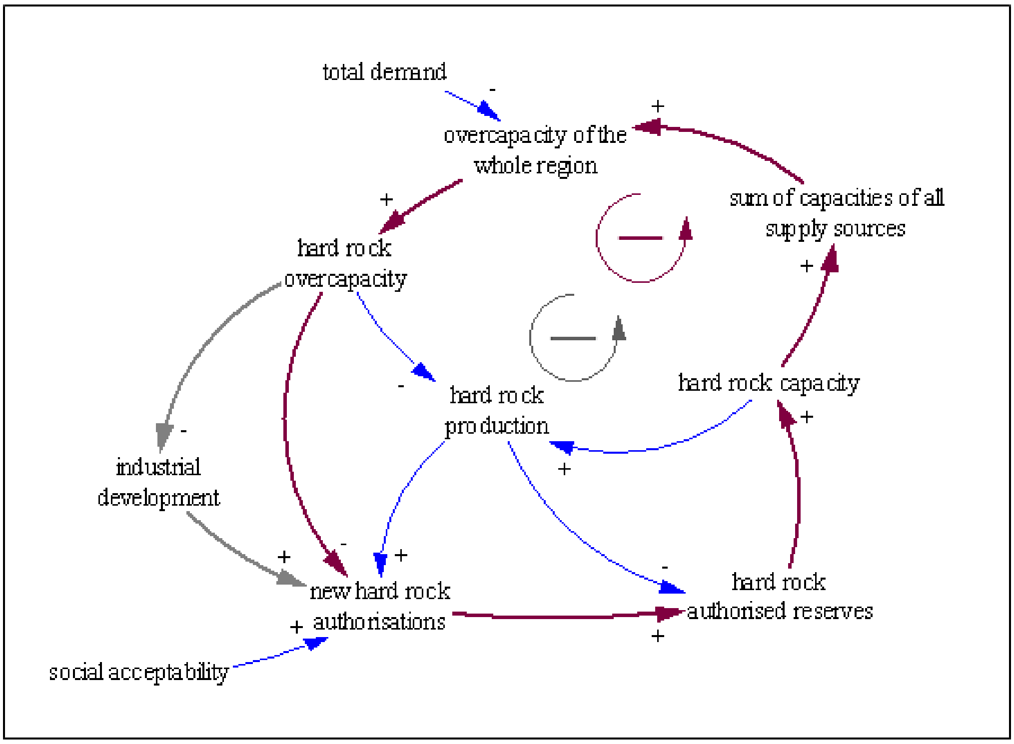


Figure 44: Monitoring overcapacity - causal loop diagram

We now want to formulate an equation for the new authorised reserves taking into account the current overcapacity (two new causal relations). Firstly, the idea of the mechanism is that a fraction of the overcapacity of the respective primary source in a certain year is not being renewed the following year (Equation 30). Thus, this part of lost production is subtracted from the extraction the year before, which would be the reserves, originally intended for renewal.

Secondly, the factor of industrial development d changes as a function of the overcapacity of the respective primary source. Since the industrial development refers to the long-term, it only can vary by a maximum of 10%. Either it increases, if the overcapacity is below the chosen lower limit, or it decreases, if the overcapacity is above the chosen upper limit. How this idea in causal loop diagram has been implemented in the existing stock-and-flow structure from the base case, is shown in Figure (45).

$$a_t = (e_{t-1} - oc_t \bullet X_{UROC}) \bullet \left(\frac{e_t}{e_{t-1}} \bullet SA \bullet d \right) \quad (30)$$

Where

oc_t …	overcapacity in year t
X_{UROC} …	fraction of un-renewed overcapacity
a_t …	new authorisations in year t
e_t …	extraction in year t
e_{t-1} …	extraction in year t-1
SA …	social acceptability
d …	factor of industrial development

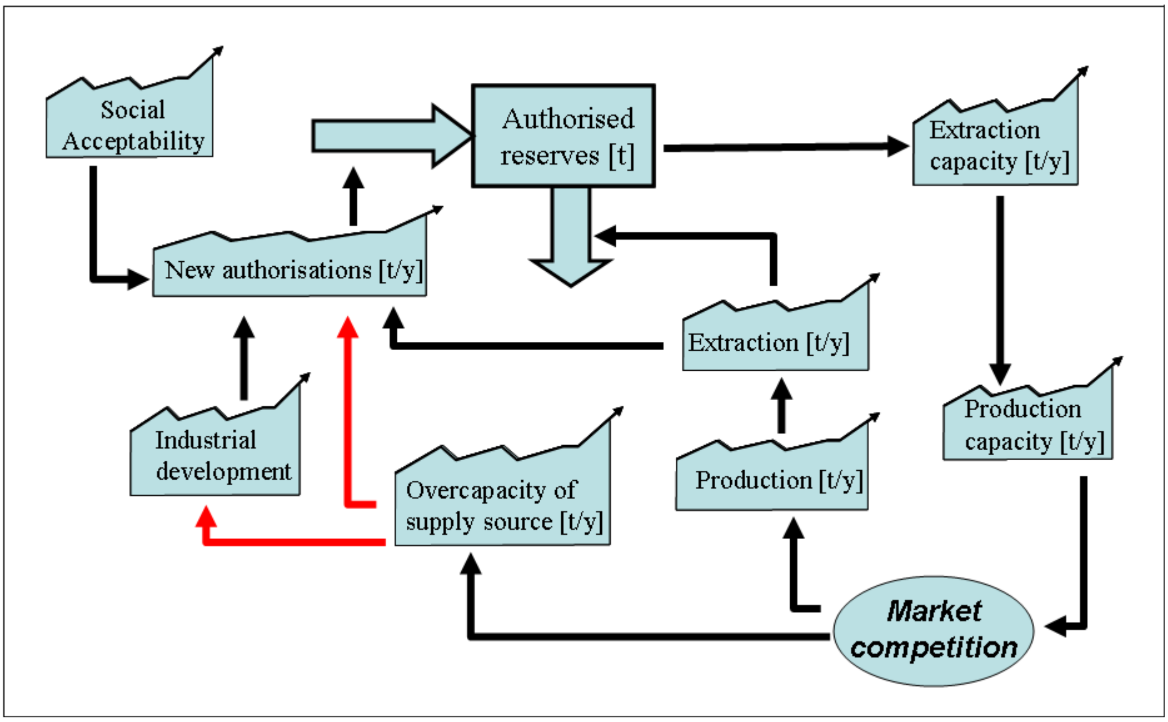


Figure 45: Stock-and-flow structure for monitoring overcapacity (identical for hard and soft rock)

7.3 Creating additional capacity momentarily

During the scenario simulations additional capacity is created by different means:
Firstly, it can be created by the overcapacity regulating mechanism itself, whereas in this case the mechanism acts inversely. If we imagine a situation of shortage, where not enough capacity is created by the supply sources, the overall overcapacity naturally will tend to move towards zero. In addition to the classic capacity monitoring mechanism, the decreasing unused capacity will also have an influence on the fraction of un-renewed overcapacity X_{UROC} (fraction of the overcapacity of the respective supply sources which is not renewed within the new authorisations). As a consequence of the two forces acting in the same direction their product - the part of the overcapacity which is not being renewed the following year $oc_t \bullet X_{NROC}$ - tends to move towards zero as well. Consequently, the new authorisations of hard rock are being increased, until the unused capacity of the region reaches 0 tonnes. In case of a shortage an implicit partial capacity support is guaranteed by the overcapacity regulating mechanism. On the other hand, the factor d can only increase by a maximum of 10% compared to its initial value. Therefore, its instant capacity support remains rather limited. In order to create large quantities of additional capacity, an additional mechanism has been created.

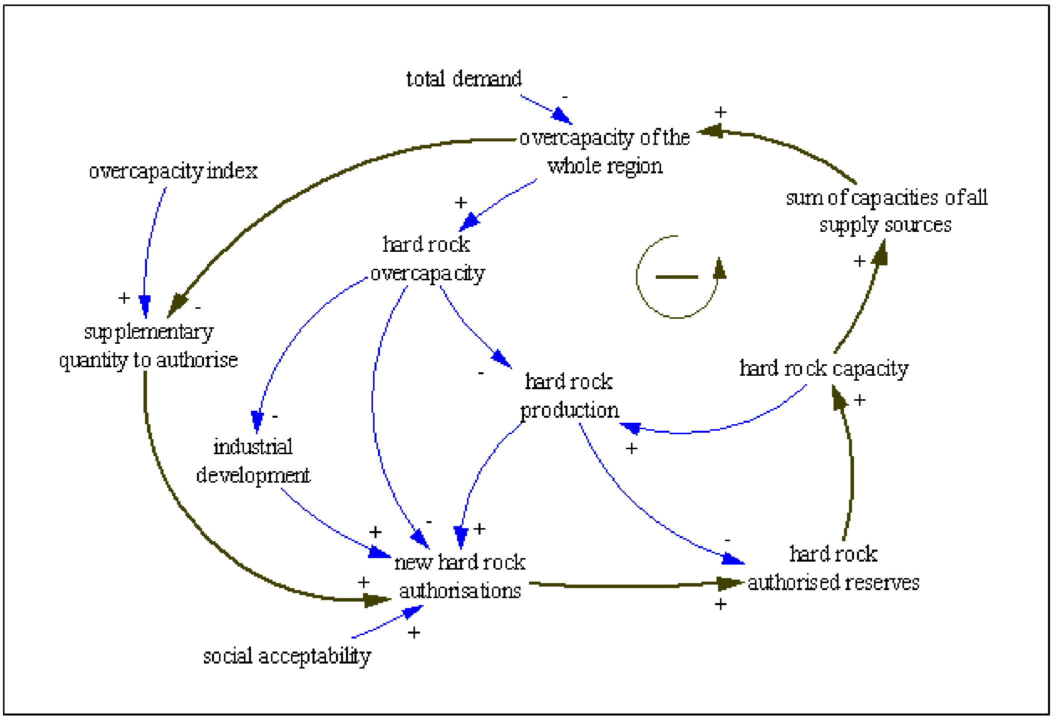


Figure 46: Creating new capacity - causal loop diagram

The causal loop diagram in Figure (46) shows that a decrease in overall overcapacity (unused capacity of the whole region) means a higher risk of facing a shortage. Therefore a supplementary quantity is authorised in order to create new capacities (similar to the previous mechanism whereas in this case it functions more as a security).

In the model the difference of a chosen limit and unused capacity of the whole region serves as an index for the risk of the market facing a shortage. Once the unused capacity falls below this index, the difference between the two is the amount of supplementary authorisations, Q in Equation (31).

$$a_t = (e_{t-1} - oc_t \bullet X_{UROC} + Q) \bullet \left(\frac{e_t}{e_{t-1}} \bullet SA \bullet d \right) \tag{31}$$

The transfer to the corresponding stock-and-flow structure is shown in Figure (47).

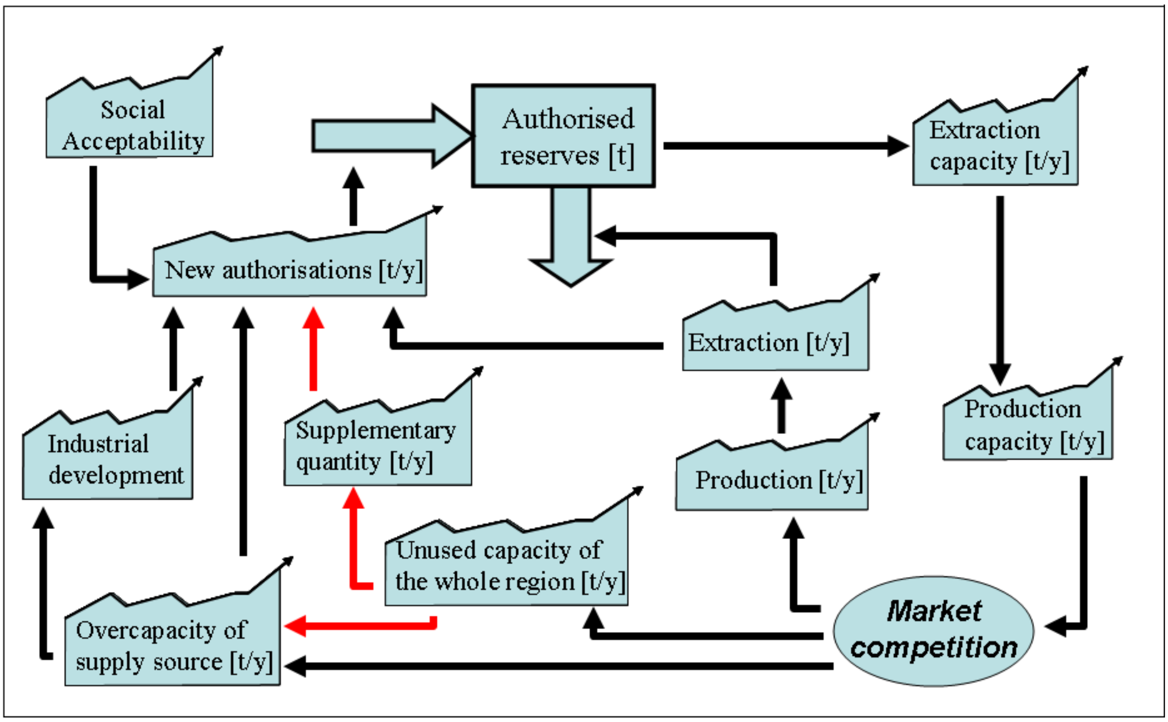


Figure 47: Stock-and-flow structure for creating new capacity (e.g. hard rock balancing a shortfall of soft rock)

7.4 Shift in market equilibrium due to penetration of a new primary source

If a new player introduces high capacities to the market, the current market equilibrium will be disturbed. The new player will not be able to distribute all of his capacity, which would be the case in a niche market, for example. The mechanism of market competition described in chapter 4.2 allows the control of the relative competitiveness of a niche player, for instance the imports.

The causal relations in Figure (48) suggest that a significant capacity increase of a niche player will cause a decrease in its own relative competitiveness. A decrease in its relative competitiveness results, ceteris paribus, in an increase of the niche player's overcapacity. If the capacity remained constant, this would cause a decrease in the niche player's production, but since the niche player's capacity has been significantly increased, we also expect a rise in production. A decrease in relative competitiveness of the niche player would normally also cause a decrease of overcapacity of the other supply sources, hard and soft rock, but since the sum of capacities and the overcapacity have been increased by the niche player's capacity rise, more overcapacity will be distributed over all the supply sources. The specific outcome of the model depends on the values chosen.

It is important to note that the relative competitiveness of the supply sources is not an explicit variable in the base model, where it is implicitly introduced in the computation of the overcapacity of each supply source. In this new feature, it had to be taken out.

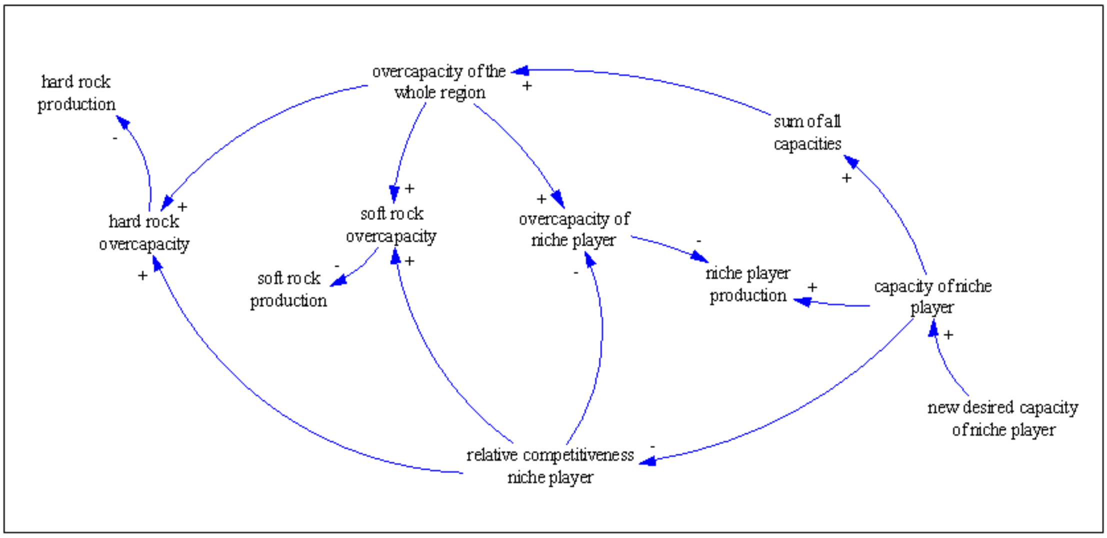


Figure 48: Causal relations for change in market balance due to a significant capacity increase of a niche player

The market balance in the model adapts in an elegant manner. If the capacity increases, the slope of competition of the imports becomes steeper (step 1 in Figure (49)) which means that the relative competitiveness of the imports changes (decreases). Consequently not only the import capacity and the actual imports will rise, but also the unused imports capacity. The sum of the slopes obviously has to increase as well, which means that (for a same value of unused cumulative capacity) the indicating line hits the competition curves of the other supply sources at an earlier turn (step 2 in Figure (49))! The overcapacity of those supply sources would therefore be reduced. The competition among the supply sources in the market submodel thus adapts exclusively as a function of the import capacity introduced, in other words: the balance adapts by changing only one single parameter. This mechanism allows a clear consideration of the difficulties encountered when foreign actors penetrate the market.

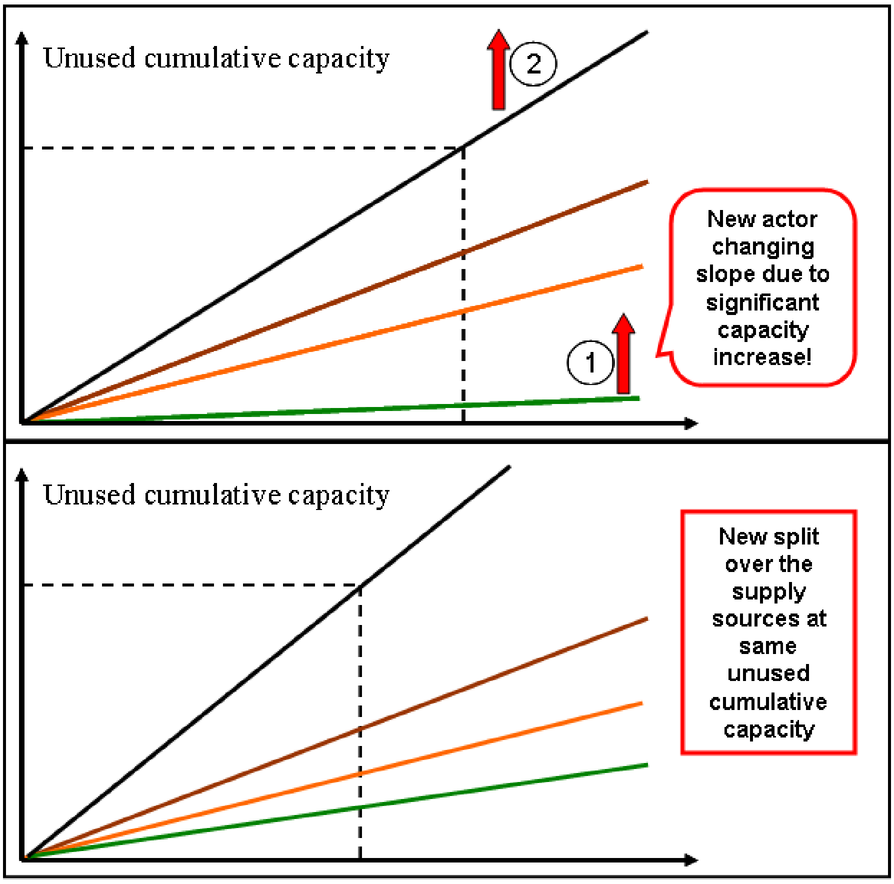


Figure 49: Shift in market equilibrium due to penetration of a new big player

7.5 Multimodal transport split and saturation feedback

Two of the following scenarios presented consider a move away from road transport towards alternative transport modes such as rail and the waterway. One scenario refers to the transport of locally sourced aggregates, the other one to imports from abroad which become a primary supply source. The transport-split submodel has been extended introducing feedback in order to perform these two scenarios adequately.

The first causal loop relationship (Figure 50) shows two balancing loops. A decrease in split factor road-alternative by a new target split causes (by definition in the model) an increase of tonnage conveyed by alternative transport modes, rail and waterway. This will increase the saturation of railways (upper loop in dark green) and waterways (lower loop in brown). Both cause an increase of overall saturation, which acts like a brake so the split factor road-alternative increases and more tonnage is transported on road and less by alternative modes.

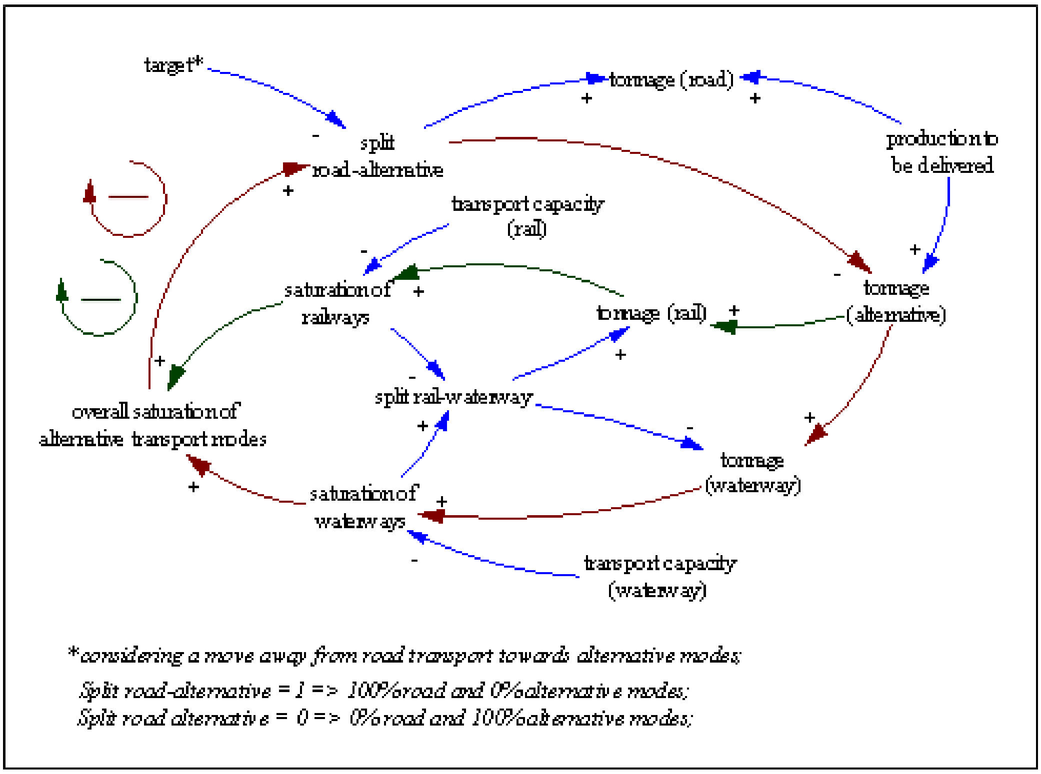


Figure 50: Causal loop diagram for the transport split (1)

Figure (51) shows two additional balancing loops, whereas these two focus on the interaction of the alternative transport modes with their corresponding split factor. A rise in tonnage transported by waterway causes an increase in saturation of the waterways, which by definition of the model causes an increase in split factor rail-waterway. This causes, ceteris paribus, a fall in tonnage transported by waterway. The same applies to the rail sector where a fall in tonnage transported causes a fall in railway saturation, which, ceteris paribus, results in an increase of the split factor rail-waterway and an increase in tonnage transported by rail.

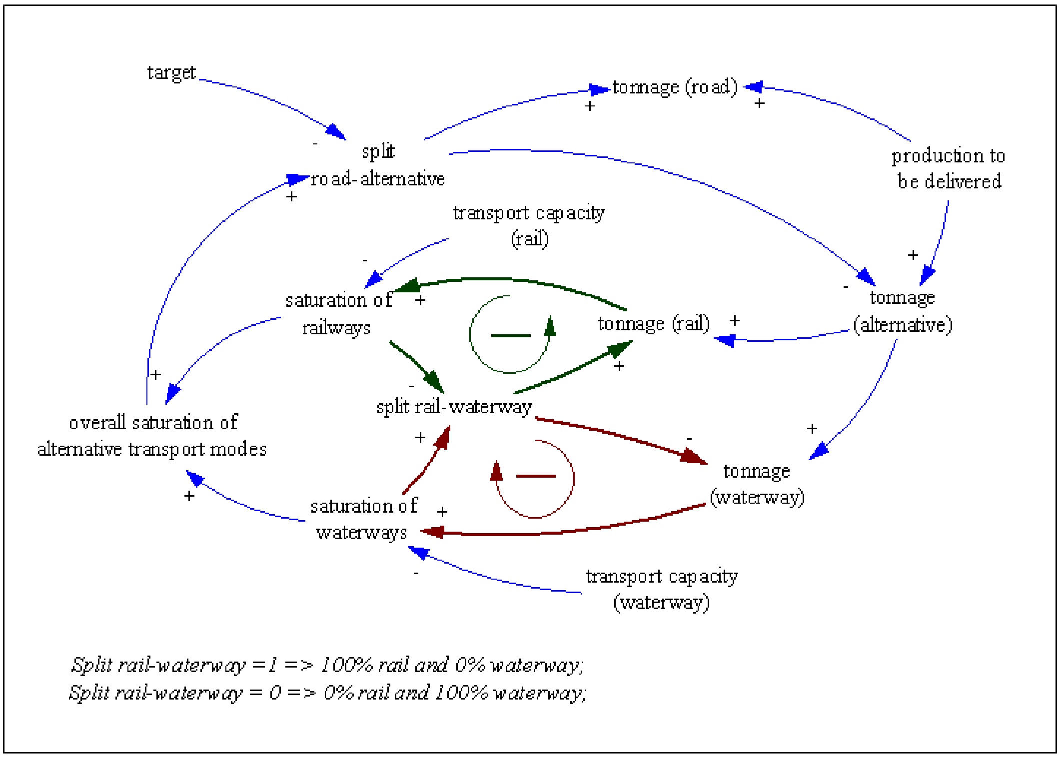


Figure 51: Causal loop diagram for the transport split (2)

The mechanism introduced as a stock-and-flow structure follows the idea that the target split factor and the imposed duration of transition between the initial and the target split are introduced using a PID controller. Ideally, the difference of the target split and the actual split factor in a given year would determine the magnitude of change of the split factor. Consequently the change per year would be higher in the first years since the actual value is still further away from its final target than in later years. Since it is impossible to move an infinite tonnage towards the alternative modes, transport capacities for rail and waterway are introduced into the model as constraints for the split factor.

The approach follows a calculation of transport capacity saturations, which serve as criteria for determining whether the respective transport mode still has capacities available. The split factors road-alternative transport and, among the alternative modes, rail – waterway are computed within two different levels of competition (indicated by the two circles in Figure (52)). The split target is dampened by the overall saturation of the alternative transport modes, while, secondly, the rail and waterway transport saturation are in a competition with each other. If the alternative transport saturation is close to 1, the target split factor might not be reached at all (Equation 32). The difference of the target split and the actual split factor road-alternative therefore accounts for the accelerating effect, while the saturation has a decelerating effect on the progression of the split factor (Rodriguez Chavez et al., 2010c). In this way, if the rail saturation, for instance, is closer to 1 than waterway in a given year, the split factor will push the alternative transport more towards the waterway (Equation 33). The competition among the transport modes is thus not a result of the quality parameters, as, for instance, presented in the study of Salini and Karsky (2003) but of their respective saturation.

$$X_{R\text{-}A_{t+1}} = X_{R\text{-}A_t} + \left[1 - X_{R\text{-}A_t}\right] \bullet \frac{\Delta P}{1+\Delta P} \bullet S_{A_t} + \dots$$
$$\dots + \left[X_T - X_{R\text{-}A_t}\right] \bullet \left[1 - S_{A_t}\right] \bullet f(d) \qquad (32)$$

$$X_{R\text{-}W_{t+1}} = X_{R\text{-}W_t} + \left[1 - X_{R\text{-}W_t}\right] \bullet \frac{\Delta F}{1+\Delta F} \bullet S_{W_t} \bullet \frac{1 - S_{R_t}}{1 - S_W(t) \bullet S_{R_t}} - \dots$$
$$\dots - X_{R\text{-}W_t} \bullet \frac{\Delta F}{1+\Delta F} \bullet S_{R_t} \bullet \frac{1 - S_{W_t}}{1 - S_{W_t} \bullet S_{R_t}} \qquad (33)$$

Where

$X_{R\text{-}A_t} \dots$	split factor between road and alternative transport modes in year t
$X_{R\text{-}A_{t+1}} \dots$	split factor between road and alternative transport modes in year t+1
$X_{R\text{-}W_t} \dots$	split factor between rail and waterway transport modes in year t
$X_{R\text{-}W_{t+1}} \dots$	split factor between rail and waterway transport modes in year t+1

X_T …	target split factor between road and alternative transport modes
ΔP …	net increase in percent of local production delivered within region from year t-1 to year t
ΔF …	net increase in percent of freight conveyed by alternative modes in tonnes from year t-1 to year t
f(d) …	function imposing the theoretical number of years until the target split is reached if there was no decelerating effect due to saturation
$S_{A\,t}$ …	overall saturation of alternative transport modes in year t
$S_{R\,t}$ …	rail saturation in year t
$S_{W\,t}$ …	waterway saturation in year t

The stock-and-flow structure in Figure (52) shows the interaction of the split factors of transport modes and the saturations.

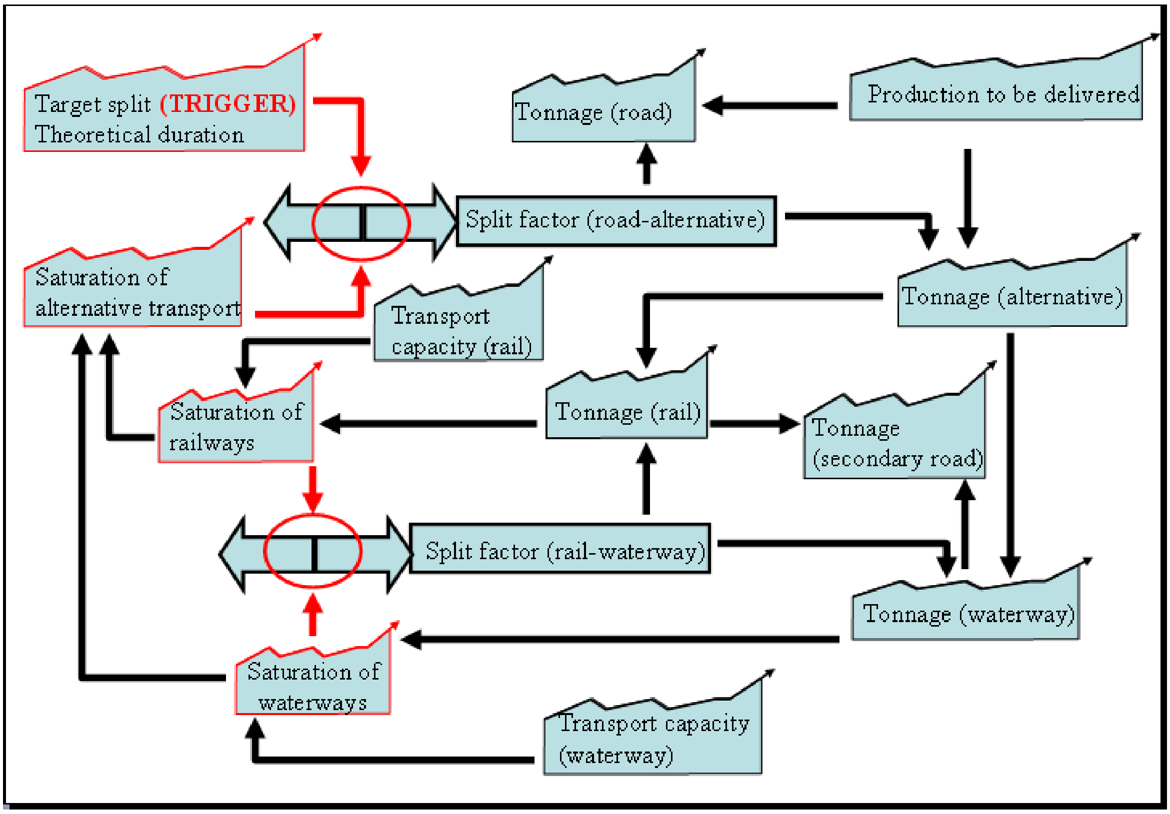


Figure 52: Stock-and-flow structure within the transport split submodel extension

7.5.1 Monte Carlo uncertainty analysis for the transport-split submodel extension

The importance of uncertainty analysis when developing a decision support system (Refsgaard et al., 2007) and in the scenario construction itself (Mahmoud, 2009) has been stated clearly. In the base case the ANTAG-model shows the highest sensitivity to the GDP rate, its macroeconomic driver (Rodriguez Chavez et al., 2010a). Data for the transport capacities was required for the submodel extension. While railways are almost saturated in the region this extension will be applied to, and the freight transported is known, the transport capacity on the waterway are difficult to estimate. Therefore the waterway capacity remains the most uncertain factor and it made to test the model extension's sensitivity to it. As in the base case model this was done by performing Monte Carlo simulation. 100 million tonnes being the current value of the waterway capacity in the model, the outer bounds were chosen at 120 million as a maximum and 80 million as a minimum. Figure (53) shows the transport split submodel in Vensim layout.

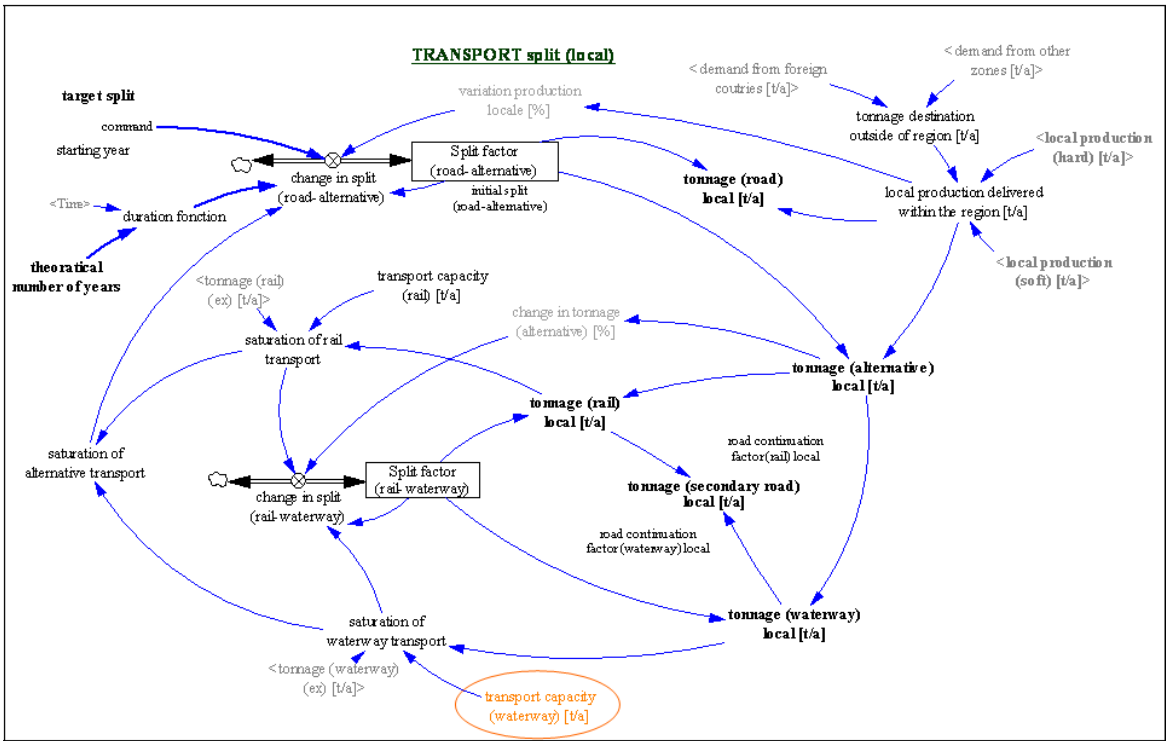


Figure 53: Testing point of the model transport split extension (Vensim layout)

Although it directly affects the waterway saturation (Figure 54), there is no significant impact on the transport split between road and the alternative modes (Figure 55). The freight per transport mode, the resulting average transport distances and consequently the environmental impacts will not change significantly.

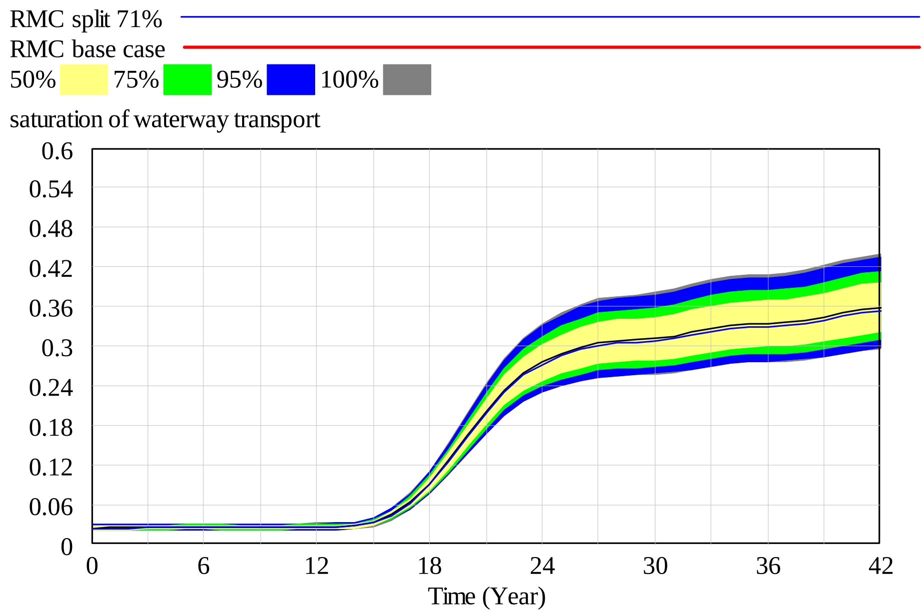


Figure 54: Waterway saturation uncertainty for Rhône-Méditerranée (sensitivity tested to waterway capacity)

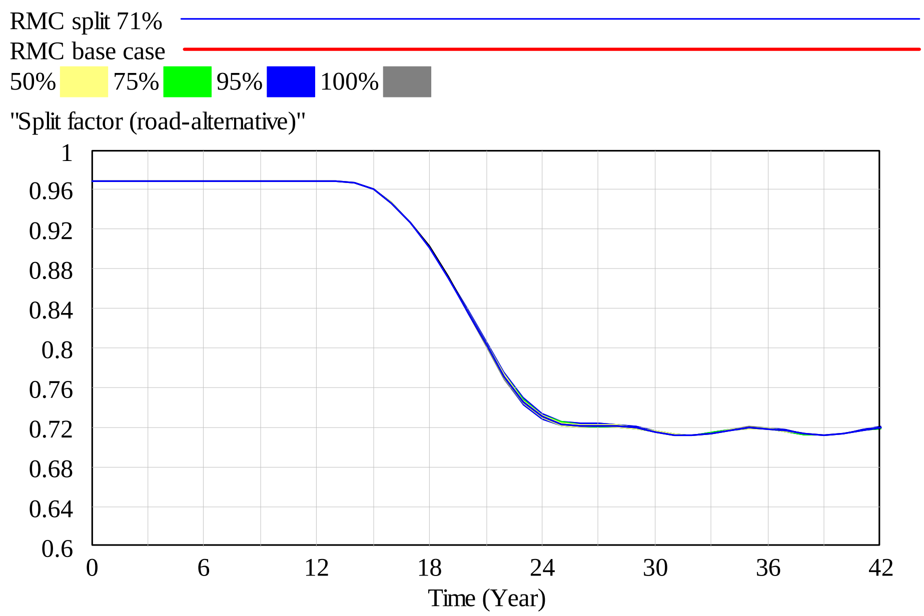


Figure 55: Transport split between road and alternative modes uncertainty for Rhône-Méditerranée (sensitivity tested to waterway capacity)

8. Scenario simulation and assessment of results

8.1 Introduction

Being a decision support system, the model focuses on anticipating the effect of "breaking actions". The scenarios differ from the base case in their functionality with regard to the access to aggregates in the consumption profile, the supply pattern and the transport modes. The conception of the scenarios is based on the question of what could become of the access if an external force disturbed or even broke an integral part of the current functioning. Their goal is therefore to simulate long-term evolutions of consumption, supply and transport provoked by a trigger.

A scenarios' trigger can practically be introduced at each stage of the submodel chain. The reason for the trigger action could be political, strategic or economic but knowing their origin is not crucial for the model or the analysis of its repercussions.

Apart from the trigger mechanism which can be abrupt or transient, secondary mechanisms and new feedback relations might have to be introduced depending on the scenario. Since those secondary mechanisms are not included in the base case model, they can be considered as consequences of the new behaviour upstream. The implementation of additional features and the extensions of the model require hypotheses.

One model will thus be developed for each scenario performed per region. The model output per region consists of the whole set of parameters year by year of each submodel. The end time has been fixed at 2037, 30 years since the beginning of the project.

While developing the scenarios the project's consortium focused on the future gross trends and tendencies. The scenarios presented are not meant to be forecasts, but rather alternative images of how the future could unfold. Scenarios should portray possible futures and long-term consequences of decisions no matter how improbable the occurrence may be (Mahmoud et al., 2009). In this way, extreme target values have been chosen as triggers. The triggering itself is sometimes sudden in nature, abruptly modifying a parameter from one year to the next.

The results and explanation of seven scenarios will be presented. Four of them have been performed in all of the regions (like the base case), whereas three of the scenarios, which will be presented, have been performed exclusively in region Rhône-Méditerranée. The reasons for choosing this region for a more detailed analysis are as follows:

- The region Rhône-Méditerranée is quite representative of France as a whole, since its 15 million inhabitants are close to constituting a fourth of the French population.
- With a gross domestic product per capita of 38 000 Euros, Rhône-Méditerranée is a rich zone where aggregates demand can be expected.
- The ability of the port of Marseille to take huge freights.
- The Rhône represents an excellent waterway opportunity for potentially transporting large freights.

8.2 Economic slowdown

8.2.1 Reasons of development and background

The first scenario studies the effects of a potential long-term economic slowdown directly affecting the aggregates market. A reduction in local demand compared to the base case can be concluded as a primary effect. This scenario has been developed since a national demand of 550 million tonnes in 2035, resulting from the base case, is questionable. Between 1975 and 2005 the average growth rate of the demand showed an increase of 0.8% per year. However, the economic crisis could have a dampening effect on construction activities in the long-term.

The scenario trigger is a dropping GDP growth rate which is slowing down the GDP per capita growth (Figure 56). Starting in 2010, the GDP growth rate decreases by 0.1% per year for a certain number of following years depending on the region (in average from 1.6% to 1.2%). This makes the local demand in aggregates for both branches of new buildings and public works decrease (Figure 57) and the national demand is eventually reduced from 550 to 480 million tonnes. As a consequence the supply sources produce less (Figure 58), and the transported tonnage and environmental impacts are decreased (Figure 59). Since the GDP per capita is the main driver of the model, a reduction of all activities is a logical consequence. This slowdown can be considered realistic, even though it is permanent.

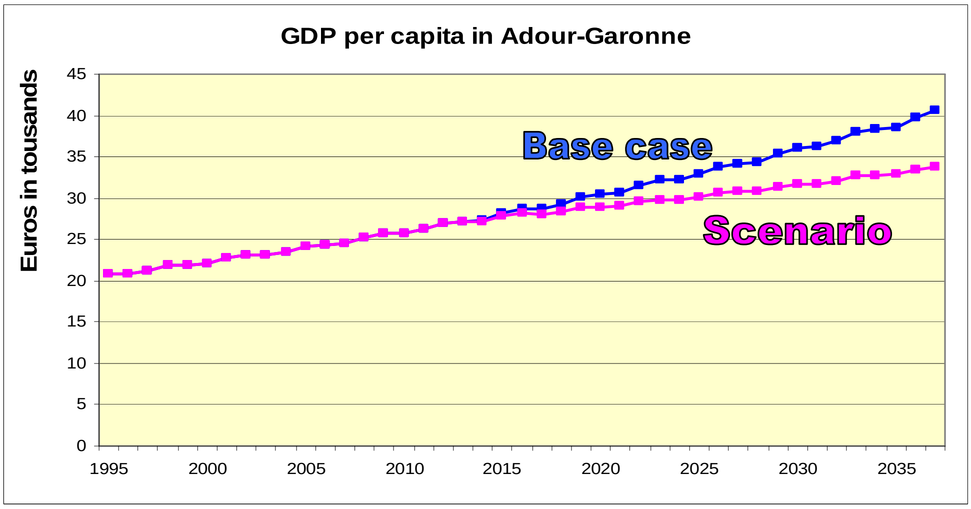


Figure 56: GDP per capita in the scenario of economic slowdown in Adour-Garonne

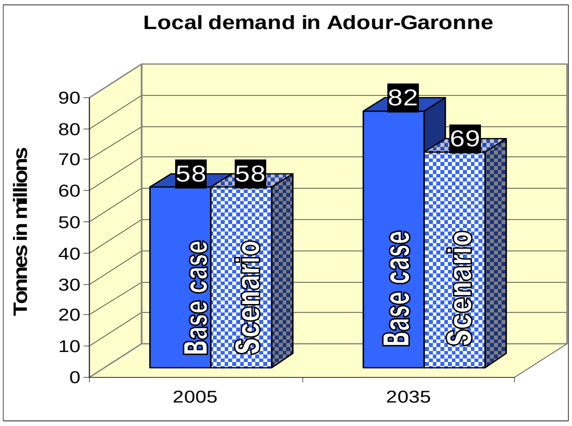


Figure 57: Local demand in the scenario of economic slowdown in Adour-Garonne

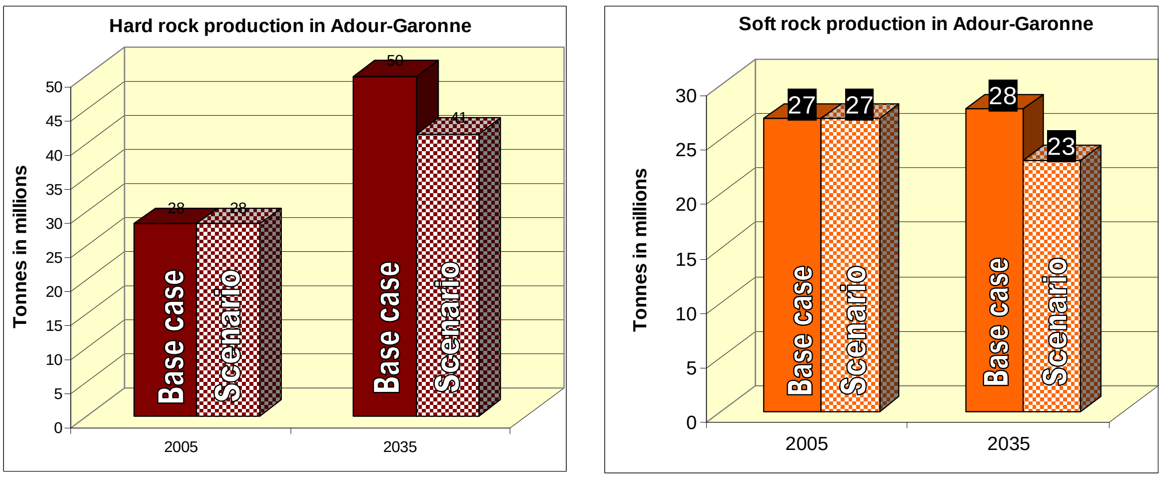


Figure 58: Hard and soft rock production in the scenario of economic slowdown in Adour-Garonne

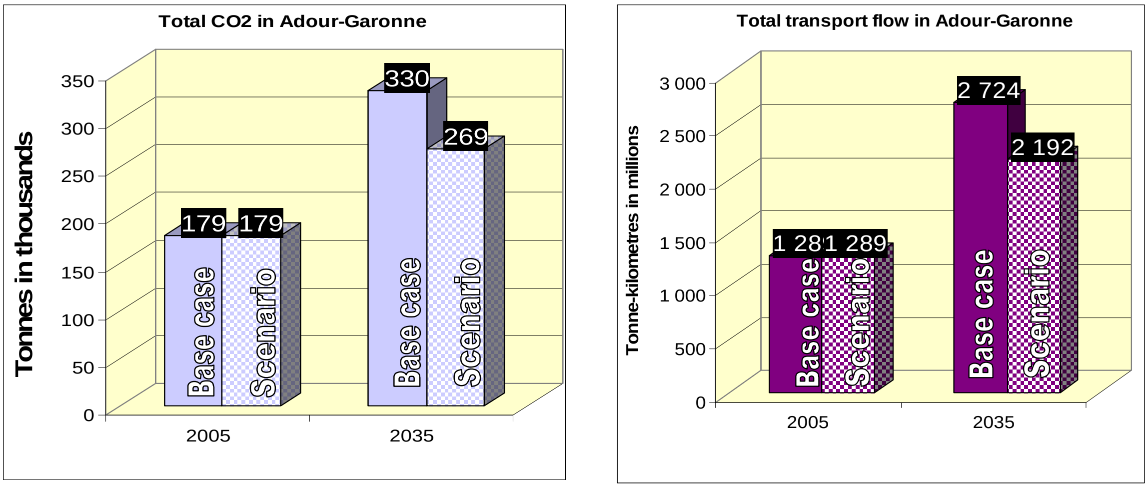


Figure 59: Total CO2 emissions and total transport flow in the scenario of economic slowdown in Adour-Garonne

As a secondary effect, the mechanism of monitoring overcapacity is implemented. This is necessary since the demand is being reduced significantly which would result in a growing difference between the total demand and the sum of capacities. Its goal is to control, on the one hand, the factor of industrial development of each of the two primary supply sources, and, on the other hand, the new quantities to be authorised. The unused capacity of a region will hence not explode and remain balanced, as in the base case. No branch of industry will seek to grow beyond the demand to a large extent.

As described in chapter 5.3, the ANTAG-model is the most sensitive to the regional GDP growth rate. Nevertheless, a reduction of the whole industrial sector due to a GDP growth rate reduction seems realistic. This scenario has been performed in each of the six zones.

8.2.2 Cross check by consolidation

A national consolidation makes perfect sense in this scenario since the GDP per capita, which is a classic macroeconomic driver, is the driver of the model. Apart from the dampened national consumption profile, also all the capacities of the country decelerate their growth. This is due to the overcapacity regulation implemented for the primary resources hard and soft rock. The maximum unused capacity corresponds to 20% of the national consumption, which is very close to the value in the base case consolidation (Figure 60).

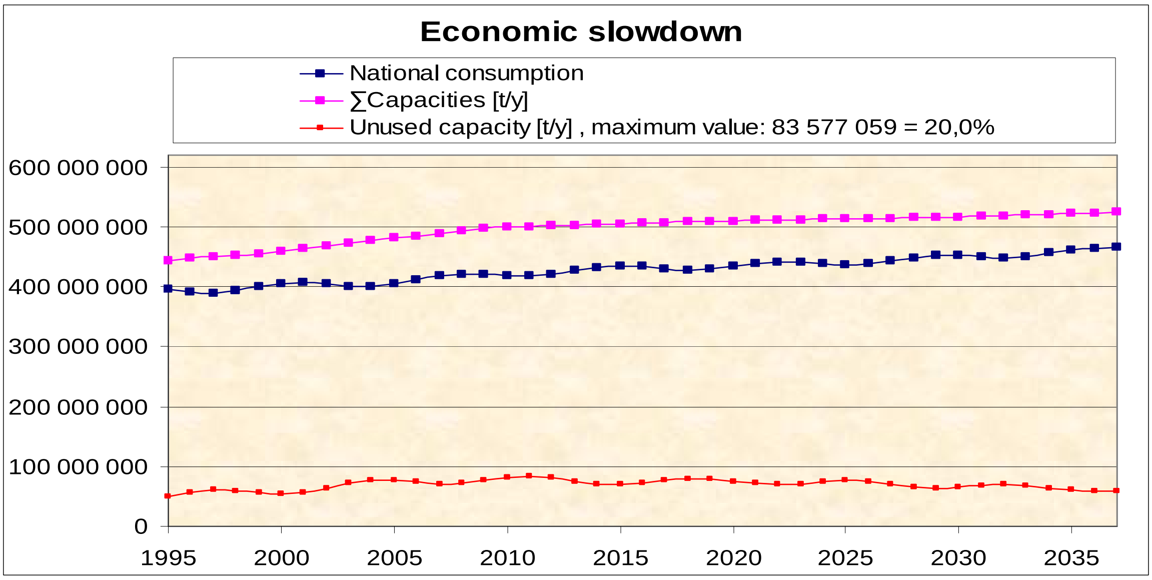


Figure 60: Economic slowdown consolidation: consumption and capacity

The reduced total demand affects the local production. The hard rock sector growth is reduced whereas the soft rock production decreases faster (Figure 61). Both curve profiles are plausible. The niche markets remain unaffected and stay the same as in the base case consolidation.

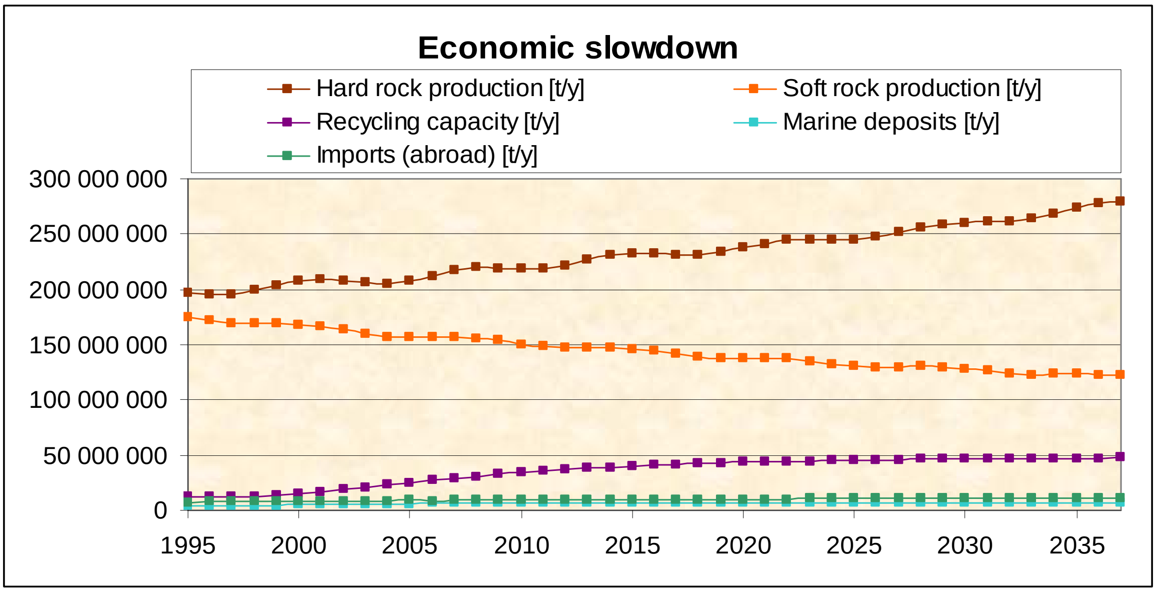


Figure 61: Economic slowdown consolidation: supply sources

The imports from other regions change slightly since they result from the market balance (Figure 63). The error interval of the imports-exports difference, however, practically remains the same as in the base case (Figure 62).

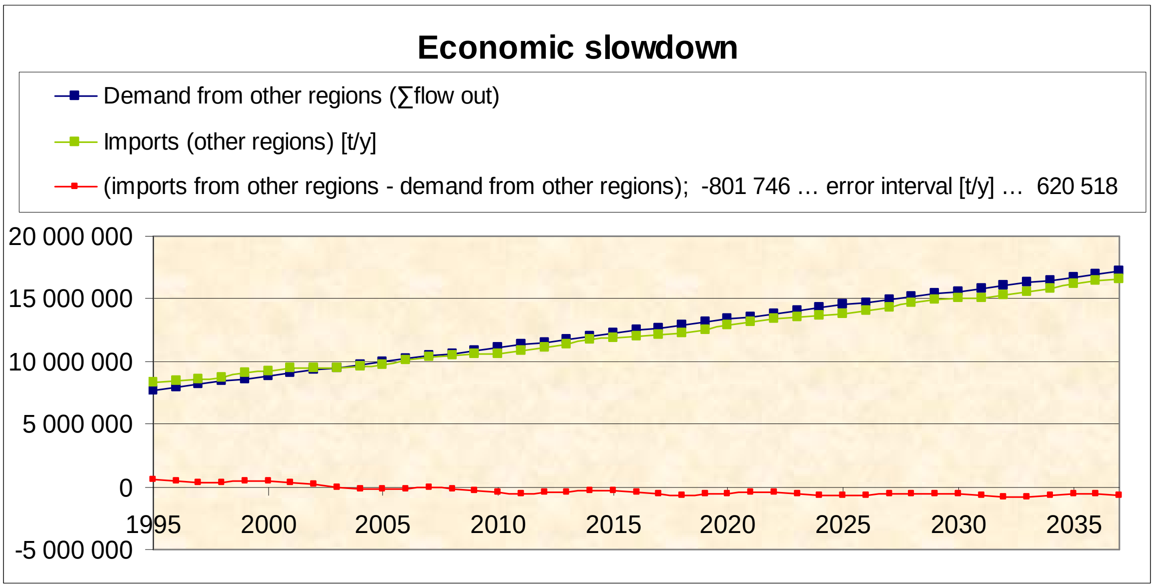


Figure 62: Economic slowdown consolidation: flow balance

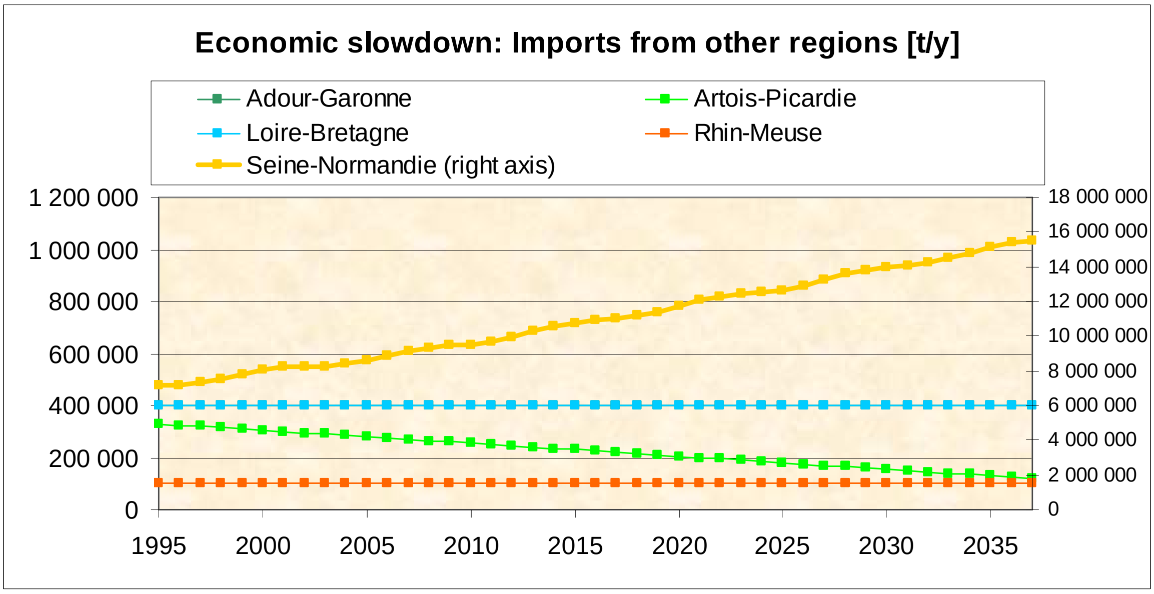


Figure 63: Economic slowdown consolidation: imports from other regions

The CO2 emissions and the total transport flow decrease by 15% compared to the base case, whereas the road transport flow decreases by 17% (Figure 64).

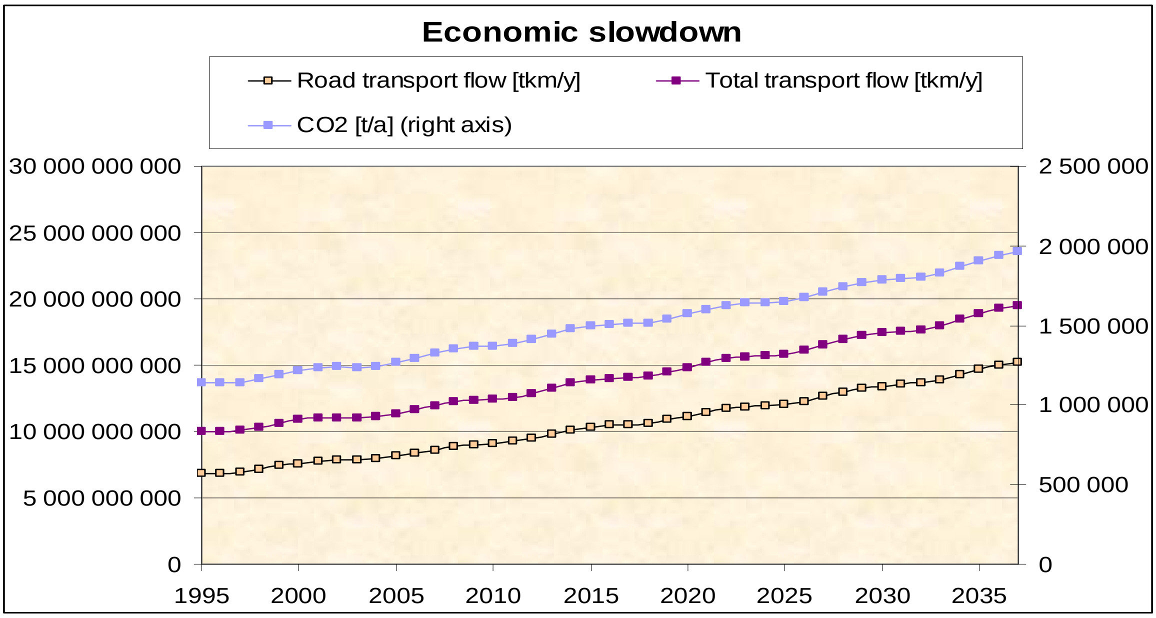


Figure 64: Economic slowdown consolidation: impacts

8.3 Increase in recycling capacity and an economic slowdown

8.3.1 Trigger and implementation per region

In 2005, 24 million tonnes have been recycled in the construction aggregates market in France. This scenario studies the repercussion of a significant increase of recycling in the following 30 years. The expected effects are the preservation of local natural resources namely hard and soft rock. This scenario is based on the event of an economic slowdown. We are thus observing two separate effects reducing the demand of new aggregates. This scenario has been performed in each of the six zones.

The type of curve remains the one described in chapter 4.3, used in the base case. The asymptotic limit of recycling capacity of the S-curve, however, has been changed in the long-term for each region (Figure 65). The asymptotic value has been fixed at 124 million tonnes in 2035 on a national basis. The additional 100 million tonnes are assigned to each one of the regions by weighting according to its respective consumption as of the year 2005. The more a region consumes, the higher is its new recycling capacity limit.

The new capacities developing in the market require the implementation of the overcapacity regulating mechanism for the local primary sources. However, the relative competitiveness of the recycled materials in the market competition module does not change. This means that recycling as an actor remains a niche market, which is highly competitive in the proximity of consumption centres. Its whole capacity will be absorbed by the market.

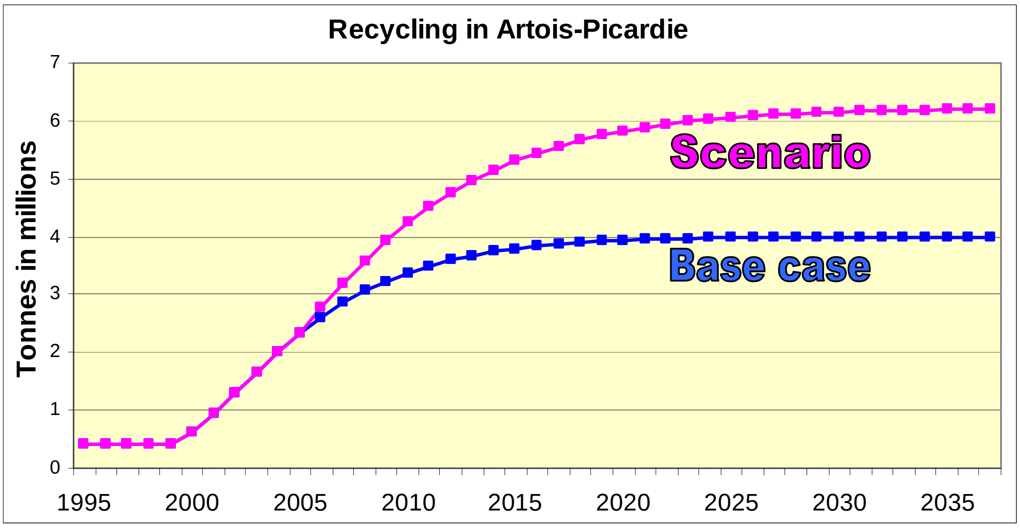


Figure 65: Capacity in the scenario of recycling increase in Artois-Picardie

The assertion that 124 million tonnes of capacity are recycled in an industry producing 480 million tonnes in 2035 is questionable. Furthermore, this scenario does not consider the following aspects:

– The practical feasibility of raising 124 million tonnes in the long-term, which corresponds to over 4 times the current tonnage without even knowing their origin;
– No secondary mechanism linking the capacity to the building construction branch has been implemented.

As expected, local resources are preserved (Figure 66). The reduction of impacts upon the environment compared to the base case, however, is a result of the lower transport distances of recycled aggregates compared to the extraction of primary supply sources (Figure 67). The installation of a recycling platform itself consumes the same amount of energy and generates the same amount of CO_2 per tonne as a hard rock quarry.

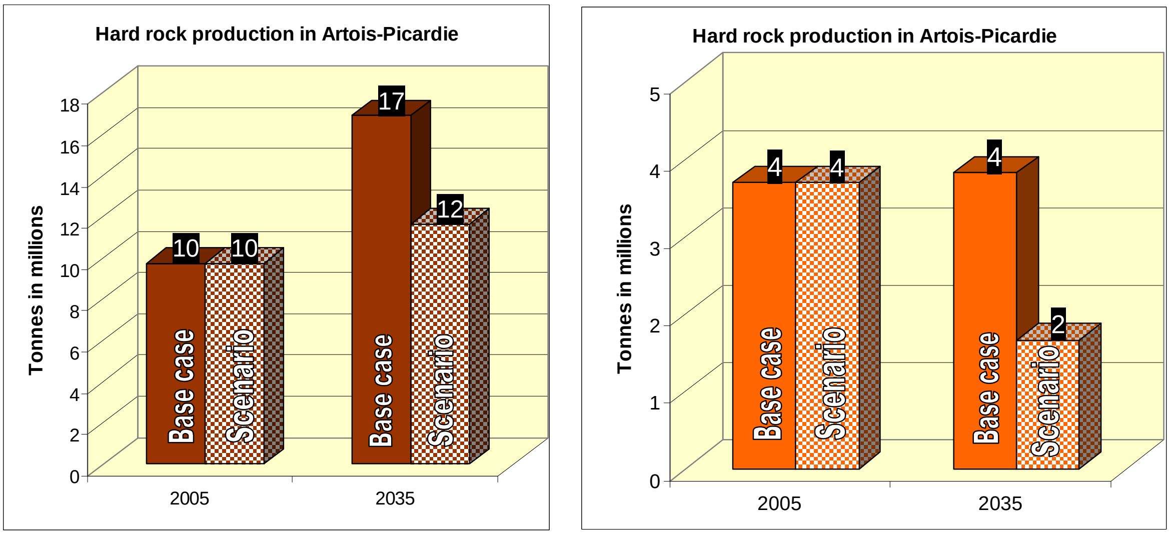


Figure 66: Hard and soft rock production in the scenario of recycling increase in Artois-Picardie

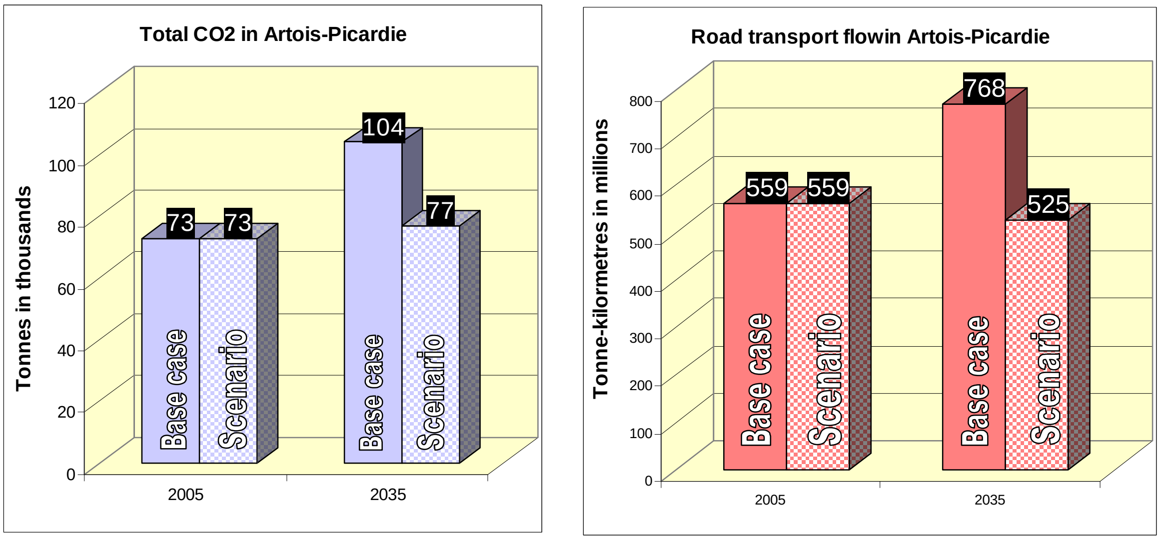


Figure 67: Total CO2 emissions and road transport flow in the scenario of recycling increase in Artois-Picardie

8.3.2 Consolidation and check-up on global repercussions

National consumption is identical to the one in the previous scenario. The sum of all capacities and thus the maximum value of unused capacity are slightly higher since the overcapacity regulating mechanism adapts to the new circumstances with a slight delay (Figure 68).

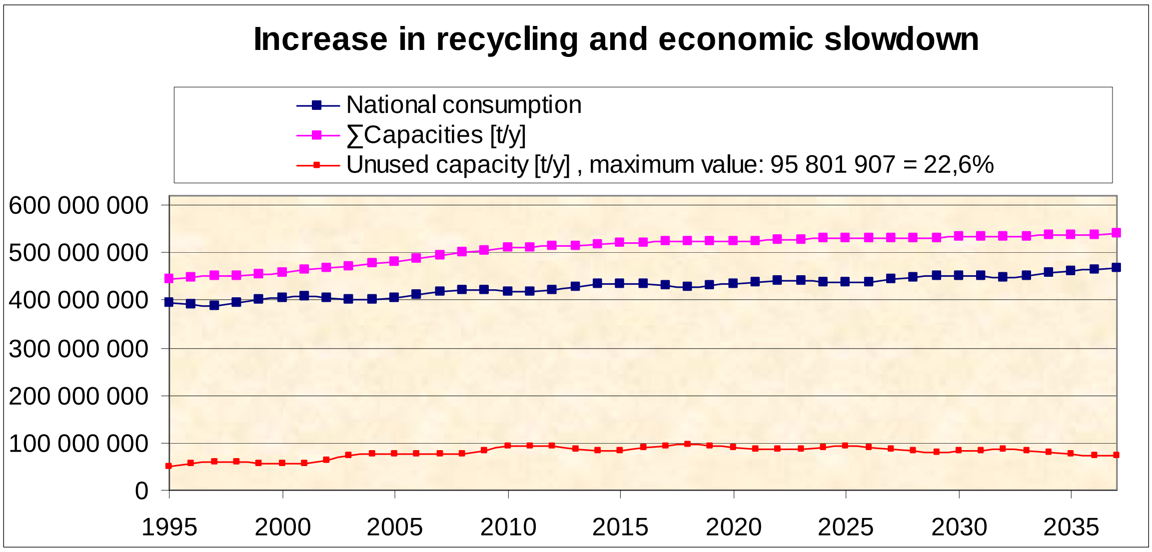


Figure 68: Recycling and economic slowdown consolidation: consumption and capacity

Figure (69) shows that the fixed recycling capacity growth limit of 124 million tonnes is not fully reached, yet. By 2035 the curve becomes flatter, but still continues to grow. Hard and soft rock production are both reduced compared to the base case. Furthermore, the imports from other regions (towards Seine-Normandie, Figure (71)) are reduced, leading to a slightly broader error interval in flow balance (Figure 70).

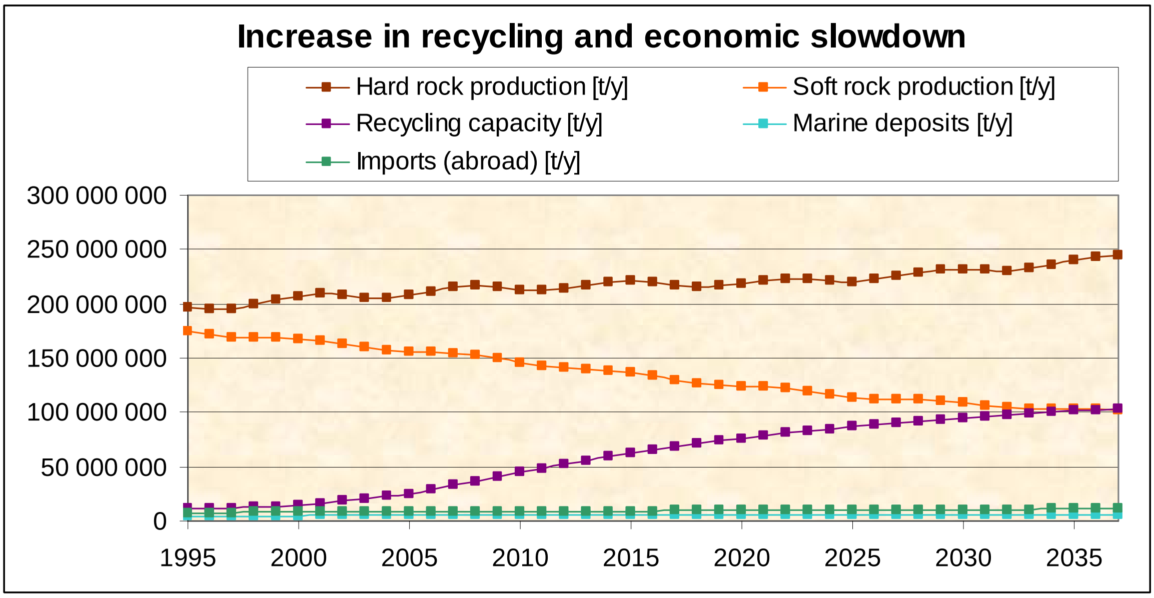


Figure 69: Recycling and economic slowdown consolidation: supply sources

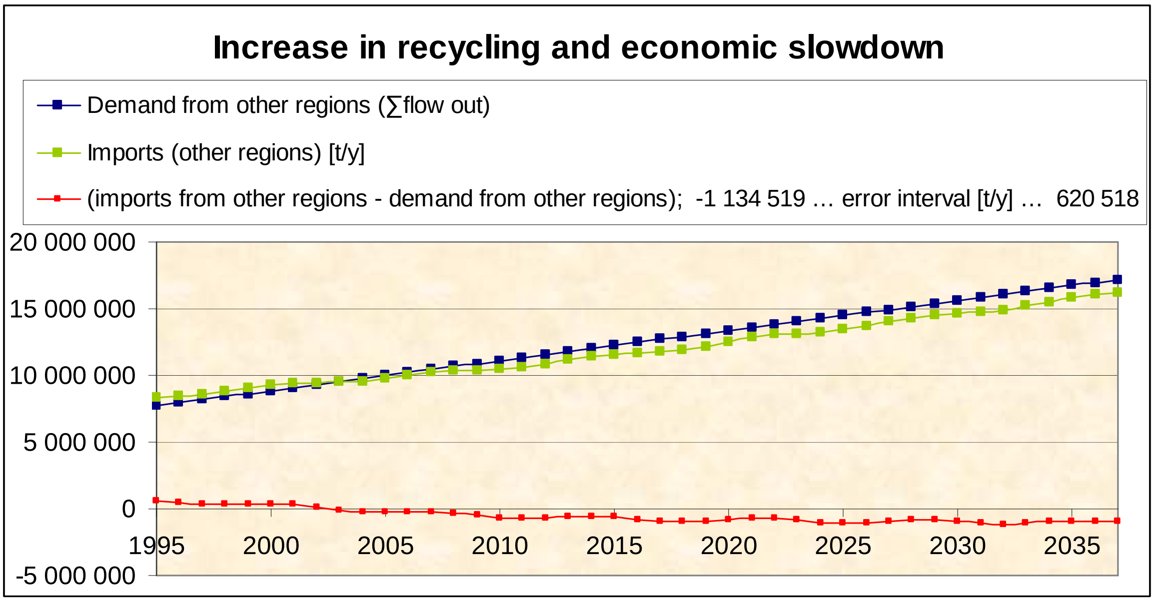


Figure 70: Recycling and economic slowdown consolidation: flow balance

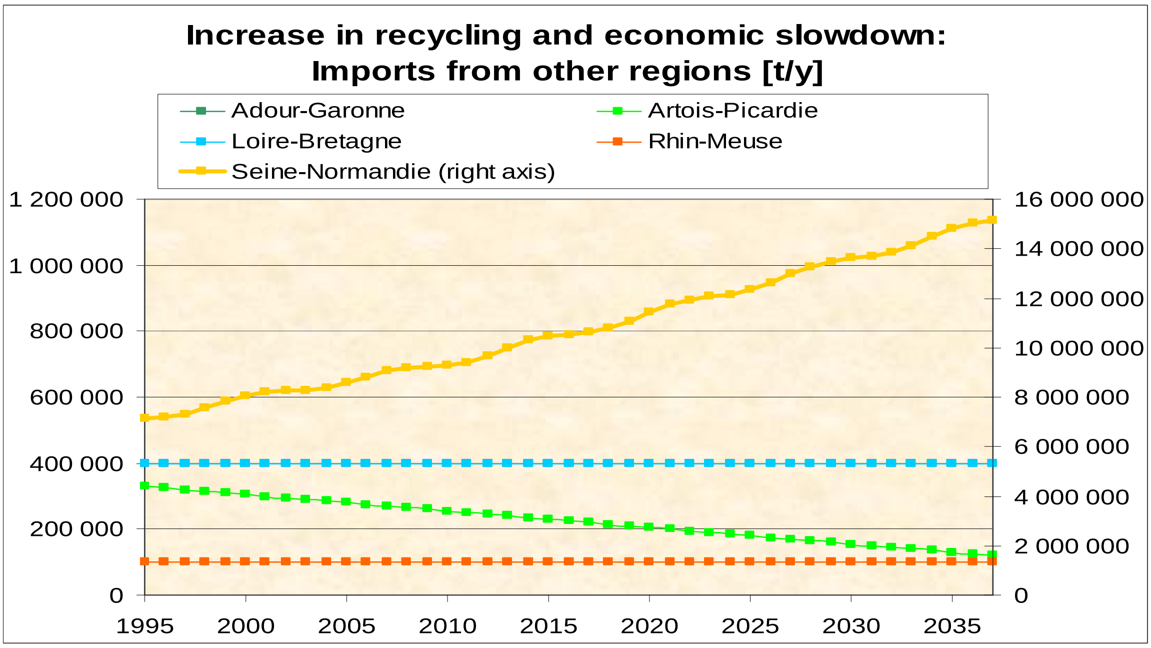


Figure 71: Recycling and economic slowdown consolidation: imports from other regions

The impacts upon the environment are slightly reduced within each region as well as nationwide (Figure 72). The reasons have been named in the previous section.

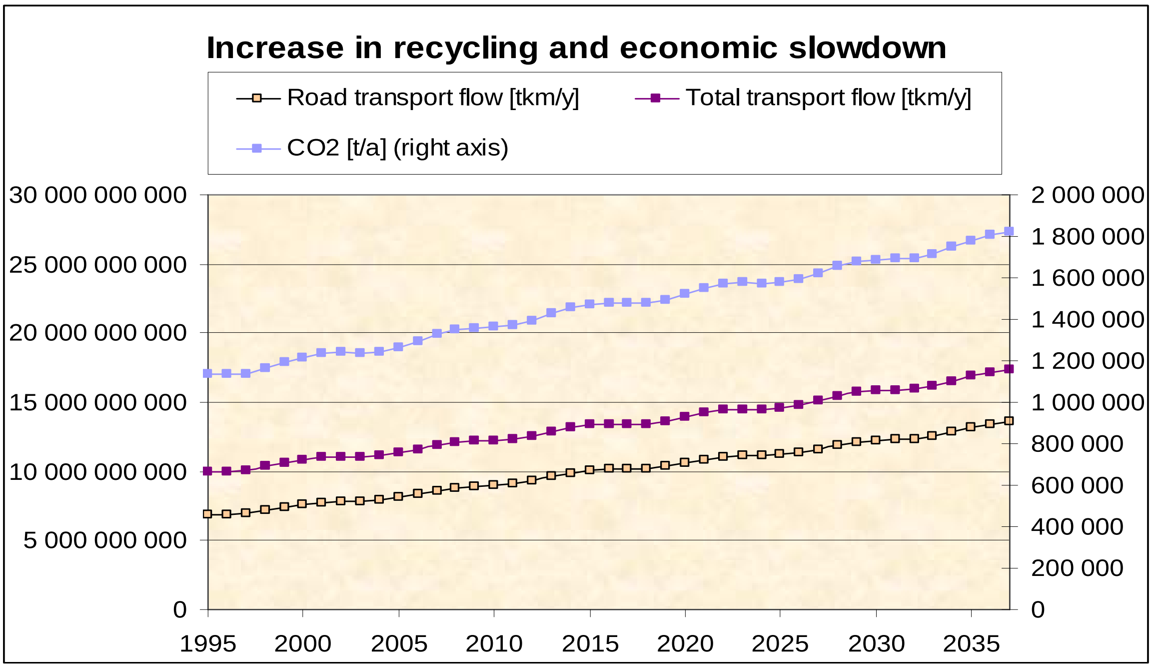


Figure 72: Recycling and economic slowdown consolidation: impacts

8.4 Substitution of aggregates and reduction of the demand

The following scenario studies the effects of an acceleration in substitution of aggregates by other materials and new technology for building construction as well as a reduction of the demand for public works at equal progression of GDP per capita. The expected effect is a decrease of local demand for new aggregates. Consequently, this scenario aims at reducing production, transport flows and environmental impacts. This scenario has been performed in Rhône-Méditerranée only.

In this scenario two trigger mechanisms have been implemented downstream of the economic driver (GDP per capita), one in each sector:

– For the branch of building construction an accelerated continuous progression over 15 years starting in 2010 towards the new target of 1 tonne per square metre has been programmed. As described in chapter 4.1 this parameter considers, on the one hand, the use of a substituting material and, on the other hand, the technological progress that enables a more efficient use of aggregates for the same number of square metres (Figure 73).

– In the branch of public works an acceleration of the reduction of the demand at equal wealth. No separate handling of the effective demand for civil engineering constructive works and the substitution by materials disposable on site was available (Figure 74).

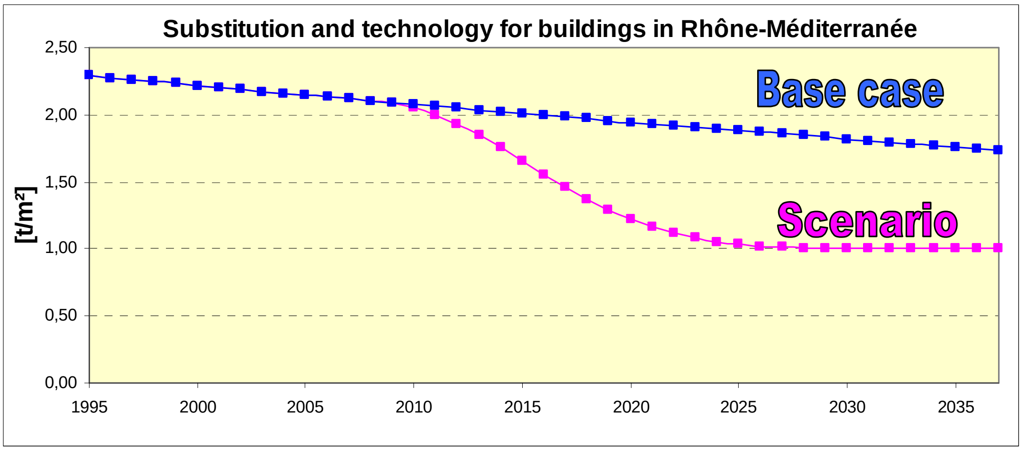


Figure 73: Tonnes per square metres for buildings in Rhône-Méditerranée

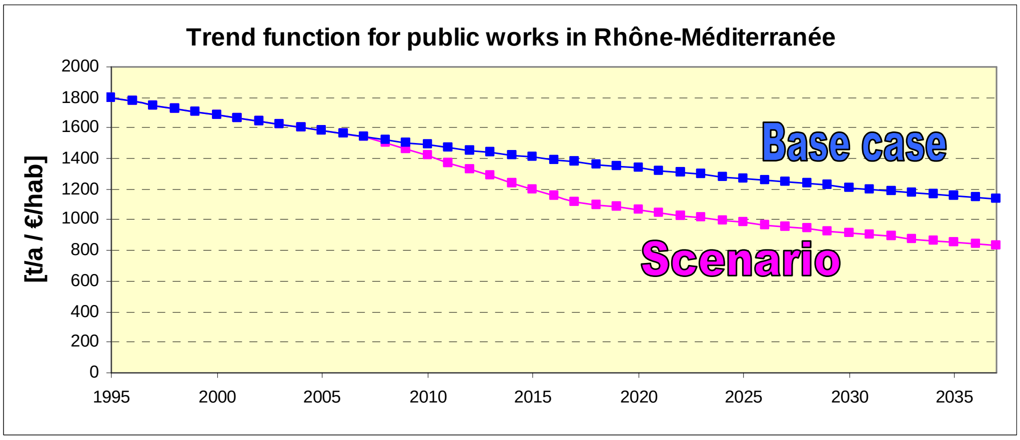


Figure 74: Trend function for public works in Rhône-Méditerranée

Since the demand is being reduced significantly (Figure 75), the overcapacity regulating mechanism has been implemented.

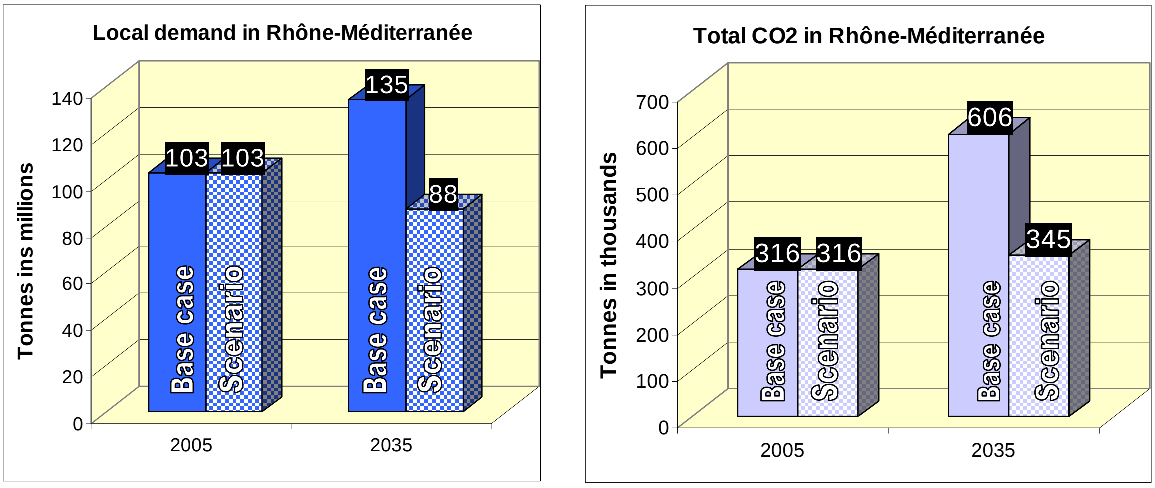


Figure 75: Local demand and total CO2 in Rhône-Méditerranée

The model and its applications only cover the access to the aggregate resource and do not consider the following aspects:

– The additional costs due to higher use of substituting material;
– The environmental impacts generated by substituting material.

As for the substitution of building construction, 1 tonne per square metre in 2035 (as well as 1.75 tonnes per square metre in the base case) is very optimistic and would necessitate a radical change of behaviour for the branch. This scenario aims at studying the repercussions under extreme conditions.

8.5 A move towards alternative transport in Rhône-Méditerranée

The objective of this scenario is to estimate the repercussions of favouring alternative transport modes, rail and waterway, in order to reduce the high road use, which is greater that 90% in each of the regions. Today 97% of the aggregates in Rhône-Méditerranée are transported by road. Multimodal transport has already been implemented using a constant split factor road—alternative in the base case model. The challenge was therefore the modelling of a continuous transition of the split factor towards a new target in a predefined time period considering two forces (see chapter 7.5):

– An accelerating effect as a result of the difference of the target split and the actual split factor road-alternative;
– A dampening effect due to the saturation of alternative transport modes.

This scenario has been developed only for the region Rhône-Méditerranée due to the availability of the Rhône as a waterway but also due to strong limitations of railways in the east-west direction.

The target split is fixed at 71% of road transport and 29% of alternative modes. Furthermore, 1 million tonnes of railway capacity and 100 million tonnes of waterway capacity have been considered. The duration between the initial and the target split is fixed at 10 years. The scenario trigger is thus the target split, which is abruptly changed in the year 2007 (Figure 76). The fluctuations of the split curve in the scenario are a result of permanently increasing saturation. Since the target split is still 71%, the split curve, tending to increase due to capacity restrictions, is adjusted in each time step. The expected effects are reductions of transport-related environmental impacts compared to the base case. The impacts due to production will obviously not change.

A feature already treated in the base case is the consideration of secondary road transport. This issue becomes even more important in this scenario, because favouring the alternative modes will also affect road transport. It has been assumed that 75% of the freight conveyed by alternative modes will not reach their final destination without being transported by road. 15 kilometres constant have been assumed for the average distance.

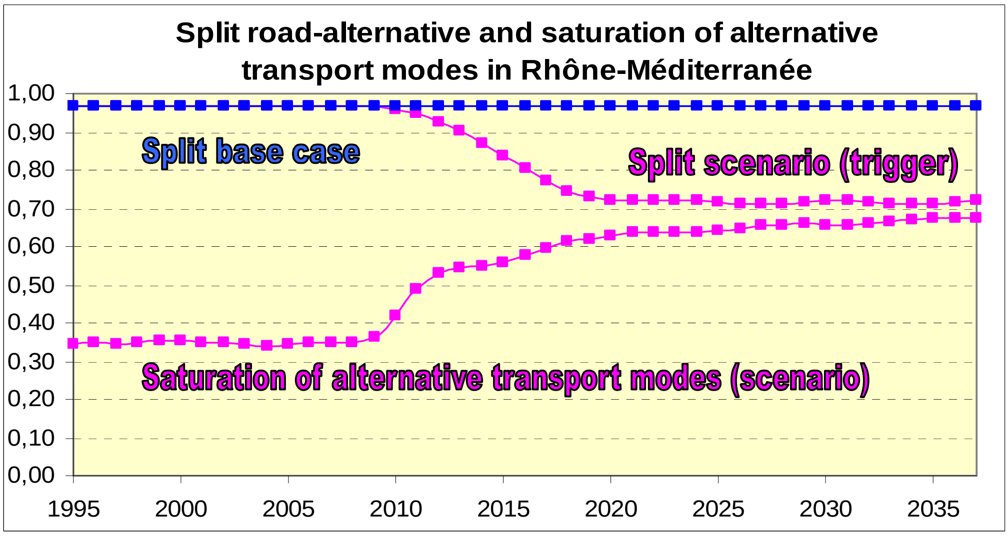
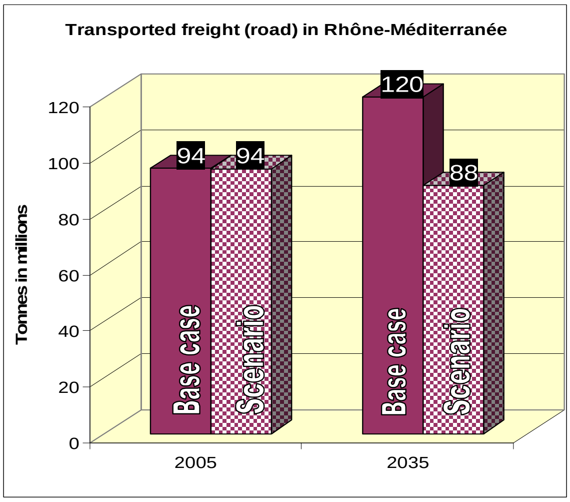


Figure 76: Transport split road-alternative transport modes and saturation of alternative transport modes in the scenario of alternative transport increase in Rhône-Méditerranée

The increase in average road transport distance, which almost doubles in the base case, is mitigated because the split factor of road-alternative is reduced. Furthermore, the decrease in freight transported by road (Figure 77) allows the conclusion that the local transport flows on the road could be reduced. The increase in tonnage transported by alternative modes (Figure 77) makes their average transport distances grow.



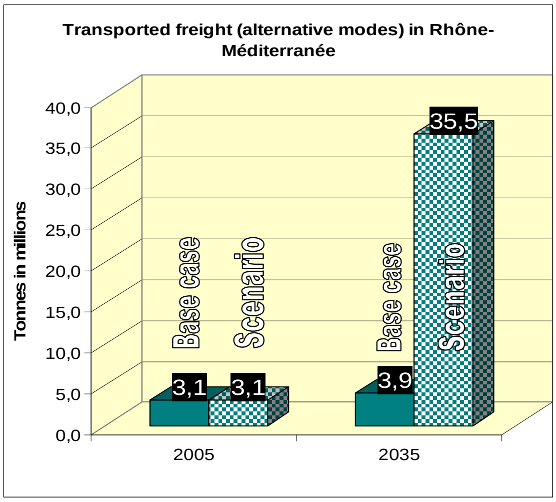


Figure 77: Transported freight by road and alternative transport modes in the scenario of alternative transport increase in Rhône-Méditerranée

Since railways, in contrast to waterway, are already close to their transport capacity in 2005, the split factor of the alternative modes will move towards a value lower than the initial 22% of rail transport (Figure 78). This makes the average waterway distance increase while the rail distance nearly stays constant (Figure 79).

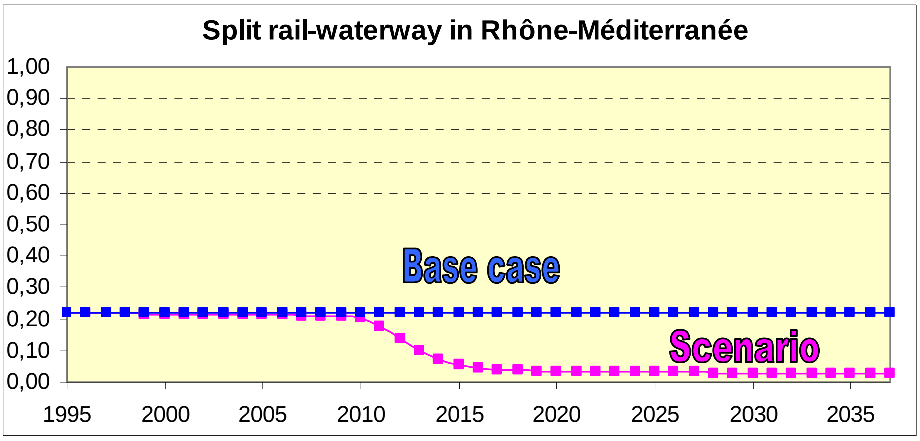


Figure 78: Transport split between rail and waterway in the scenario of alternative transport increase in Rhône-Méditerranée

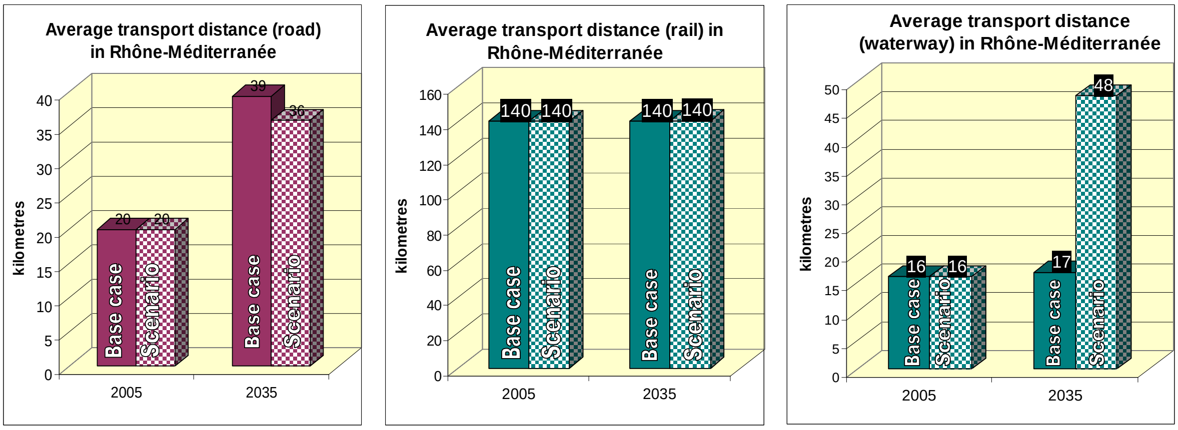


Figure 79: Average transport distance for road, rail and waterway in the scenario of alternative transport increase in Rhône-Méditerranée

However, a move away from road transport towards alternative transport modes does not result in a significant decrease in environmental impacts. A partial decrease of total CO2 due to a move away from road transport together with a relative CO2 increase due to waterway transport and the secondary road transport results in a reduction of less than 10% of overall CO2 emissions by 2035 compared to the base case (Figure 80). If we agree on the assumptions made in this scenario, yet, the question of commercial viability for a move towards alternative transport modes, which are regarded as being cost-intensive, has still not been studied adequately.

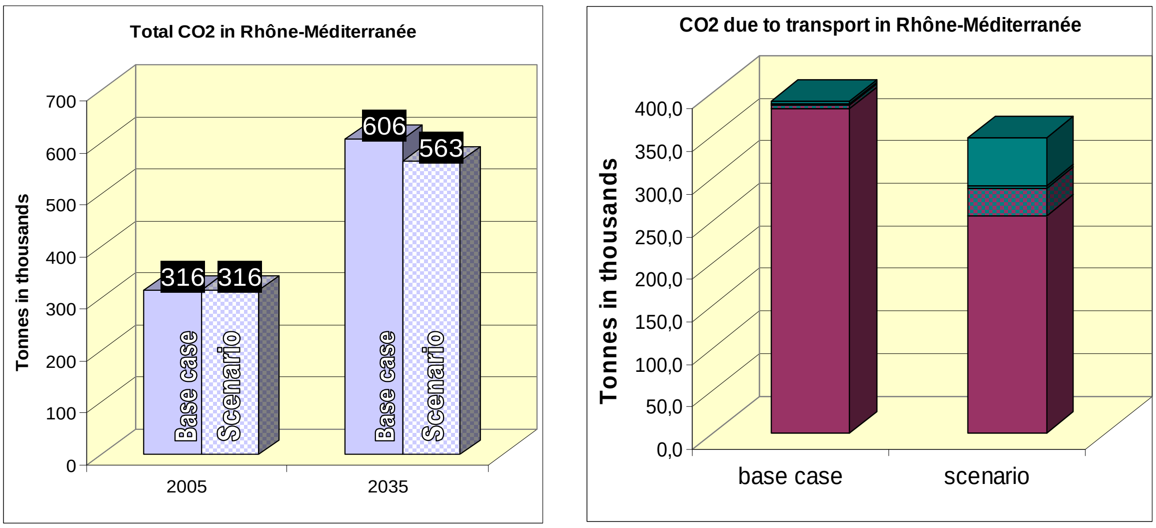


Figure 80: Total CO2 and CO2 due to transport in 2035 (from top to bottom: waterway - rail - secondary road – road) in the scenario of alternative transport increase in Rhône-Méditerranée

8.6 Imports become a primary supply source

This scenario treats the effects of the penetration of foreign aggregates into the French market in Rhône-Méditerranée. The goal is to progressively increase the imports up to 30 million tonnes of aggregates by 2037 via the Rhône through the port of Marseille, which could take large quantities coming from the North of Africa. The scenario trigger is the import capacity, which now follows an S-curve tending to move towards the capacity limit of 30 million tonnes. The imports are transported 75% on waterway. The initial average waterway haul distance of this breaking scenario has been set at 200 kilometres, since aggregates can be conveyed up to Lyon. The expected effects are the preservation of local resources and the reduction of environmental impacts.

Since large quantities penetrate the region, the market equilibrium is being disturbed. The secondary mechanism, which has been implemented in order to take into account the effects on the market equilibrium is described in chapter 7.4. In the base case the actual imports (800 000 tonnes) are very close to the import capacity (1 000 000 tonnes). If the capacity increases up to 30 million tonnes by 2037, the imports become a primary supply source. Note that the total demand in this year is at about 135 million tonnes in Rhône-Méditerranée. Thus, they will no longer serve the market as close to capacity as in the base case. The relative competitiveness among the supply sources in the market submodel adapts as a function of the import capacity introduced. Consequently not only the import capacity and the actual imports will rise, but also the unused imports capacity (Figure 81). This mechanism allows consideration of the difficulties of foreign actors penetrating the market. Since, suddenly the market is confronted with high capacities, the overcapacity regulating mechanism has been implemented for the local supply sources.

As in the last scenario, the saturation feedback within the local transport split and the transport split for imports is considered whereas the latter one is crucial for this scenario.

As expected, increasing the import capacity up to 30 million tonnes in Rhône-Méditerranée would lead to a decrease in local production (Figure 82) and hence their preservation. The reduced extraction rate which directly affects the new authorisations makes the land-use decrease (Figure 83).

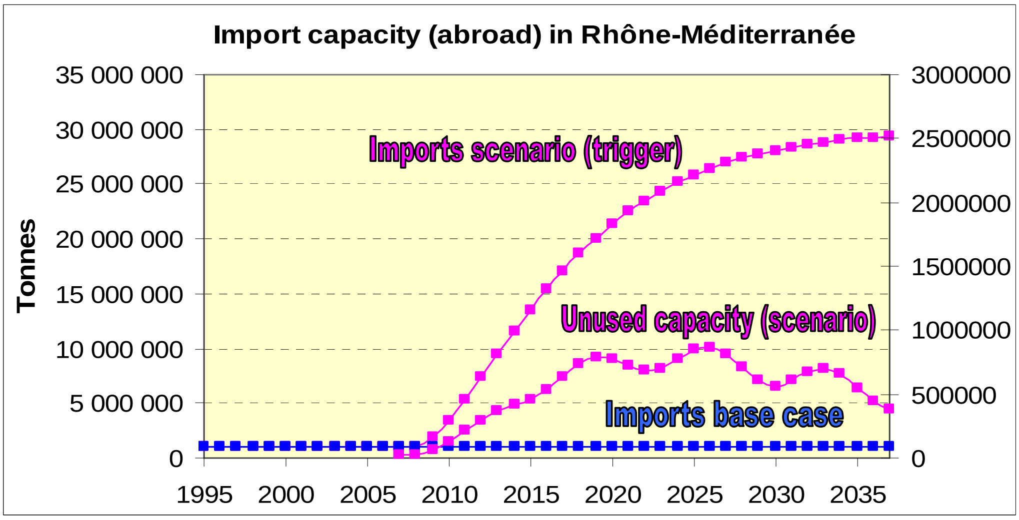


Figure 81: Imports capacity and unused capacity (right axis) in the scenario: imports increase in Rhône-Méditerranée

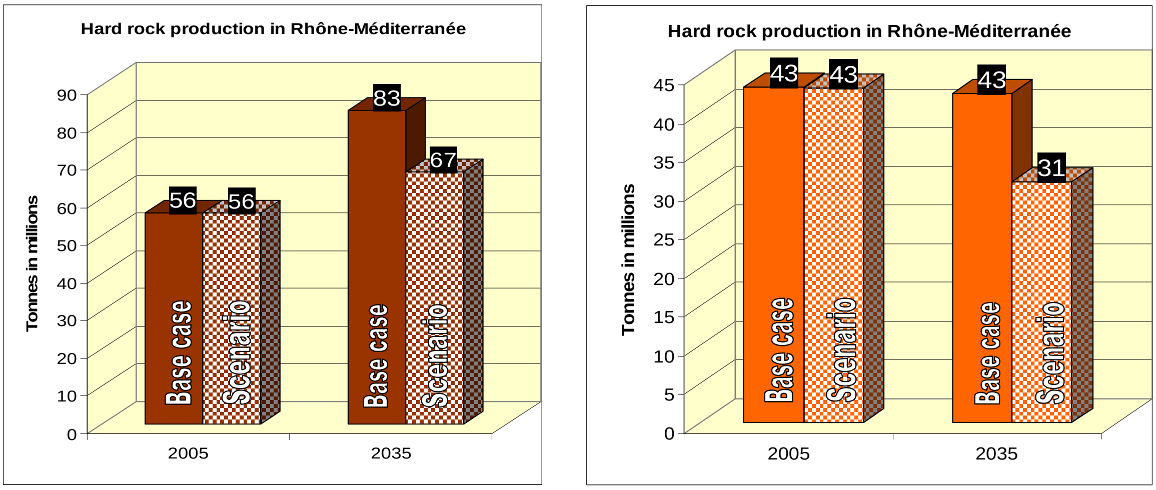


Figure 82: Hard and soft rock production: scenario of imports increase in Rhône-Méditerranée

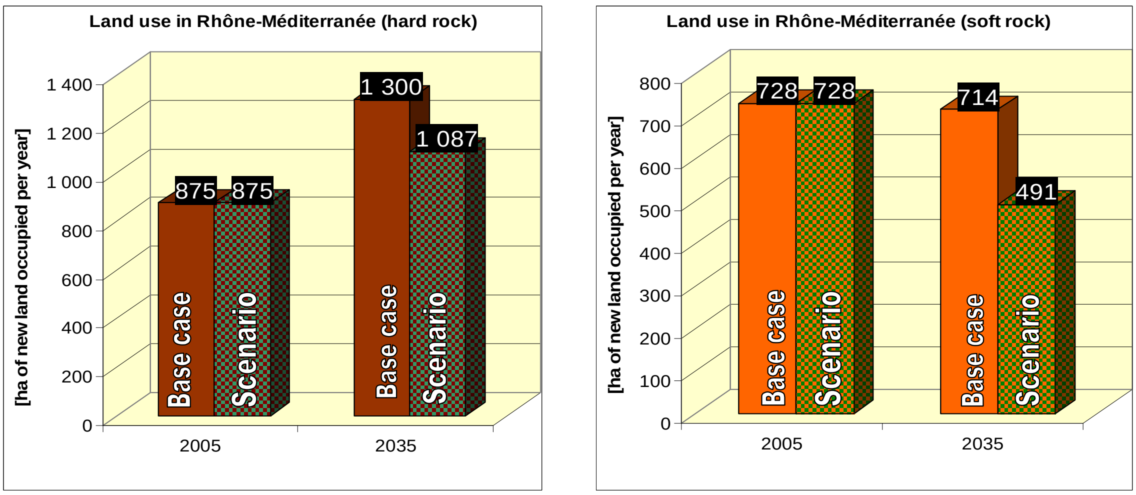


Figure 83: Land-use of new authorisation: scenario of imports increase in Rhône-Méditerranée

Since foreign aggregates would be transported mainly on the waterway, its average transport distance, initially at 200 kilometres, would rise, leading to an increase of nearly 70% of transport flows. The CO2 emissions, however, do not change significantly, since the grams of CO2 emitted per tonne-kilometre for waterway transport, are much lower than for road (Figure 84). Externalities and impacts due to extraction and transport outside France are not considered.

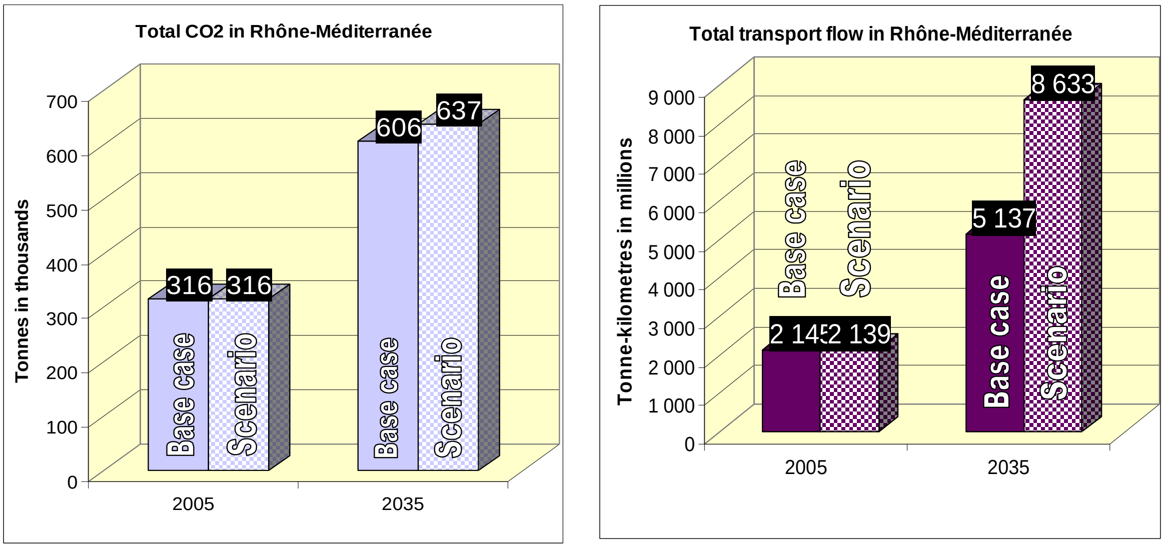


Figure 84: Total CO2 and total transport flow in the scenario of imports increase in Rhône-Méditerranée

8.7 Shortfall of alluvial deposits

8.7.1 Trigger and limitations

This scenario studies the potential effects of growing constraints on the access to production sites of alluvial deposits. The trigger is the factor of social acceptability, which controls the flow of new authorisations and consequently the production capacity of alluvial deposits. The trigger action is the abrupt change of social acceptability of new authorisations of soft rock, which is set (from 100% initially) to 0% from 2015 onwards. As a consequence, there is no access to new reserves of alluvial deposits, the capacity level can no longer be maintained (Figure 85) and soft rock production starts to decrease

(Figure 86). In order to mitigate the predicted severe equilibrium disruption of demand and primary supply sources development, the economic slowdown described in chapter 8.2 has been considered. In this way, the demand is already mitigated before it is satisfied by the supply sources.

The overcapacity regulating mechanism has been implemented, but it shows the inverse effect in this case. Since the overcapacity of all the supply sources tend to move towards zero, the part of the overcapacity, which is not being renewed the following year tends to move towards zero as well. As a consequence the new authorisations of hard rock partially increase, until the unused capacity of the regions reaches 0 tonnes (see chapter 7.2). The factor of industrial development d can only increase by a limited amount.

The market competition mechanism will make the market equilibrium move towards hard rock production (Figure 87). The reason is that the crushed rock sector, developing the most, now can exploit its whole capacity. The hard rock production will thus be close to or at its capacity. Once the unused capacity reaches 0, the mechanisms will not be active anymore, since all the sources left on the market produce their whole capacity. Figure (87) also shows that hard rock capacity is reached in year 2022.

The two supporting mechanisms do not suffice in order to prevent the fact that in four of the six regions (Adour-Garonne, Rhône-Méditerranée, Seine-Normandie and Rhin-Meuse) the remaining resources at the supply end can no longer satisfy the demand by 2020-2022, depending on the region (Figure 88).

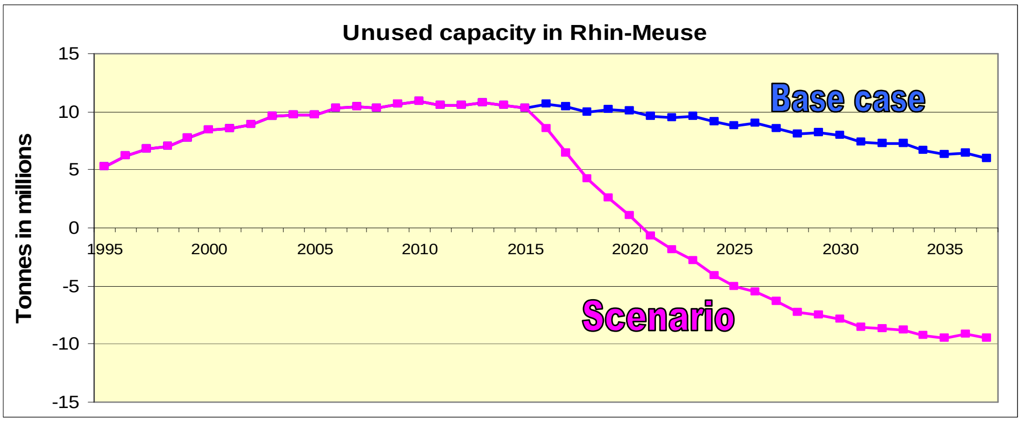


Figure 85: Unused capacity in the scenario of soft rock shortfall in Rhin-Meuse

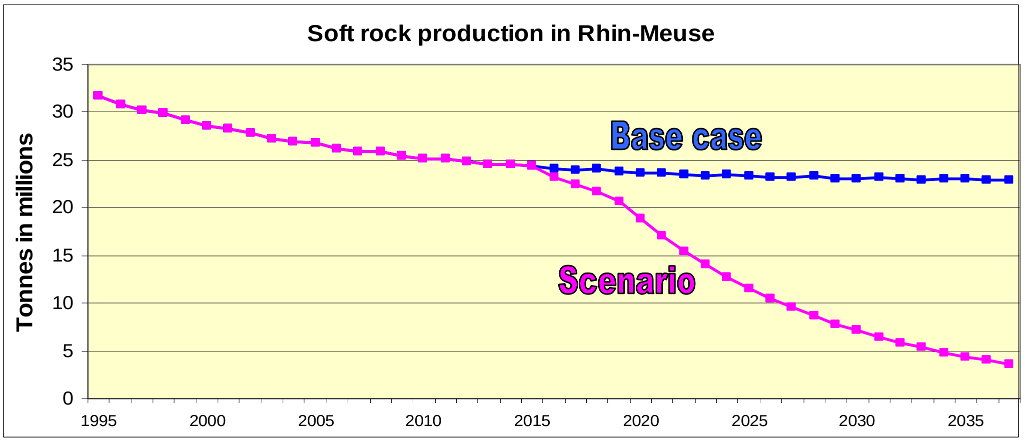


Figure 86: Soft rock production in the scenario of soft rock shortfall in Rhin-Meuse

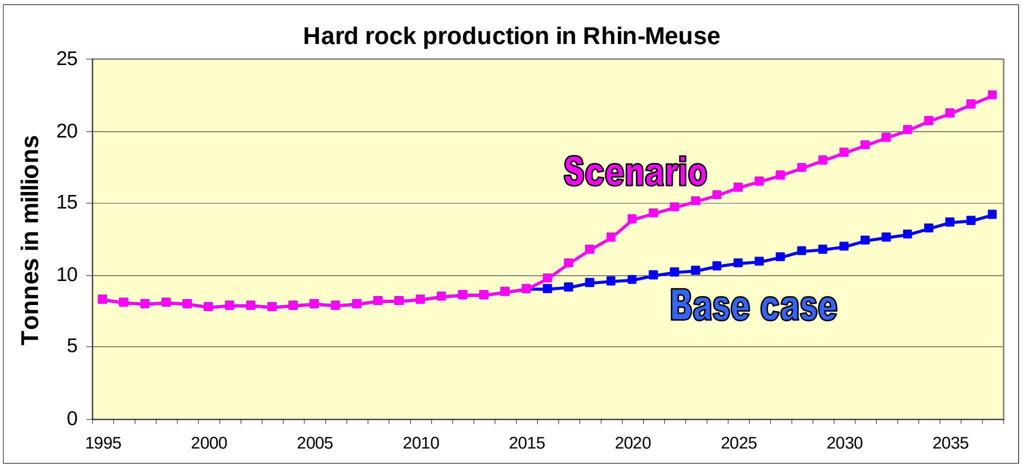


Figure 87: Hard rock production in the scenario of soft rock shortfall in Rhin-Meuse

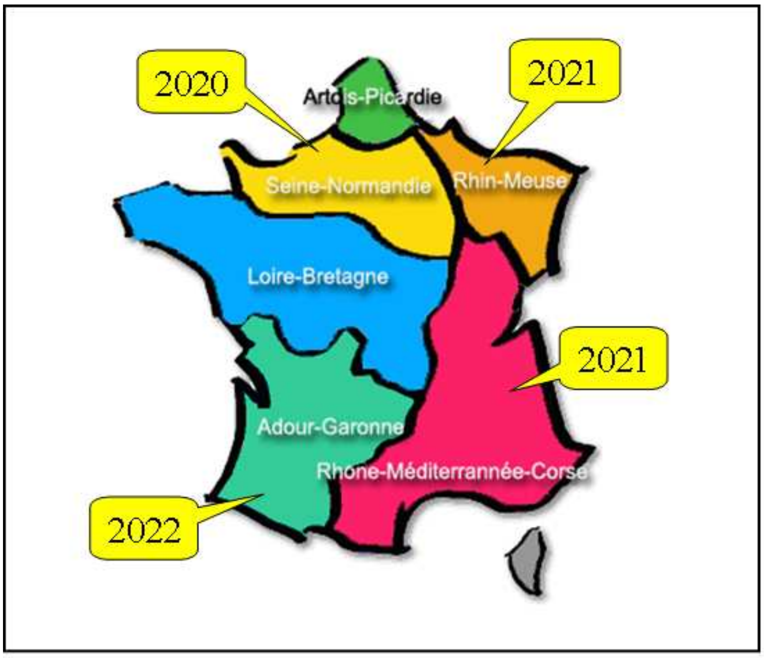


Figure 88: Shortage of aggregates

The model output beyond this date is not realistic due to the fact that it creates a disequilibrium. This phenomenon is known as the Hubbert Peak in the oil industry, a situation where the reserves do not suffice to satisfy the oil demand of the consumers. The difference in the present case is that the aggregates reserves continue to exist but are no longer locally accessible. Furthermore no mechanism accounting for compensation by another local foreign source has been modelled.

This scenario has been performed in each of the six zones.

8.7.2 Consolidation on a national scale and limitations

The national demand of 480 million tonnes still refers to the scenario of economic slowdown. Summing up the unused capacities of the six regions results in an overall shortage due to the fact that the remaining reserves do not suffice to satisfy the demand in four regions (Figure 89).

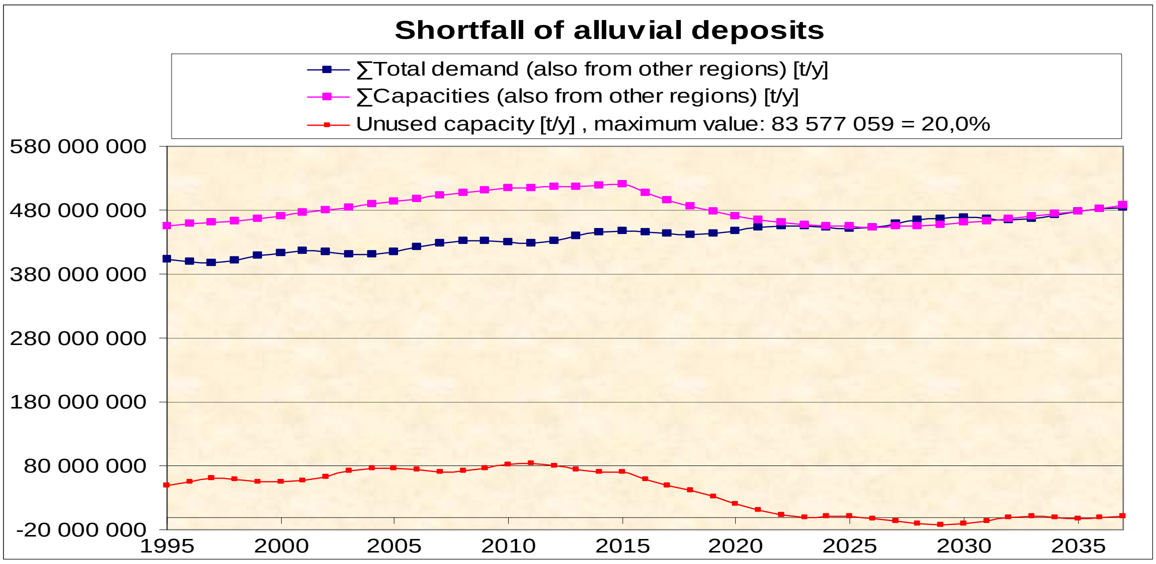


Figure 89: Shortfall of alluvial deposits consolidation: consumption and capacity

It is not expected that the asymptotic decline of soft rock production will happen as shown in Figure (90) or Figure (86). The decrease of the curve shows a deceleration in time whereas the expected profile in such a scenario would be an accelerating downward movement until the curve hits the time-axis. The existing model does not allow this type of soft rock production profile due to the fact that the capacity is directly derived from the dropping stock of authorised reserves. The hard rock production is increasing faster than in the base case and in the economic slowdown consolidation due to the auto-reaction of the market balance.

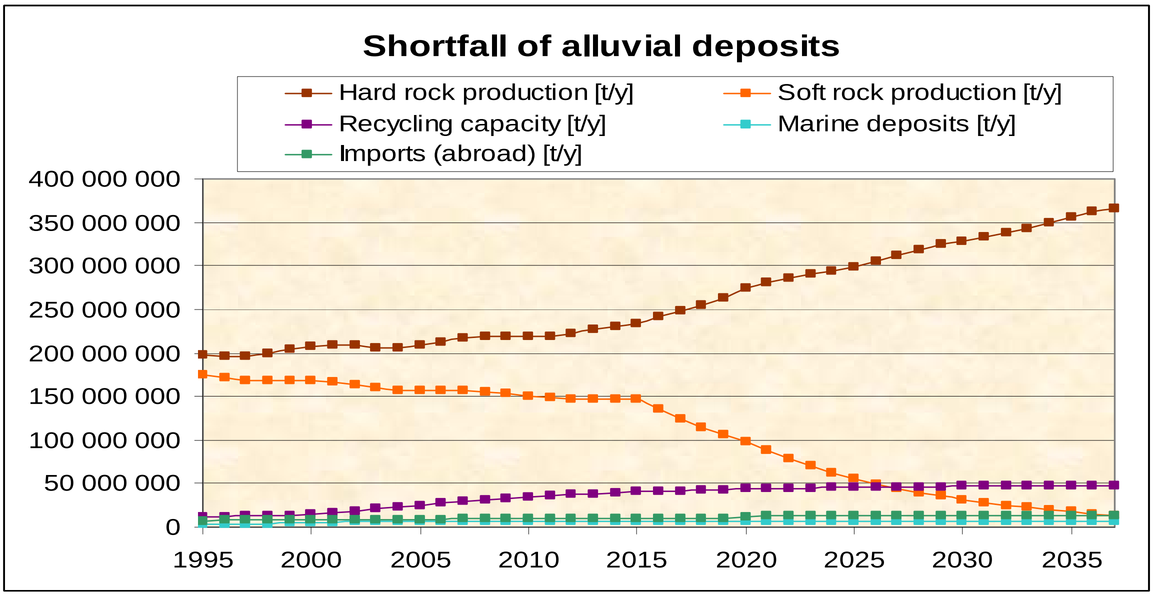


Figure 90: Shortfall of alluvial deposits consolidation: supply sources

The increased imports from other regions within France cause a deviation of the inter-regional flow balance from the base case and the economic slowdown consolidation (Figure 91). However, the maximum error (1,69 million tonnes) represent less than half a percent when put in relation to consumption.

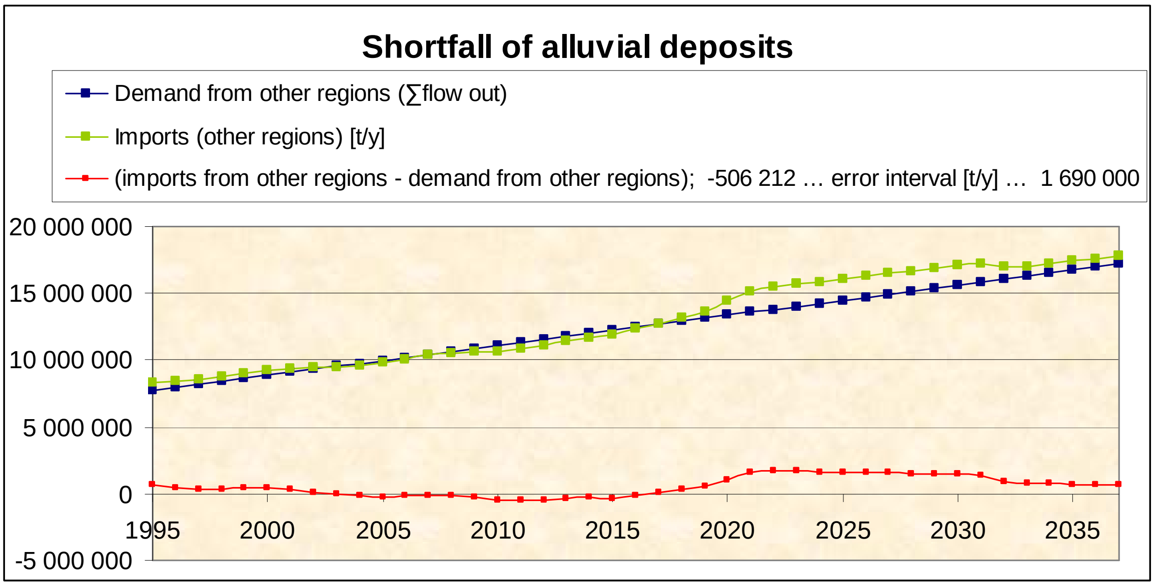


Figure 91: Shortfall of alluvial deposits consolidation: flow balance

In all regions affected by an aggregates shortage the imports from other regions within France increase up to their level of capacity (Rhône-Méditerranée does not import from other national regions) (Figure 92).

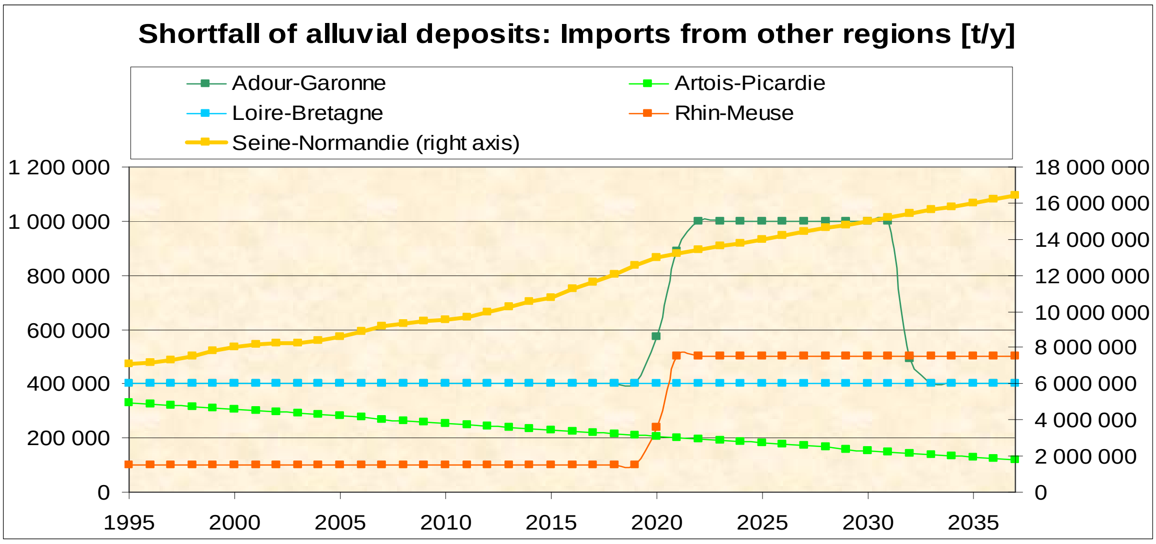


Figure 92: Shortfall of alluvial deposits consolidation: imports from other regions

The shortage of mineral resources obviously makes the whole set of impacts upon the environment decrease, even if only to a small extent (Figure 93).

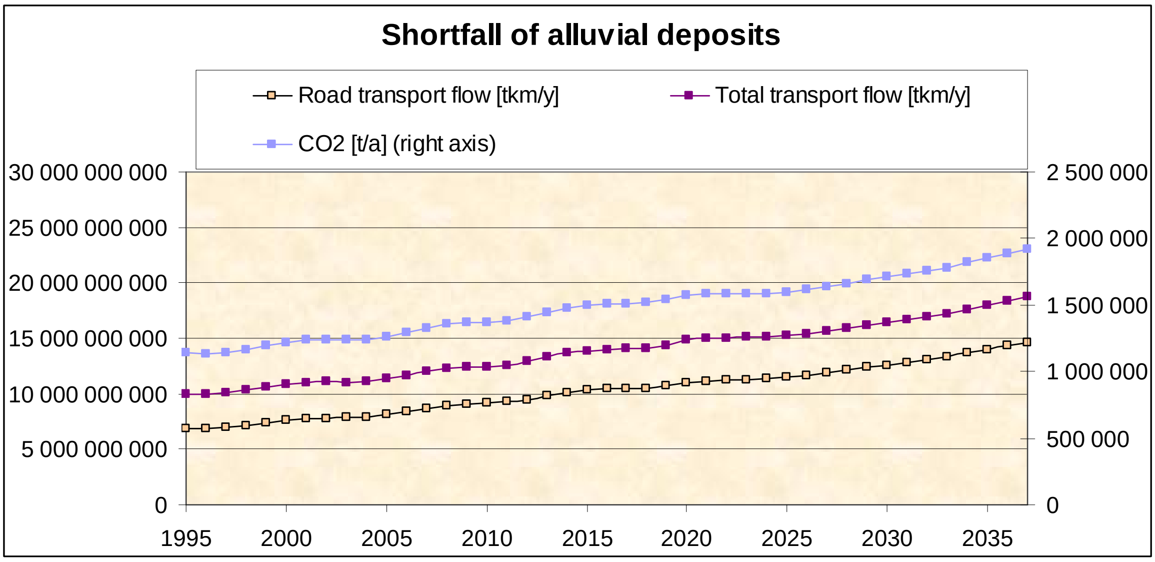


Figure 93: Shortfall of alluvial deposits consolidation: impacts

8.8 Shortfall of alluvial deposits and a move towards hard rock

8.8.1 Implementation of additional capacity

Based on a shortfall of alluvial deposits (and an economic slowdown), this scenario presents a possible response to the shortage. The idea is to balance the deficit due to no access to new soft rock reserves by locally increasing hard rock production. Compared to the last scenario the capacity creating mechanism presented in chapter 7.3 has been implemented. In this manner, a surplus amount of new hard rock authorisations can be handled in an intelligent manner. Consequently, the stock of authorised reserves and thus the capacity increases, which makes a higher production as a result from the market competition possible. This compensation cannot happen instantly since hard rock production installations would need time to develop successively in that order of magnitude. This move can therefore only happen continuously (Figure 94). This scenario has been performed in the four regions Adour-Garonne, Rhône-Méditerranée, Seine-Normandie and Rhin-Meuse, which would experience a shortage of aggregates in case of not having access to new soft rock reserves.

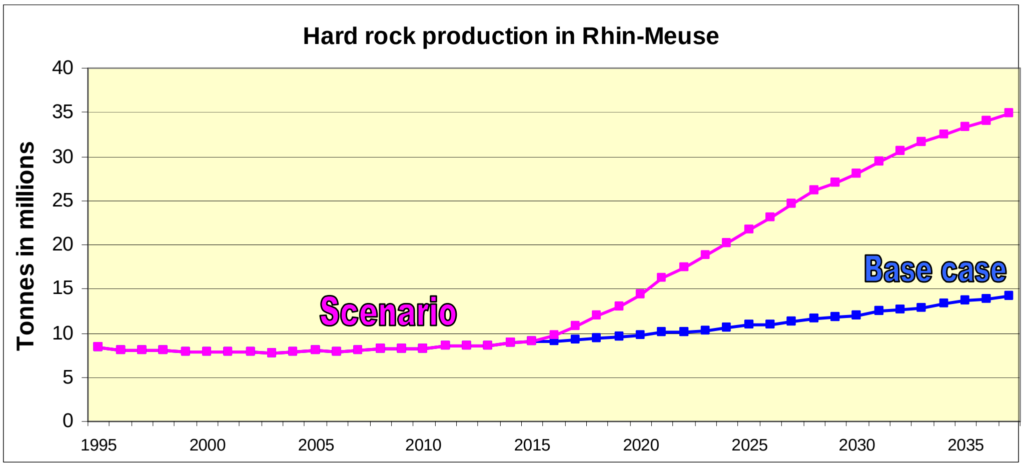


Figure 94: Hard rock production in the scenario of soft rock shortfall and move towards hard rock

The shortage could barely be avoided, as shown by the curve of unused capacity (Figure 95).

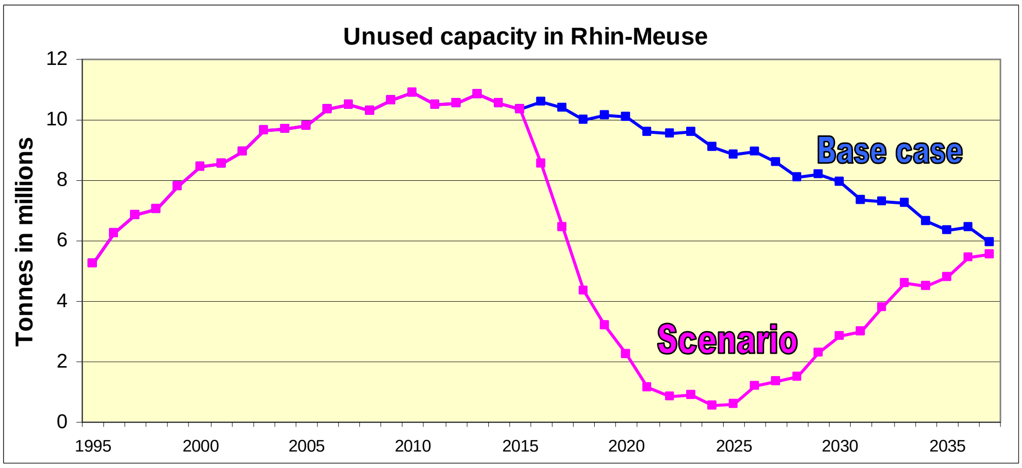


Figure 95: Unused capacity in the scenario of soft rock shortfall and move towards hard rock

It should be noted that at this stage the scenario does not consider the following aspects:

- Secondary mechanisms have been implemented only in the hard-rock-production submodel. The current equilibrium relies on the suitability of the product quality and the demand of each branch of industry.
- Furthermore it depends on the proximity of production sites to consumption centres, which currently is about 25-30 kilometres of road transport, but increasing as the quarries close to consumption areas are being exploited. In this extreme case the geological characteristics could make road transport distances increase up to 80 kilometres in certain zones. The consequences of the increasing distance in this order of magnitude still need to be studied.

8.8.2 Consolidation of six balanced regions

This national consolidation concerns four regions, which benefit from additional hard rock production avoiding a shortage, and two regions facing a shortfall of alluvial deposits but still remaining balanced. The country's capacity stays superior to national demand (Figure 96). The hard rock production balances the disappearing soft rock sector by producing nearly 400 million tonnes by 2035 (Figure 97). The error interval is tighter compared to the previous scenario (Figure 98). In the regions that face the risk of a shortage, the imports from other regions within France increase only briefly due to the delay of reaction of the hard rock sector after the stop of new authorisations of alluvial deposits. Once the overall unused capacity gets away from zero and creates a certain buffer, the imports get closer to their base case value (Figure 99). The impacts upon the environment increase by comparison to an economic slowdown, even if only marginally. The reason therefore is higher CO2 emissions per extracted tonne of crushed rock (Figure 100).

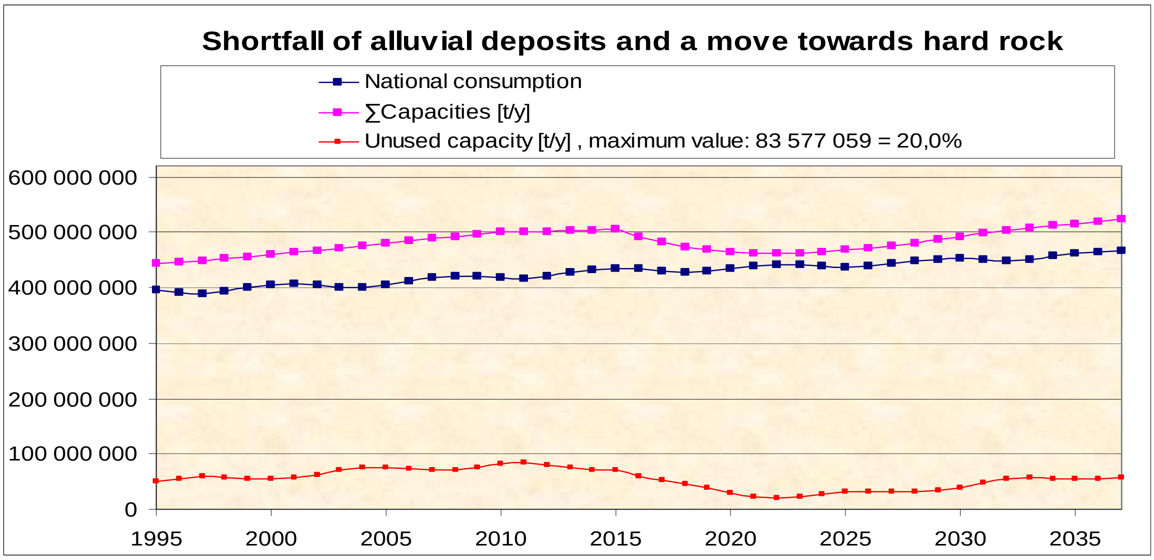


Figure 96: Shortfall of alluvial deposits and move towards hard rock consolidation: consumption and capacity:

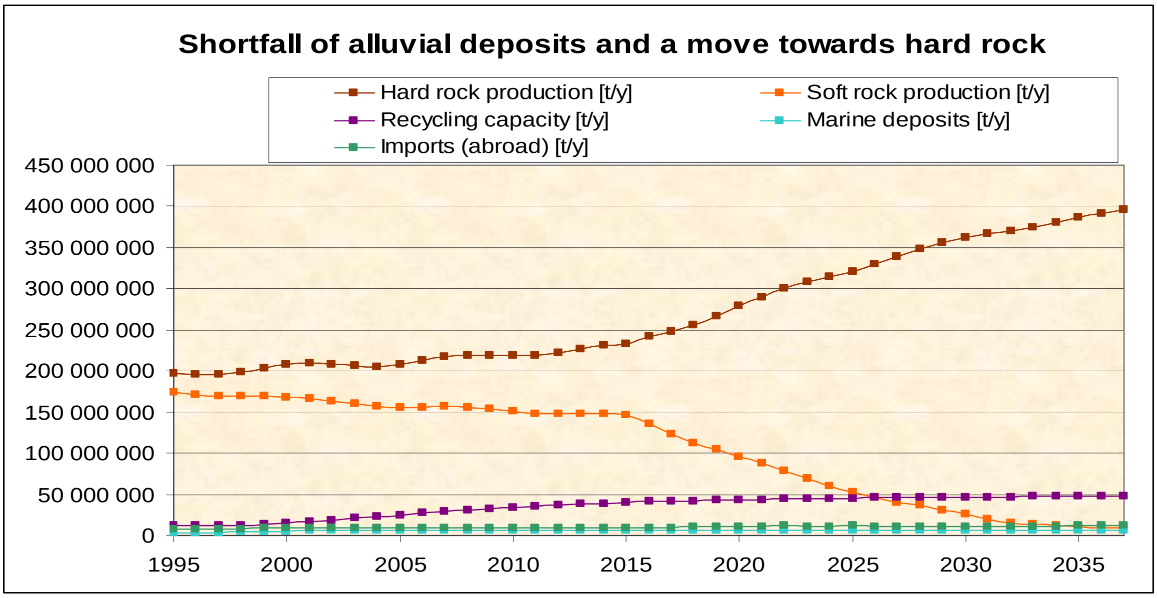


Figure 97: Shortfall of alluvial deposits and move towards hard rock consolidation: supply sources

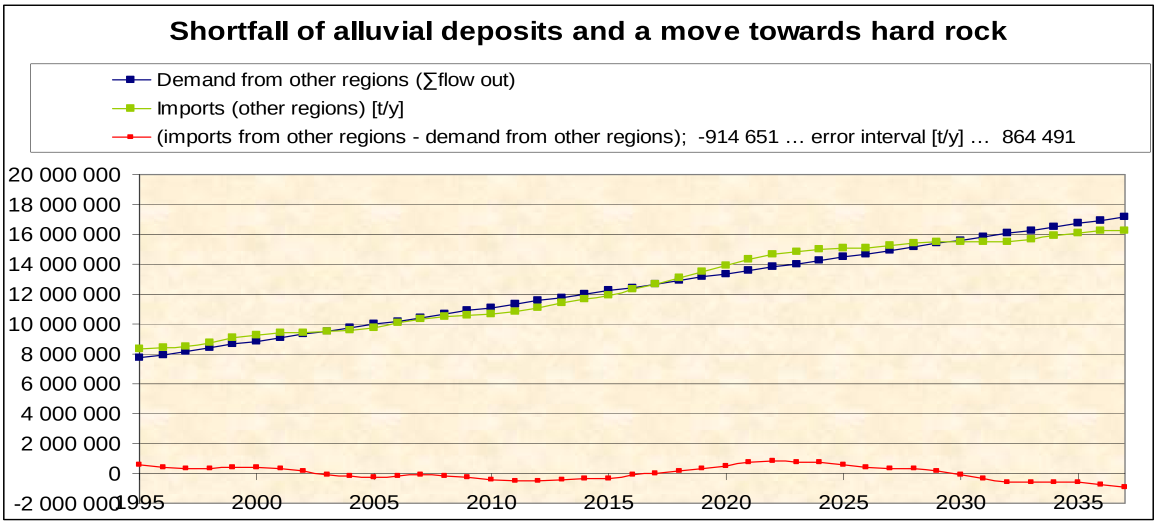


Figure 98: Shortfall of alluvial deposits and move towards hard rock consolidation: flow balance

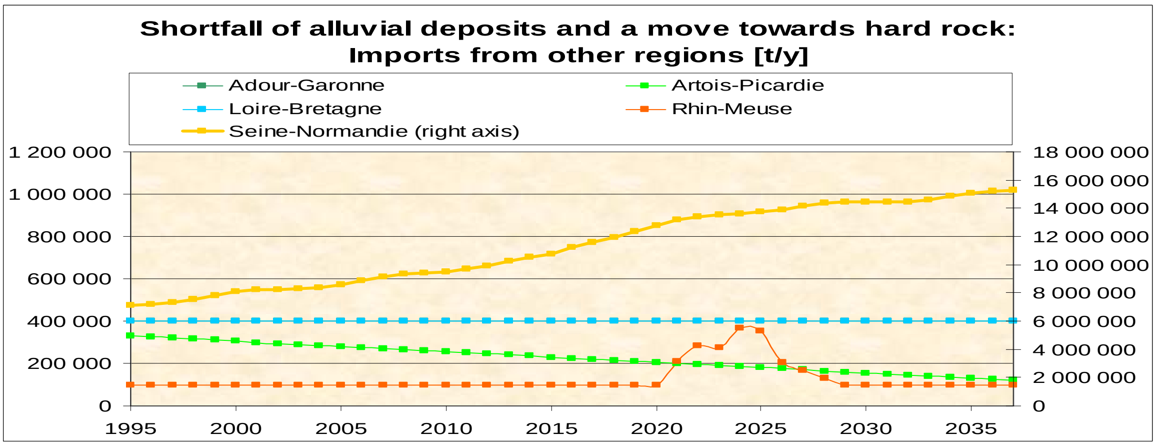


Figure 99: Shortfall of alluvial deposits and move towards hard rock consolidation: imports from other regions

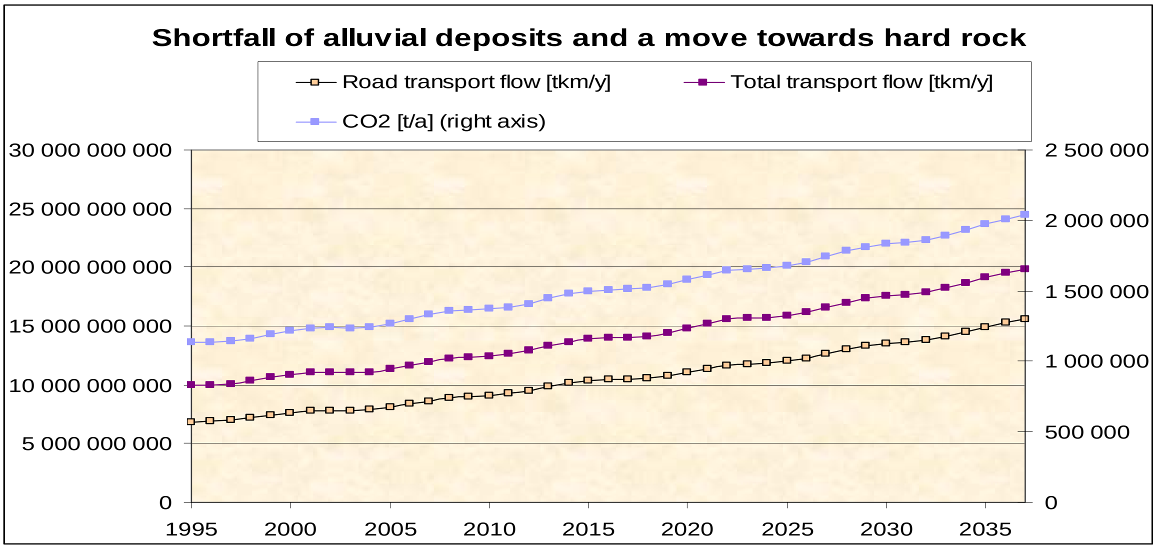


Figure 100: Shortfall of alluvial deposits and move towards hard rock consolidation: impacts

9. Summary and closing remarks

The ANTAG-model allows outputting a set of key economic and environmental parameters in the French aggregates supply and transport market. This allows comparative analyses among different scenario simulation runs and the base case. Each scenario is caused by a trigger. In order to take into account new chains of cause and effect, secondary mechanisms have been developed by construction causal loop diagrams and then implemented in the model. The model feature extensions describe modelling approaches of macroeconomic feedback relationships and secondary mechanisms, which are likely to happen in the aggregates market as a result of suddenly facing a change of current functioning. This has been done in order to consider realistic effects within long-term scenarios.

Extreme values have been chosen for triggering the scenario. Since a big exterior force is disturbing the current functioning, the robustness and realistic behaviour of the model has been checked by consolidation of the six regions, as shown in chapter 8.

The main results are the following:

1. A long-term economic slowdown will have a decelerating effect on the activity of the whole industry. All supply sectors except the niche markets will face reduced growth. Consequently the impacts upon the environment will be smaller compared to the base case.
2. An increase in recycling capacity of 100 million tonnes will result in a decreased local production of crushed and soft rock. CO2 emissions, road transport flow and total transport flow are decreased by 25% compared to the base case. This is due to lower transport distances, since, according to UNICEM and BRGM data basis, recycling of aggregates produces as much CO2 per tonne as producing crushed rock from a quarry.
3. A substitution of aggregates and new technology for buildings construction and a reduction of the demand of public works reduce the activity of the production industry similar to an economic slowdown.
4. A move away from road transport towards alternative transport modes (from 97% to 71% of road transport) results in a poor CO2 reduction, since the secondary road transport contributes to a larger extent and the waterway distances increase faster

leading to additional CO_2 emissions. The implementation of transport capacity saturations of the alternative modes was required. Uncertainty analysis was performed for the submodel extension.

5. Foreign aggregates penetrating the French market on a large scale by increasing the import capacity will have the preservation of local resources as a primary effect. This will happen at the cost of significantly higher transport flows on the waterway. The relative competitiveness of the supply sources is altered since the market equilibrium is altered. The transport capacity saturations were implemented like in the previous scenario.
6. A shortfall of alluvial deposits due to a lack of social acceptability will result in a shortage of construction minerals in four out of the six regions in the next 30 years. The import capacities from other regions are not being increased, since every region in France is confronted with an overall drop of production capacities and therefore needs its own resources. Note that a long-term economic slowdown has been considered which will delay the date when the sum of all the capacities can no longer satisfy the total demand. The reason therefore is reduced local demand.
7. Based on a shortfall of alluvial deposits and an economic slowdown, the lack of capacity can be balanced with an increase in hard rock capacity. The sum of capacities stays superior to the total demand and the shortage can be avoided in each of the four regions.

An increase in capacity of marine production would have similar effects on the market balance as the capacity increase of recycling. This is due to the fact that both actors represent niche markets. They would reduce the production of the primary supply sources.
Figure (101) shows that most of the scenarios are based on a previous one and all of them are ultimately derived from the base case. The model allows creating new scenarios by adding triggers and new features and expanding the scenario tree.

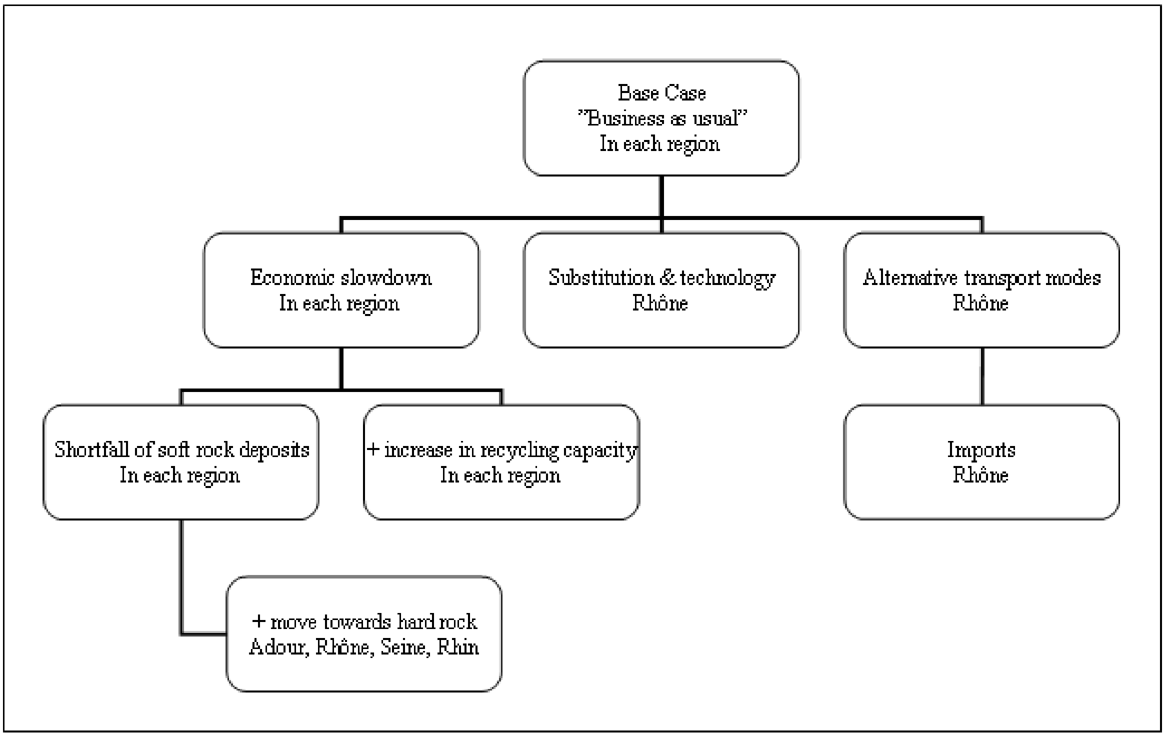


Figure 101: Scenario tree

PART IV

GENERAL CONCLUSIONS

10. Model construction and application

The access to aggregate resources and securing the supply is a local concern as well as a European challenge. The conception, building process and the application of a decision support system for the construction aggregates market was the focus of this work. A macroeconomic top-down model based on the principle of System Dynamics has been calibrated reforming the traditional approach, not considering any geographical inventory or resources. The transfer of the local aggregates market to a global scale required hypotheses in different stages of the aggregates supply chain during the modelling work such as the consumption of a macro-region, the supply end and the transport.

Calibrating a market equilibrium considering competition among the actors, which are represented by the different kinds of supply sources, was the key issue of this work. This has been done by introducing a mechanism which distributes the total unused capacity of a region over the supply sources. The mechanism differs between the dynamics of primary sources and niche markets. The flexibility of the market balance submodel allows one to monitor the relative competitiveness of the supply sources. The factors of social acceptability and industrial development have been quantified and implemented in the production submodels. They either slow down or accelerate the flow of new authorisations.

The transfer from a microeconomic problem to a macroeconomic scale required optimistic assumptions when data was not available. Missing data for model calibration has been rebuilt by making assumptions, so that the calibration of a market equilibrium could be made possible. Production constraints are introduced by the extraction capacities, which have been modelled on a macroeconomic scale by deriving them from the stock of authorised reserves.

This study also emphasises the importance of the conception and calibration of a macroeconomic competition mechanism representing the construction aggregates market. If we assume that there is a balanced market (no shortage of mineral resources), a future trend estimation of the different players in the market requires competition among them. Market equilibrium, where demand equals supply, was the initial condition which the model calibration is based upon.

A baseline case simulation over 30 years of the ANTAG-model shows that it is operational, robust and that it generates reasonable results. The parameters, to which the model reacts sensitively, have been established. The output is highly sensitive to the GDP growth rate, which can also be considered as the biggest uncertainty of the macroeconomic input parameters. The fact that System Dynamics has been chosen as the modelling principle allows the application of the commonly integrated multiple-parameters-sensibility-testing software feature.

The benefit of this System Dynamics model is that it calculates the value of each variable in each time step. This allows a very precise tracking of the evolution of each parameter, which makes the model transparent for analysis, especially in the case of unexpected behaviour.

The flexibility of the model allows the implementation of scenarios by adding triggers within each submodel. Programming scenarios concerning the implementation of secondary feedback relations and new mechanisms are possible, as shown by the breaking scenarios. Transport is responsible for the main CO_2 emissions in the aggregates market. In this regard, two breaking scenarios have been designed for that purpose, favouring alternative transport modes, because they produce less pollution per tonne-kilometre than road transport. The uncertainty of new parameters implemented has been analysed performing Monte Carlo simulation. The biggest uncertainty in the model feature extension is the waterway transport capacity. However, the model output did not show any significant sensitivity to this factor.

Mechanisms can be refined and, when programming scenarios, secondary feedback relations can be added. The transfer to different geographical regions is possible whenever data can be gathered or estimated under hypotheses.

11. Limitations and potential sources of false interpretation

The market equilibrium, computed by the market submodel, allocates parts of the whole market overcapacity over the supply sources. This mechanism is stable within a certain interval. If the gap between the capacities of equally scaled sources (e.g. crushed rock and alluvial deposits) becomes too large – in which case the "loss" of potential production (unused capacity) imposed by the market balance mechanism could exceed the production capacity of the smaller producer, the model output could result in negative extraction profiles for this source. It is important to understand that the market competition mechanism can always only be calibrated on a certain scale and that it will only be robust operating within this scale.

The assumption made in order to model the extraction capacity states that the number of years of lifetime of reserves left for hard and for soft rock is constant. We know that in reality the number of years of lifetime can become small enough to justify new authorised reserves greater than the total demand of the same year. If the lifetime remains high, only small quantities may be authorised. The flow of new authorised reserves is modelled continuously. In this manner the extraction could be elegantly introduced as the driving factor of the new authorisations.

The production of alluvial deposits is expected to considerably decrease in the next decades. The asymptotic decline of soft rock production resulting from the scenario of shortfall of alluvial deposits is not expected to happen in this way. However, the modelling of a (more realistic) accelerating downward movement until the curve hits the time-axis is impossible due to the fact that the soft rock capacity is directly derived from the decreasing stock of authorised reserves.

Providing a good estimate of the impacts upon the environment is a tricky task. When computing the CO2 emissions for road transport a vast number of coefficients, which can be applied to the tonne-kilometres, can be found in the literature. Also note that the coefficient of CO2 emissions per kWh consumed during extraction in the ANTAG model refers to the French electricity market, which is highly dependent upon nuclear energy. This, however, can be changed easily in the model.

A debatable scenario is the increase in recycling capacity, which is based on the scenario of economic slowdown. This could be interpreted as a contraction, since recycling will most probably depend on subventions, which in turn depend on the economic situation of the country. The aim of this scenario, however, was to show the effects of a very optimistic reduction in demand of new aggregates.

It has to be noted that the regions act independently of each other in both the base case and the scenarios. In the case of the shortfall scenario this means that the deficit of aggregates is compensated on a regional basis. It could be expected that a region facing a shortage earlier than its neighbour might import aggregates if the neighbouring region has overcapacities left. Another scenario initially planned was the concentration of the national production in the region Loire-Bretagne. Hard rock reserves supplying the whole country would have been the challenge of the transport modelling. This scenario, however, was eventually not performed.

The consolidation, in general, is a task, which can only be performed by exporting Vensim simulation output data sets of all the six regions to one single spread sheet. The consolidation itself is performed independently of Vensim.

The limitations of the model listed always also represent potentials for improvement and suggestions for striking new paths.

12. Future research and potential

One of the most difficult tasks in modelling is the treatment of social or so-called soft factors. A thorough investigation of social acceptability would be crucial for a more representative analysis. The social acceptability is the complex result of various social and economic factors. Decomposition into sub-parameters might be the first step, but would it be possible to express them properly? A more precise understanding might be achieved on the basis of a long-term survey. Those, however, are usually quite time consuming. In this manner, the change over time could be observed, which might allow a separate calibration of this factor, independent of the factor of industrial development. Note that the past hard and soft rock evolution of industrial development and social acceptability could not be separated within the calibration period. In the ANTAG-model the factor of industrial development implies these two phenomena, since the factor of social acceptability itself is kept constant at 100%. What is known is the historic evolution of the product of these two parameters. If in the past the product of industrial development and social acceptability was greater than 1 (as in the case of hard rock, where it usually was around 1,15), the supply source showed an increase in capacity, and vice versa. If the social acceptability was fully understood, a more profound feedback study could cover the effects of the impacts upon the environment on this social parameter which would directly influence the new authorisations of local reserves.

This example shows that the potential for feedback introduction is vast. Another possible feedback study concerns the introduction of price elasticity. At current prices the costs of construction minerals contribute only a few percent to the total civil engineering costs, which makes the demand of aggregates practically inelastic to price. At what price increase (or what tax) would the demand show effects on the sectors' activities? This mechanism would have to be formalised in a scenario where, for instance, a significant tax per tonne extracted would dampen the demand in aggregates.

During workshops and promotions organised by the consortium, the idea of cutting down the six big regions into smaller ones was a constant topic of discussion. These regions would not necessarily cover the whole French territory, but treat the biggest consumption centres instead. The idea of applying the model to smaller regions, once the ANTAG-project was finalised, was discussed in detail. Concentration on the regionalisation of a macroeconomic System Dynamics model was also one of the conclusions made by De

Vries et al. (1999). Its feasibility for the ANTAG-model has been proven by the calibration of the region Artois-Picardie, which clearly is smaller than all of the other regions. The market balance of such a region might be sensitive to other factors depending on the location. Furthermore, the model parameters would have to be recalibrated on the basis of regional data sets.

A very demanding future task would consist in the modelling of the market equilibrium of the inter-regional transport flows nationwide. The demand from other regions within France of a certain region could no longer be an exogenous stock-and-flow structure, which is the case in the present model, but would result from the imports determined by the market balance of at least one other region. Which region would be concerned, would depend on the relative proximity.

One enormous advantage of the model is the fact that it offers a vast potential of implementation of new features and add-ons. Note that the scenarios are all derivations of the base case model files. When we decide to program a new add-on, we have to make new hypotheses. Once a new mechanism is conceived, it has to be expressed as a stock-and-flow-structure. In most of the cases this means that an initially exogenous constant parameter is being endogenized and is now controlled by the variables and mechanisms upstream. Examples would be the factor of industrial development and the change in the transport split factor described in the model feature extensions in chapter 7. Another example, finally not implemented, would be an increase in the transport capacities of the alternative transport modes as a logical consequence of an increasing tonnage, which has to be transported by these modes. The transport capacities remain constant in the scenarios 8.5 and 8.6.

A new model add-on can be based on an already previously defined add-on. If we just think of the current credit crunch, which repeatedly shows new unexpected secondary effects, the benefits of such a model, which enables one to build a scenario on top of an existing scenario, become even clearer. However, this conceptual framework does not avoid the need of precise specifications of new feedback mechanisms and parameters to implement.

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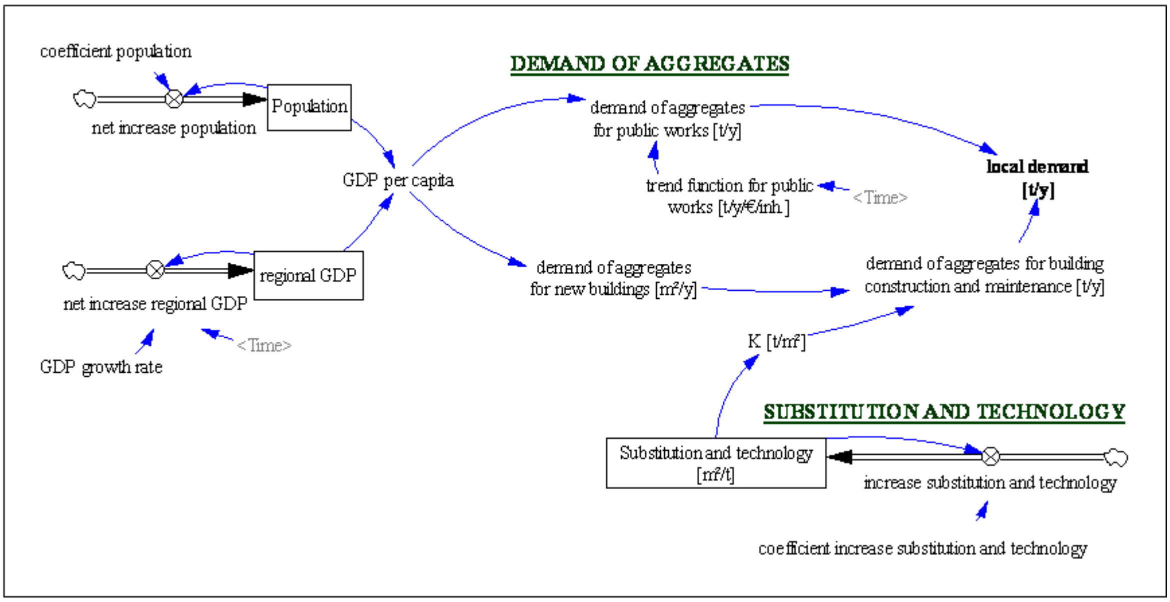
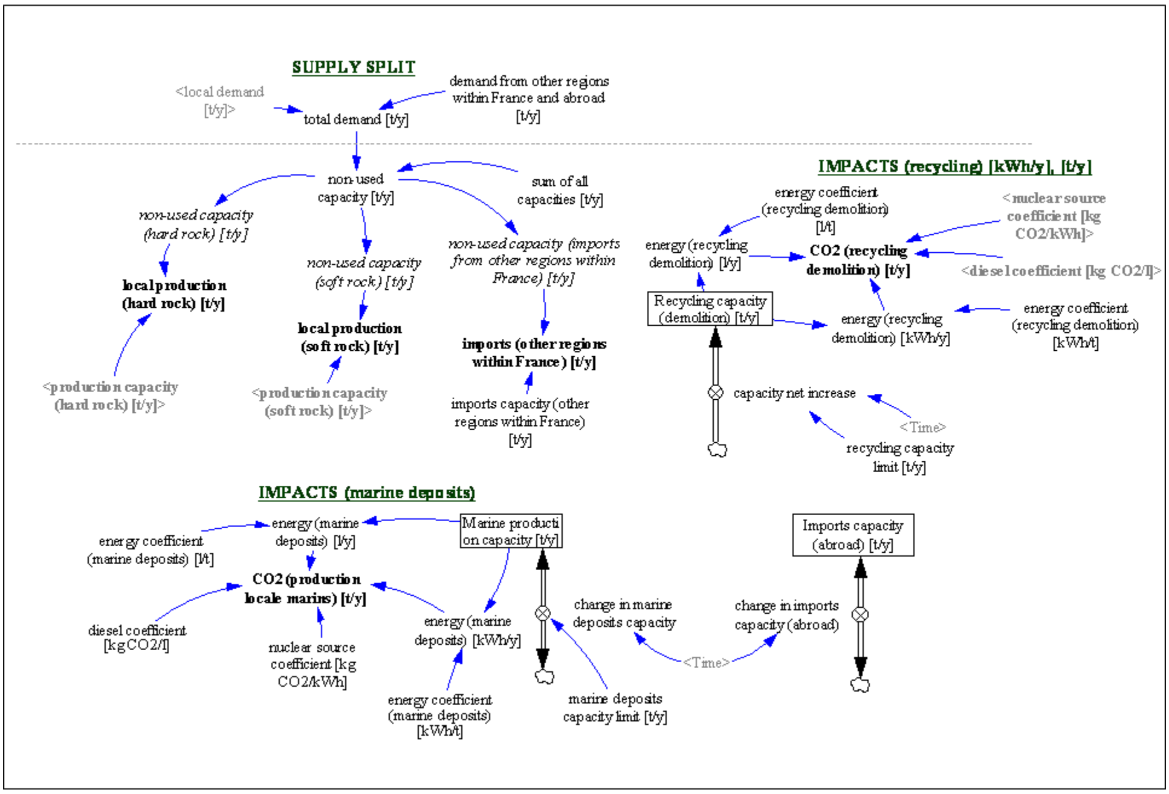
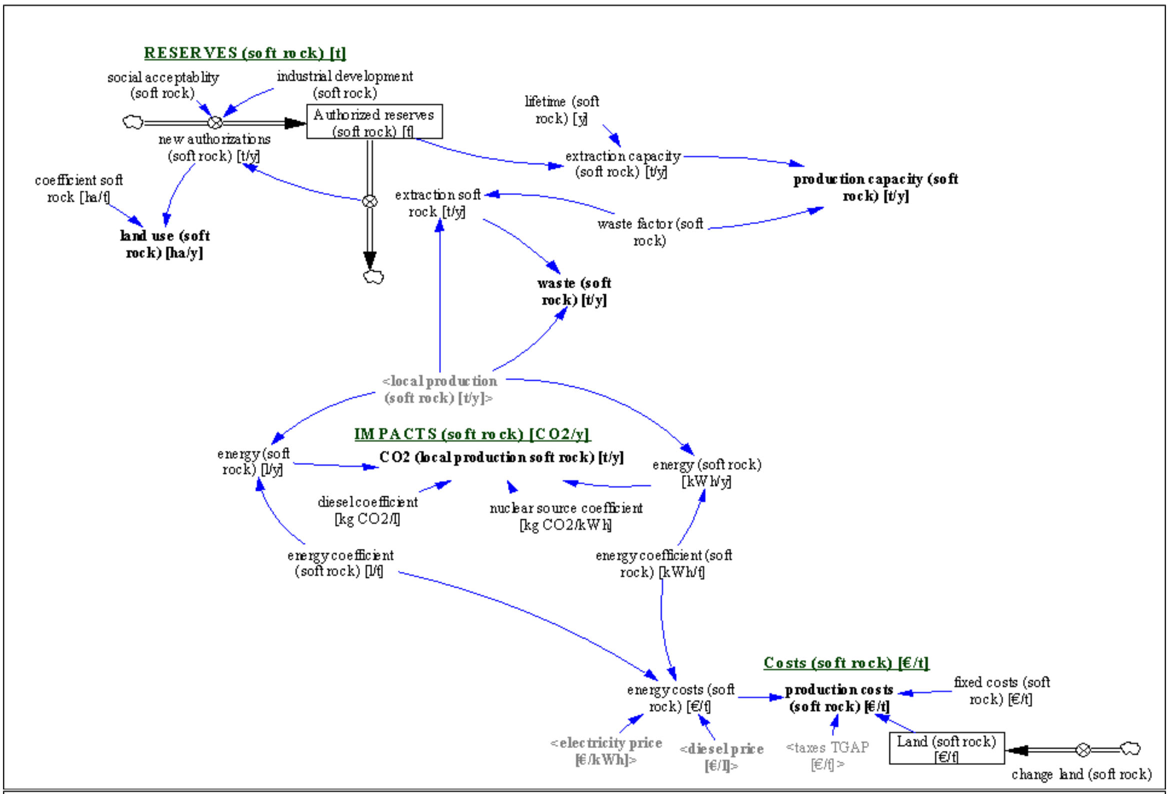
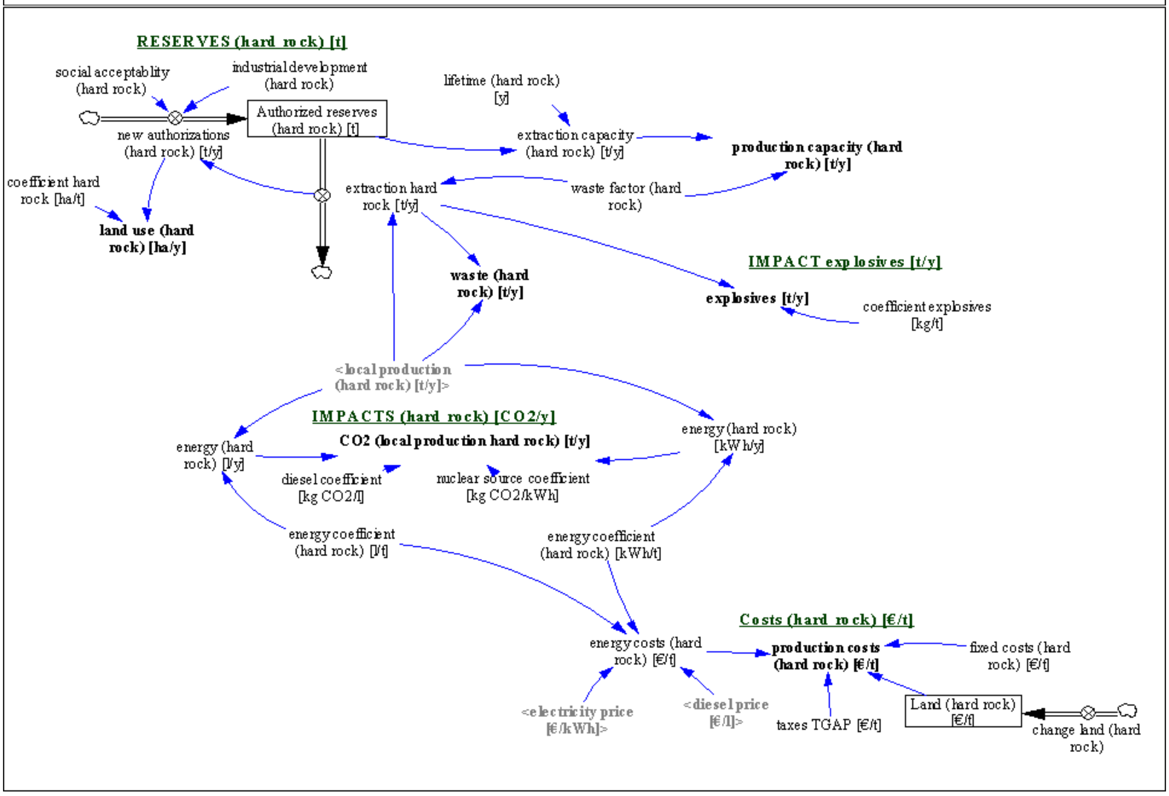
(Accessed July 07)

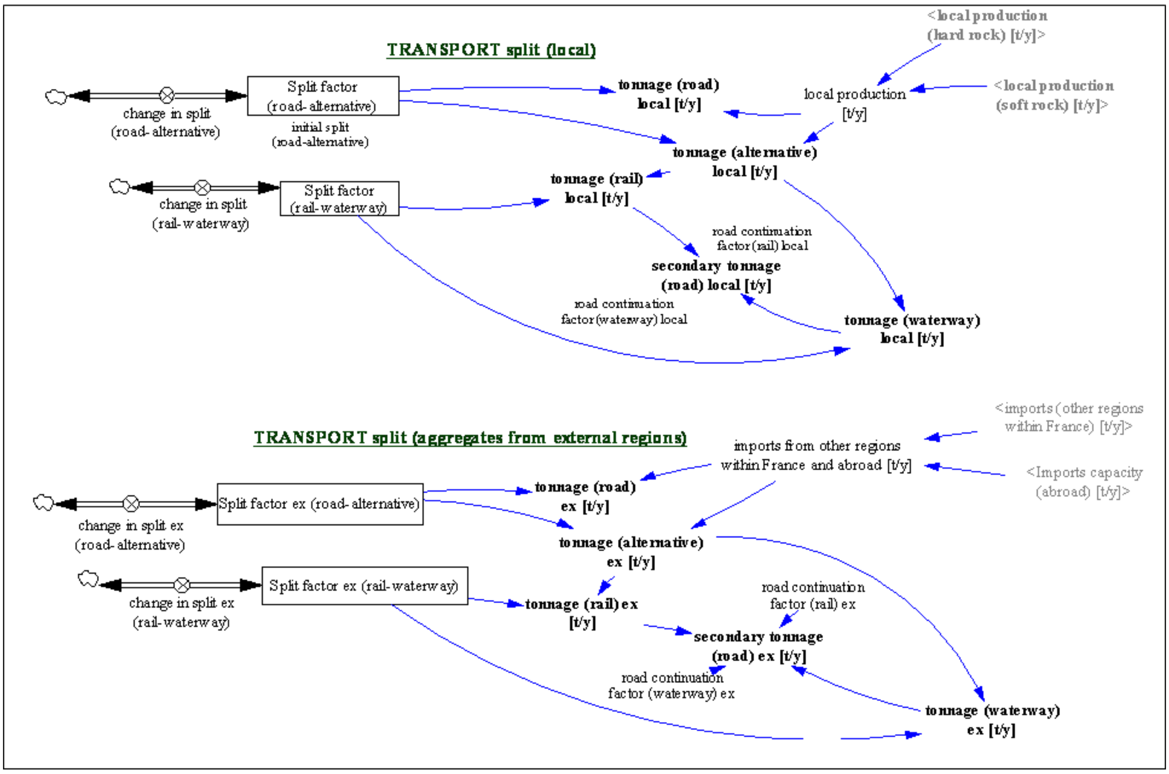
Appendix - Full Model for Adour-Garonne

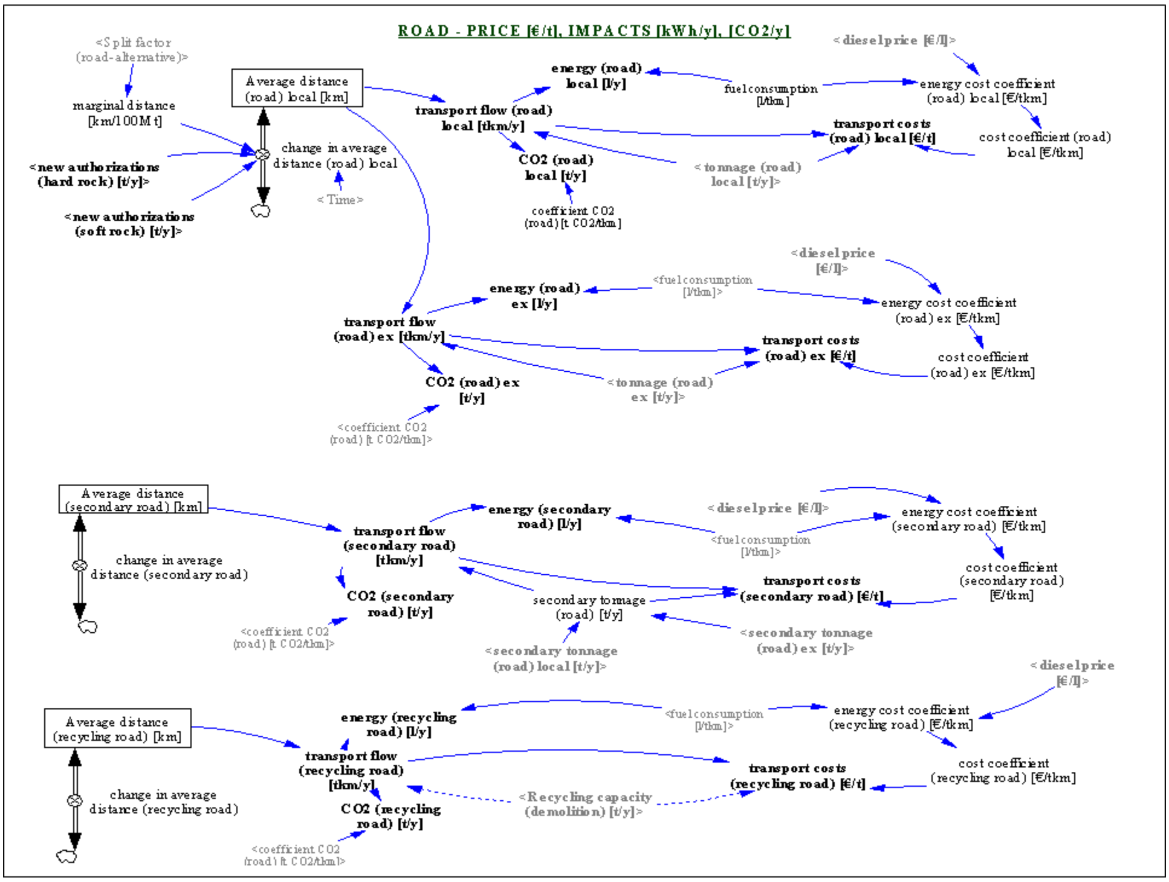


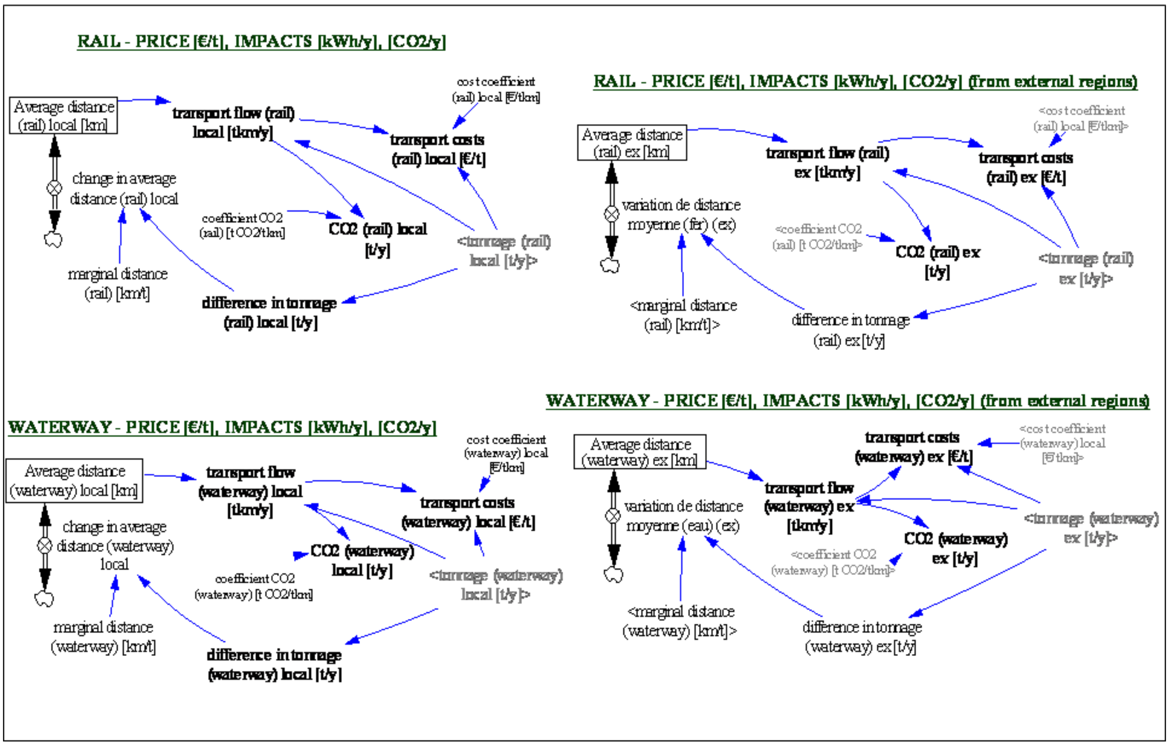



RESERVES (soft rock) [t]
social acceptablity (soft rock)
industrial development (soft rock)
Authorized reserves (soft rock) [t]
new authorizations (soft rock) [t/y]
lifetime (soft rock) [y]
extraction capacity (soft rock) [t/y]
production capacity (soft rock) [t/y]
coefficient soft rock [ha/t]
land use (soft rock) [ha/y]
extraction soft rock [t/y]
waste factor (soft rock)
waste (soft rock) [t/y]
<local production (soft rock) [t/y]>
IMPACTS (soft rock) [CO2/y]
energy (soft rock) [l/y]
CO2 (local production soft rock) [t/y]
energy (soft rock) [kWh/y]
diesel coefficient [kg CO2/l]
nuclear source coefficient [kg CO2/kWh]
energy coefficient (soft rock) [l/t]
energy coefficient (soft rock) [kWh/t]
Costs (soft rock) [€/t]
energy costs (soft rock) [€/t]
production costs (soft rock) [€/t]
fixed costs (soft rock) [€/t]
<electricity price [€/kWh]>
<diesel price [€/l]>
<taxes TGAP [€/t]>
Land (soft rock) [€/t]
change land (soft rock)

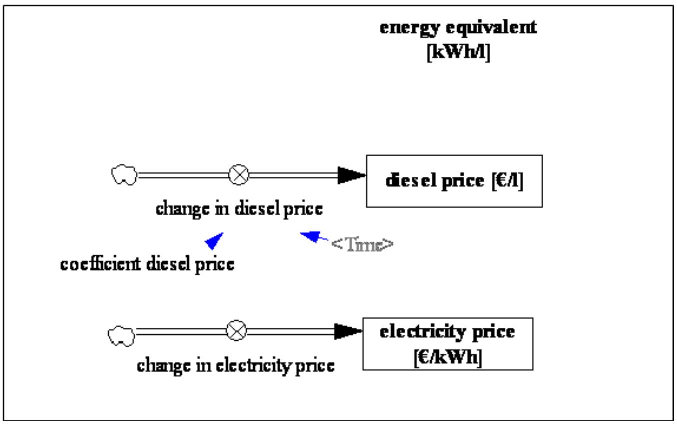

RESERVES (hard rock) [t]
social acceptablity (hard rock)
industrial development (hard rock)
Authorized reserves (hard rock) [t]
new authorizations (hard rock) [t/y]
lifetime (hard rock) [y]
extraction capacity (hard rock) [t/y]
production capacity (hard rock) [t/y]
coefficient hard rock [ha/t]
land use (hard rock) [ha/y]
extraction hard rock [t/y]
waste factor (hard rock)
waste (hard rock) [t/y]
IMPACT explosives [t/y]
explosives [t/y]
coefficient explosives [kg/t]
<local production (hard rock) [t/y]>
IMPACTS (hard rock) [CO2/y]
energy (hard rock) [kWh/y]
energy (hard rock) [l/y]
CO2 (local production hard rock) [t/y]
diesel coefficient [kg CO2/l]
nuclear source coefficient [kg CO2/kWh]
energy coefficient (hard rock) [l/t]
energy coefficient (hard rock) [kWh/t]
Costs (hard rock) [€/t]
energy costs (hard rock) [€/t]
production costs (hard rock) [€/t]
fixed costs (hard rock) [€/t]
<electricity price [€/kWh]>
<diesel price [€/l]>
taxes TGAP [€/t]
Land (hard rock) [€/t]
change land (hard rock)


TRANSPORT split (local)
<local production (hard rock) [t/y]>
Split factor (road-alternative)
change in split (road-alternative)
initial split (road-alternative)
tonnage (road) local [t/y]
local production [t/y]
<local production (soft rock) [t/y]>
tonnage (alternative) local [t/y]
tonnage (rail) local [t/y]
Split factor (rail-waterway)
change in split (rail-waterway)
road continuation factor (rail) local
secondary tonnage (road) local [t/y]
road continuation factor (waterway) local
tonnage (waterway) local [t/y]
TRANSPORT split (aggregates from external regions)
<imports (other regions within France) [t/y]>
imports from other regions within France and abroad [t/y]
<Imports capacity (abroad) [t/y]>
Split factor ex (road-alternative)
change in split ex (road-alternative)
tonnage (road) ex [t/y]
tonnage (alternative) ex [t/y]
Split factor ex (rail-waterway)
change in split ex (rail-waterway)
tonnage (rail) ex [t/y]
road continuation factor (rail) ex
secondary tonnage (road) ex [t/y]
road continuation factor (waterway) ex
tonnage (waterway) ex [t/y]

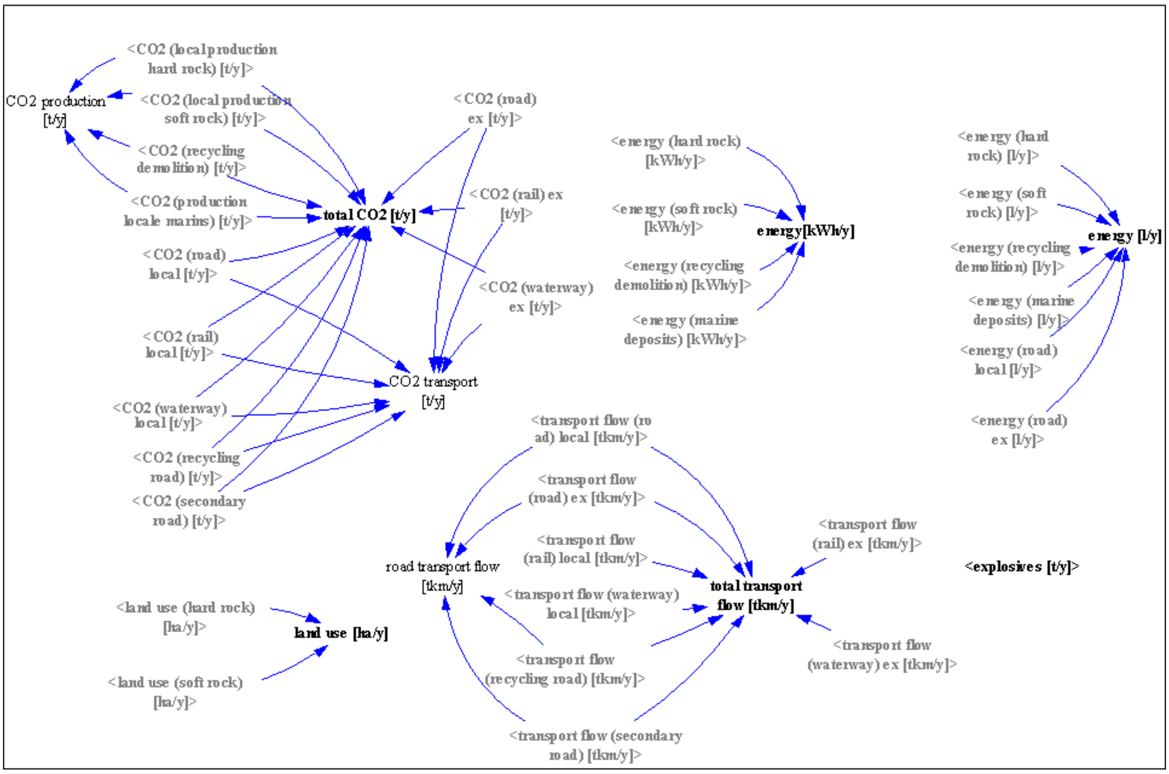

ROAD - PRICE [€/t], IMPACTS [kWh/y], [CO2/y]
<Split factor (road-alternative)>
marginal distance [km/100M t]
<new authorizations (hard rock) [t/y]>
<new authorizations (soft rock) [t/y]>
Average distance (road) local [km]
change in average distance (road) local
<Time>
energy (road) local [l/y]
transport flow (road) local [tkm/y]
CO2 (road) local [t/y]
coefficient CO2 (road) [t CO2/tkm]
fuel consumption [l/tkm]
<diesel price [€/l]>
energy cost coefficient (road) local [€/tkm]
transport costs (road) local [€/t]
cost coefficient (road) local [€/tkm]
<tonnage (road) local [t/y]>
<diesel price [€/l]>
<fuel consumption [l/tkm]>
energy (road) ex [l/y]
energy cost coefficient (road) ex [€/tkm]
transport flow (road) ex [tkm/y]
transport costs (road) ex [€/t]
cost coefficient (road) ex [€/tkm]
<tonnage (road) ex [t/y]>
CO2 (road) ex [t/y]
<coefficient CO2 (road) [t CO2/tkm]>
Average distance (secondary road) [km]
change in average distance (secondary road)
transport flow (secondary road) [tkm/y]
energy (secondary road) [l/y]
<diesel price [€/l]>
<fuel consumption [l/tkm]>
energy cost coefficient (secondary road) [€/tkm]
cost coefficient (secondary road) [€/tkm]
transport costs (secondary road) [€/t]
CO2 (secondary road) [t/y]
<coefficient CO2 (road) [t CO2/tkm]>
secondary tonnage (road) [t/y]
<secondary tonnage (road) local [t/y]>
<secondary tonnage (road) ex [t/y]>
<diesel price [€/l]>
Average distance (recycling road) [km]
change in average distance (recycling road)
energy (recycling road) [l/y]
<fuel consumption [l/tkm]>
energy cost coefficient (recycling road) [€/tkm]
transport flow (recycling road) [tkm/y]
transport costs (recycling road) [€/t]
cost coefficient (recycling road) [€/tkm]
<Recycling capacity (demolition) [t/y]>
CO2 (recycling road) [t/y]
<coefficient CO2 (road) [t CO2/tkm]>



RAIL - PRICE [€/t], IMPACTS [kWh/y], [CO2/y]
Average distance (rail) local [km]
transport flow (rail) local [tkm/y]
cost coefficient (rail) local [€/tkm]
transport costs (rail) local [€/t]
change in average distance (rail) local
coefficient CO2 (rail) [t CO2/tkm]
CO2 (rail) local [t/y]
<tonnage (rail) local [t/y]>
marginal distance (rail) [km/t]
difference in tonnage (rail) local [t/y]
RAIL - PRICE [€/t], IMPACTS [kWh/y], [CO2/y] (from external regions)
<cost coefficient (rail) local [€/tkm]>
Average distance (rail) ex [km]
transport flow (rail) ex [tkm/y]
transport costs (rail) ex [€/t]
variation de distance moyenne (fer) (ex)
<coefficient CO2 (rail) [t CO2/tkm]>
CO2 (rail) ex [t/y]
<tonnage (rail) ex [t/y]>
<marginal distance (rail) [km/t]>
difference in tonnage (rail) ex [t/y]
WATERWAY - PRICE [€/t], IMPACTS [kWh/y], [CO2/y]
Average distance (waterway) local [km]
transport flow (waterway) local [tkm/y]
cost coefficient (waterway) local [€/tkm]
transport costs (waterway) local [€/t]
change in average distance (waterway) local
CO2 (waterway) local [t/y]
coefficient CO2 (waterway) [t CO2/tkm]
<tonnage (waterway) local [t/y]>
marginal distance (waterway) [km/t]
difference in tonnage (waterway) local [t/y]
WATERWAY - PRICE [€/t], IMPACTS [kWh/y], [CO2/y] (from external regions)
Average distance (waterway) ex [km]
transport costs (waterway) ex [€/t]
<cost coefficient (waterway) local [€/tkm]>
transport flow (waterway) ex [tkm/y]
variation de distance moyenne (eau) (ex)
<tonnage (waterway) ex [t/y]>
CO2 (waterway) ex [t/y]
<coefficient CO2 (waterway) [t CO2/tkm]>
<marginal distance (waterway) [km/t]>
difference in tonnage (waterway) ex [t/y]



energy equivalent [kWh/l]
diesel price [€/l]
change in diesel price
<Time>
coefficient diesel price
electricity price [€/kWh]
change in electricity price


<CO2 (local production hard rock) [t/y]>
CO2 production [t/y]
<CO2 (local production soft rock) [t/y]>
<CO2 (recycling demolition) [t/y]>
<CO2 (production locale marins) [t/y]>
total CO2 [t/y]
<CO2 (road) ex [t/y]>
<CO2 (rail) ex [t/y]>
<CO2 (road) local [t/y]>
<CO2 (waterway) ex [t/y]>
<CO2 (rail) local [t/y]>
CO2 transport [t/y]
<CO2 (waterway) local [t/y]>
<CO2 (recycling road) [t/y]>
<CO2 (secondary road) [t/y]>
<energy (hard rock) [kWh/y]>
<energy (soft rock) [kWh/y]>
energy[kWh/y]
<energy (recycling demolition) [kWh/y]>
<energy (marine deposits) [kWh/y]>
<energy (hard rock) [l/y]>
<energy (soft rock) [l/y]>
energy [l/y]
<energy (recycling demolition) [l/y]>
<energy (marine deposits) [l/y]>
<energy (road) local [l/y]>
<energy (road) ex [l/y]>
<transport flow (ro ad) local [tkm/y]>
<transport flow (road) ex [tkm/y]>
<transport flow (rail) local [tkm/y]>
<transport flow (rail) ex [tkm/y]>
road transport flow [tkm/y]
total transport flow [tkm/y]
<explosives [t/y]>
<transport flow (waterway) local [tkm/y]>
<transport flow (recycling road) [tkm/y]>
<transport flow (waterway) ex [tkm/y]>
<transport flow (secondary road) [tkm/y]>
<land use (hard rock) [ha/y]>
land use [ha/y]
<land use (soft rock) [ha/y]>

Anticipation de l’accès à la ressource granulats
par rupture des schémas actuels à long terme

RESUME

L’objectif de ce travail est d’anticiper l’accès à la ressource granulats au-delà des schémas actuels à long terme en France. Cette thèse, qui s’inscrit dans le cadre du projet ANR « ANTAG », a principalement pour but la création et l’exploitation d’un système d’aide à la décision pour le marché national des granulats permettant de simuler les effets à l’échelle de 30 ans de décisions liées à l’approvisionnement des granulats et au développement de la consommation et du transport. L’approche suivie s’appuie sur un modèle de type top-down, macro-économique et il est fondé sur le principe de modélisation System Dynamics. L’apport principal est le mécanisme qui décrit l’équilibre du marché entre les sources d’approvisionnement par distribution de la surcapacité sur les sources d’approvisionnement et qui permet de modéliser et de piloter la compétition entre les acteurs. Un scénario de base, construit à partir de données historiques, sert à concevoir sept scénarios provoqués par des « actions de rupture » qui sont analysés en termes d’évolution des variables clés économiques et environnementales. La puissance du modèle réside dans sa capacité à s’enrichir de nouvelles fonctionnalités permettant d’introduire de nouveaux mécanismes secondaires.

Mots clés: Anticipation, accès à la ressource; Granulats; matériaux de construction; modélisation macroéconomique; compétitivité; System Dynamics; mode de transport; scénarios; système d’aide à la décision; reconstitution des données;

Anticipation of the access to the aggregate resource
by breaking present schemes in the long term

ABSTRACT

This research aims at anticipating the access to construction aggregates in France in future years. The thesis, which is based on the ANTAG-project funded by the French national research agency, focuses on the construction and application of a decision support system for the national aggregates market allowing for the simulation of the consequences of decisions concerning the supply end as well was for consumption and transport over a 30 year period. The macroeconomic top-down model is calibrated using the principle of System Dynamics. One key issue in this work is the introduction of a mechanism detailing the market balance between the supply sources by a distribution of the overcapacity. This allows one to model and monitor the relative competitiveness of the actors. A base case scenario was performed using historical data and formed the starting point of seven scenarios, which are caused by “breaking actions” and analysed based on their economic and environmental output parameters. One enormous advantage of the model is the fact that it offers vast potential for new features and add-ons, which are essential for the introduction of secondary feedback mechanisms.

Keywords: Anticipation, access to the resources; aggregates; construction minerals; macroeconomic modelling; competition; System Dynamics; multimodal transport modelling; scenarios; decision support system; data reconstruction;

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