Breaking present schemes of the access to the aggregate resource

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ABSTRACT

The classic belief that construction minerals are available in virtually infinite quantities has been dampened in many European countries by the permanently rising difficulties in access to the resource. A growing demand in construction aggregates has to face 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 macro-economic predictions difficult. This paper presents the results of the French-Austrian research project "ANTAG". It shows an innovative approach of modelling macroeconomic mechanisms in the aggregates market to conceive and simulate long-term scenarios. The model calibration of the base case scenario is performed using the principle of System Dynamics. The sub-models reflect the dynamics of demand, accessibility, production, transport and environmental impacts, and their interaction. Four selected breaking scenarios are presented and their simulation results will be compared to the base case.

1. INTRODUCTION

France consumes about 400 millions of tonnes of aggregates per year. The general trend of aggregates production in Metropolitan France in the last 30 years shows an increase in demand. The production history curve is cyclic, however increasing by 0.8% on average per year (Figure 1). 95% of the current demand in aggregates is sourced locally and 93% 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 our society are currently confronted with a situation where the future demand has to be satisfied under growing social, political, environmental constraints as well as rising difficulties in access. Which transport modes will be used?

The ANTAG-project *(Anticipation of the access to the aggregate resource by breaking present schemes in the long term)* aims at simulating long-term evolutions of economic and environmental key parameters in the French aggregates market.

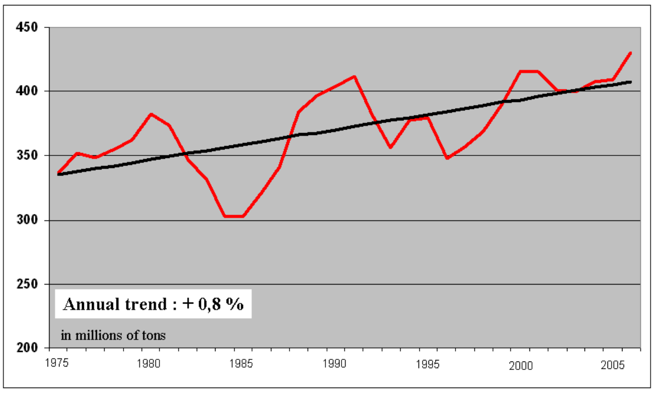

Figure 1: Aggregates production in France

2. CHARACTERISTICS OF THE AGGREGATE MARKET

The aggregates supply sources are divided into different groups. Those are hard rocks, won from quarries, unconsolidated or soft rock, won from streambeds, marine deposits, won offshore and recycled materials. Furthermore imports from other regions within France and from abroad penetrating the market have been separated for each of the regions. They are regarded as separate sources independently of their origin.

A determining factor in terms of reserves provision is the social acceptance. This socio-political phenomenon is a result of the stakeholders' strategy, psychology and the public debate. The best known keyword perhaps is the so called NIMBY-effect (Not-In-My-BackYard) which expresses the attitude of people admitting the fact that there is a need for aggregates but at the same time opposing their extraction in their environment.

The aggregates market is a local market characterised by a low average transport distance. This makes global predictions difficult. Restricting environmental policies make the access to the resource more and more difficult. Furthermore, urbanisation and depletion of reserves near consumption areas result in increasing transport distances from the quarry to the consumption centre.

Surprising may be the fact that the demand of aggregates is not price-elastic [1]. The reason might be the fact 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 difficulty in substitution.

The French aggregates market shows geographical inhomogeneities in consumption and production behaviour. This required a national subdivision. The *Schéma Directeur d'Aménagement et de Gestion des Eaux (outline for the organization of the development and management of water resources in France)* proposes a division into six distinctive macro-zones (Figure 2). Those are:

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

Figure 2: France divided into six regions

Adour-Garonne, for instance, is an autonomous region. The consumption of the whole region is produced within the 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 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.

A model for each of the six zones has been build. The subsequent consolidation of all regions has to confirm that the sum of the transport flows into all zones must equal the sum of the transport flows out of all zones.

The difficulties in the model construction are obvious. The transfer of a local market, in other words a microeconomic problem, to a macroeconomic scale will require strong hypotheses.

3. MODEL STRUCTURE

The structure of each of the sub-models is identical for each of the six regions in the base case scenario. The sub-models are defined as:

- Consumption
- Market
- Production hard rock
- Production unconsolidated rock
- Multimodal transport split
- Road transport
- Alternative transport
- Energy
- Environmental impacts

A simplified scheme of the chaining of the main sub-models is presented below (Figure 3). The *Consumption* sub-model computes a local demand in aggregates for each year. In the *Market* sub-model the demand is satisfied by the different supply sources. The sub-models treating the two primary supply sources, hard rock and unconsolidated rock, basically function the same way, but need to be separated for obvious reasons. The secondary sources are handled in the *Market* sub-model. The three modes of transportation road, rail and waterway are separately modelled. The environmental impacts due to production and transport are collected in the *Impact* sub-model.

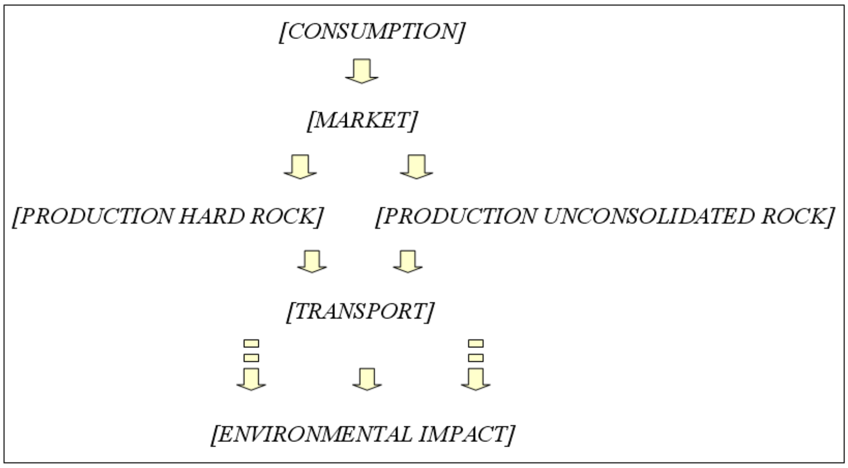

Figure 3: Chaining of the main sub-models

Since feedback relations exist between the *Market* and the *Production* sub-models, this structure is not to be understood as a strict computational chaining but rather as a logical sequence of the sub-models.

4. MODELLING PRINCIPLE

A variable Y can be a function of X and Y perhaps might influence X through a chain of cause and effect. Feedback was expected from the early stages of the model construction which made the introduction of a System Dynamics software practical [2]. Different System Dynamics packages have been used in related problems [3]. The ANTAG-models have been built with the use of Vensim®. This icon-based programming language allows the introduction of endogenous variables. Therefor it uses stock-and-flow-structures (Figure 4). 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. System Dynamics computes the values of variables incrementally from one time point to the next. The results are obtained in the form of time series.

The excerpt of a sub-model shows a specific example of a stock-and-flow-structure.

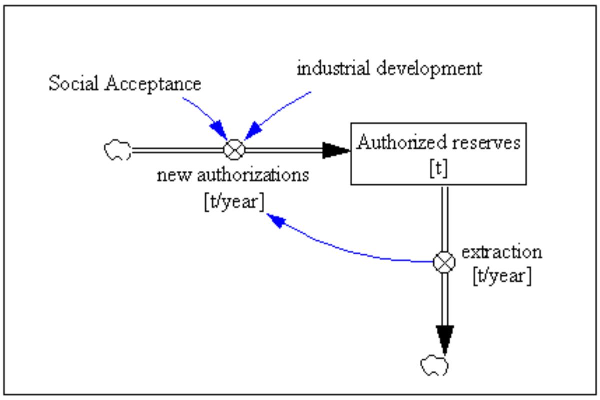

Figure 4: Example of a stock-and-flow structure

In each time step the stock of authorised reserves is calculated as follows:

$$R_{a_{t+1}} = R_{a_t} - e_t + a_t \qquad \textbf{(1)}$$

whereas

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

The stock of authorised reserves is a quantity of reserves ready for extraction. Every year its 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 by the relationship between extraction and new authorisations: the new authorisations depend among two other constant factors on the extraction.

5. REQUIRED DATA SERIES FOR A BASE CASE MODEL CALIBRATION

Time series in the period 1995-2005 of aggregates consumption in [m²/year] of new buildings (and in [t/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). Production time series for all supply sources including waste production for the primary resources were available as well at least in this period. No data were available neither for production capacities nor for the authorised reserves of the primary supply sources. The fact that the demand is not price-elastic required another competitive criterion for a supply-and-demand equilibrium than the market clearing price. However, the introduced macroeconomic competition mechanism presumes that the capacities and the authorised reserves are known. Thus, the missing time series data have been rebuild by making strong assumptions. The quantification of the social acceptance was necessary since piloting this factor must be possible in order to make the model flexible for scenarios. Since the measuring of social acceptance 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. Primary production sources data could be traced back to 1982. The unitary energy consumption in kilowatt-hours and litres of diesel oil per tonne produced were available. The coefficients allowing a subsequent conversion of production-related energy consumed to the emitted CO_2 depending on the energy source were selected after consulting different bibliographical sources [4], [5], [6], [7], [8], [9] 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 CO_2 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.

The following graphs show the results of the calibration for the zone Seine-Normandie. For the total demand and the production sources the calibration error is less than 10% in the six regions. The reconstructed capacities from which the actual production is derived are also marked.

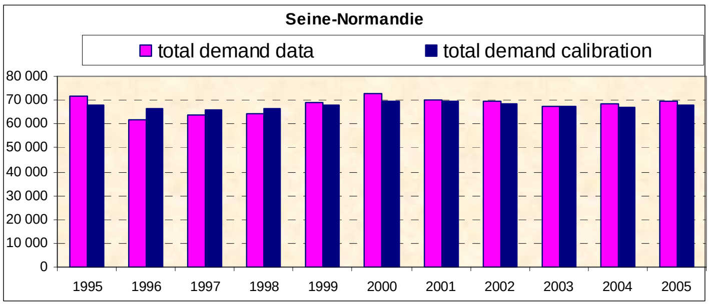

Figure 5: Calibration results of the total demand of Seine-Normandie

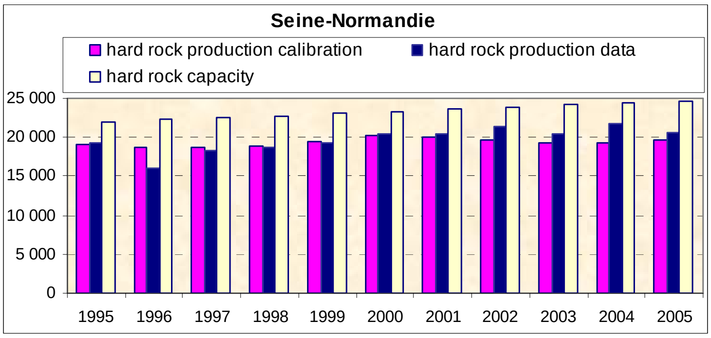

Figure 6: Calibration results of the hard rock production of Seine-Normandie

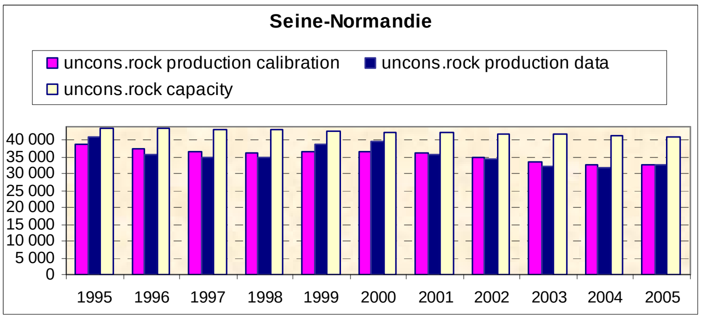

Figure 7: Calibration results of the unconsolidated rock production of Seine-Normandie

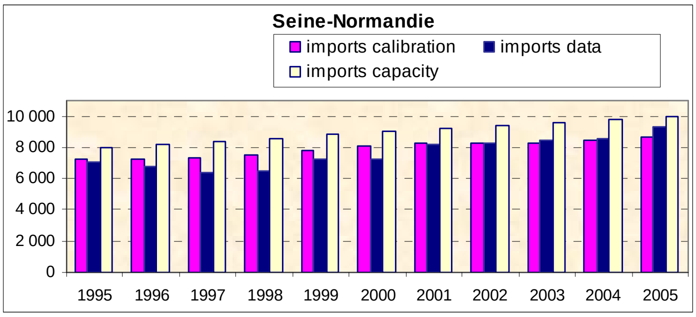

Figure 8: Calibration results of the imports of Seine-Normandie

6. SENSITIVITY ANALYSIS

Sensitivity testing was performed in the base case scenario in the period 1995 - 2035. The local demand of a region is the driver of the model. The market competition will adjust to it and the environmental impacts are derived from production and transport. Understanding to which parameters the demand is sensitive, is crucial since it determines the output of the model to a large extent.

The four parameters tested in the *Consumption* sub-model determine the growth of the gross domestic product, the population, the substitution and new technology for building construction, and the decelerating force for aggregates consumption of public works. The growth rate of the gross domestic production intuitively remains the most uncertain factor. The demand also showed the highest sensitivity to the GDP growth rate, since it is the only coefficient which has not been tested symmetrically with ±5% (Figure 9).

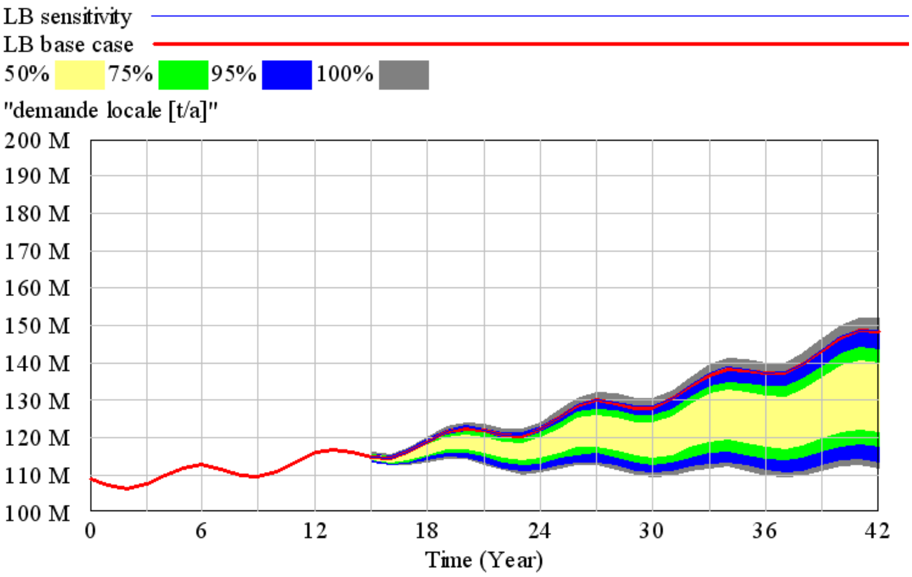

Figure 9: Local demand uncertainty for Loire-Bretagne (sensitivity tested to local demand input parameters) - (starting time 1995)

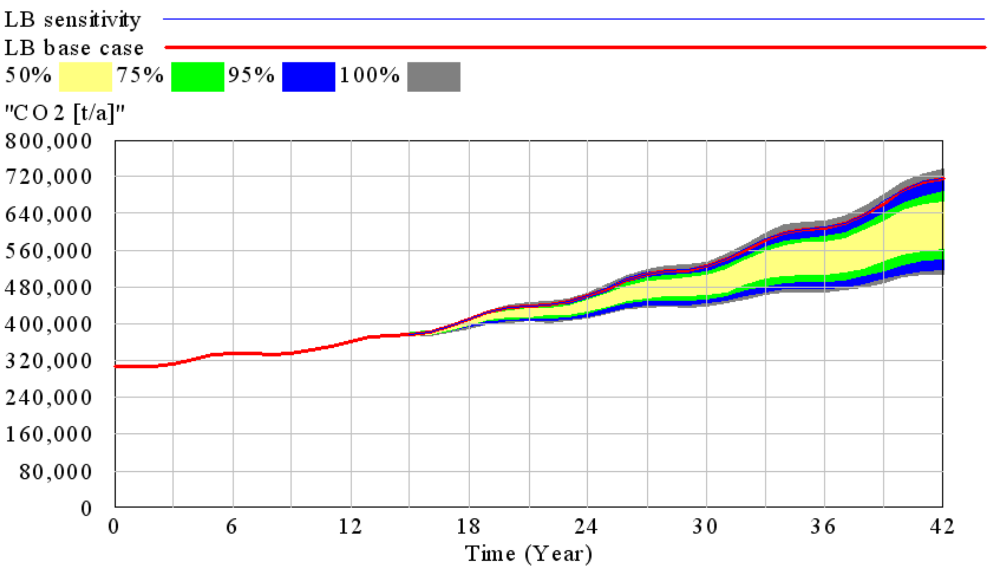

Figure 10: Total CO2 uncertainty for Loire-Bretagne (sensitivity tested to local demand input parameters) - starting time 1995)

Testing the recycling capacity by ±15% (Figure 11) showed no significant effect on the model output (Figure 12).

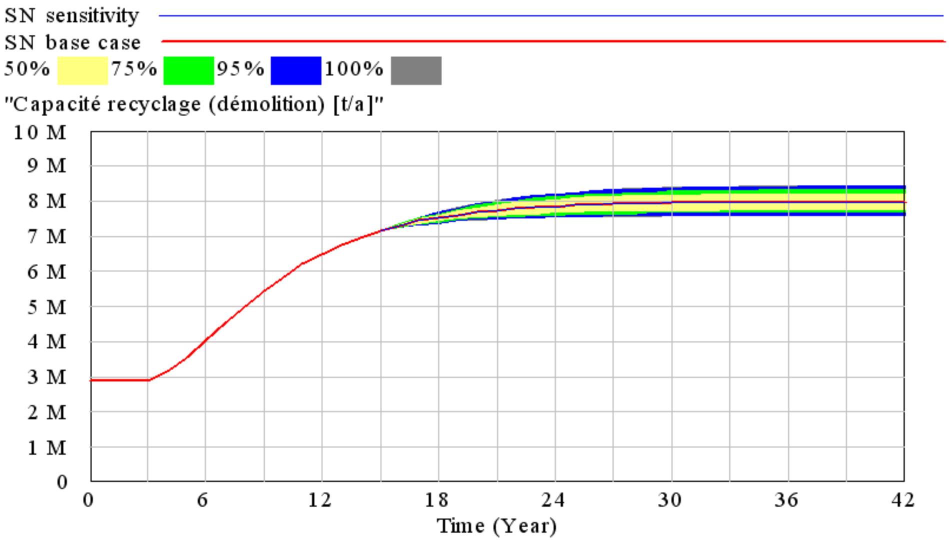

Figure 11: Recycling capacity uncertainty for Loire-Bretagne (sensitivity tested to recycling capacity limit) - (starting time 1995)

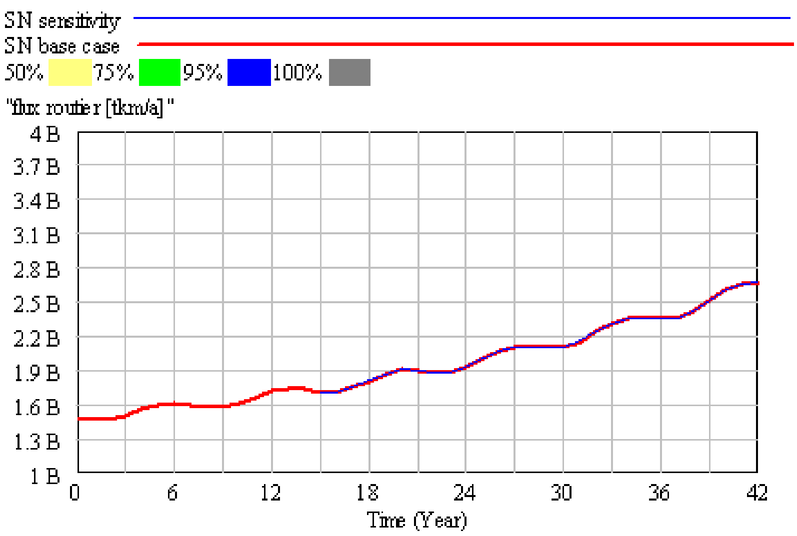

Figure 12: Road transport flow uncertainty for Loire-Bretagne (sensitivity tested to recycling capacity limit) - (starting time 1995)

The model output did not show any particular sensitivity to the waste factor and only little to the factor of industrial development.

7. SCENARIO POTENTIAL

A scenarios trigger can practically be introduced at each stage of the sub-model chaining. The scenarios anticipate the effect of breaking actions by simulating long-term evolutions. Secondary mechanisms and new feedback relations have been introduced depending on the scenario.

One scenario studies the effects of a potential long-term economic slowdown on the aggregates market. The scenario trigger is a dropping GDP growth rate. This makes the demand in aggregates for new buildings and public works decrease compared to the base case. As a consequence the supply sources produce less, and the transported tonnage and the environmental impacts are decreased. This scenario has been performed in each of the six zones.

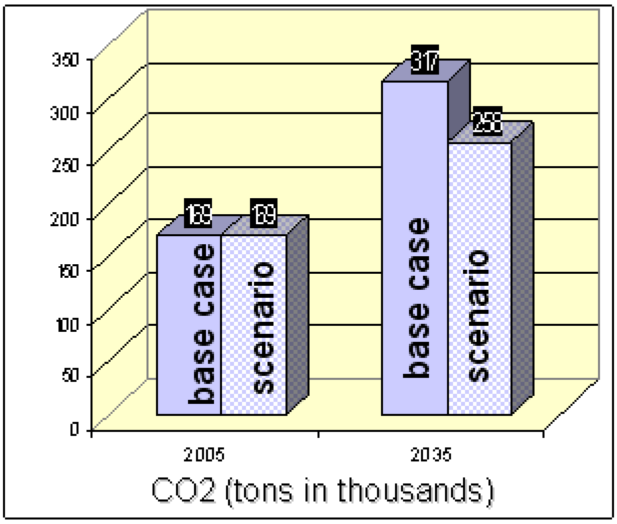

Figure 13: Total CO2 emissions - Scenario economic slowdown in Adour-Garonne

The second scenario shows how acceleration in substitution of aggregates by other materials and new technology for building construction and a reduction of the demand for public works reduces the local demand. This scenario has been performed in Rhône-Méditerranée only.

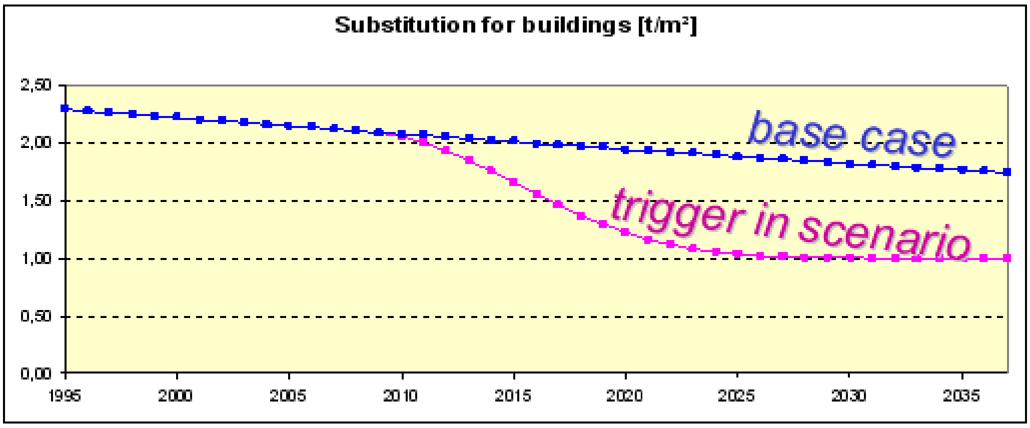

Figure 14: **Trigger for the branch substitution for buildings [t/m²] - Scenario substitution of aggregates in Rhône-Méditerranée**

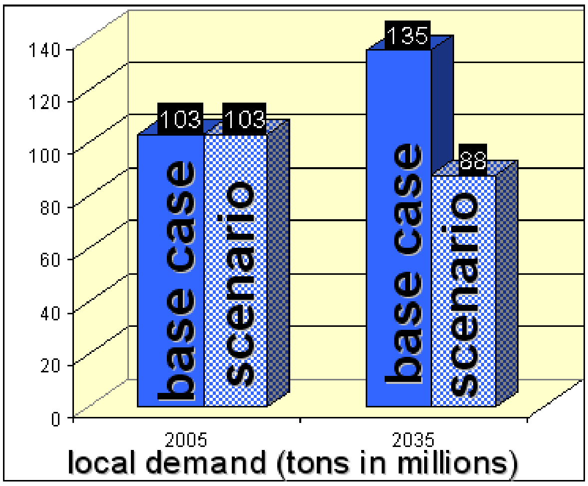

Figure 15: **Local demand - Scenario substitution of aggregates in Rhône-Méditerranée**

A further scenario covers the penetration of foreign aggregates into the French market on a large scale and the effects on the market equilibrium. Increasing the import capacity up to 30 million tonnes in Rhône-Méditerranée would lead to a decrease in local production and hence their preservation. Since foreign aggregates would be transported mainly on the waterway, its average transport distance would rise, leading to a significant increase of transport flows. This scenario has been performed in Rhône-Méditerranée only.

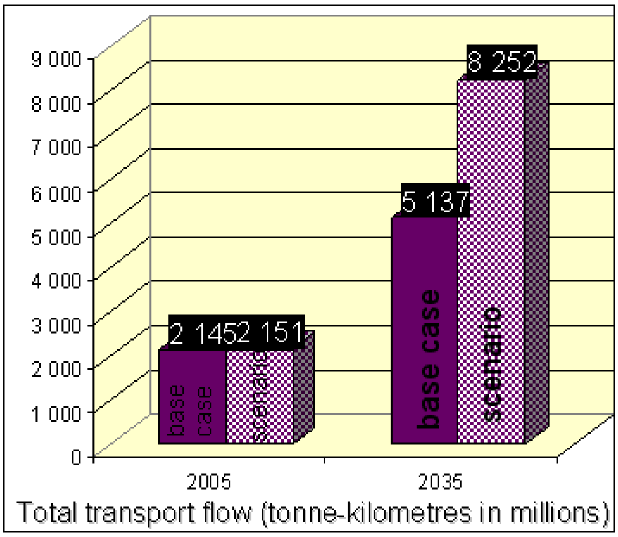

Figure 16: Tonne-kilometres - Scenario imports aggregates in Rhône-Méditerranée

A fourth scenario shows why a move away from road transport towards alternative transport modes does not result in an expected 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 alternative transport modes and the secondary road transport, leads to a reduced increase of overall CO2 emissions. This scenario has been performed in Rhône-Méditerranée only.

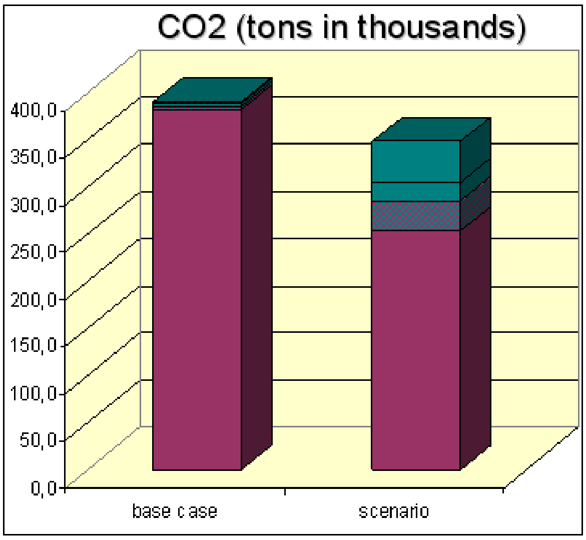

Figure 16: CO2 transport in 2035 (from top to bottom: waterway - rail - secondary road – road) – Scenario alternative transport modes aggregates in Rhône-Méditerranée

8. CONCLUSION

The model is operational, robust and generates reasonable results. The parameters, to which the model reacts sensitive, have been detected. Its flexibility allows the implementation of scenarios by adding triggers within each sub-model. The benefit of the model is that it calculates the value of each variable in each time step. 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.

LITERATURE

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