FORE • SCENE

FMM – First scenarios and modelling results for Europe

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Stefan Bringezu, Mathieu Saurat
Roy Haines-Young, Alison Rollett
Mats Svensson

Wuppertal Institute for Climate, Environment and Energy
University of Nottingham, Centre for Environmental Management
Lund University, Centre for Sustainability Studies

Wuppertal Institute for Climate, Environment and Energy
The University of Nottingham
CEM Centre for Environmental Management
Lund University

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1. Introduction

The structure of the model, the system boundaries and the dealing with time are described in details in background paper 1. These aspects are briefly reminded here.

The model (also called FMM which stands for FORESCENE Metal Model) is organised in submodels, one for each of the environmental themes considered (‘resource use and waste generation’, ‘water’, ‘biodiversity, landscape and soils’). The submodels consist of modules. Submodels and modules and interlinked into a Bayesian network.

The geographical system boundaries encompass the EU-25 when considering input variables and the EU-25 or the world when considering output variables.

With regard to the time dimension, the model start point is the year 2000. The timeframe covers middle and long term objectives (until 2020 and 2050, respectively). Separate networks are produced to cover the modelling time horizon in 5-year time steps.

This paper presents the construction and modelling of the baseline scenario and some alternative scenario elements.

In chapter 2, the baseline assumptions for the input nodes (representing, for example, the driving forces) are presented for the different submodels and their modules. The time series of input parameters are built in two steps.

First, initial values (i.e. for the year 2000) are assumed for the input nodes. For this purpose, existing published empirical or modelled data are used. If a quantification of the uncertainty is available for the data chosen, it is implemented in the initial input value (using, for example, a normal distribution). If such a quantification does not exist, the chosen data is assumed to be accurate and a point value is used.

Second, growth rates are assumed for the input parameters. Data from the literature and existing business-as-usual forecasts are used. Here again, point values or probability distributions are used depending on the uncertainty surrounding the forecasts. However, normal distributions are preferred over single point values because this approach reflects better the forecast uncertainty. Starting from the year 2000, the times series of the input values are calculated outside the Bayesian networks (but using Bayesian techniques in the case of non-point values).

Once the time series of input parameters are built, they are fed into the corresponding Bayesian networks for modelling. The target nodes deliver then the modelling results that make up the “predictions” for the baseline scenario. Results are presented in chapter 3. The networks are built using Netica, a commercially available software. The results can be observed qualitatively directly within the graphical interface of Netica. A quantitative representation of the results as full probability distributions is however needed to provide a more complete representation of predictive uncertainty. For this, Netica is used to perform Monte Carlo simulation, the results of which are analysed outside the software. Presenting full distributions is expected to both enhance theoretical understandings and inform practical decision making.

In chapter 4, input parameters are allowed to take alternative values with regard to the baseline. The influence of parameters expected to play a key role in sustainability strategies are tested in particular. It is possible to infer the suitable values for some input parameters (drivers) for particular targets to be reached (backcasting-like reasoning). Because the simulation-based modelling results include uncertainties of model predictions, the degree of confidence required by decision makers can be taken into account when inferring a value for a driver, suitable to reach a pre-defined sustainability target.

Note that the FMM prototype is a work in progress. Baseline assumptions are available for the input parameters of most modules (see chapter 2), but the modelling of output nodes in the baseline scenario may not be available yet. Consequently, alternative scenarios cannot be implemented on nodes for which a baseline is not yet available.

2. Baseline scenario: Assumptions for the input nodes

2.1. Resource use and waste generation submodel

2.1.1. Economy module

Projections of *population* growth are taken from Eurostat. From 2000 to 2015, population in EU-25 increases at a 1% rate per 5-year interval. The growth rate then slows down and becomes negative from 2030. In 2050, the EU-25 hosts 2.3 million inhabitants less than in 2000.

Empirical data for *economic activity*[1] (GDP/cap) are taken from Eurostat for the period 2000-2005 (7.5% increase over the period). For the period 2005-2020, an annual average growth rate of 2% is taken for GDP per capita from the baseline of the GINFORS economic model (MOSUS project). Other sources are slightly more optimistic, for example EEA (2005) assumes an average annual growth rate of 2.5% for GDP per capita in the EU-25. To take this observation into account and build the FORESCENE baseline scenario as a “corridor” including both pessimistic and optimistic views, the growth of GDP per capita is modelled with a normal distribution (mean = 2%, standard deviation = 0.3%). The distribution chosen is centred on 2% growth and 90% of its values occur in the interval 1.5%-2.5%. EC (2008), for example, uses a +1.8% annual average growth rate in its baseline scenario. For the period 2020-2050, *economic activity* is assumed to continue growing at a similar rate.

As a result, real *GDP* increases on average by 2% per year until 2050. But, due to the uncertainty about the growth rate of GDP per capita (represented by a normal distribution), the confidence interval around the mean value of GDP widens at each time step.

Domestic demand and *exports* are determined in comparison to *GDP*. In 2000, domestic demand is as high as GDP[2] while exports represent 36% of that value. The development trends given by Eurostat until 2009 are prolonged until 2020 (-0.1% and +1.3% per year for the ratios domestic demand and export to GDP, respectively). After that date, domestic demand and exports are assumed to remain in the same proportions in comparison with GDP (98% and 51%, respectively).

2.1.2. Mineral materials module

Given the level of *domestic demand*[3] and *exports*, the level of *DMI minerals* is driven by the respective shares of services and goods in *domestic demand* and *exports* and their respective material intensities. The corresponding input data are estimated from NAMEA[4]-based input-output analyses conducted by the EEA ETC/RWM[5] for 8 EU

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[1] Like in background paper 1, italics indicate the use of the name of a node from the Bayesian network, or a direct reference to a node.
[2] At the EU-25 level, foreign trade is almost balanced (the difference between exports and imports represents only 1% of GDP) which explains why domestic demand is as high as GDP.

countries[6] with monetary and physical IO tables from 1995 (2 countries) and 2000 (6 countries).

Averaging over the complete set of input-output results, the *share of services*[7] *in domestic demand and export* is estimated at 64% and 19%, respectively. These input values are assumed constant over the whole timeframe in the baseline scenario.

Uncertainties arise from the sometimes questionable accuracy of the input-output analyses and from scaling up the results for application at the EU-25 level. For example, MFA results for Europe (Eurostat 2002, Moll et al. 2005, Schütz 2007) have been used to re-calibrate material intensities which come out too high from the input-output analyses (because indirect foreign used extraction associated with imports is included in the material inputs activated by final use of a product, whereas DMI contains only imports and domestic used extraction). The proportionality relation between material intensities of services vs. that of goods is preserved in the process. The point values found for different material intensities in 2000 are presented in Table 1. Furthermore, it is usually considered that DMI bears with itself an error of ±5% (we consider it as the 90% confidence interval). To account for it, material intensities are modelled as normal distributions parameterised with means as shown in Table 1 and standard deviations of 3% of the mean.

Table 1: Mean material intensity values in EU-25 in 2000

DMI activated by final use t / Mill. euros	**Metal ores**	**Industrial minerals**	**Construction minerals**	**Total minerals**
Goods	52	47	440	539
Services	5	7	69	81

[3] Includes the items “Final consumption expenditure by households”, “Final consumption expenditure by non-profit organisations serving households (NPISH)”, “Final consumption expenditure by government”, “Gross fixed capital formation” and “Changes in inventories and valuables”.

[4] NAMEA: National Accounting Matrix including Environmental Accounts.

[5] European Topic Centre on Resource and Waste Management (ETC/RWM, Topic Centre of the European Environment Agency): Implementation Plan 2006 - task 7.1.2.1 "NAMEA-based Input-Output Analyses".

[6] Germany, Denmark, Spain, Hungary, Italy, The Netherlands, Sweden and the United Kingdom.

[7] The term ‘services’ includes the aggregated product groups “Wholesale and retail trade, repair of motor vehicles, motorcycles and personal and household goods; hotels and restaurants; transport, storage and communication”, “Financial intermediation; real estate, renting and business activities” and “Public administration and defence, compulsory social security; education; health and social work; other community, social and personal service activities; private households with employed persons; extra-territorial organizations and bodies”. The term ‘goods’ corresponds to the aggregated product groups “Agriculture, hunting, forestry and fishing”, “Total industry (excluding construction)” and “Construction”.

The material intensity of goods is expected to decrease by 1.7% per year in the baseline scenario, i.e. without the implementation of any particular policy instrument. It reflects the observed inherent increase of material productivity. Further *improvements in manufacturing* are not expected to occur in the baseline. Material intensities of services are assumed constant.

The *self-sufficiency of EU* regarding minerals (i.e. the imported share of *DMI minerals*) is taken from EU-15 MFA studies (Schütz 2007). According to the same source, the share of imports in DMI metal ores and industrials minerals increased on average by 1.5% and 1.8 % per year during the decade 1990-2000 (from 62% and 24% up to 72% and 29%, respectively). This trend is prolonged until 2020 and the share of imports is assumed to remain constant afterwards. Imports of construction minerals are neglected in view of the massive domestic extraction (mainly sand, gravels, stones etc).

Moving from DMI to TMR, the indirect flows associated with imports and unused domestic extraction needs to be calculated. Hidden flows (*HF*) and indirect flows (*IF*) coefficients come from EU-15 MFA studies (see Table 2). For the baseline, the trends observed in the decade before 2000 are prolonged until 2020 and flattened afterwards. Depending on the type of mineral materials, domestic hidden flow and foreign indirect flow intensities are expected to further decrease, and respectively increase, until 2020 at annual average rates presented in Table 2. TMR is usually said to come with an error of ±15% (we consider it as the 90% confidence interval). To account for it and the error already included in DMI, HF and IF coefficients are modelled as normal distributions parameterised with means as shown in Table 2 and standard deviations of 9% of the mean.

Table 2: Mean values for hidden and indirect flow coefficients for EU-25 in 2000 and baseline assumptions for the development until 2020

t / t	Metal ores	Industrial minerals	Construction minerals	Total minerals
Hidden flows of domestic extraction	1.07	0.43	0.22	0.56
Annual change until 2000-2020	-2.9%	-3.1%	-0.3%	-0.9%
Indirect flows of imports	13	4.01	:	8.09
Annual change until 2000-2020	+1.9%	+3.8%	:	+1.1%

2.1.3. Fossil fuel module

The use of fossil fuels has in common with the use of mineral materials modelled in the previous module the issues of extraction of non renewables, and the unused extraction and associated indirect flows. The problem of greenhouse gases emissions is, however, specific to this category of materials, burnt for energy generation.

Table 3 presents the initial conditions (year 2000) and the assumptions for the dynamics of the *energy intensity* and energy mix parameters in the baseline scenario. The data come from EC (2008) until 2030. Depending on the degree of detail used in the graphical model (i.e. the Bayesian network), the energy mix is either reduced to the ratio of non renewables and renewables, or detailed as in Table 3.

In any case, the fossil fuel mix is implemented (partly or totally exogenously) to calculate the *DMI fossil fuels* of EU-25, starting from primary energy use. EU's *self-sufficiency*, and *HF* and *IF* coefficients for the domestic and foreign parts of *DMI fossil fuels* are also derived in accordance with the fossil fuel mix. These coefficients are adapted from EU material flow data available at the WI, similarly to the mineral materials case.

Table 3: Baseline assumption for gross inland energy consumption (GIC) (EC 2008)

Initial conditions (year 2000)		2000-10	2010-20	2020-30	2030-50
toe GIC / Mill. Euro GDP		Annual average % change			
Energy intensity	170.4	-1.3	-1.7	-1.6	-1.6
% of gross inland consumption		Annual average % point change			
Solid fuels	14.8	-0.1	+0.07	-0.03	0
Oil	40.4	-0.23	-0.08	-0.02	0
Natural gas	23.3	+0.2	+0.08	-0.01	0
Nuclear	15.3	-0.1	-0.25	-0.15	?
Renewable energy forms	6.0	+0.22	+0.19	+0.19	?

2.1.4. Biofuel module

The biofuel module consists of a separate simplified transport model. Because the aim is to determine the demand for biofuels, the module is limited to road transport, where these types of fuels are employed.

The initial conditions of *demand for freight and passenger transport* are taken from Eurostat (EU-25). The evolution over time of these two parameters is given by elasticity coefficients with regard to *GDP*. The baseline scenario uses elasticities as shown in Table 4. Data up to 2030 come from the baseline scenario of EC (2008) and are prolonged until 2050.

The probability distributions describing *fuel intensity for freight and passenger transport*, respectively, were generated using a Markov Chain Monte Carlo method, using Eurostat data sets for freight and passenger transport demand, and total energy use for road transport. The annual average decrease rates in energy intensity for each type of transport are taken from the baseline scenario of EC (2008).

Seventy-five percent of the demand for biofuels is assumed to be covered by biodiesel (own assumption). The rest is bioethanol. The total shares of biofuel implemented in 2000 and 2005 are taken from Eurostat. From then until 2030, the baseline scenario values of EC (2008) are used (7.4% in 2020; 9.5% in 2030). After 2030, the highest objective of the EU Biofuel Directive (10%) is used until 2050. The degree of *self-sufficiency* of EU regarding biofuels is assumed as shown in Table 4 (Schütz 2007).

Table 4: Baseline assumptions for the biofuel module

	Unit	Initial conditions (year 2000)	Evolution over time (2000-2050)
EU freight transport demand	Mt-km	1 472 506	GDP elasticity: 1.45 (2000-2005); 0.92 (2005-2010); 0.72 (2010-2050)
EU passenger transport demand	MP-km	4 718 122	GDP elasticity: 1 (2000-2005); 0.65 (2005-2050)
EU fuel intensity (freight)	toe / Mt-km	Normal distribution (μ = 60.24; σ = 14.54)	Annual energy intensity change: -0.38% (2000-2050)
EU fuel intensity (passenger)	toe / MP-km	Normal distribution (μ = 40.48; σ = 4.40)	Annual energy intensity change: -0.95% (00-05); -0.8% (05-50)
Error	toe	Normal distribution (μ = -210 000; σ = 330 000)	
EU share biodiesel	% (en-ergy)	0.19	5.6% in 2020; 7.1% in 2030; 7.5% afterwards
EU share bioethanol	% (en-ergy)	0.06	1.9% in 2020; 2.4% in 2030; 2.5% afterwards
EU self-sufficiency in biodiesel	%	66	constant
EU self-sufficiency in bioethanol	%	60	constant

2.1.5. Greenhouse gases emissions module

In the actual version of the model prototype, *greenhouse gases emissions* are calculated in two steps with, first, the emissions from fossil fuels, and, second, the emissions from biofuels. Regarding the first step, the baseline assumptions presented above for the energy mix, and especially the fossil fuel mix, translate as follows in terms of carbon intensity (EC 2008): in 2000 the economy of the EU emitted 2.23 tonnes of CO_2 per toe of gross inland energy consumption (all inclusive, i.e. with renewable sources); between 2000 and 2010 the *carbon intensity* is assumed to decrease on average by 0.3% per year; during the following decade the status quo is assumed; and between

2020 and 2030 the *carbon intensity* is expected to decrease on average by 0.2% per year.

With regard to biofuels, Menichetti and Otto (2008) summarize activities and findings of a comprehensive review of the most recent Life Cycle Assessment (LCA) studies and energy and environmental balances of biofuels publicly available. For the model, the GHG emissions saved life-cycle wide through the use of biofuels in the transport sector need to be assessed for biodiesel and bioethanol produced in EU and outside (i.e. four estimates of GHG savings needed). The geographical scope of the studies reviewed by Menichetti and Otto (2008) usually does not match that of the EU-25. The overall GHG saving ranges given by the different LCAs considered together are very wide for each of the four types of biofuels. To reflect these results, normal distributions are built from the data in Menichetti and Otto (2008), assuming that the ranges given represent 99.8% confidence intervals (i.e. 3.09 standard deviations) for the GHG emissions improvement compared to conventional fuel. The baseline assumptions finally retained are presented in Table 5 and are assumed constant for the whole timeframe.

It is planed to further extend the biofuel module in combination with the agriculture land use module to try and model GHG emissions due to the conversion of land for the production of biofuels, notably outside Europe for the supply of Europe. The methodological framework and baseline data shall use Fargione et al.'s (2008) study.

Table 5: GHG emissions improvements due to the use of biofuels compared to conventional fuel (without land use change)

	Crops considered	GHG emissions improvement compared to conventional fuel
Biodiesel produced in EU	Rapeseed	Range: 20% - 80% Normal distribution: $\mu = 50$; $\sigma = 9.7$
Biodiesel produced outside EU	Soybean and palm oil	Range: -17% - 110% Normal distribution: $\mu = 46.5$; $\sigma = 20.5$
Bioethanol produced in EU	Wheat	Range: 2% - 90% Normal distribution: $\mu = 46$; $\sigma = 14.2$
Bioethanol produced outside EU	Sugar cane	Range: 70% - 100% Normal distribution: $\mu = 85$; $\sigma = 4.9$

2.1.6. Agriculture land use module

The agriculture land use module experiences quite a paradoxical development. Data sources for baseline assumptions have been chosen. FAO statistics and FAPRI (2007) shall provide data regarding the development of overall agricultural land use, yields, consumption and production of biomass, and biomass trade. EEA (2006, 2007) has modelled, within a precise framework of assumptions, the area of agricultural land available for bioenergy production.

Two main hurdles still need to be jumped over in order to produce a consistent module. First, data from the sources mentioned above need to be adapted for use in a Bayesian network model aggregated at the EU-25 geographical scale. Second, the relationships with the driving forces present in the meta model (whether in the same agriculture land use module or not) that may influence the baseline assumptions into alternative scenarios need to be worked out and operationalized. It might turn out in the end that some drivers cannot be explicitly modelled in FMM at the level of aggregation considered. For example, the influence of diet on biomass production and land use would probably require a detailed, bottom-up model which we cannot afford for the moment in FMM.

2.2. Water use submodel

Input data for the water submodel still require some effort before they can be presented as consistent baseline time series. Therefore, the baseline assumptions for this part of the model are not further described at this stage.

2.3. Biodiversity, soils and landscape submodel

2.3.1. Biodiversity and landscape module

The Agri-environment support node represents the proportion of Common Agricultural Policy Pillar II (Rural Development) spending on agri-environment programmes. The baseline data (2000) is derived from mid-term Rural Development reports by Member States/regions, giving an overview on agri-environmental measures applied in the 2000-2006 Rural Development programming period (European Commission, 2003; European Commission Directorate General for Agriculture and Rural Development, 2005). EU Member States report a wide range of proportionate spending on agri-environment measures and a mean value was used to establish the baseline. In the subsequent rural development period, 2007-2013, expenditure on agri-environment measures has been reported at 22% of the EAFRD budget. As a result the model includes a growth in the expenditure on agri-environment programmes at the start of the period 2000-2050. Due to lack of data on spending beyond 2013 the value is held constant from this point forward.

Non-adherence to cross compliance is modelled at a constant level from 2005 onwards (approximately 12% - Alliance Environnement, 2007); prior to 2005 there was no requirement for cross compliance. Due to the short time cross compliance regulations have been in operation data is fairly limited and predictions of future trends are, therefore, not available.

The quality of forest management is difficult to assess; in the model forest management is defined as either ‘green’ or ‘brown’. One indicator of that can be used to determine ‘green’ or ‘brown’ status is the area of forest that has been certified by the two main certifying bodies operating in Europe (the Forest Stewardship Council and the Pan European Forest Certification Council). Thus in the model ‘green management’ is taken to be the proportion of forest area under certification. Using data for forest management taken from the European Forest Sector Outlook, it is estimated that ‘green’ or certified forest area accounted for about 20% of forest area in 2000, growing to about 29% by 2005. The UNECE FAO Forest Products Annual Market Review (2006) reports that the area of certified forest increased by 12% between 2005 and 2006. However, the figures for Europe show that over the same period the growth in certified forest area was much smaller from 78.5 million hectares in 2005 to 78.9 million hectares in 2006; representing an annual increase of about 0.5%. An increase of 0.5% per annum is, therefore, assumed in this model from 2005 onwards.

The conservation status of habitats data is derived from Article 17 reporting requirements under the Habitats Directive (European Commission, 1992) for the period 2001-2006 for the EU25[8]. A major component of the report is an assessment of the conservation of all habitats listed on Annexes I and II of the Directive. The assessment is based around the definition of 'favourable conservation status' set out in the directive, and combines assessments of range, area, structure and functions and future prospects. Each of the parameters is reported as one of four classes, favourable, unfavourable-inadequate, unfavourable and unknown. When the results from all four assessments (range, area and so on) are unequal the results are weighted according to the following rules:

- If more than 25% is unfavourable bad then the result is unfavourable bad
- If more than 75% is favourable then the result is favourable
- If more than 25% is unknown then the result is unknown
- All other combinations the result is unfavourable-inadequate.

For the purpose of this model assessments returning the parameter value unknown have been equally distributed between the other three categories. Combining the results of all four categories makes an overall assessment; the habitat status nodes for 2000-2005 are populated with this data, which was used to build the conditional probability tables (Table 6). As noted above the assessment includes a prediction of future prospects for conservation status for the subsequent reporting period. The future prospects data has been used to establish the trends in future conservation status from 2010. Data is held constant from 2010 to 2050 due to lack of predictive data beyond this point.

Table 6 Conservation status of habitat types

Habitat Type	Conservation Status	2000	2005	2010-2050
Grassland habitat status	Unfavourable – bad	54%	54%	46%
	Unfavourable – inadequate	27%	27%	32%
	Favourable	19%	19%	22%

[8] http://biodiversity.eionet.europa.eu/article17/habitatsprogresswebsite

Forest habitat status	Unfavourable – bad	41%	41%	27%
	Unfavourable – inadequate	33%	33%	37%
	Favourable	26%	26%	36%
Bogs and mires habitat status	Unfavourable – bad	56%	56%	42%
	Unfavourable – inadequate	37%	37%	43%
	Favourable	8%	8%	15%
Heath and scrub status	Unfavourable – bad	37%	37%	28%
	Unfavourable – inadequate	40%	40%	36%
	Favourable	23%	23%	36%
Sclerophilus scrub status	Unfavourable – bad	10%	10%	16%
	Unfavourable – inadequate	46%	46%	32%
	Favourable	43%	43%	52%
Aquatic habitat status	Unfavourable – bad	34%	34%	20%
	Unfavourable – inadequate	45%	45%	52%
	Favourable	20%	20%	27%

The data on the percentage of protected area in the EU was taken from the World Database on Protected Areas[9] and has been used to establish the baseline level at 12%. Given the prediction by the Global Biodiversity Outlook (Secretariat of the Convention on Biological Diversity, 2006) that the coverage of protected areas is expected to increase the model includes a small rise in this area over the period 2010 to 2050, so that the protected area reaches 13.25% by 2050.

[9] http://sea.unep-wcmc.org/wdbpa/

2.3.2. Soils module

Research and development data was derived from Eurostat statistics on gross domestic expenditure on R & D as a percentage of GDP (Eurostat, 2007); the 2000 baseline was established as 1.9%. Despite the target set by the Lisbon summit for research expenditure to reach 3% of GDP by 2010 there has been little change in the proportionate spending on R & D over the last decade (Table 7). In line with these findings the expenditure on GDP was modelled at a constant 1.9%.

Table 7 Gross domestic expenditure on R & D (% of GDP).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EU25	1.9	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9

Source: Eurostat Yearbook 2006-2007

Amongst the aims of the proposed Soil Framework Directive are the establishment of a common framework to “protect soil on the basis of the principles of preservation of soil functions, prevention of soil degradation, mitigation of its effects, restoration of degraded soils and integration in other sectoral policies” (European Commission 2006, p.5). However, the Soil Framework Directive has not yet been implemented. Despite this it was felt that the future introduction of such legislation could have important implications for a number of soil-based parameters, which made this an interesting node to include within the sub model. The baseline state for the Soil Framework Directive has been set to ‘none’. Due to uncertainty about when the Directive will be implemented, and in what format, the node is set to this state throughout the baseline scenario.

Greenhouse gas emissions data is obtained from IPCC data, which reports emissions of 44.7 $GtCO_2$-eq in the year 2000 (IPCC, 2007). Due to the uncertainty associated with this estimate this is modelled as a normal distribution with a standard deviation of about 5 $GtCO_2$-eq. The SRES[10] Scenarios project an increase of baseline global gas emissions of between 25 to 90% between 2000 and 2030. Beyond 2030, the situation is less clear-cut with SRES scenarios predicting both increases and decreases in greenhouse gas emission. However, data from the CAIT databases[11] suggests that on average emissions of CO_2 (MtCo2 from energy) will increase by an average of 1.5% between 2002 and 2050. Although not accounting for all sectors or all types of emissions this value is used as an indication of future greenhouse gas emissions and a 1.5% per annum increase is taken forward in this model.

Nutrient transfer efficiency data is taken from a number of sources (Domburg et al., 2000, Raun and Johnson, 1999; IGER) and so the baseline value has been established using a normal distribution with mean values of 28% (standard deviation 14%)

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[10] SRES scenarios are those described in the IPCC Special Report on Emissions Scenarios (2000). The scenarios are grouped into four families, A1, A2, B1 and B2, which explore a wide range of driving forces (economic, demographic and technological) and their resulting greenhouse gas emissions.
[11] http://cait.wri.org/

for grassland and 52% (standard deviation 26%) for arable crops. Improvements in nutrient use efficiency might be expected in the future, however, the level of increase in efficiency that might be expected is difficult to quantify. For that reason the level of nutrient transfer efficiency is kept constant throughout the baseline scenario.

Fertiliser use intensity for the EU is taken from the CAIT database, 2002 data for EU 27 (excluding Slovakia, Luxembourg and Latvia). Using this resource a mean and standard deviation were calculated so that fertiliser use for the baseline year could be modelled as a normal distribution, reflecting the variability of this statistic. The European Fertiliser Association (EFMA) (2007) predicts an increase in the use of nitrogen in the EU27 of 3.6% between 2007 and 2017. In contrast, over the same period EFMA suggest that the use of phosphorus will decline by 4.4% and potassium by 2.6%. The FAO report, World Agriculture: 2015/2030 suggests that overall fertiliser use will continue to grow in the developed world until 2030 by about1% per annum. This latter figure represents all nutrient sources so was used to model the growth in fertiliser use intensity until 2030. Beyond 2030, the direction of future fertiliser use intensity is uncertain so between 2030 and 2050 the value in the baseline scenario will be held constant.

3. Baseline scenario: Modelling results for interim and target nodes

In this chapter and in the one that follows, first results are presented for modules that provide input to other modules rather than receive input from them. It is a logical progression since some clusters of baseline assumptions are currently under development for certain modules (e.g. water and agriculture land use modules) which are then expected to deliver input values to other modules (e.g. biodiversity module) that need these data to function.

3.1. Economy

Gross domestic product (GDP), calculated in the economy module is not a model output *per se*. It is, however, directly or indirectly, an important cross-cutting driver relevant for all the other modules and submodels. Therefore, we present here European real GDP (reference year 2000) as it is calculated in the baseline scenario, as a result of the baseline assumptions described above.

Figure 1 shows the evolution of GDP from 2005 to 2050 in the baseline scenario. GDP per capita is assumed to increase on average by 2% every year and even though the European population is assumed to stabilize and even decline in the long term, the behaviour observed for GDP is that of a sustained increase.

It is also very visible in Figure 1 that predictive uncertainty increases, the further we look into the future. This intuitive behaviour is intrinsically modelled by the Bayesian network since we have modelled the growth of GDP per capita with a normal distribution, i.e. we have accounted for uncertainty. Figure 2 presents the modelling results for GDP for four time slices (2010, 2020, 2030 and 2050). The simulation-based modelling approach allows to depict the results for GDP as full probability distributions which convey information not only on median values (i.e. the values that traditional models would deliver) but also on uncertainties. In Figure 2, 50% confidence intervals are given along with the distributions, and they broaden with time.

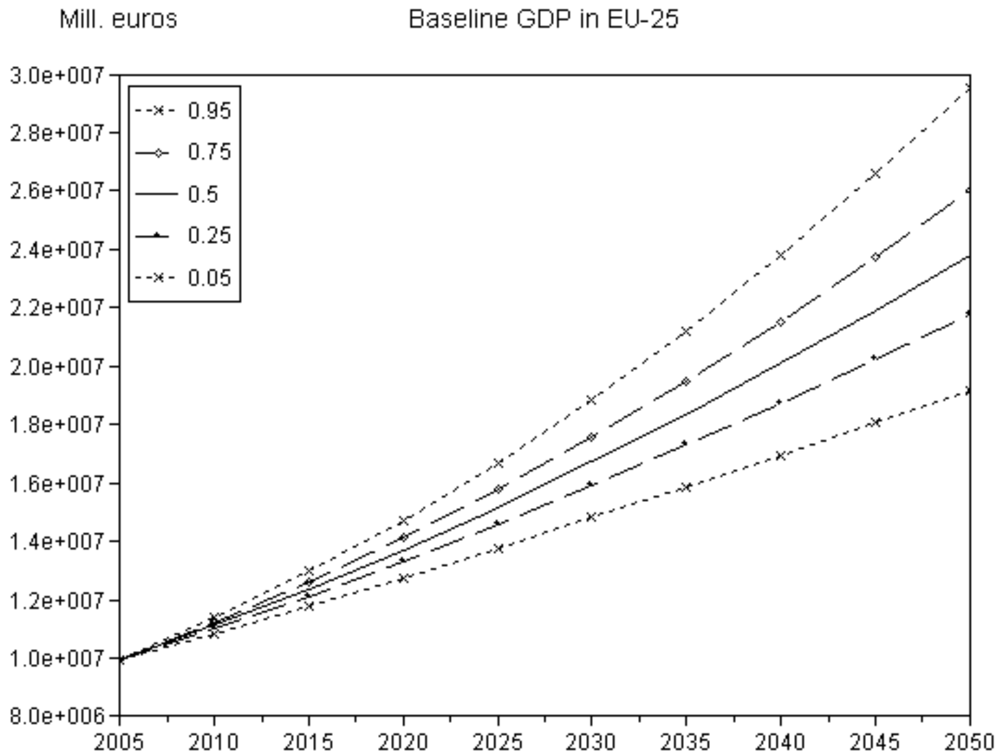

Figure 1: Modelled development of EU-25 GDP in the baseline scenario. Lines represent percentiles of predictive distributions, as indicated in legend.

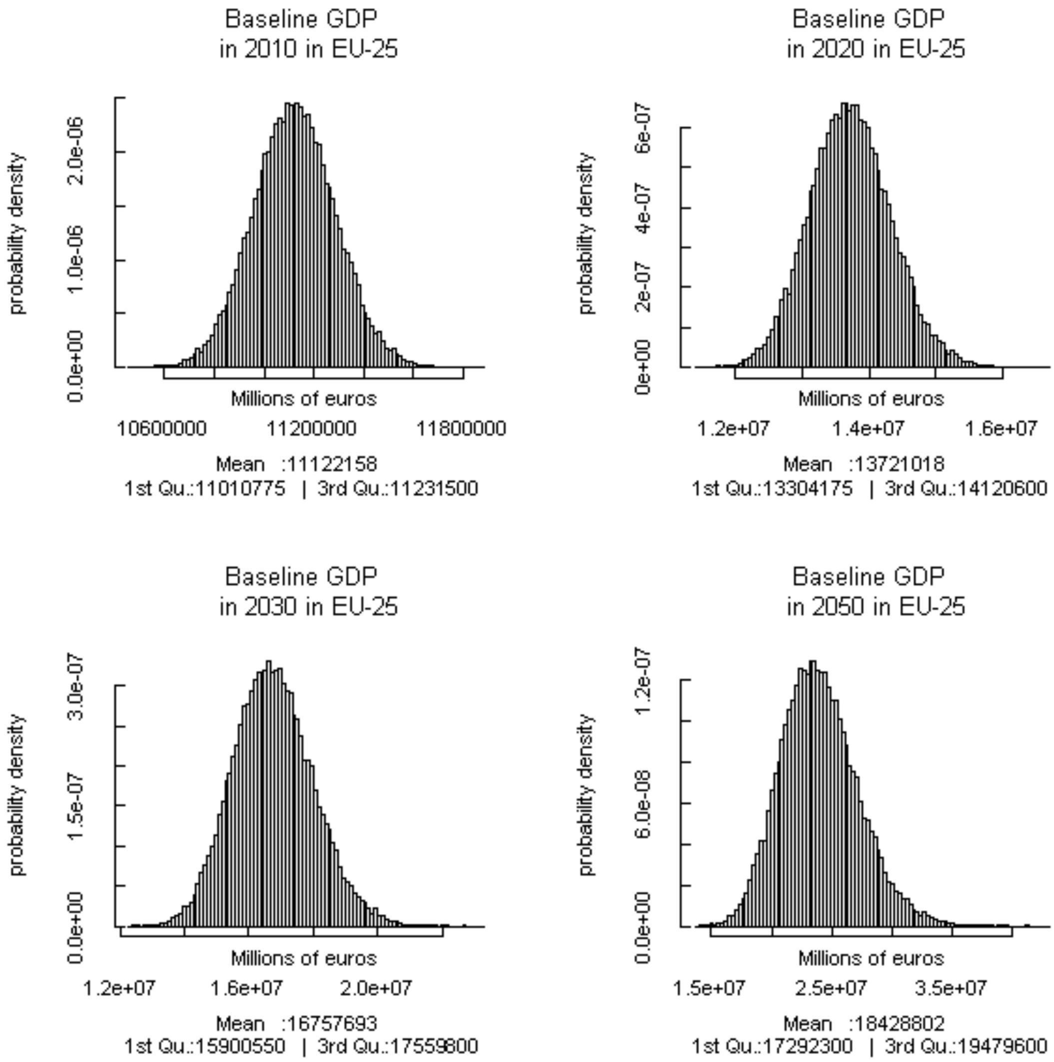

Figure 2: Probability distributions for GDP of EU-25 in 2010, 2020, 2030 and 2050, in the baseline scenario. Below each distribution, following values are shown: mean, first quartile and third quartile.

3.2. Non-energetic mineral resources

Economy parameters modelled as described in the previous section are fed into the mineral materials module. Figure 3 and Figure 4 show the baseline results for the end-point TMRminerals, i.e. used and unused domestic extraction, and imports and their indirect flows, of the module in its aggregated form (i.e. metal ores, industrial minerals and construction minerals are aggregated). The assumptions used for the input parameters are those described in chapter 2, except that the parameter trends used until 2020 have been prolonged until 2050 instead of being flattened. Only the share of services in domestic demand and exports have been kept constant after 2015 (hence, the change in the slope in Figure 3 at that date).

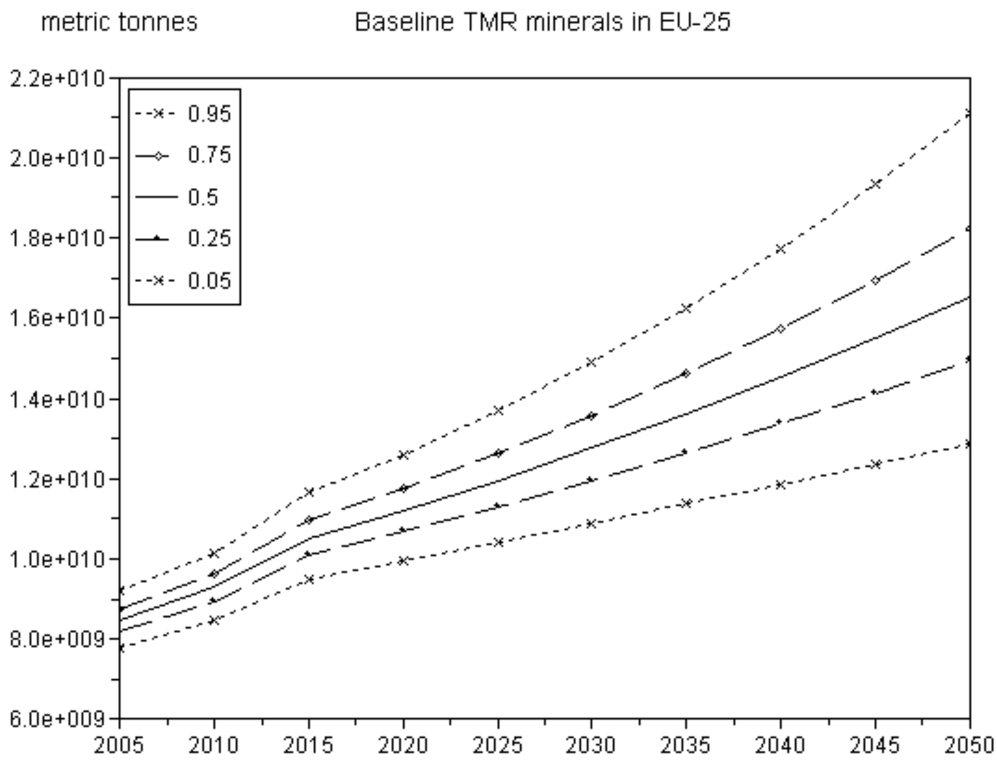

Figure 3: Modelled development of EU-25 TMR minerals in the baseline scenario. Lines represent percentiles of predictive distributions, as indicated in legend.

Here also, it is quite visible how the initial uncertainty in 2005 (90% CI represents about 15% of the mean) increases with time. This representation has consequences in terms of target setting and use for decision making. Models that do not account for uncertainty use median predictions only (the middle curve) to inform decision making. If a higher degree of confidence is required (e.g. from the policy maker side), then the curve of a higher percentile must be used.

Figure 5 shows the development of the ratio of foreign TMRminerals on domestic TMRminerals. The growing ratio shows, that under the baseline assumptions, the physical basis of European society, in terms of mineral materials, is increasingly going to be mined outside EU. As a consequence, indirect material flows induced by the EU outside its borders will also increase, in absolute values and in comparison with domestic hidden flows. Therefore, environmental burden associated with material extraction is increasingly shifted towards the rest of the world.

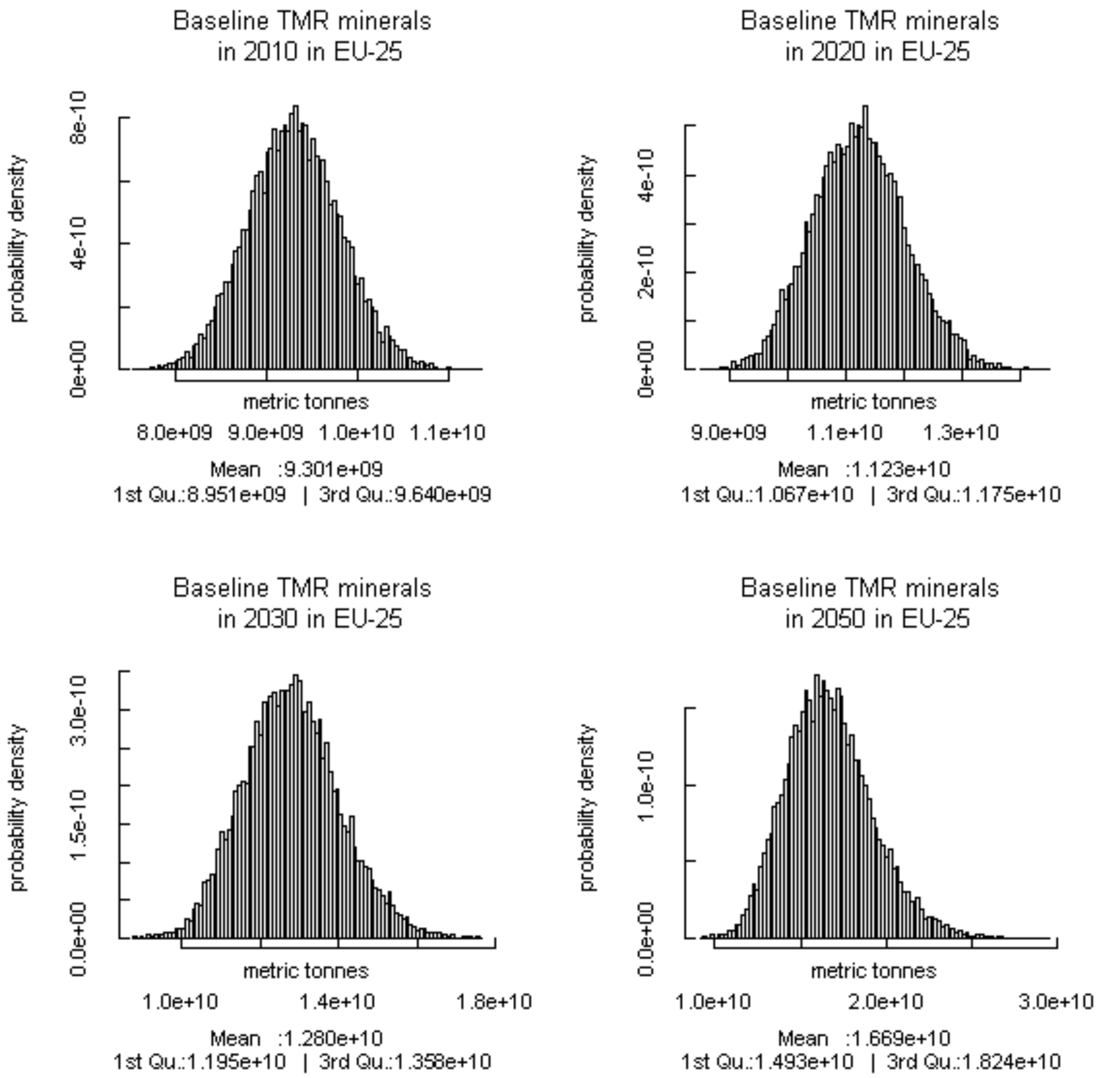

Figure 4: Probability distributions for TMR minerals of EU-25 in 2010, 2020, 2030 and 2050, in the baseline scenario. Below each distribution, following values are shown: mean, first quartile and third quartile.

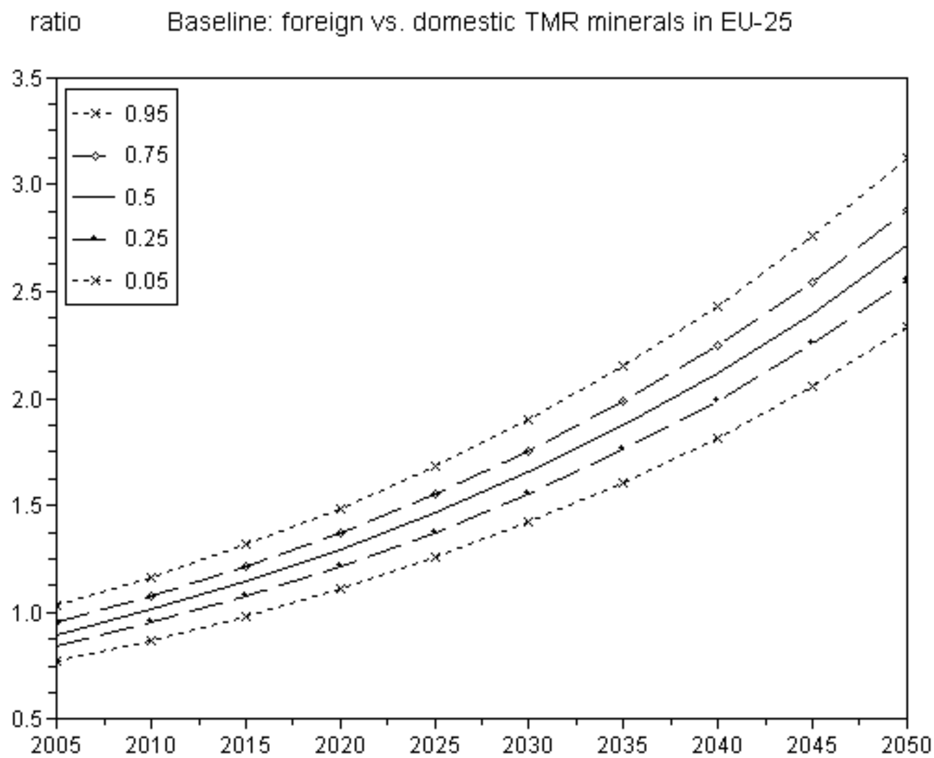

Figure 5: Modelled development of the ratio between foreign and domestic TMR minerals in EU-25 in the baseline scenario. Lines represent percentiles of predictive distributions, as indicated in legend.

4. Alternative scenarios

4.1. Targets

Table 8 shows a non-exhaustive overview of the targets that can be applied more or less directly in the modelling process to evaluate results from output in comparison with the baseline, or to infer the input values that would lead the system to develop towards the target. In practice each target should be detailed for different years that would work as milestones on the path towards sustainability. Targets can also be expressed in quantitative terms as ranges, to account for more or less challenging targets.

In the next section, the first target listed (reduce TMR by 80%) will be considered for the year 2050. The simulation-based modelling possibilities offered by the Bayesian meta-model allows to graphically look for a combination of input parameters that would work to reach the target.

Table 8: Overview of the targets to be integrated in forecast and backcast modelling

Submodels	Targets
Resource use	- Reduce TMR by 80% - Ratio (foreign TMR) / (domestic TMR) should not increase - Net import of land should not increase - Net agricultural land use per capita in Europe should not increase world average land availability
Water	Water supply and water abstraction should be balanced
Biodiversity, landscape and soils	- Overall biodiversity status: favourable - Terrestrial biodiversity status: favourable - Aquatic biodiversity status: favourable - Soil carbon: high - Soil erosion: low - Soil quality: high

4.2. Backcasting from sustainability goals

The model is simulated for different values of the input variable *share of services in domestic demand*, *share of services in exports* and *material intensity decrease in the manufacturing of goods* (besides the baseline inherent improvement in material productivity), respectively. In each case the other parameters are kept as in the baseline scenario. Figure 6, Figure 7 and Figure 8 show the modelling results, respectively.

Figure 6 shows the predictions for TMR minerals of EU-25 when demand for services equals respectively 65% to 100% (in 5% steps) of domestic demand. The first value is that of the baseline scenario. As expected, TMR decreases when the share of services increases. The predictive uncertainty tends to slightly decrease with higher values of demand for services. Similar patterns can be observed when the share of services in exports increase or the material productivity of goods production increases.

Considering for the year 2050 the target of a TMR reduced by 80% (compared e.g. to 2005 level and assuming this target applies also to TMR minerals) shown in Table 8, one can look for an adequate combination of the three drivers considered here. In 2005, TMR minerals amounted to about 8.5 billion tonnes (see Figure 3). A reduction by 80% would mean that, in 2050, TMR should amount to around 1.7 billion tonnes. Considering the mean value of TMR in that year in the baseline scenario (about 17 billion tonnes, see lower right part of Figure 4), it means that TMR should be reduced by about 15.3 billion tonnes that year.

For a first example calculation, one may assume that the three parameters whose influences are shown in Figure 6, Figure 7 and Figure 8, respectively, contribute approximately equally to the TMR reduction. It means that each should contribute to a reduction of about 5 billion tonnes TMR. The suitable values for the three parameters can be graphically determined from the plot of model results shown in Figure 6, Figure 7 and Figure 8.

Drawing, first, a horizontal line about 5 billion tonnes below the median value of the baseline scenario (first value plotted on the left of each graph) and observing where it intersects the curve of predictions, and, second, drawing a vertical line from this intersection to the horizontal axis, suggests the suitable value for each of the parameters.

Figure 9 shows the probability distributions of two alternative combinations of the three parameters. The upper graph uses the parameter values graphically determined in Figure 6, Figure 7 and Figure 8. However, it appears that the effect of the three alternative parameters combined is lower than the sum of the separate effects. It is due to the fact that increasing the share of demand for services partly off sets material productivity increases in goods production, because the latter see their share in demand decreasing. Therefore, a second, more ambitious, alternative combination of the three parameters is modelled (with a 70% increase in material productivity of goods, while the other two parameters remain as in the first combination) and this time the first quartile of the distribution equals the target, which that there are about 25% chances that, with this combination of input parameters, the mean value of TMR minerals will decrease by 80% in 2050, in comparison to 2005.

Finally, given the uncertainty in model predictions, the choice of suitable values for the three parameters depends on the degree of confidence required by decision makers. In a model using only mean or median predictions (or, equivalently, model predictions that do not account for uncertainty), there would *de facto* be 50% confidence that the criterion will be met (here the criterion was that each parameter achieves independently an absolute reduction of 5 billion tonnes TMR). If a higher degree of confidence is required, then the intersection with the curve of a higher percentile must be used to determine the target value for “demand for services” (Borsuk et al. 2003).

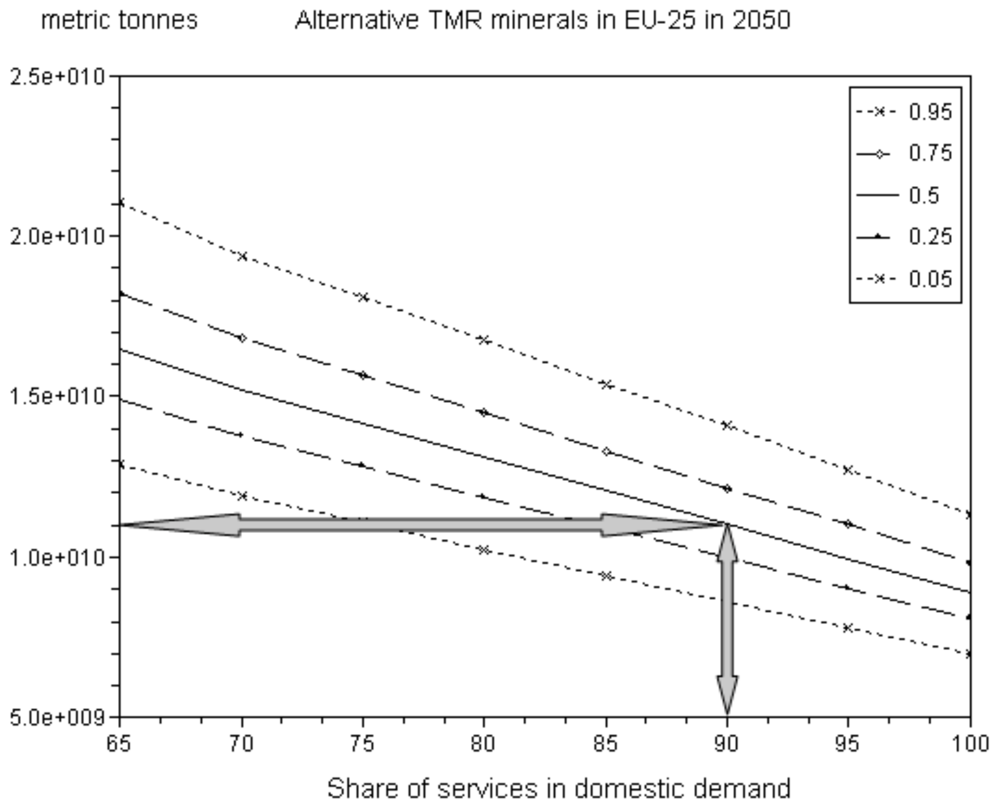

Figure 6: Predicted response of end-point module variable 'TMR minerals' to varying domestic demand for services. Lines represent percentiles of predictive distributions, as indicated in legend. Bold arrows correspond to graphical method of selecting strategies, as described in the text.

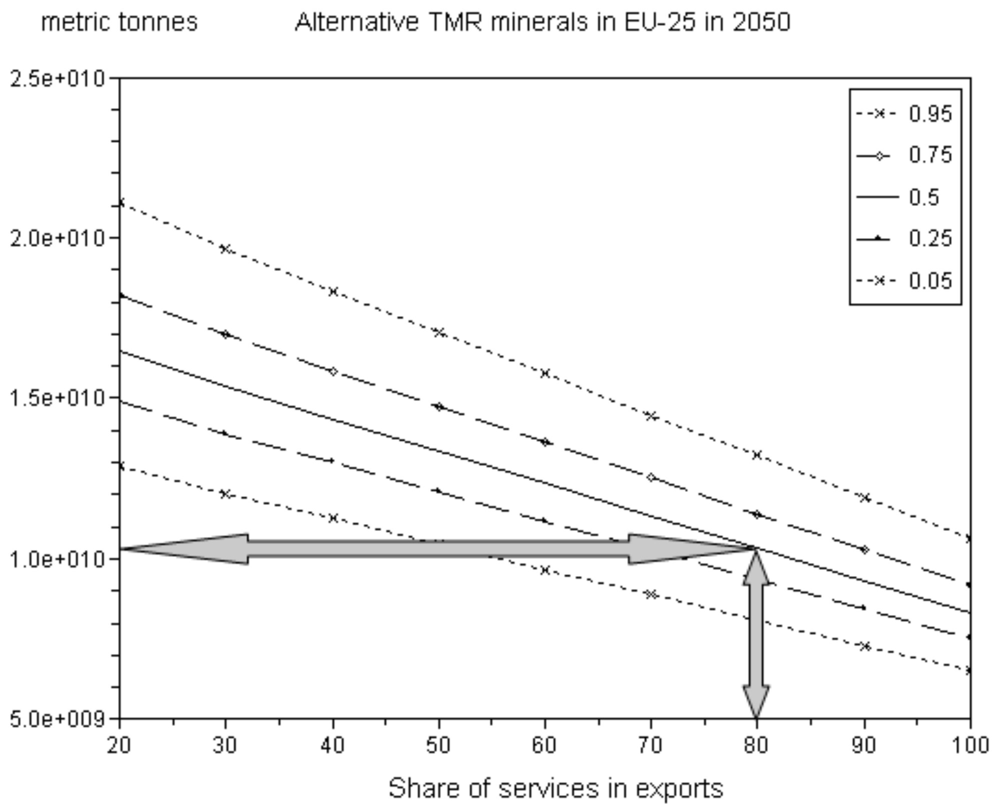

Figure 7: Predicted response of end-point module variable 'TMR minerals' to varying shares of services in exports. Lines represent percentiles of predictive distributions, as indicated in legend. Bold arrows correspond to graphical method of selecting strategies, as described in the text.

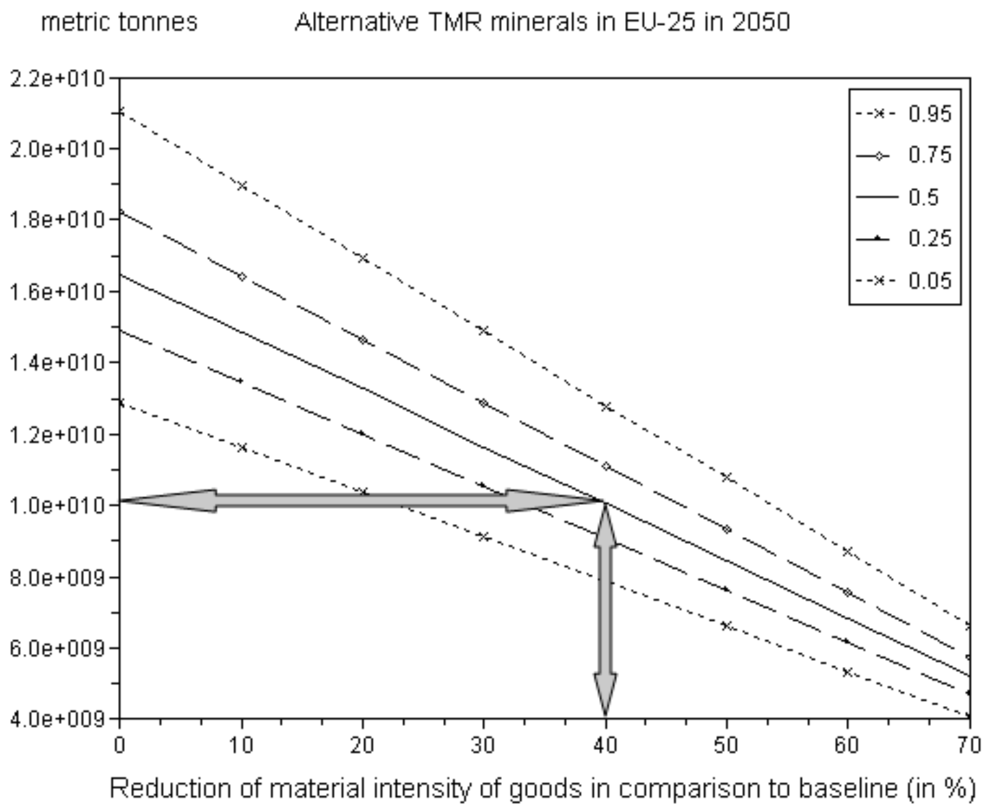

Figure 8: Predicted response of end-point module variable 'TMR minerals' to varying resource intensity of goods manufacturing. Lines represent percentiles of predictive distributions, as indicated in legend. Bold arrows correspond to graphical method of selecting strategies, as described in the text.

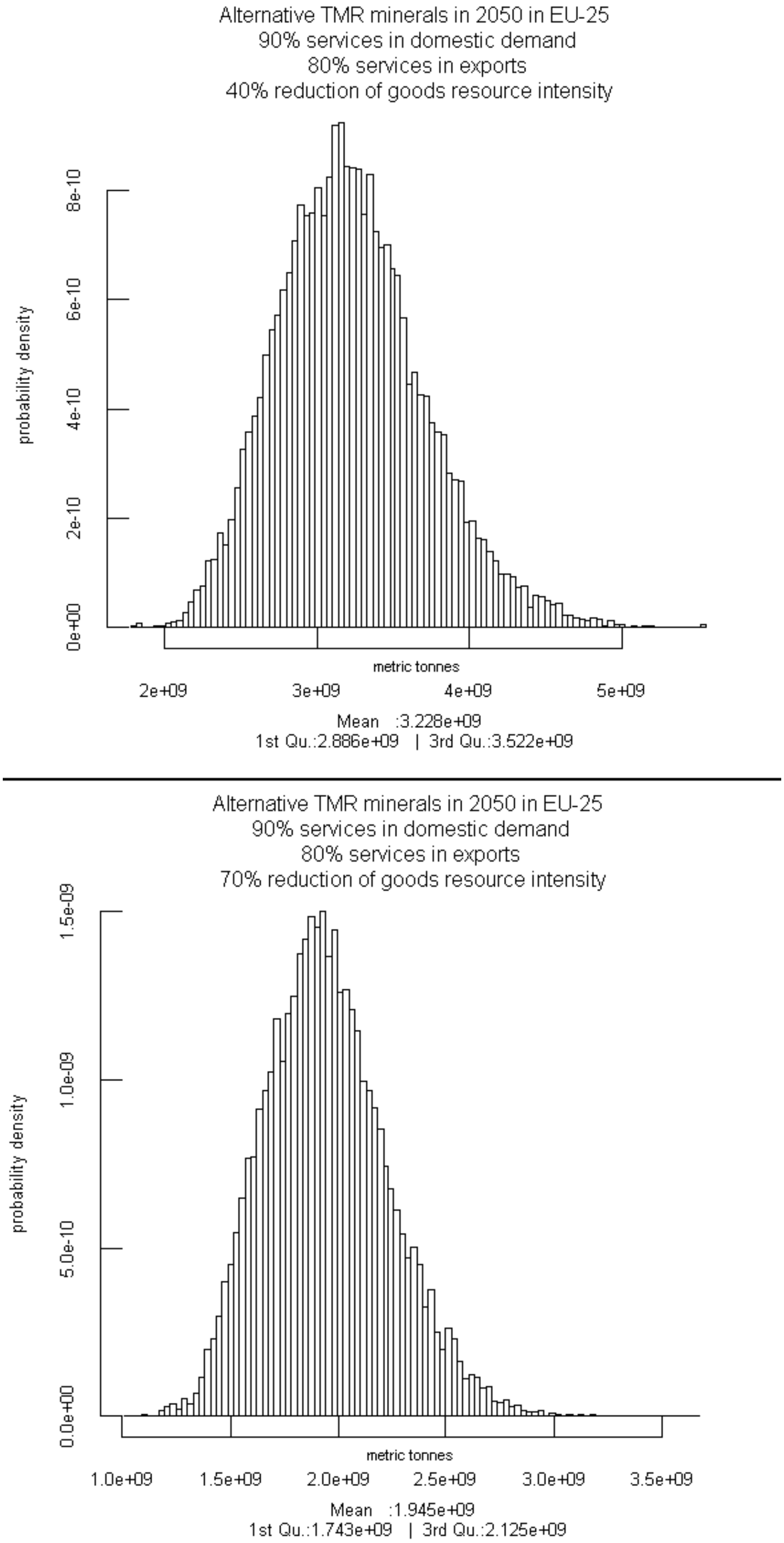

Figure 9: Modelling example: Predicted response of end-point module variable 'TMR minerals' to two slightly different combinations of strategies.

5. Interim conclusions

The FORESCENE meta-model (FMM) is still under development. First Business-as-Usual or baseline development parameters have been described for the modules “resource use and waste generation” and “land use, soils and biodiversity” as well as most of their submodules. The relations between the model parameters have been estimated with probabilities, based on either functional relations or expert judgement.

A model run of the baseline to forecast Total Material Requirement (TMR) as one of several target indicators exemplified how the FMM can quantify the probability of the outcomes. As a first example for modelling alternative scenario elements, the use of the FFM backcasting mode was shown. The first results indicate that the model can be used to search for effective combinations of key strategies to reach certain sustainability targets.

The further development of the prototype within the FORESCENE project will require the completion of the basic modules and their inclusion into a basic version of the working model. Then a systematic search can be performed for those combinations of strategies which can effectively contribute to reach a bundle of sustainability targets across the various environmental problems and activity fields covered.

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7. Annex