Assessment of Scenarios and Options towards a Resource Efficient Europe

An Analysis for the European Built Environment

Backgrounds of the project: Assessment of Scenarios and Options towards a Resource Efficient Europe

The Europe 2020 Strategy, endorsed by the European Council in June 2010, establishes resource efficiency as one of its fundamental flagship initiatives for ensuring the smart, sustainable and inclusive growth of Europe. In support of this flagship initiative, the Commission placed a contract with The Netherlands Organisation for Applied Scientific Research TNO, Leiden University - CML, PE International and Alpen Adria University – Social Ecology (AAU/SEC) for a project with the following aims. The project identified inefficient use of resources across different sectors and policy areas at the meso- and macro levels and then quantitatively assessed the potentials and socio-economic and environmental effects of efficiency improvements, both from singular as well as system-wide changes, up to the year 2030. The built environment was the focus area of this work. The core methodology applied was a hybrid modelling approach: identification of technical improvement options, their costs and improvement potentials at micro/meso level, and evaluation in a macro-model (EXIOMOD) to assess economy-wide impacts of improvement scenarios. Stakeholder engagement via workshops formed an important part of the project. The project started in January 2012 and ended early 2014.

The study is underpinned by about 10 background reports (‘Topical papers’ (TPs)). Drafts of these TPs were used to inform stakeholder meetings and get feedback on crucial elements of the scenario modelling from stakeholders.

Final report, 18 March 2014

Summary

Introduction

This report gives the result of a study commissioned by the European Commission. Its aim was to identify the potential for improving resource efficiency in the built environment. This includes assessing the economic, social and environmental effects of efficiency improvements quantitatively up to 2030, both from single technical options and more system wide changes.

The core methodology is a hybrid modelling approach: identifying technical improvement options, their costs and improvement potential at the micro/meso level, and then feeding them into a macro-model (EXIOMOD) to assess economy-wide impacts of improvement scenarios. Validation of assumptions and data via stakeholder engagement via workshops was an important part of the project.

Hot spots' for European resource use in the built environment

The first step in the study was to assess the 'hot spots' for European resource use in the built environment (chapter 2 in this report). Figure 0.1 shows Europe's Domestic Material Consumption (DMC) between 2000 and 2009. In most countries, non-metallic minerals, which consists mainly of building materials, make up 40-55% of total DMC. Figure 0.2 shows that the DMC, but also the share of non-metallic minerals varies considerably between EU member states. The countries with a relatively high use of construction materials are: Ireland, Cyprus, Spain, Austria, Portugal, Romania, Slovenia, and Finland. Driving factors behind the high use of construction materials are phases of accelerated economic growth (which are usually related to investments in infrastructure), colder climates, and lower population densities.

Figure 0.1: Material use (DMC, Mio ton, EU-27)

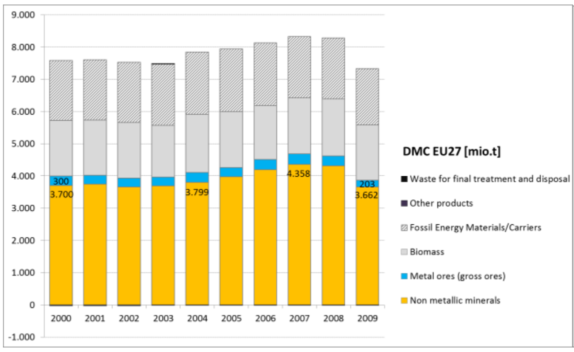
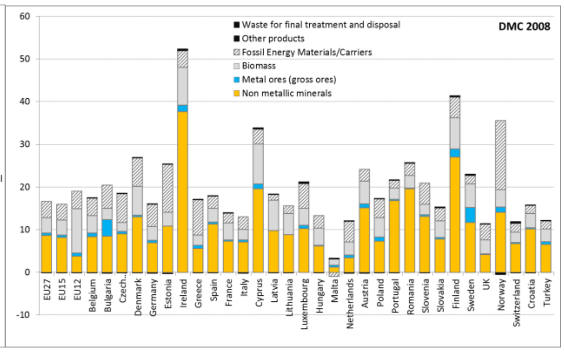


Figure 0.2: DMC per EU Member state (ton/cap, 2008)



An analysis of 'hot spots' of material use was done to analyse the residential and non-residential floor space, land coverage by buildings and infrastructure, and the use of aggregates by end use. The analysis identified the following priorities:

1. **residential buildings**, which occupy three times more floor space than non-residential buildings in the EU-27;
2. **commercial buildings**, particularly retail, wholesale and office buildings as they collectively occupy more than 50% of the total non-residential floor space and are broadly representative of other non-residential buildings, e.g. schools; and

3. **roads**, as the most significant component of non-building infrastructure, e.g. roads in England occupy more than 15 times more land than rail and slightly more land than residential and non-residential buildings combined.

For the UK building and infrastructure system a full Material Flow Analysis (MFA) was available. By expanding the MFA to a life cycle impact assessment scaled up to EU level, 'hot spots' with regard to impacts could be identified. Abiotic resource depletion is dominated by the production stage of materials whilst emission related indicators are dominated by the use stage of buildings and infrastructure. Materials like metals, cement, paint, wood products, glass and worked stone, and clay and clay products showed up as materials used in the built environment with relatively high environmental impacts.

Technical improvement options and scenarios

A list of over 100 technical improvement options related to these 'hot spots' was developed. With expert judgement and stakeholder consultation, this list was prioritised into 21 options in 10 clusters for a more detailed economic and environmental assessment. The assessment thus concerns the following technical improvement options:

1. Design for deconstruction (case focused on magnetic adhesive flooring)
2. Increase durability and service life of products (cases: paint an flooring)
3. Increase recycling of waste at end of life (cases: asphalt, concrete, PVC, float glass, carpet and plasterboard)
4. Increase renovation rate to improve energy efficiency
5. Increase use of recycled material (construction and demolition waste, stockpiled fly ash, landfill mining)
6. Intensify use of buildings
7. Reduce land used by the built environment (intensification)
8. Reduce construction waste arising
9. Select materials with low impact (timber construction instead of masonry; increasing production of low-impact building and construction products, moving from hot mix to warm mix asphalt).
10. Use construction materials more efficiently

Additionally, policy instruments were identified which could support the implementation of these options. The options and instruments were grouped and analysed in the following scenarios:

1. Baseline scenario: no additional policies, autonomous development of technical improvement options
2. Best practice uptake: an uptake rate for the different technical improvement options was assumed for the EU-27 as a whole that is equal to the country with the current highest uptake rate
3. Policy package of voluntary instruments: the modelling assumption is made that uptake rates are higher than the current EU-27 average, but lower than in the 'Mandatory' scenario.
4. Policy package of 'Mandatory' instrument: uptake rates for the different technical improvement options increase to a technically feasible maximum.
5. Environmental tax reform (ETR) a). This scenario combines the 'Voluntary' scenario with a taxation of resources to a level such that the same resource use reduction would be reached as in the 'Mandatory' scenario.
6. Environmental tax reform b). This scenario assumes a high resource tax of 35% on all primary resource extractions and imports, with the exception of food.

Simply stated, the economic and environmental impacts of these options and related policy instruments require the development of insight and founded assumptions about:

1. How technical improvement options will change inputs or outputs of an industry sector (in the current study: in most cases the building and construction sector). For instance, improved recycling will imply the building and construction industry uses less primary materials and will not use landfill or incineration services, but will spend money on recycling activities. This translates in a lower input coefficient of primary materials per unit of output. In short, such a coefficient change is a function of:
   a. The change in coefficients that would occur if a technical improvement option would have 100% implementation;
   b. The scenario-specific penetration rate of that technical improvement option
2. Additional investment costs and labour costs that are related to implementing the technical improvement option at the scenario-specific penetration rate
3. Administrative costs for companies and governments related to the scenario-specific implementation of policy instrument mixes.
4. Changes in tax levels (most notably the shift from tax from labour to resources in the ETR scenarios).

We applied two main approaches to analyse the environmental and economic impacts of technical improvement options:

a. A bottom-up approach: life cycle analyses (LCA) and life cycle costing (LCC) studies were done for each technical improvement option. On the basis of changes in physical flows calculated in the LCA per member state, the changes in costs for resource use and waste management could be estimated.
b. A top-down approach: per scenario, input parameters reflecting the information above were gathered and provided input to a dynamic computable general equilibrium (CGE) model, EXIOMOD. As an intermediate step, the coefficient changes were first implemented in the environmentally extended input output (EE IO) database around which EXIOMOD was built, and which allowed for a static analysis.

Static bottom-up and top-down analyses: cost curves

Table 0.1 shows the results of the bottom up LCA/LCC analysis in combination with the results of the static EE IO analysis. In the static EE IO analysis we used two assumptions: the penetration rates as assumed in the LCA analysis, and the exact penetration rates in the 'Mandatory' scenario also used in the dynamic analysis given below. The three columns at the right give the potential contribution to reduction of resource use at the EU-27 level by 2030 in % of the EU raw materials consumption. The bottom up LCA analysis gives around 15% reduction of the RMC, whereas the static EE IO analysis with the same penetration rates as used in the LCA gives 10% reduction. Given the fact that two fully different data sources and approaches were used, the big picture these two approaches give is in good agreement.

Some recycling options that require laborious separation processes (e.g. for float glass, PVC, and plasterboard) do not score well – they are expensive to implement and contribute only in a limited way to reduction of resource use. Landfill mining and improved renovation rates for energy efficiency also have relatively high costs. There are also some options with high potential cost savings, but that have limited impact on the reduction of material use (e.g. prolonging life of carpet and paint). The most important measures leading to large material savings are options 9.2 (increasing production of products with lower environmental impacts) and 10.1 (producing more resource efficient products), covering the full spectrum of building materials. A key conclusion that is generally agreed up by experts, is that significant life cycle material use savings are possible at no or negative costs.

Table 0.1: Cost curve data. Reduction of material use per technical improvement option in % of EU total according to the scaled up LCA results and static EE IO results, and net costs per ton material saved (negative values reflect savings).

Option code	Option name	LCC and LCA results scaled up to EU-27 level		Static EE IO results	
		Net costs per material saving (Euro/ton)	LCA: % of EU DMC	% of EU RMC at LCA penetration rates	% of EU RMC at 'Mandatory' penetration rates
01.1	Change from adhesive fixing to tactile fixing of flooring	-3883	0,00%	0,00%	0,00%
02.1	Flooring: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology	-3902	0,00%	0,00%	0,00%
02.2	Paint: Increase typical durability from 5 to 6 years	-2779	0,03%	0,01%	0,00%
03.1	Recycle asphalt back into roads instead of landfilling	-16	0,62%	0,02%	0,01%
03.2*	Recycle concrete and soil instead of landfilling	-1114	0,08%	0,94%	0,62%
03.3	Recycle PVC at end of life instead of landfill or energy recovery	176	0,03%	0,00%	0,01%
03.4	Recycle float glass at end of life instead of landfilling	2611	0,01%	0,02%	0,01%
03.5	Recycle carpet at end of life instead of landfilling	0	0,04%	0,00%	0,01%
03.6	Recycle plasterboard at end of life instead of landfilling	10435	0,01%	0,01%	0,02%
04.1	Increase rate of take-up of renovation for energy-efficiency measures	1114	0,27%	-0,12%	-0,20%
05.1*	Use recycled construction and demolition waste in road base and building fill	-12	0,85%	0,00%	0,00%
05.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	-29	0,86%	0,02%	0,02%
05.3	Mine landfills and use as a source of secondary materials and energy	24	0,30%	0,08%	0,37%
06.1	Reduce typical size of new housing (per dwelling) and offices (per occupant)	0	1,16%	1,54%	1,54%
07.1	Increase density of new housing developments	0	0,00%	0,00%	0,00%
08.1	Reduce amount of waste from construction	-320	0,58%	0,12%	0,16%
09.1	Use lightweight timber construction instead of heavyweight masonry	-545	0,40%	0,38%	0,74%
09.2	Increased production of products with lower impact, decreased production of higher impact products	0	6,09%	3,73%	7,46%
09.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt	0	0,00%	0,00%	0,00%
10.1	Produce more resource-efficient products	0	4,57%	2,80%	4,10%
	Total		16%	10%	15%

*- Option 3.2 and 5.3 were combined in the static EE IO analysis

Dynamic top-down analysis: EXIOMOD

A key drawback of the static approaches presented above is that they do not take into account several indirect effects that can radically change the final (*ex post*) outcome of each technical improvement option compared to the evaluation *ex ante*. Indeed, the reduction in the demand addressed to the textile industry of option 1.1 is on another hand a savings that will lead to cost reductions in other sectors. The price of the related products will be lower, and therefore consumers will be able to purchase them in a higher quantity. This is a typical rebound effect that increases resource use, and generally leads to less favourable resource efficiency outcomes as originally expected. Most of the options considered here are equivalent to an increase in resource productivity, which is a sort of savings for the consumer. How these savings are reused will determine the magnitude of this rebound effect. One important factor is the resource intensity of each product. Only a general equilibrium analysis based on a detailed input output database, as the one we conduct here with EXIOMOD, can account for these indirect effects.

The results of the modelling are summarized in Figure 0.3 and 0.4. There is a reduction in the total RMC of the EU-27 by 10% in the 'Mandatory' scenario. This is lower than in the static analysis shown above, due to rebound effects. The 'Voluntary' and 'Best Practice' scenarios have, as expected, lower reductions. Both ETR scenarios come to similar reductions of resource use as the 'Mandatory' scenario. However, where the 'Mandatory' scenario mainly targets the reduction of non-metallic minerals, the ETR scenarios are based on more generic policies that create e.g. a much higher reduction of e.g. fossil energy material use and hence greenhouse gas emissions.

An important finding of this study is that the 'Mandatory' scenario is a clear win-win: the EU GDP rises around 0.8% or 150 billion Euros compared to baseline. This is understandable since this scenario stimulates mainly win-win options and stimulates their maximum penetration rate. The ETR 35% scenario is the only option with a (minor) reduction in GDP compared to baseline of around 0.2%. Sensitivity analyses did not have impact on the main results.

Figure 0.3: Reduction of EU-27 RMC compared to baseline in different scenarios

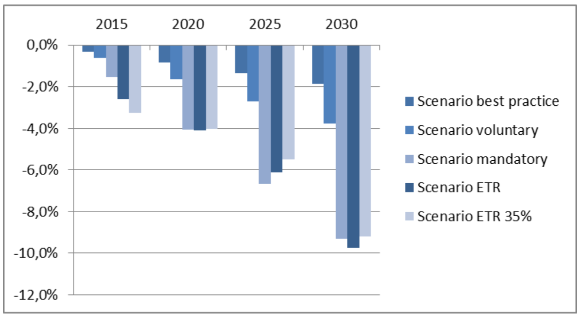
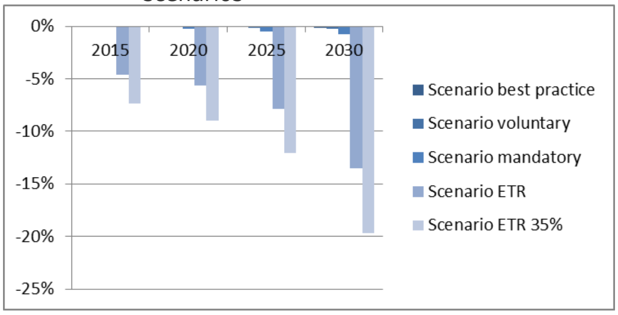


Figure 0.4: Reduction of EU-27 primary fossil energy use compared to baseline in different scenarios



Conclusions and policy implications

From this study, the following conclusions and policy implications can be derived:

1. **Significant reductions in EU-27 resource use are possible, with a positive effect on European GDP**. The current study shows that in the 'Mandatory' scenario an almost 10% reduction in resource use is possible, taking dynamic rebound effects into account. In this scenario the European GDP rises almost 150 billion Euro compared to baseline. We see in fact that many of the resource efficiency technical improvement options are win-wins. The modelling included the investment costs for technical improvement options as well as administrative costs related to policies. The modelling showed that societal benefits are higher than societal costs. The bottom-up life cycle costing in chapter 3 further suggests that in virtually all cases there is no distributional effect (i.e. benefits are for the investor), suggesting that a number of non-financial bottlenecks prevent implementation of win-win options.

2. **Resource efficiency policies need to be targeted if they are to lead to lower environmental impacts**. The 'Mandatory' scenario is very successful in reducing the use of resources, but reduces mainly the use of non-metallic minerals (over 20%, see Figure 5.8 in the main report). The reduction of fossil fuel use in the 'Mandatory' scenario is much more limited. The ETR 35% scenario, in contrast, taxes all resources (apart from food) in general. The model simulation shows in this scenario a significant reduction in the use of fossil fuels, and hence GHG emissions, as a consequence (see Figure 5.5 in the main report).

3. **Policies focusing covering high volumes of materials will have most impact.** The study covered quite different technical improvement options, ranging from across the board policies that stimulate more resource-efficient production of building and construction materials, use of building materials, and specific options like prolonging the durability of paints and flooring. Not surprisingly, this study shows that policy packages focusing on large material flows have most impact. These are
   a. Option 9.2: Increased production of products with lower impact
   b. Option 10.1:Produce more resource-efficient products / use products more efficiently
   c. Option 6.1: Reduce typical size of new housing
   d. Encouraging recycling of large flows of construction and demolition waste (option 3.2 and 5.1: Recycle concrete and soil instead of landfilling /use as road base, but probably also asphalt recycling (3.1)
   e. Option 8.1: Reduce the amount of waste from construction

   Note these options do not essentially target a priori existing infrastructure and buildings or new infrastructure and buildings. While this finding seems an open door, it shows very clearly that focusing policy attention on generic systems for e.g. EPDs, environmental performance rating of building and infrastructure works as a whole, is more effective as paying similar attention to e.g. the recycling of small flows of building and construction materials. Particularly recycling of small flows of materials that need a lot of manual labour to be collected, such as float glass and plaster board, may not be cost-effective.

4. **Mandatory instruments or an effective level of Environmental Tax Reform is required to have the highest reductions of resource use.** In the current analysis, mandatory instruments and financial instruments appeared to have the largest resource efficiency impacts. We see that the penetration rates of technical improvement options simply are much larger in the 'Mandatory' scenario which ensures that options with high resource efficiency improvements (recycling, intensification of use of buildings, stimulating use of more resource-efficient construction materials) will be implemented. An ETR focusing on building and construction materials also will result in more efficient resource use, but will result in a different mix of resources of which the use is reduced – the ETR scenarios give a relatively high reduction of fossil energy materials and hence CO_2 emissions, but relatively less reductions of the use of non-metallic minerals. It further has to be noted that the place in the value chain where the environmental tax is levied has specific advantages and disadvantages. In our modelling approach the tax was levied on domestically extracted and imported materials. This is transparent and relatively easy to implement. The disadvantage is that intermediate and final products made with these materials will become more expensive, and hence face higher competition of the corresponding imported intermediate and final products, made in countries with lower resource taxes. A tax on products for final consumption that is based on embodied resource use in these products avoids this problem. At the same time, calculating embodied resource use will introduce uncertainties and hence is likely to be contested too. There are in essence two ways to build upon this finding:

   a. Taxation and hence ETR is the mandate of EU member states. The EU however could do additional studies and embark on policy dialogues with member states to stimulate ETR.
   b. The EU itself could develop, within its mandate, more mandatory instruments that complement the largely voluntary instruments such as ecodesign, GPP, certification of buildings, etc.

5. **Standardization and certification play a major role in any policy package**. In a way it is a bit surprising that the current study found the availability of significant win-win options, which are not yet implemented. This suggests that non-financial bottlenecks exist that hinder implementation of technical improvement options. For instance, while the use of recycled materials may be cheaper, at this stage the performance characteristics of products made of recycled materials may not be tested as well as for products of primary materials. Hence in all policy packages, information about the environmental performance of materials, the quality of recyclates, and the environmental performance of buildings and infrastructure as a whole is highly relevant. This clearly calls for attention to standardization and certification in any policy package.

6. **The long life of buildings and infrastructure poses limits with regard to resource efficiency improvements on the short term**. Buildings and infrastructure have a very long life time, often of 100 years or more. The modelling in this study was done for a time horizon of 2030. As indicated above, 'greening' expenditure on building and construction materials now already gives significant environmental benefits, while over time constructing infrastructure that is more sustainable will lead to a sustainable infrastructure stock. We did further a qualitative scenario analysis was done (see TP6) that showed that the following technical improvement options are relevant, even though they only have impact on the long term
   a. Design for repair, disassembly and recycling (particularly of buildings of buildings as a whole)
   b. Ensuring a high adaptability/flexibility/functionality of design so that the building and infrastructure can have a long service life regardless of future developments.

   The policy packages proposed in this report provide in principle no conflict with policies stimulating such long-term technical improvement options. There is however always a danger that policies will focus on the short-term wins. Furthermore, if minimum environmental or technical performance criteria in administrative or informative instruments focus too much on means rather than goals, lock-ins may occur that prevent these options from being stimulated.

Table of Contents

1 Introduction

This report summarizes the results of the project 'Assessment of Scenarios and Options towards a Resource Efficient Europe'.

A baseline analysis of the resource implications of resource use in construction in Europe was established. This allowed the identification of a range of technical improvement options and accompanying policies. Modelling was then carried out of the economic, social and environmental impacts of those policy options in the form of five scenarios. One scenario assumes the maximum implementation of technological options. Two scenarios use less optimistic assumptions. Finally, additional scenarios are presented that mainly model the effects of an Environmental Tax Reform (ETR) for resources. This report summarises that analysis, and pulls it together to identify policy implications.

The project concentrates on resource efficiency in the built environment. Within built environment, it focuses on:

- Residential buildings (existing and new), with however a restricted use phase. The project includes water and heating energy. Appliances, furniture etc. are excluded since that would bring in all products an expenditure in, and expand the scope to cover 'use' that is largely unrelated to the building itself;
- Utility buildings, including offices and retail buildings (50% of the floor space), extrapolated to similar buildings such as schools, hotels and hospitals. No special attention is given to industrial buildings since this is less than 10% of utility buildings stock and very diverse;
- Infrastructure. By far dominant is road infrastructure and transport, so that only this type of infrastructure will be included.

A baseline scenario and improvement scenarios have been quantitatively modelled, with regards to economic and environmental and resource impacts: all environmental and resource impacts normally covered by life cycle assessment (LCA) have been included. The analysis looks at cradle-to-grave, economy-wide impacts and where possible and relevant, differentiated by member state, for example for 'restricted use phase' the structure of housing stock, climate zone etc. The modelling has been done to a time horizon of 2030.

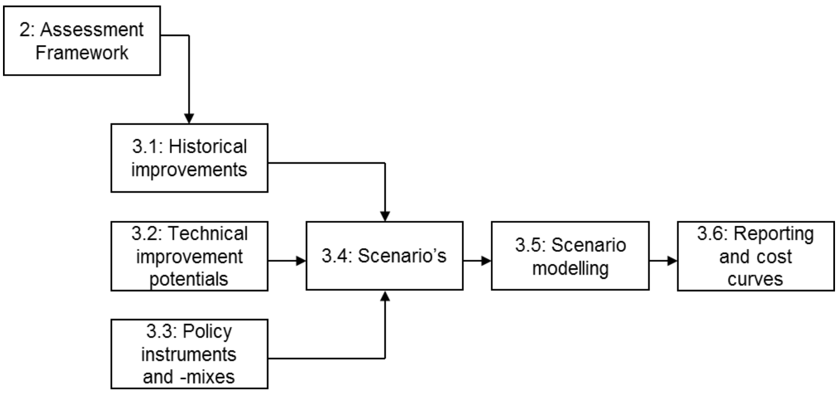
The overall structure of the project is given in Figure 1.1. The essence of the project is a hybrid modelling approach in which bottom-up life cycle costing (LCC) and LCA are fed into a macro-economic model which then calculates economy-wide economic and environmental effects for Europe. The detailed underpinning of the study is done in around 10 background reports made for the study, called 'Topical papers' (TPs). Drafts of these TPs were used to inform stakeholder meetings and get feedback on crucial elements of the scenario modelling from stakeholders. The TPs include:

- Topical paper 1 (related to Task 3.1) analyses historical improvements of resource efficiency and informs the baseline scenario, i.e. the improvements that can be expected if historical trends are extrapolated.
- Topical paper 2 gives a long list of technical improvement options and Topical paper 4 gives prioritized options for the technical improvement potentials based on life cycle assessment (LCA) and life cycle costing (LCC). These two papers (related to Task 3.2) provide detailed input into the improvement scenarios and the macro-economic and environmental modelling.
- Topical paper 5 (related to Task 3.3) analyses which policy instruments and -mixes can support the improvement scenarios. Administrative costs of the application of

such instruments are calculated, which are themselves input into the macro-economic and environmental modelling.
- Topical paper 3 discusses the baseline scenario and modelling approach.
- Topical paper 6 (related to task 3.4) discusses how technical improvement options (from TP4) and policy instruments (from TP5) were combined to define the scenarios. The Topical paper also translates scenarios into input parameters in the modelling, such as changes in input/output coefficients, investment costs, or administrative costs for specific actors.
- Topical paper 7 (related to task 3.5) presents the results of the simulation of the five policy scenarios.
- This summary report (related to Task 3.6) integrates all results and provides policy implications1.

Using the reports listed above, we review first in chapter 2 European resource use in relation to the built environment. We then review in chapter 3 the selected technical improvement options and related policies and combine them to scenarios. In chapter 4 we present the outcome of the bottom-up life cycle costing and life cycle assessments of the technical improvement options, also in the form of cost curves. In chapter 5 we describe how this information was fed into macro-economic modelling with EXIOMOD, and give the results of this macro-economic analysis. We then use this in chapter 6 to analyse the policy implications. Chapter 6 forms the summary and conclusions and gives recommendations for further research[2].Various annexes show the underlying data and inputs to the model, which are explained in more detail in the Topical papers underlying this study.

Figure 1.1: Main steps in the project



[1] Further two stand-alone Topical papers were produced that did not feed directly into this final report: Topical paper 9 on resource efficiency in the aluminum industry and Topical paper 10 on indicators for resource efficiency.
[2] Almost inevitably, chapter 2 and 3 summarize and in part repeat results of earlier Topical papers, particularly TP6 and 7.

2 European resource use and the built environment

2.1 Introduction

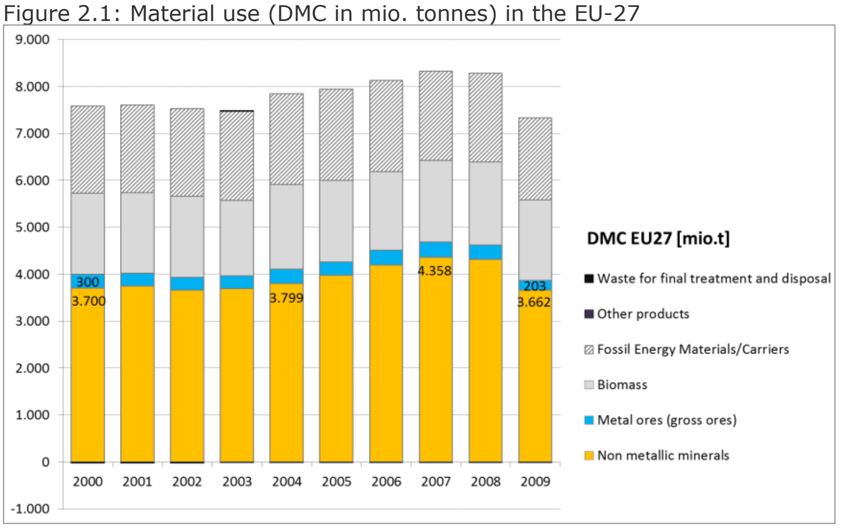
In this chapter the use of resources in the EU-27 is reviewed (section 2.2). Section 2.3 provides an attempt to identify the 'hot spots' of this resource use and related environmental impacts in the built environment. This hot spot analysis aims to identify in which areas of built environment (residential buildings, utility buildings and infrastructure) technical improvement options can most contribute to reduction of resource use and environmental impacts, supporting the selection of technical improvement options in chapter 3.

2.2 Resource use in the EU-27

The most important source of data on European material use is the economy-wide Material Flow Accounting (ew-MFA) data set from Eurostat. This data set lists at the level of EU member states the Domestic Extraction (DE), and calculates the Domestic Material Consumption (DMC) by adding the mass of imports and subtracting the mass of exports from the DE. As far as possible, this or similar data is also used in Environmentally Extended Input Output (EE IO) databases that give more sector detail, most notably the EXIOBASE database underlying the EXIOMOD CGE model.

Figure 2.1 shows that total DMC in the EU-27 was 8 billion tonnes in 2009 and only slightly less in 2000. Non-metallic minerals (mostly bulk materials such as sand, gravel, limestone etc., which are used for construction purposes) make up 50% of total material use. The other 50% are composed of 23% biomass, 24% fossil energy carriers, and 3% ores. In per capita terms, the EU-27 used 15 tonnes of materials in 2009, compared to 16 t/cap in 2000. Imports and exports are relatively important for biomass, fossil energy carriers and metal ores. Imports and exports of non-metallic minerals, which are comprised almost fully of building and construction minerals, are however only around 8% of the EU-27 use of these materials. With regard to fossil energy carriers, mining, quarrying and construction activities only use a minor share, i.e., 1% and 2% respectively, whereas energy use for residential purposes is around 25% of the total EU energy use. The energy use in the use phase of buildings is on the contrary high, some 25% of the EU energy use (for purposes like space and water heating (major share), lighting, air conditioning, refrigeration, and electronics).

Figure 2.1: Material use (DMC in mio. tonnes) in the EU-27



The resource intensity of individual EU member states can deviate significantly from the EU-27 average, suggesting potential for spreading best practices. This is exemplified by Figure 2.2 which gives the DMC in ton/cap for 2008 for individual member states.

Figure 2.2: DMC for the single European Countries, 2008 in t/cap

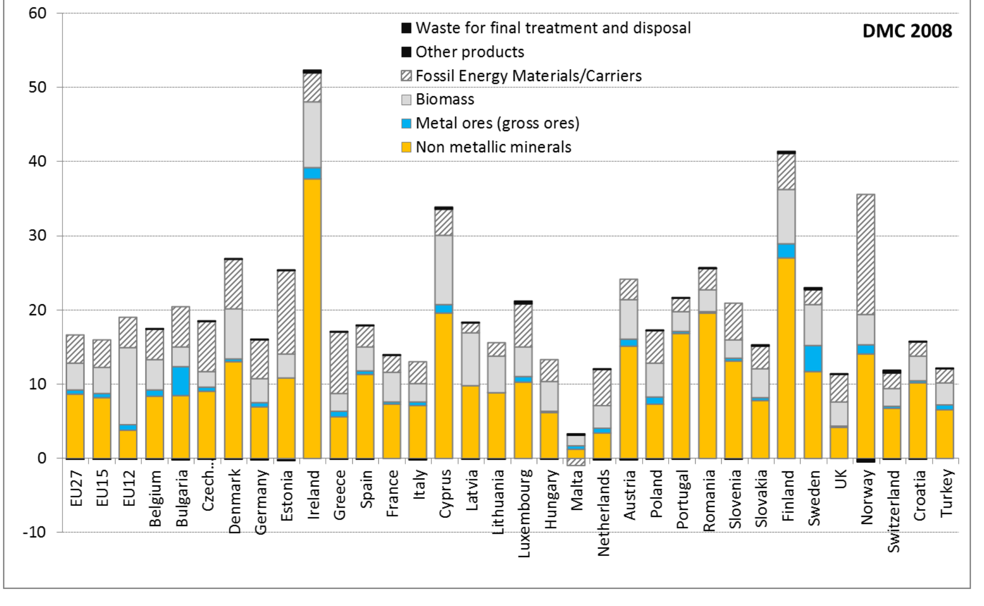
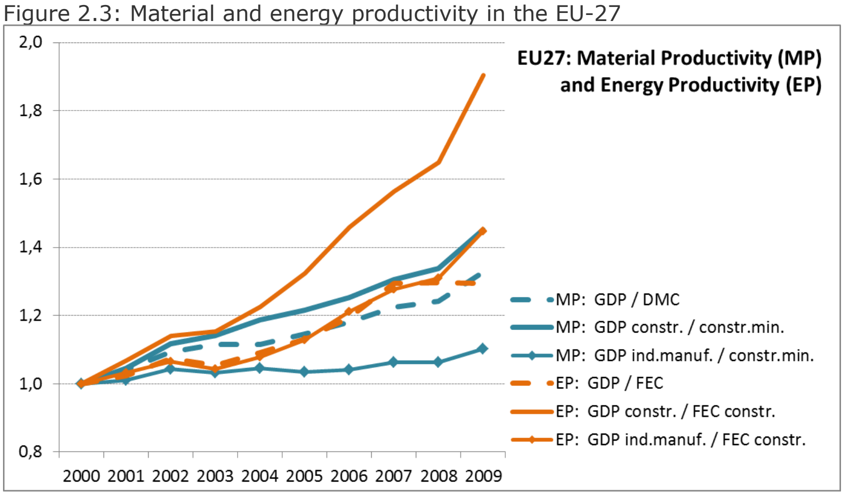


Figure 2.3 shows that material productivity, measured in GDP/DMC[3], has grown from 2000 to 2009 by 30%. If we consider material use to the construction sector, we can define the construction sector rather narrowly, i.e. the NACE construction sector, or broadly, i.e. all industrial sectors potentially related to construction activities. The latter comprises the sectors industry (incl. construction) and manufacturing. Material productivity in relation to the narrow construction sector (measured as GDP in the construction sector / DMC construction minerals) grew faster, by 45%.

[3] DMC in metric tonnes, GDP in PPS (Purchasing Power Standard)

Figure 2.3: Material and energy productivity in the EU-27



Legend:
MP = GDP/DMC, EP = GDP/FEC
GDP in million PPS (Purchasing Power Standard; Eurostat 2012)

2.3 Resource use in the built environment

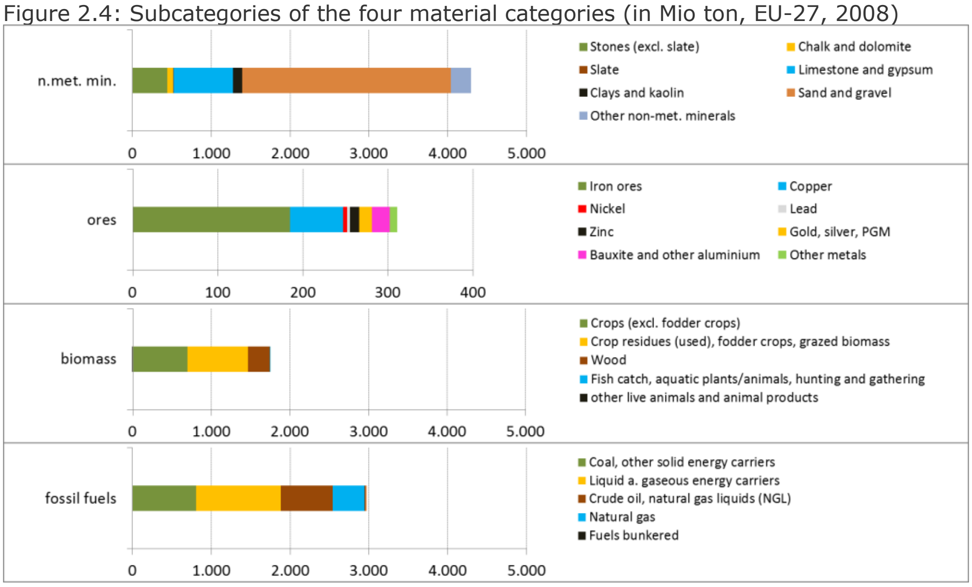
2.3.1 Resource use related to buildings and infrastructure

A more specific analysis of the four broad MFA material categories allows identifying which materials are relevant for buildings and infrastructure (see Figure 2.4).

- Non-metallic minerals: almost all materials in this category are used for construction;
- Metals: iron ores and copper make up 80% of the use of metal ores. An analysis done in one of the background reports (Topical paper 1) showed that 12-15% of these metals are directly used in the construction sector;
- Biomass: we see here that crops and crop residues are dominant, with wood, which is only partially used in the built environment, a minor material flow;
- Fossil energy materials: the former section already indicated that particularly the use stage of buildings and infrastructure are relevant here, with some 25-50% of the total use of energy materials in Europe.

Overall, this initial analysis shows that buildings and infrastructure form one of the most resource-intensive sectors in the economy, using 50% or more of the DMC. Particularly the use of non-metallic minerals and energy is relevant. The next sections zoom deeper into the building and infrastructure sector to identify ‘hot spots’ for which resource efficiency policies will have most impact.

Figure 2.4: Subcategories of the four material categories (in Mio ton, EU-27, 2008)

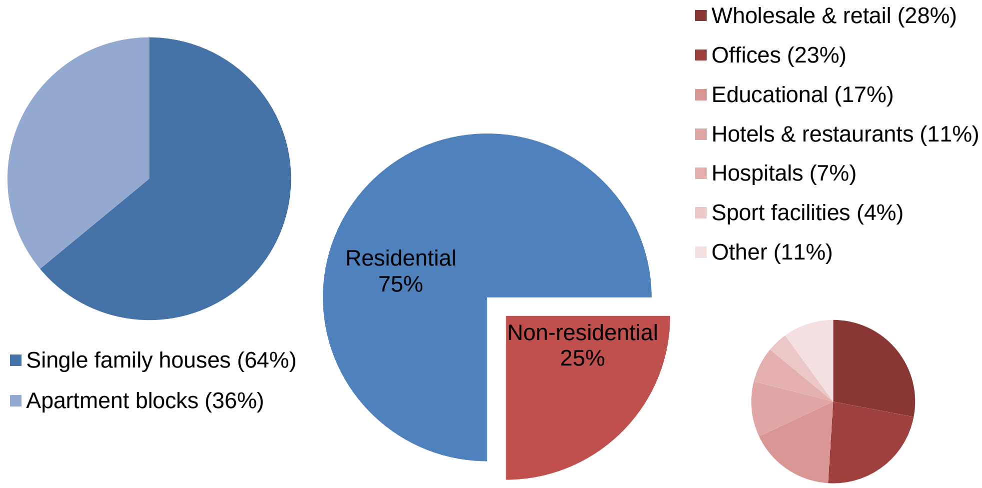


2.3.2 Priority sub-sectors in the built environment

The built environment usually is sub-divided into residential buildings, utility buildings, and other infrastructure. The following section uses additional statistics to identify the relative importance of each of these categories and the most important sub-sectors within these categories.

In the year 2000, the EU-27 had a population of 483 million and a stock of approximately 200 million dwellings.[4] In 2011, the EU-27 had approximately 24 billion m^2 of useable floor space (BPIE, 2011, p. 27), excluding floor space for specialist utility buildings. Of this, 75% was residential and 25% was non-residential (p. 30). As can be seen in Figure 2.5, single-family houses (detached, semi-detached and terraced) dominate the residential market while wholesale, retail and office space collectively dominate the non-residential market.

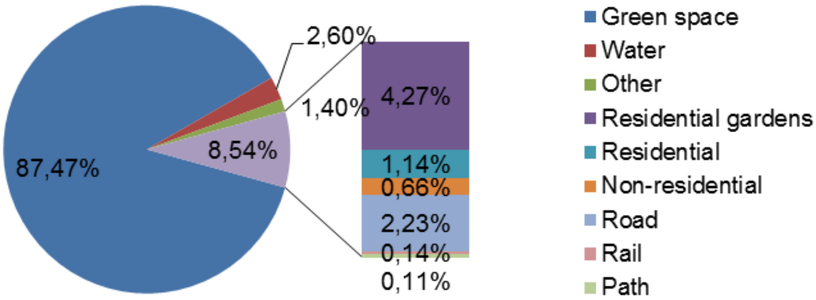
Figure 2.5: Residential and non-residential floor space in the EU-27 in 2011 (BPIE, 2011)



[4] The exact number of dwellings is difficult to estimate as member states treat vacant and secondary dwellings differently. This figure was calculated based upon tables 1.1 and 3.3 of Dol and Haffner (2010).

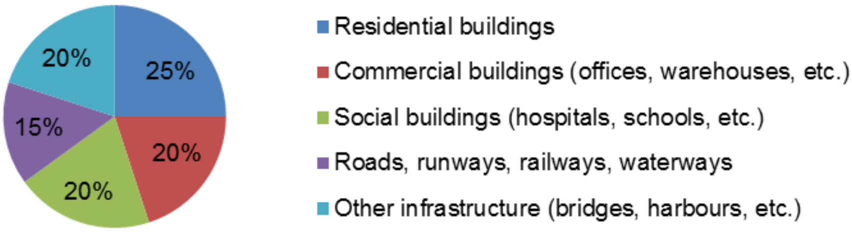
Figure 2.5 excludes roads, railways and other infrastructure. As different statistics are collected for buildings than for other infrastructure, it is difficult to present them alongside one another. One metric that can be used is total land coverage. Due to differences in reporting within Europe, England has been used as an example in Figure 2.6 below. This chart highlights that roads occupy slightly more land than all buildings combined (when residential gardens are excluded) while rail and footpaths occupy relatively little land.

Figure 2.6: Land use by type in England in 2005 (ONS, 2007)



Another metric for examining the significance of infrastructure is the share of building products used. Construction aggregates (i.e. crushed stone, sand and gravel) are materials used in virtually all parts of the built environment. As can be seen in Figure 2.7, buildings collectively account for 65% of European consumption of aggregates while other infrastructure (roads, bridges, etc.) collectively account for 35%. It is important to recognise, however, that aggregates are one of the main materials which make up roads, bridges, etc. whereas many other materials (e.g. wood, glass and plastics) are also used in the construction of buildings.

Figure 2.7: Share of construction aggregates by end use (UEPG, 2011, p. 7)



Based upon this review, priorities for this project were the following three sub-sectors of the built environment:

1. **Residential buildings**, which occupy three times more floor space than non-residential buildings in the EU-27 (Figure 2.5);
2. **Commercial buildings**, particularly retail, wholesale and office buildings as they collectively occupy more than 50% of the total non-residential floor space (Figure 2.5) and are broadly representative of other non-residential buildings, e.g. schools; and
3. **Roads**, as the most significant example of other infrastructure, e.g. roads in England occupy more than 15 times the land of rail and slightly more land than residential and non-residential buildings combined (excluding residential gardens; see Figure 2.6).

2.3.3 Hot spot assessment with LCA

To get more detailed insight into hot spots in the built environment, the current study created an LCA model for the UK's built environment in a single year[5]. Detailed data on consumption of building products were obtained from a material flow analysis (MFA) for the UK construction industry conducted by Viridis (Smith, Kersey, & Griffiths, 2003). Although the material flow analysis was from 1998, it was scaled up to 2008 using construction and use data from that year. For each stage in the life cycle of each material in the MFA, life cycle assessment data were added, which allowed to analyse which stages in the life cycle and which materials are most relevant. (2008)[6].

Figure 2.8 presents the impacts by indicator and life cycle stage. The use stage contributes more than 50% to all indicators. The exception is an indicator for resource depletion, formally called Abiotic Depletion Potential (ADP). Here the material production stage is the largest contributor. We further see that the construction stage itself has very limited environmental impacts.

Figure 2.8: Division of environmental impacts per annum by life cycle stage across the UK's built environment

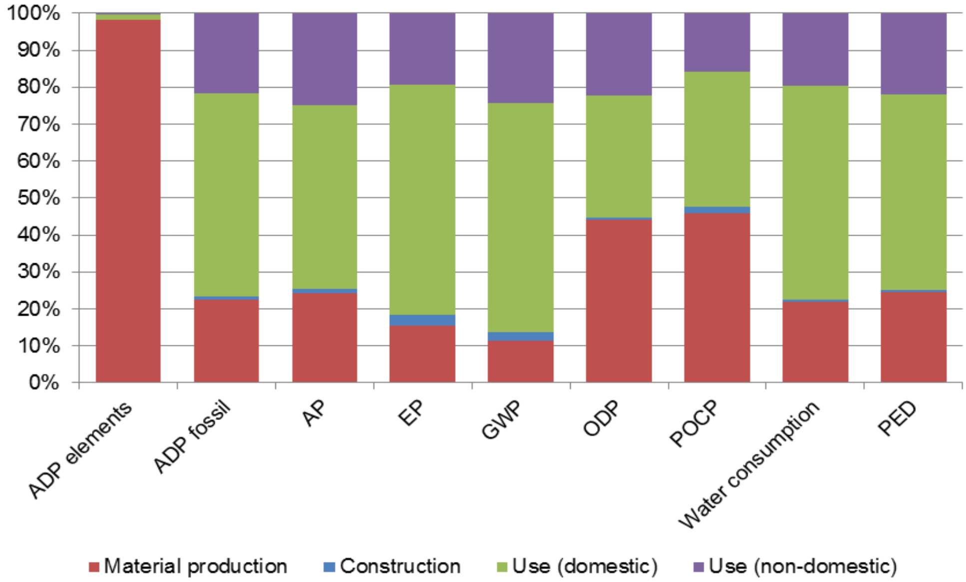


Figure 2.9 shows further which materials used in the built environment have high life cycle impacts:

1. Cement and concrete products score high on almost all indicators
2. Metals, particularly copper, score high on the LCA indicator for resource depletion (Abiotic Depletion Potential).
3. Wood products score relatively high on land use occupation.
4. Bituminous materials have seemingly a high impact. However, since bitumen itself is a waste product that otherwise would be discarded, this high score is less relevant
5. Paints and fillers have a reasonably significant contribution on all indicators.
6. Glass and worked stone contribute significantly to acidification and eutrophication potential, but have less impact elsewhere.

[5] The UK was selected for this case study purely due to the existence of a detailed material flow analysis. Unfortunately, a similar level of detail could not be found for Europe as a whole.

[6] The Viridis study was for 1998, but the construction and use data are from 2000 to 2008. While the Viridis data is for the built environment as a whole, the use data only includes residential and commercial buildings. Specialist utility buildings such as power stations have been excluded as they are outside the scope of this study. The significance of this slight difference in boundary is expected to be low as there are relatively few of these buildings.

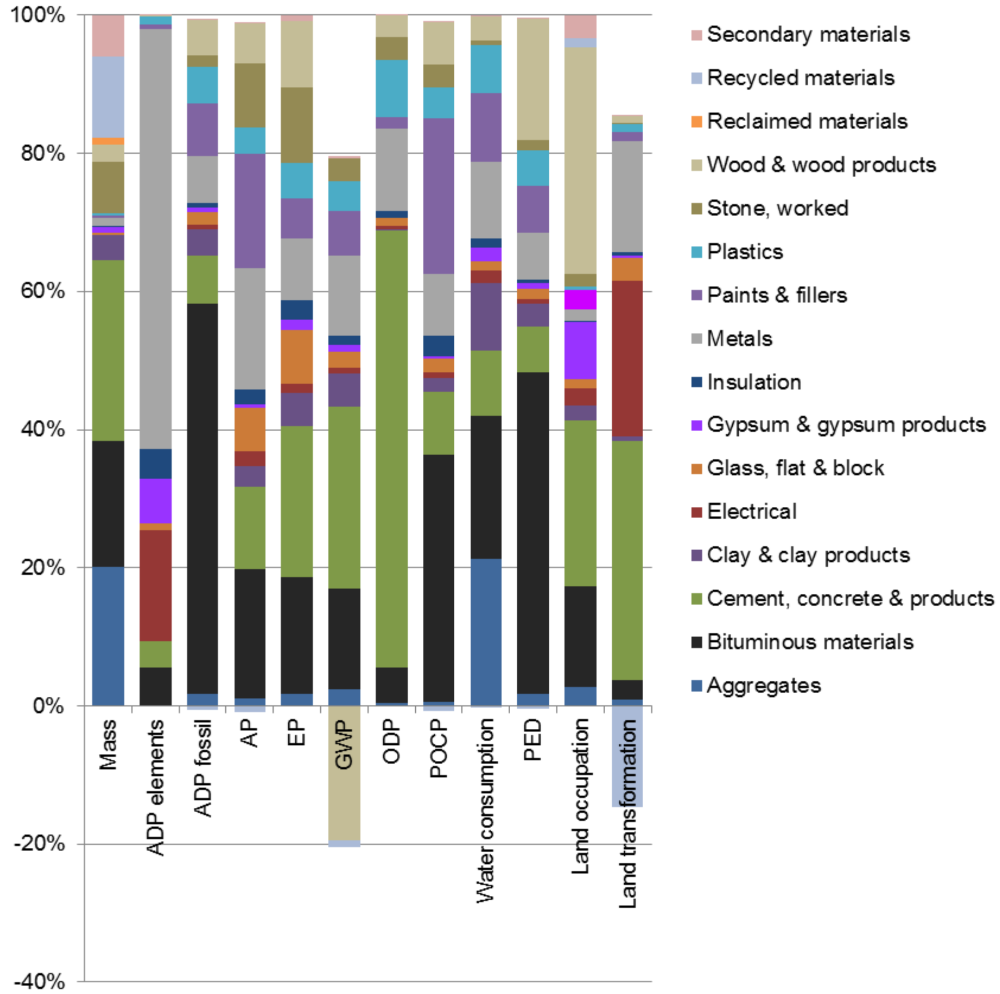
7. Plaster, clay and clay products and insulation have relatively modest contributions to impacts.

2.3.4 Conclusions

This chapter reviewed current resource use of the EU-27 and the relevance of the built environment in it. The EU has a DMC of around 8 billion tonnes annually. Buildings and infrastructure are responsible for a large part of this material use, particularly of non-metallic minerals and fossil energy materials. Significant environmental impacts are related to this material and energy use. We see further a high difference of material intensity across EU countries, suggesting the opportunity for spreading best practices.

The LCA analysis of the UK building and infrastructure system further indicated that abiotic resource depletion is dominated by the production stage of materials, while the use stage of buildings dominates emission related indicators. Materials like cement, metals (copper and steel), wood products, paints and glass showed up as materials with relatively high life cycle impacts.

Figure 2.9: Environmental impacts associated with the consumption of construction products within the UK's built environment (construction data for 2008 that were used to extrapolate a detailed material flow analysis from 1998)



3 Technical improvement options, related policies and scenarios

3.1 Introduction

In the project a long list of potential technical improvement options was generated, related to the 'hot spots' identified in chapter 2. These were then prioritized on the basis of potential resource efficiency impacts via expert judgment; the priority list was validated in a stakeholder workshop[7]. As will be elaborated in chapter 4, for the prioritized options a life cycle cost (LCC) assessment and a life cycle assessment (LCA) were performed and scaled up to the level of the EU-27.

Policy mixes were then identified that could stimulate implementation of these technical improvement options, including the administrative costs for governments and companies[8]. We present these technical improvement options and the policies that might accompany them in the next two sections. After this, we describe how the technical improvement options, policies and related expected penetration rates of technical improvement options were combined to define scenarios.

3.2 Technical improvement options

A list of over 100 technical improvement options related to the 'hot spots' identified in chapter 2 was developed, and prioritized on likely economy wide resource efficiency improvements by a number of experts in the study team. In a stakeholder workshop, this prioritization was validated (and where necessary adapted) on the basis of stakeholder input. This prioritization process resulted in 10 clusters of technical improvement options for which detailed environmental and economic data have been gathered, presented below. An important issue in the selection process was that the quantitative analysis of the study was done with a time horizon of 2030, whereas building and infrastructure often have a much longer lifetime. Various measures that only have an impact much later, such as design for deconstruction of whole buildings, were hence not considered – the resource efficiency impacts of such measures could only become visible with a time horizon as long as the end of this century.

1. Design for deconstruction: adhesive flooring
This technical improvement option is based on a change from adhesive fixing (e.g. using types of glue) to tactile fixing of flooring. It will allow for faster, more flexible and more extensive reuse of carpets. It requires limited changes from the construction sector, whereas carpet producers need not make major changes to their product.

2. Increase durability and service life: durable paint and flooring
This technical improvement option is based on an extension of the average service life of paint and carpet flooring. The durability change of carpets is assumed to be from 7 to 9 years. This is done through reducing pile depth and fibre technology. The durability change of paints is assumed to be from 5 to 6 years. This can be achieved by changing the composition of the paint, anticipating different expectations from final users.

[7] See Topical paper 2.
[8] See Topical paper 5.

3. Increased recycling of waste: increase in recycling share of asphalt, concrete, soil, PVC, float glass, carpet and plasterboard

This technical improvement option is based on a focused intensification of recycling efforts. It relates to the following materials and/ or applications: asphalt back into roads instead of landfilling, concrete and soil recycling instead of landfilling, PVC recycling at end of life instead of energy recovery, as well as float glass, carpets, and plasterboard recycling at end of life.

4. Increased renovation rate: energy efficiency improvements

There is already an assumed renovation of the existing stock, which, as shown by the IMPRO-Building study, will result in reductions in operational energy consumption (Nemry, et al., 2008). The purpose of this technical improvement option is to consider the effects of a renovation rate higher than that required by current policy. Unlike other technical improvement options considered in this study, this option directly effects energy consumption during use of the building.

5. Increased use of recycled material: increase in amount of waste used in construction process

This option complements the technical improvement options mentioned under point 3) an forms a means to boost the reuse of specific and typical construction waste. The aim is obviously to stimulate recycling options that have environmental benefits over the life cycle, rather than stimulating recycling content per se[9]. Three measures are defined. First, it concerns the use of demolition waste in road base and building fill. Second, it concerns the use of stockpiled fly ash/pulverised fuel ash (PFA) to replace cement in concrete applications. Finally, the mining of landfills as a source of secondary materials is considered.

6. Intensify use of buildings: more persons per m2

The same building can provide the same function for more people, or provide more functions, provide the same function in less space, or be adaptable to other functions at end of life. This reduces resource use and can also help to reduce impacts in the use stage as there is less space to heat and cool. It hence envisages the reduction of typical size of new housing (per dwelling) and offices (per occupant).

7. Reduce used land use: increase density of built environment

This technical improvement option is based an overall increase of density of new developments in the built environment. It relates strongly to a more intensified use of buildings, since high-density building usually also implies the use of less floor space.

8. Reduce construction waste: reduce waste flow from construction

In the UK, where the issue of construction waste has been examined carefully, at least 10% of construction materials are shown to be wasted during the construction process (BRE, 2008). Reducing the amount of waste produced and increasing the amount of this waste that is recycled would reduce the need for unnecessary manufacturing and waste disposal.

9. Select materials with low impact: use materials with low environmental impact in construction

This technical improvement option is based on the reduction of use of materials that have a high indirect raw material use, i.e. selecting materials with a low life cycle impact. It defines three variations. First the use of lightweight timber construction instead of heavyweight masonry. Second, the increased production of products with lower impact as expressed by the Raw Material Equivalent of Eurostat. Third, the

[9] Some recycling options have net environmental benefits, e.g. due to the high effort or long transport routes and related energy use it may take to turn waste into a secondary resource.

reduction of energy consumption of asphalt laying by moving from hot mix to warm mix asphalt.

10. Use materials more efficiently: produce more resource efficient products

This technical improvement option is based on an increased production of more resource-efficient products, i.e. providing the same product while using materials more efficiently[10]. It relates closely to the technical improvement options under point 9, but focuses more on resource-efficient production than on more efficient use. Examples are hollow concrete block work that can replace solid blocks in some applications and uses around 25% less material because of the voids. Another example is the use of hollow core flooring that shows a saving of about 45% for aggregates and water, and 30% for cement compared to in-situ concrete construction – and "for an average apartment this means savings of 14.4 tons of concrete and 275 kg steel" (ECHO, 2010).

Annex 1 to this document gives more information on the technical improvement options. We refer to Topical paper 4 for life cycle assessment and life cycle costing data of the technical improvement options.

3.3 Accompanying policy options

A second building block for generating improvement scenarios was analysing which policy options would stimulate the uptake of the clusters of options. This analysis included an assessment of the administrative costs of such measures for governments and industry, divided into once-off investments and annual operational costs. The administrative cost data were in general based on existing Impact Assessment studies done for the EU or EU member states, on instruments such as ecolabels. A factor for consideration was whether policy processes were already ongoing for which such administrative costs would be made anyway – if our proposals merely would imply a more stringent target or a more stringent implementation of a measure already foreseen, no further administrative costs were considered. We refer further to the extensive analysis in Topical paper 5. Table 3.1 reviews the policies that have been considered for each technical improvement option. Annex 2 gives the policies in more detail, and their administrative and implementation costs for business and government.

3.4 Scenarios

3.4.1 Introduction and baseline scenario

The scenarios consist of a baseline and five improvement scenarios, the latter combining technical improvement options and possible policy mixes superimposed upon the baseline. Each scenario would result in a different level of uptake of the technical improvement option. The baseline scenario assumes business as usual including the implementation of existing policies, and its main characteristics are given in Table 3.2. Annex 3.1 and 3.2 indicate the penetration rates of improvements under the baseline scenario. To inform such scenarios, TP4 made an estimate of a) current average EU-27 penetration rates based on penetration rates for all individual EU-27 member states, b) the best practice penetration rates reflecting the current maximum in EU member states, and c) a maximum technical realistically feasible uptake rate. These are presented in Table 3.3. The policy scenarios are:

[10] The difference with option 9 can be explained as follows. Option 9 seeks to replace a material or product with a quite different material or product that may have lower impacts (e.g. replacing masonry by timber). Option 10 seeks to make a material or a product more efficiently (e.g. cement produced with secondary materials, or in a more energy-efficient process).

Table 3.1: Potential accompanying policies per technical improvement option

No	Technical improvement option	Policies proposed
1	Design for deconstruction (case focused on magnetic adhesive flooring)	Green public procurement Ecolabelling In due time: minimum standards via e.g. the Ecodesign directive
2	Increase durability and service life of products	Green public procurement
	(cases: paint, flooring)	Including durability criteria in Ecolabels for paint and flooring; awareness campaign for using warm mix asphalt
		In due time: minimum standards via e.g. the Ecodesign directive
3	Increase recycling at end of life - Asphalt - Concrete - PVC - Float glass - Carpet - Plasterboard	More stringent versions of policies already required under the WFD to realise 70% recycling of C&D waste. It concerns mandatory administrative and financial instruments like: source separation; quality standards for secondary raw materials; re-use and recycling targets; landfill taxes This may require enhancement and subsequent enforcement of the 70% goal buy the EC
		Adjusting Ecolabels and GPP criteria to include recycled content
4	Increase renovation rate	Use existing policies to stimulate renovation rather than demolition: - Spatial planning directed on the long term use of buildings - Focus on renovation in redevelopment plans of city quarters and public buildings - More stringent evaluation criteria for getting demolition permits
		Awareness campaign and best practice exchange
5	Increase use of recycled material (C&D waste, fly ash, landfill mining)	Developing or adjusting Ecolabel and GPP criteria so that they include demands for recycled content
		Green public procurement
		In due time: minimum standards via e.g. the Ecodesign directive
		R&D support for landfill mining
6	Intensify use of buildings	Residential: allocation legislation that relates housing size to family size
		Residential: gradually adjusting housing taxes on the basis of relation between family size and housing size (number of room)
		Offices: regulating maximum space per employee
		Offices, government: planning to use offices as efficient as possible.
7	Reduce land used by the built environment	Use existing spatial planning and building permit systems to support development of compact cities and dense land use.
		Implement a supportive dissemination and research program (compare ESPON)
8	Reduce construction waste arising	Development of guidelines for construction waste minimization
		Education and training
		Making guidelines mandatory in building codes
		Use guidelines as criteria in procurement procedures
9	Select low impact material	
	a: Material level	Ecolabel criteria
		GPP
		Minimum legal standard
	b: Building level	A few dozen CEN standards
		Development of an LCA-alike database that is compatible with BIM systems
		Development of a harmonized assessment system at EU level
		Assessment and certification costs
10	Use construction materials more efficiently	Identical to option 9.a: more efficient production of construction materials leads to materials with lower impacts.

1. **'Best practice uptake of technical improvements' ('Best Practice scenario')**. This scenario includes the implementation of a policy package that makes sure that each of the EU countries reaches by 2030 the current highest cross-European level of uptake for each of the technical options[11].

2. **'Policy package with voluntary implementation of instruments' ('Voluntary scenario').** Policy packages under this scenario consist of a combination of regulatory, economic and informative policy measures that are implemented on a voluntary basis. This scenario leads to uptake rates higher than the current EU-27 average, moving into the direction of the 'Mandatory' scenario.

3. **'Policy package with mandatory implementation of instruments'** (**'Mandatory' scenario').** Policy packages under this scenario consist of a combination of regulatory, economic and informative policy measures that are implemented on a mandatory basis, leading to a maximum technically feasible uptake rate.

4. **'Environmental tax reform a: matching the Mandatory scenario' (ETR a).** This is a policy package that combines all elements of the 'Voluntary' scenario with budget-neutral (not material-neutral) shift of taxes from labour to materials through implementation of an ad-valorem tax in such a way as to reach the effects of the mandatory policy measures. The aim was to look for a tax level that would match the material use reduction in the 'Mandatory' scenario.

5. **'Environmental tax reform b: flat-rate resource tax of 35 %' (ETR b).** This final scenario was introduced based on the experience of initial trial model runs, which showed that scenario I-III led to significant rebound effects. Since shifting taxes from labour to resource is relatively easy to do in a dynamic model, we added one additional scenario where we simply used a flat-rate tax on all primary resource extraction and –imports except agricultural products (i.e. wood, metal ores, fossil energy materials, and non-metallic minerals).

Some of the key assumptions included in the baseline are detailed in Table 3.2. The baseline further assumes that the current average EU-27 penetration rates of technical improvement options will not change[12]. The five scenarios are explained in more detail in the next sections followed by a section providing a summary of the scenarios and the related uptake rates. As for the ETR scenarios, it has to be noted that the place in the value chain where the environmental tax is levied has specific advantages and disadvantages. In our modelling approach the tax was levied on domestically extracted and imported materials. This is transparent and relatively easy to implement. The disadvantage is that intermediate and final products made with these materials will become more expensive, and hence face higher competition of the corresponding imported intermediate and final products, made in countries with lower resource taxes. A tax on products for final consumption that is based on embodied resource use in these products avoids this problem. At the same time, calculating embodied resource use will introduce uncertainties and hence is likely to be contested too.

[11] In some cases exceptions were made, particularly when the current best practice uptake was 0% but when it could be assumed that by 2030 higher uptakes would be reached.

[12] This with the exception of technical improvement options that currently do not exist yet, such as 1.1: Change from adhesive fixing to tactile fixing of flooring. In such cases we assumed a very conservative change in uptake rate. We further did a sensitivity analysis in which we assumed some additional uptake of options like 9.2 (more efficient production of products) and 10.1 (more efficient use of products) above the current 0%.

Table 3.2 Overview of the baseline scenario assumptions

Scenario element	*Geographical and sectoral coverage*	*Source of data*
Population projections	Country level	European Population Projections, base year 2008 from Eurostat
Economic growth: including GDP per capita and productivity	Country level	2009 Ageing Report prepared by European Commission (baseline scenario)
Development of sectoral value added	Country and sectoral level (NACE)	"EU Energy Trends to 2030" report
Development of the energy mix	EU level	"Impact assessment of Energy Roadmap 2050" report
Policy assumptions	EU level	"Impact assessment of Energy Roadmap 2050" report
Development of sectoral productivity including labour and Multi Factor productivity	Country and sectoral level (NACE)	"Sectoral Growth Drivers and Competitiveness in European Union"

3.4.2 Scenario 1: 'Best practice uptake of technical improvement options'

In TP4 an estimation was made for the uptake rates of technical improvement options in different EU member states. The 'Best Practice' scenario assumes that all EU-27 member states will realise by 2030 the uptake rate that exists currently in the 'best in class' EU member state, unless there were clear arguments to deviate from this line of reasoning. Some of these existing uptake rates are already very high in certain member states, such as 99% for option 3.2. 'Recycle concrete and soil instead of landfilling' in the Netherlands. For these technical improvement options we hence take the current best practice across EU countries as the final level of uptake in 2030. For several technical improvement options the uptake rates are currently zero (for example for 'Design for deconstruction' and 'Increase in durability and service life'). For these options we assume no deviations from the uptake rates in the baseline scenario.

The policy package to deliver this scenario, including why it will realise the assumed uptake rate is summarized in Annex 3 and described in more detail in TP6. The policy package combines voluntary implementation of policy measures as described in 'Policy package with voluntary implementation of policy instruments' with the number of more strict policy options including ban for landfill of construction waste and targets for management of construction and demolition waste. The latter are policy instruments that have proved to be efficient in a number of European countries with high rates of recycling and waste treatment including UK, NL and DE. The technical implementation costs of measures part of this scenario, along with the administrative costs for policy instruments to governments, consumers and producers have been estimated in TP4 and TP5 and were included in the modelling (see Annex 4).

3.4.3 Scenario 2: 'Policy package with voluntary implementation of policy instruments'

Scenario 2 consists of implementation of a voluntary framework of core environmental indicators, voluntary GPP going beyond energy efficiency, voluntary targets for GPP of building by public authorities as well as voluntary labelling of environmental performance of buildings and voluntary Environmental Product Declarations (EPDs). The described voluntary framework is combined with supporting markets for secondary construction materials, introduction of quality standards for secondary materials and collaboration along the construction materials' supply chain. The main idea of this scenario is that information on environmental performance of products and technologies will speed up the uptake of cleaner alternatives under the assumption that they do not cost significantly more than the "dirty" ones. The package also includes a number of important information instruments including platforms to share best practice in land use management and efficient use of buildings. The policy measures are implemented across all EU countries.

This policy package is for most technical improvement options weaker than the policy packages applied by EU member states that realise best practice penetration rates. The resulting penetration rates always are lower than in the 'Mandatory' scenario, and usually are lower than in the 'Best Practice' scenario. (Only where in the existing situation best practice penetration rates are low or zero, we sometimes assumed that voluntary instruments would lead to higher penetration rates than in the 'Best Practice' scenario). This is for instance the case for technical improvement option 8.1 (Reduce amount of waste from construction) where voluntary stimuli are assumed to lead to a penetration rate of 33%, well below the 'Best Practice' scenario uptake of 50% or 'Mandatory' scenario uptake of 67%,, but higher than the existing EU average. The relation between uptake rates and policy package is summarized in detail in Annex 3.3 and described in more detail in TP6. The technical implementation costs of measures part of this scenario, as well as the administrative costs for policy instruments to governments, consumers and producers have been estimated in TP4 and TP5 and were included in the modelling (see Annex 4).

3.4.4 Scenario 3: 'Policy package with mandatory implementation of policy instruments'

Scenario 3 includes policies similar to the 'Policy package with voluntary implementation of policy instruments' but they are implemented in a mandatory manner. This scenario package consists of implementation of mandatory framework of core environmental indicators, mandatory GPP going beyond energy efficiency, mandatory targets for GPP of building by public authorities as well as mandatory labelling of environmental performance of buildings and mandatory environmental product declarations (EPDs). The described mandatory framework is combined with supporting markets for secondary construction materials, introduction of quality standards for secondary materials and collaboration along the construction materials' supply chain. This policy packages also includes the implementation of a ban for landfill of construction waste.

The implication of implementing such a package EU wide is that uptakes of technical improvement options will go far beyond the 'Voluntary' scenario and in many cases beyond the 'Best Practice' scenario. In TP4 we have estimated a theoretical maximum technically feasible uptake rate for each option. For instance, in the case of option 1.1 (change from adhesive to tactile flooring) an uptake of 100% is not realistic, as removable fixing is not suitable for certain floor areas, e.g. stairs. We have assumed that in the 'Mandatory' scenario usually the technical maximum uptake is realised.

The policy options included into this package are more binding for consumers and producers which might be expected to facilitate a faster uptake of the technical measures as compared to the 'Voluntary' policy scenario. However, this faster uptake is associated with the higher policy implementation costs for the governments. The policy measures are implemented across all EU countries.

3.4.5 Scenario 4: 'Environmental tax reform a: matching the 'Mandatory' scenario'

Scenario 4' combines two elements. First, it assumes implementation of policies and of the 'Voluntary' scenario for the technical improvement options that are not likely to be affected by introduction of a resource use tax. Examples are Option 2.1 and 2.2 (prolonging the life of flooring and paint). Second, the implementation of a significant resource use tax and housing and office property tax is modelled, which will reduce resource use and demand for housing and offices. Via trial and error, tax levels were established that in the macro-modelling would lead to the same EU-wide reduction of resource use as in the 'Mandatory' scenario.

The collected resource use taxes are assumed to be used in order to reduce the income taxes in a budget-neutral way. The scenario hence basically implies a shift of taxes from labour to resources.

3.4.6 Scenario 5: 'Environmental tax reform b: flat-rate resource tax of 35 %'.

As indicated, shifting taxes from labour to resource is relatively easy to do in a dynamic model and this policy has the advantage that it does not suffer from rebound effects that limit the reductions in material use from win-win technical improvement options (in that case, the monetary savings are used on other final consumption expenditures, which add to raw material consumption). We hence added one additional scenario where we simply used a flat-rate tax on primary resource extraction and –imports.

3.5 Review of uptake rates per scenario

Table 3.3 reviews the uptake rates in each scenario (see TP6), next to existing EU-27 average, best practice and technically feasible penetration rates (see TP4).

1. Design for deconstruction: In TP4 it was considered that design for deconstruction of houses as a whole only would have benefits beyond 2030. The case chosen for this technical improvement option concerns the change from adhesive fixing to tactile fixing of flooring, so that flooring can be more easily reused. The option is not yet or hardly applied in EU member states, implying a current maximum and average uptake of 0%. We assumed a modest autonomous penetration in the baseline of 15% and used this also for the 'Best Practice' scenario. Uptake rates under the 'Voluntary' scenario corresponds to the uptake estimated in the analysis of TP4. The same level of uptake is used for the 'ETR' scenario since implementation of resource use taxes does not make sense in the particular case of this technical improvement. Finally, the uptake rate in the 'Mandatory' scenario corresponds to the maximum technically feasible uptake rate (limited by the fact that in some places only adhesive flooring can be used).

2. Increase durability and service life: Also here options are not yet or hardly applied in EU member states, implying a current maximum and average uptake of 0%. We assumed a modest autonomous uptake in the baseline and 'Best Practices' scenario of 15% and 20% for life time extension of flooring and paint, respectively, half the values of the uptake rates assumed in TP4 which we used for the 'Voluntary' scenario. The same level of uptake is used for the 'ETR' scenario since implementation of resource use taxes does not make sense in the particular case of this technical improvement. Finally the uptake rate in the 'Mandatory' scenario corresponds to the maximum technically feasible uptake rate.

Table 3.3: Penetration rates in different scenarios (left, for 2030), and other information about penetration rates (right, LCA and technical maximum for 2030 and current maximum and EU average for base year)

No	Description	Baseline	Best practice	Voluntary	Mandatory	LCA - TP4	Current maximum	EU average	Technical maximum
1.1	Change from adhesive fixing to tactile fixing of flooring	15%	**15%**	**30%**	**80%**	30%	0%	0%	80%
2.1	Flooring: Increase typical durability from 5 to 7 years	15%	**15%**	**30%**	**40%**	30%	0%	0%	40%
2.2	Paint: Increase typical durability from 5 to 6 years	20%	**20%**	**40%**	**50%**	40%	0%	0%	50%
3.1	Recycle asphalt back into roads instead of landfilling	60%	**100%**	**80%***	**100%**	100%	100%	60%	100%
3.2	Recycle concrete and soil instead of landfilling	71%	**99%**	**85%***	**99%**	99%	99%	71%	99%
3.3	Recycle PVC at end of life instead of landfill or energy recovery	5%	**30%**	**30%**	**60%**	30%	30%	5%	60%
3.4	Recycle float glass at end of life instead of landfilling	8%	**30%***	**20%***	**45%**	60%	60%	8%	45%
3.5	Recycle carpet at end of life instead of landfilling	7%	**30%**	**20%**	**70%**	30%	9%	7%	70%
3.6	Recycle plasterboard at end of life instead of landfilling	9%	**65%**	**30%**	**70%**	65%	65%	9%	70%
4.1	Increase rate of take-up of renovation for energy-efficiency measures	2%	**3%***	**2.5%***	**4.0%**	3%	3%	2%	4%
5.1	Use recycled construction and demolition waste in road base and building fill	71%	**99%**	**71%***	**99%**	99%	99%	71%	99%
5.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	0%	**0%**	**5%**	**10%**	10%	0%	0%	10%
5.3	Mine landfills and use as a source of secondary materials and energy	0%	**0.0%**	**1.4%**	**7.0%**	1%	0%	0%	7%
6.1	Reduce typical size of new housing (per dwelling) and offices (per occupant)	0%	**0.0%**	**0.5%**	**5.0%**	5%	0%	0%	5%
7.1	Increase density of new housing developments	0%	**0.0%**	**0.5%**	**1.0%**	5%	0%	0%	5%
8.1	Reduce amount of waste from construction	0%**	**0%****	**50%**	**67%**	67%	0%	0%	67%
9.1	Use lightweight timber construction instead of heavyweight masonry	5%	**30%**	**20%***	**40%**	30%	30%	5%	40%
9.2	Increased production of products with lower impact, decreased production of higher impact products	0%**	**0%****	**5%**	**20%**	10%	0%	0%	20%
9.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt	3%	**14%**	**40%**	**90%**	90%	14%	3%	90%
10.1	Produce more resource-efficient products/more efficient use	0%**	**34.5%**	**68.2%**	**100.0%**	68.2%	0%	0%	100%

*Some countries have already reached this penetration rate in the base year. In these cases these countries will keep their initial uptake level. The EU average uptake rate will therefore be different from the shown uptake rate

** Changed to 5% in one of the sensitivity analyses; 34.5% for option 10.1

3. Increased recycling of waste: The 'Best Practice' scenario usually takes highest recycling rates in EU member states as a basis. The exception is option 3.4 'Recycle float glass', since the stakeholder interaction lead to the assessment that the conditions under which the Netherlands realises 60% recycling are difficult to realise in all of Europe. The 'Voluntary' scenario assumes in general penetration rates half way between the current EU average uptake and the 'Mandatory' scenario. The uptake rates of 'Mandatory' scenario represent the technological maximum that is achieved either under the implementation of landfill ban for construction waste or under the implementation of resource use tax.

4. Increased renovation rate: The renovation considered is a combination of insulation, instalment of new boilers, and other measures. The improvement applies to all buildings. The *Roadmap to a Resource-Efficient Europe* calls for a refurbishment rate of at least 2% per annum (EC, 2011, pp. 18-19) which was used for the baseline. One of the background reports (TP4) suggests current average levels of 0.35% for full building renovation and 2.1% for partial building renovation in the EU, with some EU member states already realizing higher levels. Assuming EU member states continue to realize their existing high levels and other EU member states catch up, a 3% renovation rate is deemed realistic in the 'Best Practice' scenario. The 'Mandatory' scenario would enhance this. Stakeholder comments from a.o. EURIMA and calculations by Nemry et al. (2008) show renovation at this high level may not be cost effective.

5. Increased use of recycled material: Uptake rates under the 'Baseline' and 'Best practice' scenarios correspond to the current average and best uptake rates within the EU countries respectively. The uptake rates in the 'Mandatory' scenario are assumed to be equal to technical maxima (10 out of 147 landfills suitable for landfill mining). A very modest uptake of landfill mining in the 'Voluntary' scenario has been assumed, with 2 out of 147 landfills suitable for landfill mining.

6. Intensify use of buildings: In the current situation the number of m^2 of housing and offices per person is gradually increasing in all countries of the EU. In the 'Baseline' scenario we made the relatively generous assumption that at least this trend will be stopped, but that no further improvements will be made: an uptake rate of 0%. The same applies for the 'Best Practice' scenario. The rate of uptake is assumed to be slightly higher that zero under the 'Voluntary' scenario where the information platform is being implemented. Addition of Green Public Procurement (GPP) under the 'Mandatory' scenario leads to even higher uptake rate.

7. Reduce land occupation: The idea is that new buildings and infrastructure will be built more compactly, occupying less space. With no clear policies implemented yet, the current EU average and maximum penetration rate is 0%, a number used for the 'Baseline' and 'Best Practice' scenarios. The 'Mandatory' scenario uses a 1% uptake and the 'Voluntary' scenario half of this. Since this option only reduces land use and not the volume of buildings, the option is not critical in the macro-economic resource efficiency assessment.

8. Reduce construction waste: The 'Baseline' and 'Best Practice' scenarios have zero uptake rate because this improvement is not implemented yet in any EU country. The uptake rate for the 'Voluntary' scenario is based on the analysis in TP4 and the uptake rates under the 'Mandatory' and 'ETR' scenarios correspond to the maximum technically feasible uptake rate. This high rate can be achieved either

under the implementation of landfill ban for construction waste or under the implementation of resource use tax.

9. Select materials with low impact: For option 9.2 (low impact products) and 9.3 (moving from hot mix to warm mix asphalt) the Baseline and 'Best Practice' scenario have the average and the maximum current uptake rates across EU countries respectively. The uptake rates of 'Voluntary' scenario is based on the analysis in TP4 and the uptake rates under 'Mandatory' and 'ETR' scenarios correspond to the maximum technically feasible uptake rate. These high rates are assumed to be realised by mandatory EPDs, mandatory GPP, and minimum standards with at building and / or material or component level. For option 9.1 (moving from masonry to timber construction) we felt the current best practice (30% in Nordic countries) is met under circumstances that are country-specific and cannot be replicated to Europe as we whole, leading to lower assumptions in all scenarios.

10. Use materials more efficiently: The 'Best practice' scenario has zero uptake rate as this improvement is not implemented yet in any EU country. The uptake rate of the 'Voluntary' scenario is based on the analysis in TP4 and the uptake rates under 'Mandatory' corresponds to the maximum technically feasible uptake rate. These rate can be achieved either under the implementation of landfill ban for construction waste or under the implementation of resource use tax.

4 Bottom-up assessment: Life cycle costs and life cycle assessment of technical improvement options scaled up to the EU-27 level

4.1 Introduction

As indicated in Table 3.1, the study resulted in 10 areas of improvement encompassing 20 specific technical improvement options. For each of these technical improvement options life cycle cost analyses and life cycle impact assessments were made. This gives insight into costs and benefits of options via the so-called 'bottom-up' approach. This bottom-up approach in essence is based on micro-level data indicating the cost and resource use difference between the existing practice and the improvement, and scaling this up to the EU-27 level[13]. This approach gives valuable insights in the 'static' resource efficiency gains of the 20 technical improvement options, and their net economy-wide costs or benefits. Such data also allows constructing cost curves.

In the next section we first discuss the results from the life cycle assessment and life cycle costing analysis. After this, we present the cost curves. The final section of this chapter ends with conclusions[14].

4.2 Life cycle assessment and life cycle costing

4.2.1 Methodology

Introduction

For each implementation measure, a life cycle inventory (LCI) and life cycle impact assessment (LCIA) has been generated for a functional unit ("product function") in the baseline and improvement scenario. For instance, for Option 3.1 *Recycle asphalt back into roads instead of landfilling* the baseline would be an LCI/LCA for 1 ton of asphalt made with primary materials and landfill of asphalt residues, whereas the improvement scenario would be an LCI/LCA for 1 ton asphalt where asphalt residues is recycled. In addition to the LCA, an estimate of cost differences between the 2 baseline and technical improvement option were made.

Life cycle inventory and life cycle assessment

The life cycle inventory (LCI) was made using the GaBi database and other in-house data sets, for product systems representing the baseline situation and each technical improvement options[15]. After this, the LCIs had to be scaled up to a European total (e.g.

[13] It must be noted that the bottom-up approach with LCAs scaled up to EU-27 level will not necessarily lead to the same results as the top-down approach with EXIOMOD in the next chapter. First, EXIOMOD is a dynamic model that gives insight in the dynamic effects on the economic structure (including rebound effects) over time, something that static LCAs do not give. But second, data sources simply are different. LCAs are based on micro-level data on resource uses and emissions in specific technical processes from LCI databases like Eco-invent and Gabi. Production volumes of products were for the purpose of this study scaled up to EU-27 level. EXIOMOD uses macro-economic data and macro-economic estimates of resource extractions and emissions at EU-27 and country level from e.g. Eurostat. While in theory LCI data scaled up to EU-27 level should be consistent with such macro-economic statistical data, in practice they are not, simply since the databases are made via different approaches and different organisations. This project is not the place to embark on the significant effort that this harmonization of bottom-up and top-down data would entail.

[14] For all backgrounds to this chapter we refer to TP4.

[15] With the exception of the specific improvement under study, it is assumed all other variables remain the same as in the no uptake scenario. For instance, any improvements in the electricity grid mix and other underlying technologies by 2030 are not considered in the LCI/LCA. In this way, all calculations represent the "pure" potential savings from a given option/measure without accounting for improvements in underlying technologies that will happen anyway

in the example of asphalt recycling, 1 ton of asphalt is scaled up by multiplying with the amount of asphalt that in principle is available for recycling per member state). In this, it would be not realistic to assume that the technical improvement option would be 100% implemented. Indeed, the actual improvement potential for a given member state will depend on:

1. current implementation within that member state, and
2. the maximum improvement thought possible by 2030.

If these figures were 10% and 50% respectively, the baseline scenario for that member state would include 10% of the benefits from the technical improvement option already, while the improvement scenario would include the full 50%. The actual improvement compared to baseline is hence in this example 40% of the difference between 0% and 100% implementation. The uptake rates assumed in the LCI/LCA technical improvement options were already given in Table 3.3 and are between the voluntary and mandatory scenarios[16].

In this way the total change (usually a reduction) in emissions and resource use per technical improvement option was calculated for the EU-27. As usual in LCA, this data was then expressed as aggregated indicators for environmental impacts, e.g., Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), etc. These changes were finally expressed, via a normalisation step, as % reduction of the total EU-27 for each impact category (GWP, ADP, etc.)

<u>Life cycle costing</u>

TP4 also estimated a change in life cycle costs. For this purpose, member state specific estimates of unit costs of resources, labour and waste management options were made. On the basis of changes in physical flows calculated in the LCI/LCA per member state, the changes in costs for resource use and waste management could be estimated. Next to this, estimates of changes in labour costs could be made (e.g. more labour needed in the case of separated collection of e.g. float glass in Option 3.4). One technical improvement option (4.1: Increase rate of take-up of renovation for energy-efficiency measures) would lead to a reduction of energy needs, in the use stage – these avoided costs also were calculated. Amongst others as result of stakeholder consultations, during the project it appeared that the cost calculations needed some adjustments, particularly since capital investments were sometimes under-represented (e.g. Option 3.1: Asphalt recycling can be done with dedicated asphalt production plants – if recycling capacity expansion is needed before existing asphalt plants are at the end of their economic life, this leads to additional needs for investments). TP6 hence made improvements in the cost calculations, with the adjusted cost overview provided in Table 4.3.

4.2.2 Results

The tables below give the results of the life cycle assessment and the life cycle costing analysis for each technical improvement option. In short:

1. Table 4.1 and 4.2 give change in use of resources and emissions expressed in life cycle impact assessment themes, respectively, at EU-27 level, as % of the EU-27 total.;
2. Table 4.3 gives an estimate of the financial implications of the technical improvement options, and also indicates if there is likely to be a distributional effect (i.e. costs and benefits do not fall upon the same economic actor).

[16] The LCA calculations were made early in the project, whereas the scenarios for the macro-modelling were developed later in interaction with stakeholders. This process resulted in improved shared insights on realistic uptake rates in the Voluntary scenario, but also led to the situation that uptake rates in the LCA calculation deviates now for some technical improvement options.

Some important findings can be drawn from the tables. Table 4.1 and 4.2 show that few options reduce emissions and resource use in the EU-27 with more than 1%. The following options have the highest environmental benefits:

Table 4.1: EU-27 resource savings per technical improvement option (in % of the EU-27 total)

	Materials	*Energy*			*Water*	*Land*	
	ADPE	**ADPF**	**PED NR**	**PED R**	**BWC**	**Occupation**	**Transformation**
01.1	0.0007%	0.0057%	0.0059%	0.0012%	0.0037%	N/A	N/A
02.1	-0.0001%	0.0024%	0.0025%	0.0006%	-0.0012%	N/A	N/A
02.2	0.0010%	0.0158%	0.0162%	0.0084%	0.0034%	N/A	N/A
03.1	0.0002%	0.1470%	0.1508%	0.0184%	0.0290%	N/A	N/A
03.2	0.0003%	0.0154%	0.0158%	0.0113%	-0.0461%	N/A	N/A
03.3	0.0044%	0.0252%	0.0258%	0.0118%	0.0051%	N/A	N/A
03.4	0.0014%	0.0053%	0.0054%	0.0015%	0.0000%	N/A	N/A
03.5	0.0075%	0.0686%	0.0715%	0.0100%	0.0517%	N/A	N/A
03.6	0.0001%	0.0051%	0.0052%	0.0014%	-0.0001%	N/A	N/A
04.1	-0.2303%	1.5157%	1.5549%	0.5962%	0.0765%	N/A	N/A
05.1	-0.0003%	0.0198%	0.0203%	0.0393%	0.0754%	N/A	N/A
05.2	0.0340%	0.0830%	0.0852%	0.0704%	0.0201%	N/A	N/A
05.3	0.1480%	0.0732%	0.0751%	0.0576%	-0.0255%	N/A	N/A
06.1	0.1426%	0.6424%	0.6594%	0.6392%	0.1253%	N/A	N/A
07.1	0.1426%	0.6424%	0.6594%	0.6392%	0.1253%	N/A	N/A
08.1	0.0724%	0.1709%	0.1755%	0.2947%	0.0114%	N/A	N/A
09.1	0.9888%	0.0527%	0.0541%	-0.4098%	0.0163%	N/A	N/A
09.2	0.8242%	1.8360%	1.8854%	3.2830%	0.3510%	N/A	N/A
09.3	0.0001%	0.0754%	0.0774%	0.0012%	0.0018%	N/A	N/A
10.1	0.6182%	1.3770%	1.4141%	2.4623%	0.2633%	N/A	N/A
Key	ADP(E,F) = Abiotic Depletion Potential (Elements, Fossil), PED(NR,R) = Primary Energy Demand (Non-Renewable, Renewable); BWC = Blue Water Consumption/Footprint; N/A = Not Applicable						

Table 4.2: EU-27 emissions savings per technical improvement option (in % of the EU-27 total)

	AP	**EP**	**GWP**	**GWP(EB)**	**ODP**	**POCP**
	kg SO_2-e	**kg PO_4-e**	**kg CO_2-e**	**kg CO_2-e**	**kg R11-e**	**kg C_2H_4-e**
01.1	0.0038%	0.0010%	0.0066%	0.0058%	0.0001%	0.0011%
02.1	0.0009%	0.0005%	0.0056%	0.0050%	0.0001%	0.0007%
02.2	0.0161%	0.0012%	0.0110%	0.0108%	0.0000%	0.0038%
03.1	0.0184%	0.0007%	0.0181%	0.0183%	0.0000%	0.0724%
03.2	0.0278%	0.0033%	0.0144%	0.0142%	0.0000%	0.0071%
03.3	0.0109%	0.0017%	0.0245%	0.0260%	0.0000%	0.0060%
03.4	0.0129%	0.0013%	0.0046%	0.0046%	0.0000%	0.0015%
03.5	0.0531%	0.0163%	0.1008%	0.0826%	0.0014%	0.0161%
03.6	0.0130%	0.0004%	0.0041%	0.0040%	0.0000%	0.0016%
04.1	0.4402%	0.0120%	1.2639%	1.2658%	-0.0004%	0.0901%
05.1	0.0053%	0.0001%	0.0205%	0.0208%	0.0000%	-0.0035%
05.2	0.0997%	0.0126%	0.3133%	0.3007%	0.0000%	0.0307%
05.3	0.0551%	-0.0006%	-0.0804%	0.0160%	0.0000%	0.0109%
06.1	0.3703%	0.0435%	0.4110%	0.4464%	0.0012%	0.0997%
07.1	0.3703%	0.0435%	0.4110%	0.4464%	0.0012%	0.0997%
08.1	0.1226%	0.0111%	0.1030%	0.1314%	0.0006%	0.0470%
09.1	0.0373%	0.0040%	0.1343%	0.1067%	0.0000%	0.0073%
09.2	1.1979%	0.0989%	0.7370%	1.0622%	0.0071%	0.4330%
09.3	0.0456%	0.0049%	0.0707%	0.0707%	0.0000%	0.0086%
10.1	0.8985%	0.0742%	0.5528%	0.7966%	0.0053%	0.3247%
Key	AP = Acidification Potential; EP = Eutrophication Potential; GWP = Global Warming Potential (EB = Excluding Biogenic Carbon); ODP = Stratospheric Ozone Depletion Potential; POCP = Photochemical Ozone Creation Potential					

Table 4.3: EU-27 Financial Costs (+) and savings (-) per technical improvement option

	Total	**Construction**			**Use**	**Removal**			**Disposal**					**Production**	**Remarks on potential distributional effects**
	000 EUR	**Materials**	**Capital**	**Labour**		**Materials**	**Capital**	**Labour**	**Landfill**	**Capital**	**Incin.**	**IER**	**R**	**Capital**	
01.1	-1.136.218	-194.997	0	-582.045	0	-31.067	0	-323.953	-1.769	0	-535	-1.852	0	0	
02.1	-706.075	-117.285	0	-431.145	0	-23.013	0	-131.636	-1.275	0	-384	-1.336	0	0	
02.2	-6.822.429	-1.469.100	0	-5.325.155	0	0	0	0	-28.174	0	0	0	0	0	
03.1	-797.073	-1.308.013	797.073	0	0	0	0	0	-286.133	0	0	0	0	0	
03.2	-7.598.912	0	0	0	0	-5.266.625	481.298	0	-2.702.612	0	-19.822	-91.150	0	0	
03.3	421.263	0	0	0	0	-126.069	314.982	314.982	-38.366	0	-6.160	-38.107	0	0	
03.4	2.024.975	0	0	0	0	-524.068	0	2.589.798	-40.755	0	0	0	0	0	
03.5	0	0	0	0	0	0	0	58.073	-43.609	0	-10.862	-32.638	0	29.036	
03.6	6.229.308	0	0	0	0	1.097.637	0	5.298.171	-166.500	0	0	0	0	0	
04.1	25.184.430	18.784.390	0	26.158.414	-19.758.375	0	0	0	0	0	0	0	0	0	Rental houses: yes. Owner invests, tenant saves energy
05.1	-818.486	-818.486	0	0	0	0	0	0	0	0	0	0	0	0	
05.2	-2.066.615	-2.066.615	0	0	0	0	0	0	0	0	0	0	0	0	
05.3	600.000	0	0	0	0	-500.000	0	0	1.100.000	0	0	0	0	0	
06.1	0														
07.1	0														
08.1	-15.366.599	-5.169.989	0	-7.391.040	0	-1.623.464	0	-1.182.107	0	0	0	0	0	0	
09.1	-17.730.286	-9.888.675	0	-7.841.611	0	0	0	0	0	0	0	0	0	0	
09.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
09.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
10.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Key	IER = Incineration with Energy Recovery; R = Recycling. All costs in 000 EUR. A negative represents a saving.														

- Measures 9.2 and 10.1 – both of which are broad-brush measures focussing on producing lower-impact, more resource efficient products across the board – consistently have the most potential at the European level and do not cause increased emissions across any of the indicators considered in this study. Both can be achieved without net societal costs.
- The next most significant measures are 6.1 and 7.1, both of which focus on reducing the amount of new-build construction required to satisfy demand, e.g. through the use of multi-purpose buildings and intensification of newly-built housing stock. It was not feasible to calculate the cost of these measures using bottom-up assessment – most likely there will be a net reduction in building and construction activities and related investments.
- Measure 3.1, recycling asphalt back into roads instead of landfilling, and 9.3, reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt, offer small but not insignificant environmental benefits at the EU-27 level, at net economic benefits.
- Measure 4.1, increasing the rate of take-up of renovation for energy efficiency measures, offers significant energy savings, but worsens elemental resource efficiency (abiotic depletion potential, elements (ADPE)). This is largely due to the assumption of $^{1}/_{3}$ glass wool insulation. The other forms of insulation specified yield almost negligible impacts. The cost savings with regard to energy do not offset the initial investments needed, however.

The cost estimates in Table 4.3 make clear that many technical improvement options in principle can be realised with net societal benefits, and that in virtually all cases the actor doing the investment in the technical improvement option also has the financial benefits[17]. Several measures however (e.g., 3.3 - PVC recycling, 3.4 - float glass recycling, and 3.6 - cardboard recycling) come at net societal costs. It is more expensive to separately sort waste for recycling than it is to dispose of it as mixed C&D waste. Option 5.3, landfill mining, also has in general environmental benefits but comes at significant net costs – the revenues related to the materials recovered do not offset the investment and operational costs. Finally, there are other measures that can be realised with net cost benefits for society, but given the low volume of products involved do not give high absolute improvements. This is the case for Option 2.1 (increased durability of carpets) and 2.2 (increased durability of paint), for instance.

4.3 Cost curves with bottom-up data

4.3.1 Methodology

Cost curves show for each technical improvement option the total amount of primary resource extraction saved and the monetary costs or benefits per ton resource saved. The technical improvement options are ranked on cost-effectiveness, i.e. the option with the highest economic benefits per ton saved is presented first.

The financial implications of implementing each of the 20 technical improvement options were already presented in the former section. And further, the life cycle assessments performed also can help to give insight in the total amount of resources used to make a specific product. The so-called life cycle inventory gives all emissions and all extractions of primary resources to make a specific product. Normally in life cycle assessments these primary resources are added up using weighting factors to a score on 'Abiotic depletion potential (ADPE)' (see Table 4.1). This ADPE takes into

[17] The lack of uptake implies that there are hence non-financial bottlenecks, such as lack of priority, certainty about performance of current practices and uncertainty about performance of new practices, etc. (e.g. the question if recycled asphalt is equally robust as primary asphalt), which need a specific effort to overcome in a sector that often is regarded as risk-averse. Note further that these calculations do not yet include any administrative costs of stimulating policies. The data here simply present annual costs and benefits calculated in a way resembling the cost curve studies of McKinsey.

account a measure of 'scarcity' of materials. For instance, a reduction of the use of a kg of copper or zinc would have more weight as the reduction of the use of a kg of clay.

In our case, we are however also interested in the primary resource extraction in itself. We therefore did an additional calculation with the life cycle inventory results, which also give primary resource extraction in kg for materials, and MJ for primary energy carriers. The values for the energy carriers were expressed in kg using MJ/kg values found in the ILCD database and the Gabi database, respectively. We then simply added all primary resource extraction inventory items in the LCI together to a number of kilograms of primary extracted material, and calculated the difference between the baseline and improvement penetration levels used in the LCA calculations.

Both for the ADPE indicator as the simple mass indicator, we then divided by the net economic costs given in Table 4.3. This resulted in the cost per unit of resources saved, which in combination with the total amount of resources saved are the elements needed to present cost curves. It has to be stressed that these cost curves do not include any dynamic effects (such as rebounds)[18].

4.3.2 Results

Table 4.4 and 4.5 give the result of the calculations for the simple mass based indicator and the ADPE indicator, respectively. Table 4.6 shows clearly that a number of recycling options that require laborious separation processes (e.g. for float glass, PVC, and plasterboard) do not score too well – they are expensive to implement and contribute only for a limited part to reduction of resource use. Landfill mining and improved renovation rates also are less of a priority. We further see some options with high potential cost savings, but that have limited impact on the reduction of material use (e.g. prolonging life of carpet and paint). The most important measures leading to large material savings are (as already indicated) options 9.2 and 10.1, covering the full spectrum of building materials. On average, TP4 suggested that these options can be implemented cost-neutral. This was substantiated by a review of cases added as an annex to TP6. In this table, we neglected option 7.1 since in the scaled up LCAs this option was assumed to give exactly the same benefits at option 6.1. Using less land for construction however does not automatically imply a reduced use of building space, as is the explicit assumption in option 6.1. Under the assumption that all other options are additive one could calculate a reduction of material use of around 1.4 Bio tons, which is between about 15% of the European DMC / RMC (Eurostat estimated the EU DMC in 2007 was around 8.3 billion tonnes).

Table 4.5 gives a somewhat different picture, mainly due to the fact that now the scarcity of the materials saved plays an important role. Indeed, some options make the Abiotic Depletion Potential higher instead of lower, since the LCA methodology apparently gives a high weight to some materials used in the technical improvement option that were used less in the baseline. Concrete recycling becomes more important due to the related recycling of iron weaponing part of the concrete. We see further that landfill mining scores much less negative as when the simple mass indicator is used – the LCA has assumed materials are mined that score relatively high on the LCIA ADPE indicator. Overall however the picture provided by Table 4.6 and 4.7 does not deviate too much from each other.

[18] Also administrative costs are not included in this bottom-up calculation.

Table 4.4: Cost curve data based on a simple mass-based indicator

Option code	Option name	Total material savings (1000 ton)	Net costs (Mio Euro)	Net costs per material saving (Euro/ton)	% of EU DMC
02.1	Flooring: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology	181	-706	-3902	0,00%
01.1	Change from adhesive fixing to tactile fixing of flooring	293	-1136	-3883	0,00%
02.2	Paint: Increase typical durability from 5 to 6 years	2455	-6822	-2779	0,03%
03.2	Recycle concrete and soil instead of landfilling	6822	-7599	-1114	0,08%
09.1	Use lightw eight timber construction instead of heavyw eight masonry	32529	-17730	-545	0,40%
08.1	Reduce amount of w aste from construction	47948	-15367	-320	0,58%
05.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	70478	-2067	-29	0,86%
03.1	Recycle asphalt back into roads instead of landfilling	50796	-797	-16	0,62%
05.1	Use recycled construction and demolition w aste in road base and building fill	70066	-818	-12	0,85%
03.5	Recycle carpet at end of life instead of landfilling	3106	0	0	0,04%
06.1	Reduce typical size of new housing (per dw elling) and offices (per occupant)	95626	0	0	1,16%
09.2	Increased production of products w ith low er impact, decreased production of higher impact products	501071	0	0	6,09%
09.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to w arm mix asphalt	160	0	0	0,00%
10.1	Produce more resource-efficient products	375803	0	0	4,57%
05.3	Mine landfills and use as a source of secondary materials and energy	25042	600	24	0,30%
03.3	Recycle PVC at end of life instead of landfill or energy recovery	2393	421	176	0,03%
04.1	Increase rate of take-up of renovation for energy-efficiency measures	22608	25184	1114	0,27%
03.4	Recycle float glass at end of life instead of landfilling	775	2025	2611	0,01%
03.6	Recycle plasterboard at end of life instead of landfilling	597	6229	10435	0,01%
07.1	Increase density of new housing developments	0	0	0	0,00%
	Total	1308752			16%

Table 4.5: Cost curve data based on the ADPE indicator. Options below the black thick line enhance the ADPE of the EU-27 rather than reducing it.

Option code	Option name	Total ADPE reduction (kg Sb-e)	Net costs (Mio Euro)	Net costs per saving (Mio Euro / kg Sb-e
03.2	Recycle concrete and soil instead of landfilling	2,9,E+02	-7599	-25,98
02.2	Paint: Increase typical durability from 5 to 6 years	8,5,E+02	-6822	-7,98
03.1	Recycle asphalt back into roads instead of landfilling	1,6,E+02	-797	-5,05
01.1	Change from adhesive fixing to tactile fixing of flooring	5,7,E+02	-1136	-1,98
08.1	Reduce amount of w aste from construction	6,1,E+04	-15367	-0,25
05.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	2,9,E+04	-2067	-0,07
09.1	Use lightw eight timber construction instead of heavyw eight masonry	8,4,E+05	-17730	-0,02
03.5	Recycle carpet at end of life instead of landfilling	6,3,E+03	0	0,00
06.1	Reduce typical size of new housing (per dw elling) and offices (per occupant)	1,2,E+05	0	0,00
07.1	Increase density of new housing developments	1,2,E+05	0	0,00
09.2	Increased production of products w ith low er impact, decreased production of higher impact products	7,0,E+05	0	0,00
09.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to w arm mix asphalt	1,1,E+02	0	0,00
10.1	Produce more resource-efficient products	5,2,E+05	0	0,00
05.3	Mine landfills and use as a source of secondary materials and energy	1,3,E+05	600	0,005
03.3	Recycle PVC at end of life instead of landfill or energy recovery	3,7,E+03	421	0,11
03.4	Recycle float glass at end of life instead of landfilling	1,2,E+03	2025	1,71
03.6	Recycle plasterboard at end of life instead of landfilling	4,5,E+01	6229	138,43
05.1	Use recycled construction and demolition w aste in road base and building fill	-2,2,E+02	-818	3,74
02.1	Flooring: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology	-9,2,E+01	-706	7,67
04.1	Increase rate of take-up of renovation for energy-efficiency measures	-1,9,E+05	25184	-0,13

4.4 Conclusions

This chapter presented a first assessment of options towards improved resource efficiency in Europe based on technical improvement options applied in the built environment. The assessment made use of bottom-up life cycle inventory data and life cycle cost data. These micro level LCAs were scaled up to product and production volumes of the EU-27 as a whole. Each potential improvement was calculated as the difference between the penetration rate assumed in the LCA (see Table 3.3, mix of penetration rates from the voluntary and mandatory scenarios) and the existing penetration rates per EU member state. Limitations of such a bottom up assessment include:

1. The assessment is static. It does not take into account dynamic, economy-wide effects such as rebound effects
2. It does not take into account changes in improvements of other processes in society (e.g., improved energy systems).
3. The scaling up approach implies that small errors were magnified. The results hence can help the reader rank the technical improvement options, but they should not be considered as a detailed assessment.

Yet, the assessment gives some important initial findings.

- Measures 9.2 (Increased production of products with lower impact) and 10.2 (Produce more resource-efficient products) consistently have the highest potential. This is due to the fact that they affect all building and construction products and hence concern, in contrast to other measures, broad-brushed improvements.
- The next most significant measure is 6.1, which focuses on reducing the amount of new-build construction required to satisfy demand, e.g. through the use of multi-purpose buildings and intensification of newly-built housing stock.

As also shown by the cost curve calculations, most measures can be realised with net societal benefits. Exceptions are recycling of PVC (3.3), float glass (3.4) and gypsum cardboard plate (3.6) due to the high labour costs for separate collection. The same applies for the improved rate of take-up of renovation for energy-efficiency measures (4.1) where reduced energy costs in the use phase of buildings cannot offset the initial investments. Similarly, the revenues of materials made available via landfill mining (5.3) cannot offset the investments and operating costs for this option. This chapter further showed that in general costs and benefits of technical improvement options are born by the same actor. Apart from the fact that options will change activity levels in different economic sectors, we do not see a clear indication that costs and benefits of improvements will be unevenly distributed. Usually the actor that has the benefits of resource efficiency improvements also has to bear the costs.

With the exception of measures 9.2 (Increased use of products with lower impact) and 10.2 (Produce more resource-efficient products) individual technical improvement options barely reduce the impacts of resource use or emissions of the EU-27 by more than 1%; often, the improvement is just a fraction of that. If we would assume that all technical improvement options would be additive and the individual improvements would be summed, the reduction of the EU-27 Abiotic Depletion Potential (ADP), Global Warming Potential (GWP) and Non-renewable Primary Energy Demand (PED-NR) can be estimated to be within an order of magnitude of 5%. The total material savings expressed as Raw Material Consumption calculated in tonnes in Table 4.4 is considerably higher and in the range of 15% of the total EU-27 Raw Material Consumption – but given the problems in extrapolating bottom-up data to the macro level this finding should be used with care.

5 Top-down assessment: Scenarios and main modelling results with EXIOMOD

5.1 Introduction

As indicated in chapter 3, the 20 technical improvement options and accompanying policy instruments were combined to define scenarios. Apart from this, a baseline scenario was developed that took into account expected population growth, GDP growth, and existing environmental policies[19]. The scenarios were input into a detailed, dynamic computable general equilibrium (CGE) model called EXIOMOD. This model was used to calculate the economy-wide effects on GDP, resource use and air emissions of the improvement scenarios. As an intermediate step, the effects of the scenarios were analysed using the static input-output table underlying the model. Compared to the static, bottom-up analysis from the former chapter, this gives various additional insights:

1. While the LCAs were done for just one single uptake rate of technical improvement options, i.e. the uptake rates given Table 3.3 (rates between the 'Voluntary' and maximum scenarios), this chapter provides different scenarios reflecting different uptake rates of technical improvement options and policy instruments.
2. The top-down assessment is done with a dynamic model. Such models also give insight into the indirect economic effects, such as rebound effects, and hence give insights into economic impacts via a different perspective.

The next sections describe:

- The modelling approach in more detail
- The main modelling results
- A discussion including the identification of options with the highest impacts

5.2 Modelling and assessment approach

The scenarios have been fed into an environmentally extended input-output (EE IO) databases, EXIOBASE, around which a Computable General Equilibrium (CGE) model called EXIOMOD has been built (see Annex 5). EXIOBASE is one of the most detailed global EE IO databases, and has the following characteristics:

- Covering 43 countries responsible for over 90% of global GDP and the rest of the world;
- Around 180 product groups and economic sectors per country
- Around 40 emissions to air, 80 types of resource use, water use, and land use per economic sector

CGE models such as EXIOMOD are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. To do so EXIOMOD relies on:

1. behaviour assumptions regarding the key agents of the economy (producers, consumers, government). These behaviours are represented by a set of equations defining, for example, the quantity of resource needed to produce a particular good, the substitution mechanisms between production factors, etc.;
2. an input-output national account database that allows for derivation of key economic variables such as GDP, value added, consumption, investment, labour, intermediary energy consumption, etc.;
3. physical extensions, coherent with the monetary input-output data, which allows linking between economic activity and resource use.

[19] See Topical Paper 6

EXIOMOD makes the standard Walrasian assumption of perfect price flexibility such that equality between supply and demand in all markets is ensured. It also assumes cost-minimizing behaviour by producers, average-cost pricing, and household demands based on optimizing behaviour. It includes the representation of the micro-economic behaviour of the following economic agents: several types of households differentiated by 5 income quintiles; production sectors differentiated by 180 classification categories developed in EXIOPOL project; an investment agent; a federal government and external trade sector.

To simulate these agents and effects, the improvement scenarios and their underlying technical improvement options have to be translated into parameters that can be handled by EXIOBASE/EXIOMOD. In essence this concerns changes in input-output coefficients per sector (i.e. improved resource efficiency of sectors, which are a combination of the penetration rate of a technical improvement option (see Table 3.3) and the change of input-output coefficients that would occur at a 100% penetration rate, changes in final demand[20], and investments needed to realise these technical improvement options in a specific scenario. Since there is a gap between the detailed technical improvement options part of the scenarios and the broader product groups in EXIOMOD, the bottom-up technical improvement options were translated into EXIOMOD parameters as follows:

- for the few technical improvement options where the approach was realistic and relevant, the specific and detailed technical improvement options for each scenario were extrapolated to the broader product categories of the EXIOMOD model21;
- for relevant options among the improvement scenarios, the technical coefficients in the model were adjusted according to the assumptions underlying the improvements calculated in the bottom-up LCAs and the scenario-specific penetration rates by 2030. We refer to Table 5.1 for a summary of how the assumption of technical improvement options in TP4 were translated to changes in coefficients in the model. We refer to Table 3.3 for the scenario-specific penetration rates;
- investment costs (Table 4.3 and administrative costs are summarized in Annex 422 were included in the model, whereas the model itself calculated revenues based on other factors, e.g., reduced material and energy costs.

As discussed, the scenarios include estimates of the penetration rates of technical improvement options that would be realised by 2030 (see Table 3.3). Between the start date of the model run (2010) and this end date (2030), it was assumed that penetration rates would rise progressively until the maximum is reached in 2030. All these parameters are exogenously changed in the model. Each scenario is characterised by a different set of exogenous change in these coefficients. The result of each scenario is presented in comparison to baseline scenario which corresponds to the case where no technical option takes place.

[20] For instance, policies stimulating a more efficient use of housing and office space will lead to a reduction of the need for new houses and offices, or at least their spaces.

[21] For this, we used a correspondence between the detailed PRODCOM database (over 5000 product categories) and the 180 EXIOMOD product classes. Technical improvement options such as using non-adhesive flooring could be related to flooring use in PRODCOM. At the same time, in EXIOMOD this is part of a broader product category. We analysed for which other PRODCOM products in the EXIOMOD category similar improvements as for flooring would be plausible, resulting in a fraction of the EXIOMOD product category for which the improvement would apply.

[22] Substantiated in TP4 (technical implementation costs), TP5 (administrative costs) and TP6 (translation of technical implementation and administrative costs in model input per scenario).

Table 5.1: Relation between characteristics of technical improvement options and changes in coefficients in the EE IO / CGE model EXIOMOD.

No	Description	Key assumption TP4	Translated into changes of the following co-efficients	Remarks and clarification
1.1	Change from adhesive fixing to tactile fixing of flooring	30% reduction in demand for carpet due to reuse at end of life	Intermediate use of textiles by all sectors	Demand reduction is attributed not to the whole textile sector, but only to carpet tiles production, where share of carpet tiles is based on PRODCOM data.
2.1	Flooring: Increase typical durability from 5 to 7 years	22% reduction in demand for carpet due to increased durability	Intermediate use of textiles by all sectors	Demand reduction is attributed not to the whole textile sector, but only to carpet tiles production, where share of carpet tiles is based on PRODCOM data.
2.2	Paint: Increase typical durability from 5 to 6 years	20% reduction in demand for carpet due to increased durability	Intermediate use of textiles by all sectors	Demand reduction is attributed not to the whole chemicals sector, but only to paints production, where share of paints is based on PRODCOM data.
3.1	Recycle asphalt back into roads instead of landfilling	Reduced demand for primary aggregates due to replacement by recycled content	Use of sand, stone and clay by sector ‘other non-metallic mineral products’ (ONMMP)	Demand reduction in not attributed to the whole ONMMP sector, but only to asphalt production, where share of asphalt is based on PRODCOM data. Demand reduction is further scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual reclaimed asphalt waste arising in annual production of asphalt.
3.2	Recycle concrete and soil instead of landfilling	Reduced demand for primary aggregates due to replacement by recycled content	Use of sand, stone and clay by construction sector	Demand reduction is scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual mineral CDW arising in annual use of sand, stone and clay.
3.3	Recycle PVC at end of life instead of landfill or energy recovery	Reduced demand for primary PVC due to replacement by recycled content	Use basic plastic by sector ‘rubber and plastic products’	Demand reduction in not attributed to the whole ‘rubber and plastic’ sector, but only to PVC production, where share of PVC is based on PRODCOM data. Demand reduction is further scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual PVC waste arising in annual consumption of PVC.
3.4	Recycle float glass at end of life instead of landfilling	Reduced demand for primary float glass due to replacement by recycled content	Use of stone, sand, clay and chemical and fertilizer minerals by sector ‘glass and glass products’	Demand reduction in not attributed to the whole ‘glass and glass products’ sector, but only to float glass production, where share of float glass is based on PRODCOM data. Demand reduction is further scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual glass waste arising in annual consumption of flat glass.
3.5	Recycle carpet at end of life instead of landfilling	Reduced demand for primary textiles due to replacement by recycled content	Use of textiles by sector ‘’textiles’	Demand reduction in not attributed to the whole ‘textiles’ sector, but only to carpet tiles production, where share of carpet tiles is based on PRODCOM data. Demand reduction is further scaled to the potential level of replacement of raw materials by recycled content, but in this cased TP4 implies steady-state conditions with replacement potential being 100%.

No	Description	Key assumption TP4	Translated into changes of the following co-efficients	Remarks and clarification
3.6	Recycle plasterboard at end of life instead of landfilling	Reduced demand for primary gypsum due to replacement by recycled content	Use of sand, stone and clay by construction sector	Demand reduction is scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual waste of gypsum arising in annual use of sand, stone and clay.
4.1	Increase rate of take-up of renovation for energy-efficiency measures	Energy savings in use phase; increased demand for mineral construction materials due to increased renovation rates	Use of gas, gas distribution services and heat by service sectors and households; use of construction services by service sectors and domestic final demand	Every year energy savings are growing higher due to accumulated stock of additionally renovated buildings. Increased demand for construction is linked to energy savings, based on 30 years pay-off of renovation (derived from TP4 calculations).
5.1	Use recycled construction and demolition waste in road base and building fill	Reduced demand for primary aggregates due to replacement by recycled content	Not modelled due to high similarities with option 03.2	
5.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	Reduced demand for clinker due to replacement by recycled content	Use of cement, lime and plaster by sector 'cement, lime and plaster products'	Demand reduction in not attributed to the whole 'cement, lime and plaster products' sector, but only to cement production, where share of cement is based on PRODCOM data. Demand reduction in not attributed to the whole product cement, lime and plaster, but only to Ordinary Portland Cement production, where share of Ordinary Portland Cement is based on PRODCOM data.
5.3	Mine landfills and use as a source of secondary materials and energy	Reduced demand for primary metals due to replacement by recycled content	Use of metal ores by sectors producing metal products	Demand reduction is scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of accumulated amount of metals stored in landfills in annual use of metal ores, divided by the expected life of a land mine.
6.1	Reduce typical size of new housing (per dwelling) and offices (per occupant)	Reduced demand for construction services and energy due to reduced floor area per occupant	Use of construction services by service sectors and domestic final demand; use of gas, gas distribution services and heat by service sectors and households	Demand reduction in not attributed to the whole 'construction services' sector, but only to construction of new building, where share of new buildings construction is based on Structural Business Statistics data.
7.1	Increase density of new housing developments	Reduced demand for construction materials and energy due to increased density of housing	Not modelled due to high similarities with option 06.1	
8.1	Reduce amount of waste from construction	Reduced demand for waste treatment and construction materials	Use of sand, stone and clay by construction sector; use of waste treatment services by	Demand reduction is scaled to the potential level of replacement of raw materials by recycled content, potential is defined as share of annual construction waste arising in annual use of sand, stone

No	Description	Key assumption TP4	Translated into changes of the following co-efficients	Remarks and clarification
		due to more efficient use of materials	construction sector	and clay. Demand reduction on waste treatment services is related only to construction waste, not demolition waste.
9.1	Use lightweight timber construction instead of heavyweight masonry	Replacement of masonry construction by timber-framed construction	Use of wood by construction sector; use of mineral products relevant to masonry structures by construction sector	
9.2	Increased production of products with lower impact, decreased production of higher impact products	Across the board reduction in production of 'typical basket' of construction products	Use of all the types of construction materials by construction sector	See comment for option 10.1
9.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt	Reduced demand for energy	Use of gas/diesel oil by construction sector; use of chemicals by construction sector	This option is not creating cost savings for construction sector. Demand reduction for chemicals in monetary terms is assumed to be 50% of energy savings, another 50% is financed through royalties.
10.1	Produce more resource-efficient products	More resource-efficient production of 'typical basket' of construction products	Use of all the types of construction materials by construction sector	Translation in model parameters is similar to option 09.2, which corresponds to the approach selected in TP4

As a first step of the modelling exercise, in parallel with the dynamic analysis in EXIOMOD, we conducted a static input-output analysis based on the same data used in EXIOMOD. This approach allowed clarification of the direct effects of each technical option improvement. For instance, option 1.1 (Change from adhesive fixing to tactile fixing of flooring) is equivalent to a decrease in the demand addressed to the textile sector since it increases the useful life of carpets in commercial buildings. The sectors providing the intermediary consumption of the textile sector will also be affected through the link between input and output. This approach measures the direct impact of each option on resource efficiency. It makes an *ex ante* evaluation of the technical improvement option scenarios, that is the impact that we would have if no indirect effect took place.[23] This partial equilibrium approach has several advantages:

- it relies on simple and straightforward assumptions;
- from a technical point of view, it therefore helps checking the consistency of the calibration of each shock;
- since it relies on simple assumptions, it also provides results that can be easily checked with intuitive expectations.

The main drawback of this approach is that it does not take into account several indirect effects that can radically change the final (*ex post*) outcome of each technical improvement option compared to the evaluation *ex ante*. Indeed, the reduction in the demand addressed to the textile industry of option 1.1 is also a savings that will lead to cost reductions in other sectors. The price of the related products will be lower, and therefore consumers will be able to purchase them in a higher quantity. This is a typical rebound effect that increases resource use and generally leads to a less favourable resource efficiency outcome as originally expected. Most of the options considered here are equivalent to an increase in resource productivity, which is a sort of savings for the consumer. How this savings is reused will determine the magnitude of the associated rebound effect. One important factor in this dynamic is the resource intensity of each product. Only a general equilibrium analysis based on a detailed input output database, as the one we conduct here with EXIOMOD, can account for these indirect effects.

5.3 Results of the static IO modelling

Table 5.2 gives the result of the static IO modelling, expressed in reduction of raw material consumption compared to the existing EU total in 2007. Table 5.2 provides results for the 'Mandatory' scenario only. Note that technical improvement options 3.2 and 5.1 affect the same coefficients in the IO table; therefore this option only has been included once under 3.2 (Recycle concrete and soil instead of landfilling). Further, option 7.1 is the increase of density of new housing development in order to save land. TP4 modelled this as exactly the same as option 6.1 (reduce typical size of new housing). It seems less appropriate to do so as building more densely will not by definition result in smaller houses, and merely will reduce land use. We hence assumed that option 7.1 would not change inputs to the building and construction sector nor change the use of resources.

As already indicated in chapter 4, one must be cautious in comparing these data with the bottom-up LCA data. Scaling up LCAs to a European total leads to errors, but conversely, converting the assumptions underlying the technical improvement options into changes in technical coefficients in IO tables creates its own kind of uncertainties. We see however that the big picture provided by Table 5.2 is quite consistent with that of Table 4.4:

[23] The static EE IO calculation in essence gives the same information as the bottom-up information with LCAs in chapter 4. Results however may differ due to differences in data sources, and problems in scaling up LCAs to the EU level.

Table 5.2: Changes in EU-27 raw material consumption due to changes in coefficients related to technical improvement options in the static EXIOBASE MR EE IO table in the 'Mandatory' scenario, compared to original data for 2007

No	Description	Biomass	Metals	Non-metallic minerals	Energy	Total
01.1	Change from adhesive fixing to tactile fixing of flooring	0,00%	0,00%	0,00%	0,00%	-0,003%
02.1	Flooring: Increase typical durability from 5 to 7 years	0,00%	0,00%	0,00%	0,00%	-0,001%
02.2	Paint: Increase typical durability from 5 to 6 years	0,00%	0,00%	-0,01%	0,00%	-0,005%
03.1	Recycle asphalt back into roads instead of landfilling	0,00%	0,00%	-0,03%	0,00%	-0,014%
03.2	Recycle concrete and soil instead of landfilling	0,00%	-0,01%	-1,09%	0,00%	-0,616%
03.3	Recycle PVC at end of life instead of landfill or energy recovery	0,00%	-0,01%	-0,01%	-0,01%	-0,008%
03.4	Recycle float glass at end of life instead of landfilling	0,00%	0,00%	-0,02%	0,00%	-0,010%
03.5	Recycle carpet at end of life instead of landfilling	-0,01%	-0,01%	0,00%	-0,01%	-0,005%
03.6	Recycle plasterboard at end of life instead of landfilling	0,00%	0,00%	-0,03%	0,00%	-0,015%
04.1	Increase rate of take-up of renovation for energy-efficiency measures	0,08%	0,08%	0,46%	-0,56%	0,201%
05.1	Use recycled construction and demolition waste in road base and building fill	0,00%	0,00%	0,00%	0,00%	0,000%
05.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	0,00%	-0,01%	-0,04%	0,00%	-0,025%
05.3	Mine landfills and use as a source of secondary materials and energy	0,00%	-3,34%	-0,48%	0,00%	-0,368%
06.1	Reduce typical size of new housing (per dwelling) and offices (per occupant)	-0,34%	-1,13%	-2,36%	-0,61%	-1,540%
07.1	Increase density of new housing developments	0,00%	0,00%	0,00%	0,00%	0,000%
08.1	Reduce amount of waste from construction	0,00%	0,00%	-0,29%	0,00%	-0,165%
09.1	Use lightweight timber construction instead of heavyweight masonry	0,20%	-0,06%	-1,40%	-0,03%	-0,743%
09.2	Increased production of products with lower impact, decreased production of higher impact products	-1,25%	-0,94%	-12,46%	-0,42%	-7,456%
09.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt	0,00%	0,00%	0,00%	-0,01%	0,000%
10.1	Produce more resource-efficient products/more efficient use	-0,69%	-0,52%	-6,85%	-0,23%	-4,101%
	Total	-2,01%	-5,96%	-24,61%	-1,89%	-14,87%

- In both cases, we see an overall reduction of EU-27 raw material consumption of around 15% (although it must be noted the penetration rates used in the LCAs are somewhat lower as in the Mandatory scenario; see Table 3.3);
- In both cases, the technical improvement options 10.1 (more efficient use of construction products), 9.2 (increase production of products with lower impacts), and 6.1 (reduce size of offices and houses), reduce the demand for primary materials most.
- Recycling of voluminous waste streams, such as concrete, also have a notable contribution to the reduction of primary material demand (option 3.2), as is the case for prevention of construction waste (option 8.1)
- Most other options relate to volumes of materials which are too low to have significant and visible impacts. The EE IO modelling suggests that the technical improvement option 4.1., the increased rate of take-up of renovation for energy-efficiency measures, in fact will enhance raw material consumption in the EU

slightly. Enhanced renovation will enhance the use of all materials except energy materials, and the reduction of the latter does not outweigh the first.

These changes result to a reduction of final consumption expenditure in the EU-27 in the order of magnitude of 1%. Since these savings in principle will be spent on other expenditures, an income rebound of at least this percentage can be expected in the dynamic modelling.

5.4 Results of the dynamic modelling with EXIOMOD

5.4.1 Introduction

This section compares the results of the different scenario simulations. We first look at the aggregated result at the European level, including a sensitivity analysis. Then we focus on material-specific impacts. After this we discuss country heterogeneity and sectorial impacts.

5.4.2 Main results of policy scenarios at European level

The table below gives key data regarding the baseline scenario. Between 2015 and 2030, the GDP increases from 14.2 to 19.1 billion Euros, a 34% increase. During the same period, European raw material consumption rises at a similar rate from 9.6 billion tonnes to 13 billion tonnes.

Table 5.3: GDP and RMC of the EU-27 in the baseline scenario

	2013	2015	2020	2025	2030
GDP (bln Euro)	13.605	14.265	15.915	17.490	19.059
Total Raw Material Consumption (mln tonnes)	9.157	9.631	10.816	11.916	13.006

The economic impacts of each scenario in terms of GDP are indicated in Figure 5.1. Compared to the 34% rise of GDP in the baseline, the differences between the scenarios are limited, but clearly notable. The 'Mandatory' scenario scores best, with a rise in GDP of almost 0.8% or almost 150 billion Euro compared to baseline. The 'Voluntary', ETR a) and 'Best Practice' scenarios also have positive impact on GDP, between 0.1% and 0.25% compared to the baseline. The ETR b) scenario with a 35% resource tax the impact on GDP is slightly negative.

The rationale for this outcome is relatively straightforward. As shown in chapter 3, the most important Technical improvement options are cost-neutral or have net benefits. These options are particularly stimulated in the 'Mandatory' scenario. Such options with net benefits will enlarge GDP. An ETR simply moves taxation from labour to resources, but does not by definition stimulate win-win options.

The impacts on the EU-27 raw material consumption are given in Figure 5.2, whereas Table 5.4 compares the reduction in EU-27 raw material consumption in % with absolute numbers of GDP change compared to baseline. Figure 5.2 shows in the 'Mandatory' scenario, with the highest overall reduction in raw material consumption, at around 9.5% less than the baseline. This is less than the 15% that was calculated in the former section on the basis of a static EE IO analysis. This is understandable, due to dynamic effects like income rebound and other structural changes in the economy that a dynamic model makes visible. The 'Voluntary' and 'Best Practice' scenarios lead to clearly lower reductions in RMC, which is understandable given the much lower penetration rates that had to be assumed for the technical improvement options with potentially high reductions in material use (10.1: More efficient use of construction products; 9.2: increase production of products with lower impacts; and 6.1: reduce size of offices and houses).

Figure 5.1: GDP for EU-27 in % change compared to baseline, 2015-2030

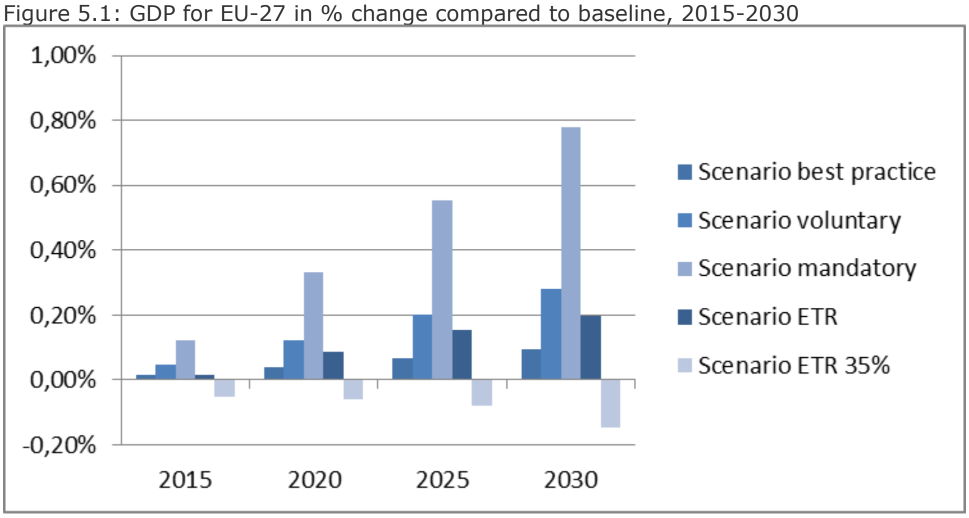


Figure 5.2: Changes in EU-27 raw material consumption in % compared to baseline, 2015-2030

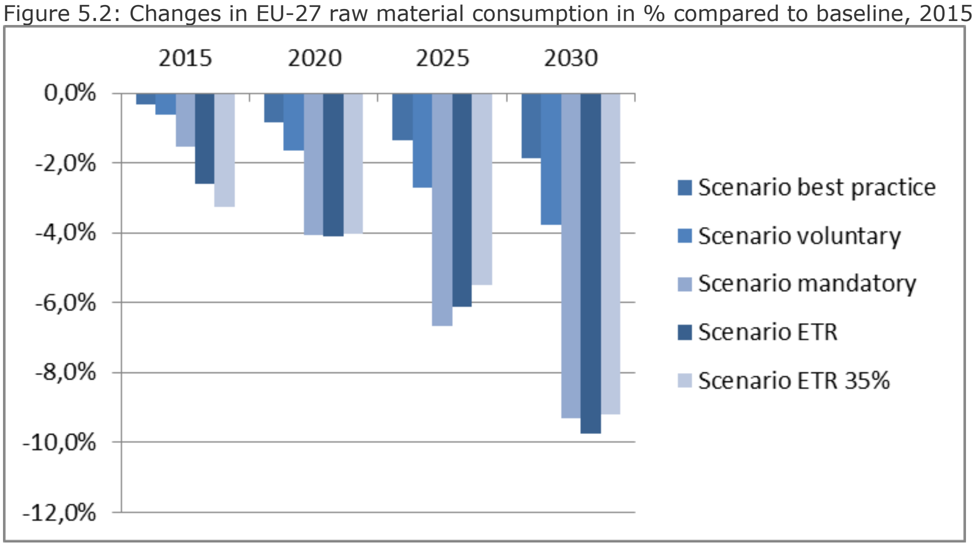


Table 5.4: EU-27 GDP change and reduction in EU-27 resource use in % compared to baseline in 2030.

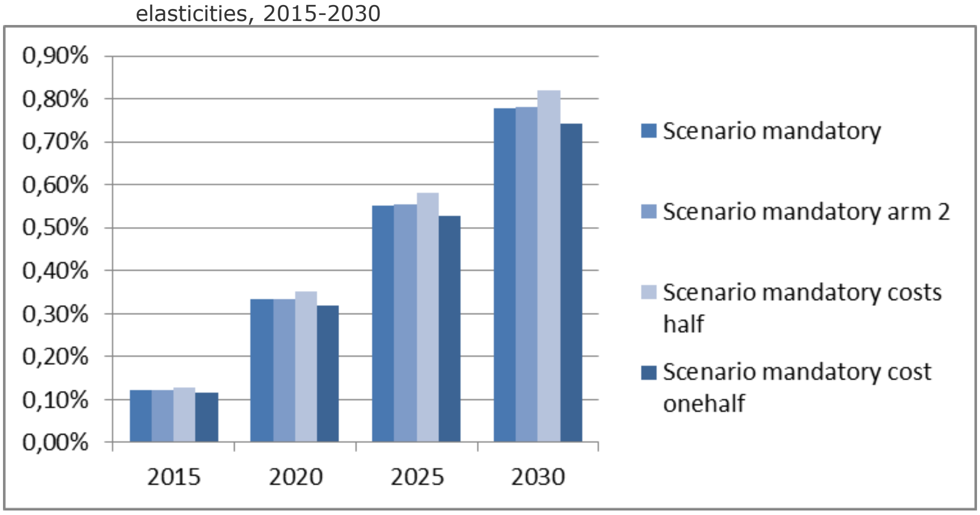
	GDP change (bio Euro)	RMC change (%)
Scenario best practice	18	-1,9%
Scenario voluntary	54	-3,8%
Scenario mandatory	148	-9,3%
Scenario ETR	38	-9,8%
Scenario ETR 35%	-28	-9,2%

As indicated, the ETR a) scenario combines the 'Voluntary' scenario with a shift of taxes from labour to resources that would overall lead to a similar reduction in RMC. The tax level needed to achieve this reduction was 20%. The ETR b) scenario with a 35% resource tax (and without voluntary action) leads to similar reductions in RMC as the 'Mandatory' and the main ETR scenario.

A first conclusion hence seems to be that stimulating maximum penetration rates of win-win options, as done in the 'Mandatory' scenario, also results in a win-win situation at the macro level. Table 5.4 shows that this scenario gives an overall reduction of EU resource use of almost 10%, with a rise of EU-27 GPD of almost 150 billion Euro.

This main conclusion is not affected too much by differences in assumptions in the calculations[24]. This can be seen from the outcome of the sensitivity analysis that we have done for the 'Mandatory' scenario in Figure 5.3 and 5.4. We have performed a preliminary screening exercise in order to identify the model parameters that are the most important for the results. From this exercise we have concluded that particularly the implementation costs of technical improvement options and Armington elasticity of substitution between domestic and imported goods were relevant. In order to test the sensitivity of model results to changes in the Armington elasticity we have multiplied this elasticity with a factor two. In the figure below this sensitivity run is denoted 'Scenario mandatory arm 2'. We have also run the 'Mandatory' scenario under two different assumptions about the implementation costs/benefits of the technical improvement options: (1) 'Scenario mandatory costs half' assumes that these costs are 50% of the initial ones; (2) 'Scenario mandatory costs one half' assumes that these costs are 150% of the initial ones[25].

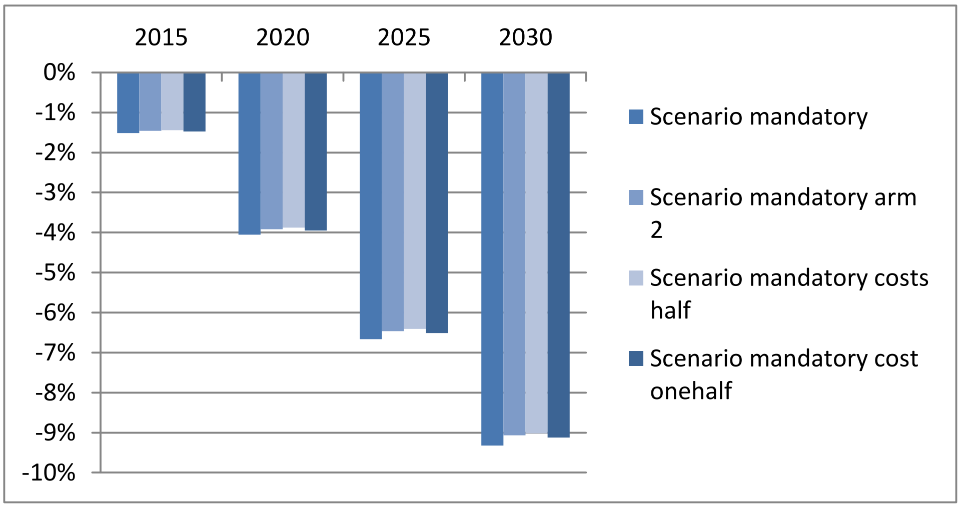
Figure 5.3: Sensitivity analysis for the 'Mandatory' scenario: change of EU-27 GDP in the 'Mandatory' scenario by adjusted technical implementation costs of +50% and -50% and Armington elasticities, 2015-2030



[24] As once can see from the differences between the Best practice, Voluntary and Mandatory scenarios the penetration rates are the most important variable determining effects on GDP and RMC.

[25] Table 4.3 shows for some options net zero costs, also for instance the broad measures 9.2 ( ) and 10.1. Due to changes in co-efficients in the dynamic model, the building sector would in fact save costs as a result of using less materials. To avoid an over-optimistic picture, cost-neutrality was maintained to add an equivalent of the savings again as costs for the building and construction sector. In the sensitivity analysis these costs were varied with 50% up and down. With technical improvement options 9.1 and 10.1 covering significant volumes of building and construction minerals, the variation of costs in the sensitivity analysis was significant.

Figure 5.4: Sensitivity analysis for the 'Mandatory' scenario: change of EU-27 RMC in the 'Mandatory' scenario by technical implementation costs of +50% and -50% and Armington elasticities, 2015-2030



Assumptions with regard to an alternative baseline did however, as expected, change results. As indicated in Table 3.3, we calculated also results with a baseline in which the penetration rates of technical improvement options 8.1 (Reduce amount of waste from construction) and 9.2 (Increased use of low impact products) were set at 5% and technical improvement option 10.1 (Use materials more efficiently) was set at 34.1%. Table 5.5 shows the results of this alternative baseline, resulting for the 'Best Practice', 'Voluntary', 'Mandatory', and ETR scenarios in lower GDP benefits and lower RMC reductions. Having said this, the comparison between Table 5.4 and 5.5 indicates that even a different baseline does not change results drastically.

Table 5.5: Sensitivity analysis: EU-27 GDP change and reduction in EU-27 resource use in % compared to the alternative baseline in 2030.

	GDP change (bio Euro)	RMC change (%)
Scenario best practice	4	-0,9%
Scenario voluntary	20	-1,6%
Scenario mandatory	114	-7,1%
Scenario ETR	4	-7,5%
Scenario ETR 35%	-28	-9,2%

5.4.3 Results for specific materials at European level

Figure 5.5 to 5.8 give the scenario results for different material categories usually discerned in material flow analysis: biomass, fossil energy resources, metal ores and non-metallic minerals. While at aggregated level the impact of the Mandatory and ETR scenarios on the EU-27 RMC is similar, there is a clear difference when looking at the individual material groups. The two scenarios with an ETR component lead to high reductions of all material groups, with the exception of biomass, since here the ETR was only applied for wood products, not for biomass used for food products. The Mandatory, Voluntary and Best practice scenarios have their highest effect on the reduction of the use of non-metallic minerals. Also this finding could be expected:

- The technical improvement options that underlie the Mandatory, Voluntary and Best practice scenarios in virtually all cases have a specific focus on materials used for buildings and infrastructure, which mainly consist of non-metallic minerals. Of course other materials are also covered by the technical improvement options, but often indirectly (e.g. as embedded energy in construction materials).

- An ETR however affects all resources. The ETR of 20% in ETR scenario a) (Voluntary measures + ETR) and the ETR of 35% in ETR scenario b) hence leads to a relatively high reduction of fossil energy resources and metallic minerals in comparison to the other scenarios.

The implication is that the ETR scenarios have as important by-effect a significant reduction in the use of fossil energy carriers (and hence greenhouse gas emission, which are reduced proportionally with the reduction of fossil fuel use in Figure 5.5). The 'Mandatory', 'Voluntary' and 'Best Practice' scenarios have a much lower effect here.

Figure 5.5: Total consumption based resource use of fossil energy resources in EU-27, in % change compared to baseline, 2015-2030

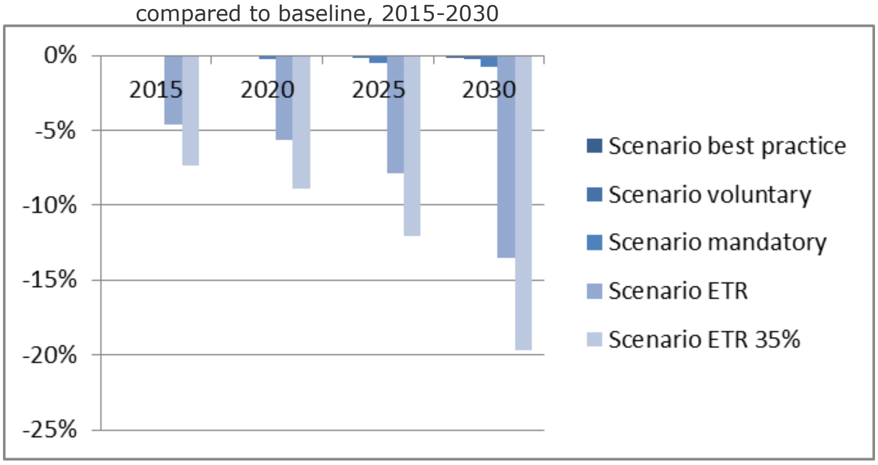


Figure 5.6: Total consumption based resource use of metal ores in EU-27, in % change compared to baseline, 2015-2030

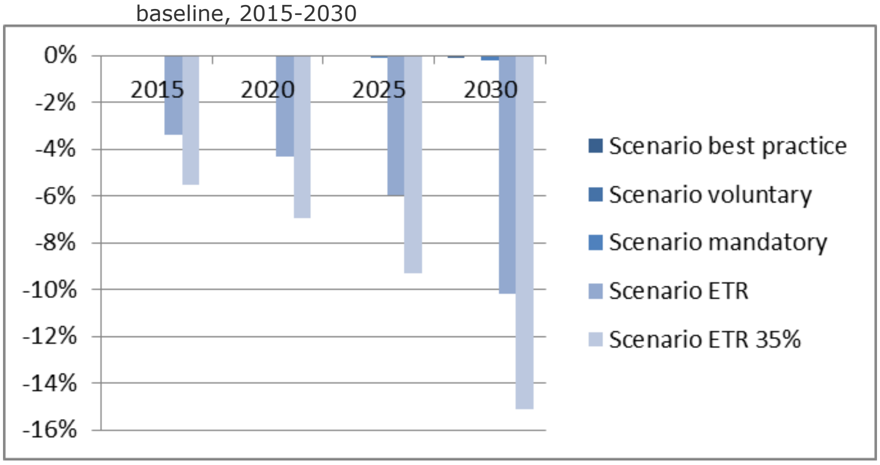


Figure 5.7: Total consumption based resource use of biomass in EU-27, in % change compared to baseline, 2015-2030

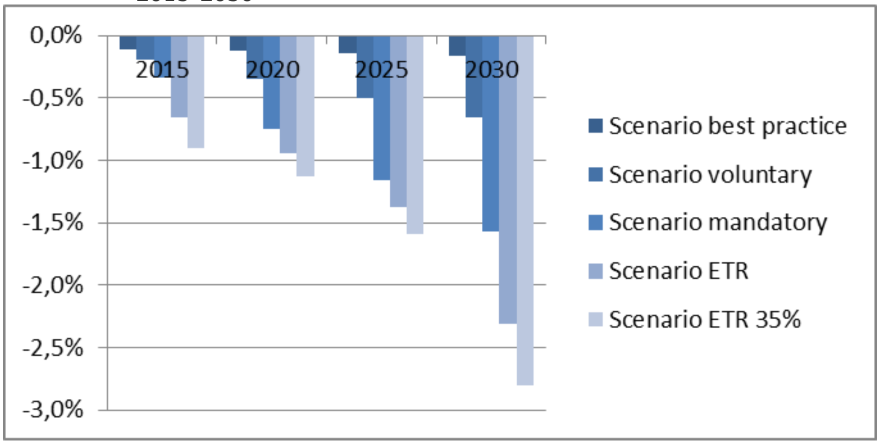
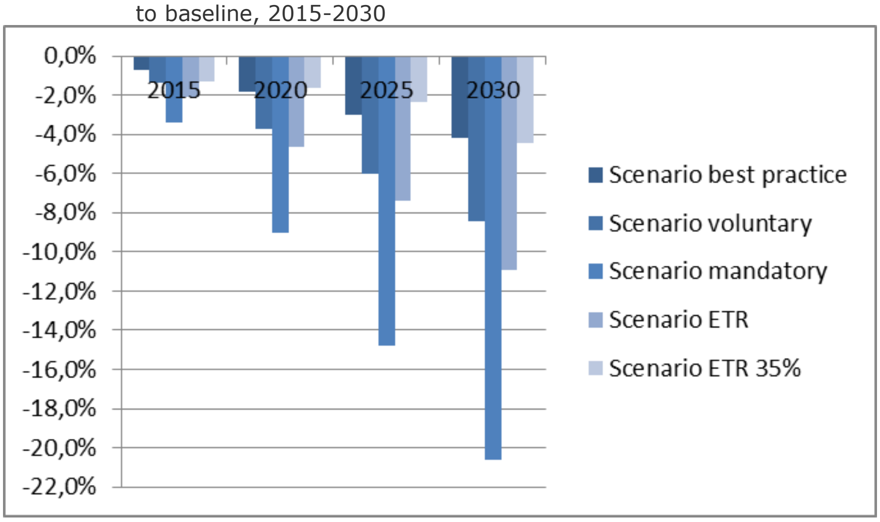


Figure 5.8: Total consumption based resource use of non-metallic minerals in EU-27, in % change compared to baseline, 2015-2030



5.4.4 Country and sector specific impacts

The effects of the simulation at country- and sector level are provided in Table 5.6-5.8. Particularly the country specific simulations need to be used with some care since as a general rule, at a more detailed level of analysis (of countries, sectors, specific resource uses) uncertainties become higher. Not surprisingly, the GDP and RMC changes per scenario per country follow the pattern shown for the EU-27 as a whole in Figure 5.1 and Figure 5.2. The differences between countries have to do with the following factors:

- size of the sectors mainly affected by the policy scenarios;
- the country specific different between baseline penetration rate and scenario-specific penetration rate for technical improvement options;
- country specific costs, input and output coefficients, etc.

The sector specific analysis in Table 5.6 shows not surprisingly that the sectors involved in mining and quarrying and production of construction materials have a reduced output in all scenarios. However, as also can be deducted from the material-specific reductions per scenario in Figure 5.5-5.8, the different scenarios have a quite different effect on sectors. The two ETR scenarios have a significant impact on the output of all sectors that extract and use primary materials, such as manufacturing of cokes and petroleum products (related to the sharp reduction in fossil fuel extraction in Figure 5.6. In the 'Best Practice', 'Voluntary' and 'Mandatory' scenario s we see that reductions in output mainly concentrate in the Mining and quarrying and the Manufacturing of other non-metallic products, which are the sectors indeed affected by the policy packages in these scenarios.

One should not mix up a change in sector output with a change in wealth in Europe; as already indicated the effects on GDP are positive in all scenarios with the exception of the ETR35% scenario. This is due to the fact that some sectors such as the construction sector enhance output, and/or that added value is not impacted in the same way as output.

Table 5.6: GDP in bln Euro and GDP in % difference compared to baseline scenario, per EU Member state, 2030. Baseline and % change adds up to the total in Table 5.1 and Figure 5.1

	Baseline	Scenario Best practice	Scenario Voluntary	Scenario Mandatory	Scenario ETR	Scenario ETR35%
AT	401	0,10%	0,31%	0,90%	0,20%	-0,19%
BE	511	0,11%	0,29%	0,81%	0,03%	-0,44%
BG	62	0,18%	0,50%	1,39%	-0,36%	-1,46%
CY	30	0,21%	0,67%	1,88%	0,67%	-0,02%
CZ	221	0,11%	0,35%	1,08%	0,29%	-0,12%
DE	3.236	0,04%	0,15%	0,42%	0,13%	-0,05%
DK	313	0,13%	0,44%	1,22%	0,38%	-0,12%
EE	31	0,23%	0,68%	1,84%	0,51%	-0,28%
ES	1.903	0,16%	0,49%	1,31%	0,30%	-0,29%
FI	265	0,17%	0,55%	1,51%	-0,04%	-0,92%
FR	2.810	0,09%	0,24%	0,64%	0,12%	-0,20%
GB	3.324	0,07%	0,19%	0,54%	0,26%	0,08%
GR	389	0,12%	0,34%	0,91%	0,04%	-0,50%
HU	171	0,14%	0,35%	0,95%	0,19%	-0,29%
IE	362	0,14%	0,41%	1,08%	0,37%	-0,08%
IT	2.204	0,11%	0,32%	0,89%	0,25%	-0,12%
LT	49	0,15%	0,40%	1,08%	0,38%	-0,03%
LU	71	0,07%	0,20%	0,58%	0,18%	-0,04%
LV	38	0,25%	0,77%	2,18%	0,79%	-0,10%
MT	10	0,09%	0,25%	0,74%	0,23%	-0,04%
NL	797	0,09%	0,28%	0,84%	0,29%	-0,03%
PL	590	0,13%	0,35%	0,99%	0,26%	-0,17%
PT	283	0,14%	0,39%	1,07%	-0,07%	-0,79%
RO	264	0,12%	0,32%	0,87%	0,19%	-0,21%
SE	529	0,06%	0,23%	0,64%	0,14%	-0,15%
SI	58	0,21%	0,55%	1,55%	0,56%	0,00%
SK	133	0,12%	0,32%	0,88%	0,11%	-0,35%

Table 5.7: Simulation outcome of RMC change compared to baseline in 2030 per EU Member state (numbers in % or million ton)

	Baseline	Scenario Best practice	Scenario Voluntary	Scenario Mandatory	Scenario ETR	Scenario ETR35%
AT	257.269	-1,8%	-4,0%	-10,2%	-9,2%	-8,1%
BE	310.851	-1,7%	-3,5%	-8,6%	-9,7%	-9,6%
BG	213.539	-1,1%	-2,0%	-5,2%	-12,1%	-16,4%
CY	41.053	-3,8%	-9,3%	-23,4%	-10,3%	-1,9%
CZ	323.643	-1,8%	-3,2%	-8,0%	-14,1%	-15,9%
DE	1.934.254	-1,5%	-2,8%	-7,2%	-8,4%	-9,0%
DK	183.387	-2,6%	-4,3%	-9,8%	-8,3%	-7,1%
EE	79.780	-1,5%	-3,5%	-9,5%	-6,3%	-4,0%
ES	1.496.209	-2,8%	-5,8%	-13,9%	-9,5%	-5,5%
FI	383.360	-1,6%	-3,5%	-9,0%	-21,3%	-25,5%
FR	1.314.805	-2,5%	-5,1%	-12,2%	-7,4%	-3,7%
GB	1.206.910	-2,3%	-4,3%	-10,6%	-12,0%	-11,9%
GR	390.916	-2,1%	-4,9%	-12,2%	-10,1%	-8,2%
HU	233.894	-2,3%	-3,6%	-8,9%	-10,0%	-10,0%
IE	316.386	-4,2%	-8,4%	-20,9%	-14,6%	-10,8%
IT	1.029.131	-1,1%	-3,0%	-7,4%	-5,7%	-4,4%
LT	68.306	-1,7%	-3,5%	-9,6%	-7,4%	-5,1%
LU	6.538	-1,0%	-1,9%	-5,5%	1,1%	4,5%
LV	57.292	-1,4%	-3,7%	-9,8%	-10,8%	-10,4%
MT	7.369	-3,3%	-6,7%	-16,5%	-7,0%	-0,6%
NL	681.692	-0,5%	-0,9%	-2,3%	-14,5%	-20,4%
PL	1.038.081	-1,6%	-2,6%	-6,3%	-6,2%	-5,7%
PT	259.414	-2,4%	-5,6%	-13,6%	-13,4%	-14,4%
RO	549.040	-1,7%	-3,0%	-7,5%	-9,6%	-9,2%
SE	398.548	-0,3%	-1,0%	-2,8%	-7,7%	-10,4%
SI	80.982	-2,9%	-6,4%	-16,3%	-11,3%	-6,7%
SK	143.282	-1,5%	-2,9%	-7,0%	-13,3%	-14,8%

Table 5.8: Output of sectors in baseline scenario in bln Euro and increase in output for scenarios in % compared to baseline scenario, 2030

Sector	Baseline (bln Euro)	Scenario Best Practice %	Scenario Voluntary %	Scenario Mandatory %	Scenario ETR %	Scenario ETR 35% %
Agriculture, fishing and mining	697	-0,02%	-0,10%	-0,27%	-1,30%	-1,92%
Mining and quarrying	258	-1,50%	-2,78%	-7,20%	-14,34%	-17,47%
Manufacturing of food and textiles	1.751	0,25%	0,29%	1,21%	0,32%	0,01%
Manufacturing of wood products	476	-0,11%	-1,25%	-3,40%	-8,60%	-12,01%
Manufacturing of coke and petroleum products and fuels	320	-0,02%	-0,02%	-0,09%	-25,14%	-35,72%
Manufacturing of chemicals	823	-0,10%	-0,05%	-0,29%	-3,44%	-5,31%
Manufacturing of other non-metallic mineral products	980	-0,78%	-2,68%	-6,80%	-4,67%	-3,46%
Manufacturing of metal	1.415	-0,02%	0,15%	0,32%	-4,23%	-6,86%
Manufacturing of equipment, machinery and n.e.c.	3.734	-0,03%	0,07%	0,05%	1,16%	1,71%
Electricity, gas and water supply	913	-0,32%	-0,32%	-1,37%	-3,37%	-4,91%
Construction	2.923	0,47%	1,09%	2,28%	2,17%	1,39%
Wholesale, retail and hotels and restaurants	4.699	-0,03%	-0,10%	-0,19%	-0,89%	-1,30%
Transport and communication	2.777	-0,04%	-0,08%	-0,11%	-0,70%	-0,99%
Business services	8.250	0,02%	0,08%	0,28%	0,33%	0,36%
Public administration, education and other services	4.503	0,00%	0,04%	0,11%	2,03%	3,31%

5.5 Scenarios and options with the highest benefits: cost curves revisited

One of the problems in the macro-economic modelling approach is that the inputs related to individual technical improvement options give interactions in the model. It is hence not possible to calculate GDP changes and changes in RMC per technical improvement options, and add them up to the overall results presented above[26].

This report however used two approaches to analyse the relevance of individual technical improvement options: by scaling up the LCAs done in TP4 to EU-27 level (table 4.6), and by calculating the changes in primary material extraction due to changes in coefficients in the EE IO table underlying EXIOMOD (table 5.2). Table 5.9 combines these two results. Since the penetration rates used in the Mandatory scenario on which the EE IO analysis in table 5.2 was based differs slightly from the penetration rates in the LCA, we added to in table 5.9 the results of a static EE IO analysis with the penetration rates used in the LCAs.

[26] To give an example: a reduction in the demand addressed to the textile industry of option 1.1 (Change from adhesive fixing to removable fixing of carpet tiles, which lead to a higher potential for re-use) normally leads to lower prices of this now less in demand product. Therefore consumers will be able to purchase them in a higher quantity. This is a typical rebound effect that increases resource use and generally leads to a less favourable resource efficiency outcome as originally expected. Option 2.1 (Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology) will reduce demand even more, but in case of a non-linear price elasticity, the impacts on prices are not additive, implying that the combined effects as calculated by the model of the two technical improvement options are not additive.

Table 5.9: Cost curve data. Reduction of material use per technical improvement option in % of EU total according to the scaled up LCA results and static EE IO results, and net costs per ton material saved (minus is a saving in cost).

Option code	Option name	LCC and LCA results scaled up to EU-27 level		Static EE IO results	
		Net costs per material saving (Euro/ton)	LCA: % of EU DMC	% of EU RMC at LCA penetration rates	% of EU RMC at 'Mandatory' penetration rates
01.1	Change from adhesive fixing to tactile fixing of flooring	-3883	0,00%	0,00%	0,00%
02.1	Flooring: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology	-3902	0,00%	0,00%	0,00%
02.2	Paint: Increase typical durability from 5 to 6 years	-2779	0,03%	0,01%	0,00%
03.1	Recycle asphalt back into roads instead of landfilling	-16	0,62%	0,02%	0,01%
03.2*	Recycle concrete and soil instead of landfilling	-1114	0,08%	0,94%	0,62%
03.3	Recycle PVC at end of life instead of landfill or energy recovery	176	0,03%	0,00%	0,01%
03.4	Recycle float glass at end of life instead of landfilling	2611	0,01%	0,02%	0,01%
03.5	Recycle carpet at end of life instead of landfilling	0	0,04%	0,00%	0,01%
03.6	Recycle plasterboard at end of life instead of landfilling	10435	0,01%	0,01%	0,02%
04.1	Increase rate of take-up of renovation for energy-efficiency measures	1114	0,27%	-0,12%	-0,20%
05.1*	Use recycled construction and demolition waste in road base and building fill	-12	0,85%	0,00%	0,00%
05.2	Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	-29	0,86%	0,02%	0,02%
05.3	Mine landfills and use as a source of secondary materials and energy	24	0,30%	0,08%	0,37%
06.1	Reduce typical size of new housing (per dwelling) and offices (per occupant)	0	1,16%	1,54%	1,54%
07.1	Increase density of new housing developments	0	0,00%	0,00%	0,00%
08.1	Reduce amount of waste from construction	-320	0,58%	0,12%	0,16%
09.1	Use lightweight timber construction instead of heavyweight masonry	-545	0,40%	0,38%	0,74%
09.2	Increased production of products with lower impact, decreased production of higher impact products	0	6,09%	3,73%	7,46%
09.3	Road asphalt: Reduce energy consumption of asphalt laying by moving from hot mix to warm mix asphalt	0	0,00%	0,00%	0,00%
10.1	Produce more resource-efficient products	0	4,57%	2,80%	4,10%
	Total		16%	10%	15%

*- Option 3.2 and 5.3 were combined in the static EE IO analysis

The static EE IO analysis, using penetration rates from the LCA analysis, results in 10% reduction of the EU RMC. The bottom-up LCA analysis estimates a reduction of 15%. Given the very different calculation approaches and data sources these two approaches use, these results can be considered as in good agreement. As for prioritizing options, Table 5.9 and the results of the dynamic modelling also give clear suggestions:

1. The dynamic modelling suggests that stimulating win-win options at micro-level also results in a win-win at macro level. The modelling with EXIOMOD of the 'Mandatory' scenario provides the highest overall reduction in EU-27 resource use,

of almost 10% compared to the baseline[27]. The 'Mandatory' scenario has the highest positive effect on economic growth as well.

2. That win-win options at the micro level lead to a positive effect on GDP is logical, since apparently then inefficiencies exist that if solved lead to a more efficient economy overall. The dynamic modelling indicated that there is a rebound effect: in the Mandatory scenario the potential 15% reduction in resource use compared to baseline in the static analysis (see right column in table 5.9) is reduced to 10% in the EXIOMOD results. This rebound hence does not erase all gains in resource efficiency that technical improvement options provide.
3. Table 5.9 now can be used to provide two rankings. The first is the ranking of options based on contribution to reduction of resource use. Here, the following options are most relevant (reductions provided for the Mandatory scenario):
   a. Option 9.2: Increased production of products with lower impact, decreased production of higher impact products (cost neutral, 6-7.5% reduction of the EU RMC compared to baseline
   b. Option 10.1: Produce more resource-efficient products / use products more efficiently (cost neutral, 4-4.5% reduction of the EU RMC compared to baseline)
   c. Option 6.1: Reduce typical size of new housing (per dwelling) and offices (per occupant) (cost neutral, 1-1.5% reduction of the EU RMC compared to baseline)
   d. Option 3.2 and 5.1: Recycle concrete and soil instead of landfilling /use as road base (net benefits; 0.5-1% reduction of the EU RMC compared to baseline)
   e. Option 8.1: Reduce the amount of waste from construction (net benefits; up to 0.5% reduction of the EU RMC compared to baseline
   f. Other options, such as landfill mining (5.3), stimulating building in wood rather than concrete (9.1), asphalt recycling (3.1) and the use of stockpiled fly ash (5.2) may give additional reductions of the RMC but the two approaches do not always agree to what extent. Landfill mining further seems not a win-win.
4. The second is to rank options on cost savings in Euro per ton RMC reduced. This is the classical ranking done in cost curves. From Table 5.7 we can see however that the list then is led by options that do not provide any significant volume reduction of the EU-27 RMC:
   a. Option 1.1: Change from adhesive fixing to tactile fixing of flooring
   b. Option 2.1: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology
   c. Option 2.2: Increase typical durability from 5 to 6 years

It is further clear that some recycling options for waste flows with a small volume, and that require expensive collection systems, hardly can be seen as a priority from a resource efficiency perspective. Particularly the recycling of plasterboard and float glass seems only sensible if there is already a reason for collecting these materials separately.

Overall, this analysis gives fairly clear set of policy recommendations. Policies that aim to increase the resource efficiency of the built environment should focus on the following options:

a. Option 9.2: Increased production of products with lower impact
b. Option 10.1: Produce more resource-efficient products / use products more efficiently
c. Option 6.1: Reduce typical size of new housing
d. Encouraging recycling of large flows of construction and demolition waste (option 3.2 and 5.1: Recycle concrete and soil instead of landfilling /use as road base, but probably also asphalt recycling (3.1)
e. Option 8.1: Reduce the amount of waste from construction

[27] Due to dynamic effects like rebounds this is lower as the 15% calculated via static approaches.

Table 5.9 shows that these options are all cost-neutral and create win-wins, and in combination count for around 80% of the potential reduction of the EU-27 RMC in 2030 compared to the baseline. The analysis also suggests that targeted policies, including mandatory approaches which stimulate maximum uptake levels of technical improvement options, have a more positive effect on GDP as compared with a generic ETR. In terms of the modelling, we assumed the following policy package could deliver it:

- A mandatory system of Environmental product declarations, GPP, labels, and minimum performance standard for building and construction products (supportive to option 9.2)
- A mandatory, harmonized system of assessing the environmental performance at building and infrastructure levels, for instance by creating LCA databases and EPFD systems compatible with BIM systems (supportive to option 10.1)
- Stringent recycling and prevention targets, supported by landfill bans and – taxes.

It must be noted that the preference for a specific policy package also will depend on the goals a policy would like to achieve. As indicated in Figure 5.2 overall the 'Mandatory' scenario, a combination of voluntary measures with a moderate ETR with a 20% resource tax, and an ETR based on a 35% resource tax can result in similar overall reductions of the European RMC. At the specific material level, however, figures 5.5 – 5.8 show quite different results. Since the 'Mandatory' scenario targets building and construction materials specifically, we see here the highest reductions in the area of non-metallic minerals. These are materials with relatively low life cycle impacts. The ETR scenarios have a much higher impact on the reduction of the use of fossil energy, and hence contribute much more effectively to climate mitigation.

6 Conclusions and suggestions for further research

6.1 Conclusions and policy implications

This report gives the result of a study commissioned by the European Commission aimed at identifying the potential for resource efficiency improvements in the built environment. This study has included modelling and assessment of the economic, social and environmental effects of efficiency improvements quantitatively up to 2030, both from single technical options and more system-wide changes.

The core methodology applied in the study was a hybrid modelling approach: identifying technical improvement options, their costs and improvement potential at the micro/meso level, and then feeding them into a macro-model (EXIOMOD) to assess economy-wide impacts of improvement scenarios. Validation of assumptions and data via stakeholder engagement and workshops was an important part of the project. From this study, the following conclusions and policy implications can be derived

1. **Significant reductions in the EU-27 resource use are possible, with a positive effect on European GDP**. The study shows that in the 'Mandatory' scenario almost 10% reduction of resource use is possible, taking dynamic rebound effects into account. In this scenario the European GDP rises almost 150 billion Euro compared to the baseline. We see, in fact, that many of the resource efficiency technical improvement options are win-wins. The modelling included as inputs the investment costs for technical improvement options as well as administrative costs related to policies. The modelling showed that societal benefits are higher than societal costs. The bottom-up life cycle costing in chapter 3 further suggests that in virtually all cases there is no distributional effect (i.e. benefits are for the investor), suggesting that a number of non-financial bottlenecks prevents implementation of win-win options.

2. **Resource efficiency policies need to be targeted if they are to lead to lower environmental impacts**. The 'Mandatory' scenario is very successful in reducing the use of resources, but reduces mainly the use of non-metallic minerals (over 20%, see Figure 5.8). The reduction of fossil fuel use in the 'Mandatory' scenario is much more limited. The ETR 35% scenario, in contrast, taxes all resources (apart from food) in general. The model simulation shows in this scenario a significant reduction in the use of fossil fuels, and hence GHG emissions, as a consequence (see Figure 5.5).

3. **Policies focusing covering high volumes of materials will have most impact.** The study covered a diverse set of technical improvement options, ranging from across the board policies that stimulate more resource-efficient production of building and construction materials, use of building materials, and specific options like prolonging the durability of paints and flooring. Not surprisingly, this study shows that policy packages focusing on large material flows have most impact. These are:
    a. Option 9.2: Increased production of products with lower impact.
    b. Option 10.1: Produce more resource-efficient products / use products more efficiently.
    c. Option 6.1: Reduce typical size of new housing.
    d. Encouraging recycling of large flows of construction and demolition waste (options 3.2 and 5.1: Recycle concrete and soil instead of landfilling /use as road base, and probably also 3.1: asphalt recycling).

e. Option 8.1: Reduce the amount of waste from construction.

Note these options do not essentially target, a priori, existing infrastructure and buildings or new infrastructure and buildings. While this finding seems an open door, it shows very clearly that focusing policy attention on generic systems for, e.g., EPDs, environmental performance rating of building and infrastructure works as a whole, is more effective than paying similar attention to, e.g., the recycling of small flows of building and construction materials. Particularly recycling of small flows of materials that need a high degree of manual labour in collection, such as float glass and plaster board, may not be cost-effective.

4. **Mandatory instruments or an effective level of Environmental Tax Reform is required to have the highest reductions of resource use.** In this analysis, mandatory instruments and financial instruments appeared to have the largest resource efficiency impacts. We see that the penetration rates of technical improvement options simply are much larger in the 'Mandatory' scenario, which ensures that options with high resource efficiency improvements (recycling, intensification of use of buildings, stimulating use of more resource-efficient construction materials) will be implemented. An ETR focusing on building and construction materials also will result in more efficient resource use, but will result in a different mix of resources of which the use is reduced – the ETR scenarios give a relatively high reduction of fossil energy materials and hence CO_2 emissions, but relatively less reductions of the use of non-metallic minerals. It further has to be noted that the place in the value chain where the environmental tax is levied has specific advantages and disadvantages. In our modelling approach the tax was levied on domestically extracted and imported materials. This is transparent and relatively easy to implement. The disadvantage is that intermediate and final products made with these materials will become more expensive, and hence face higher competition of the corresponding imported intermediate and final products, made in countries with lower resource taxes. A tax on products for final consumption that is based on embodied resource use in these products avoids this problem. At the same time, calculating embodied resource use will introduce uncertainties and hence is likely to be contested too. There are in essence two ways to build upon this finding:
   a. Taxation and hence ETR is the mandate of EU member states. The EU however could do additional studies and embark on policy dialogues with member states to stimulate ETR.
   b. The EU itself could develop, within its mandate, more mandatory instruments that complement the largely voluntary instruments such as ecodesign, GPP, certification of buildings, etc.

5. **Standardization and certification play a major role in any policy package**. In a way it is a bit surprising that the study found the availability of significant win-win options, which are not yet implemented. This suggests that non-financial bottlenecks exist which hinder implementation of technical improvement options. For instance, while the use of recycled materials may be cheaper, at this stage the performance characteristics of products made of recycled materials may not be tested as well as for products of primary materials. Hence in all policy packages, information about the environmental performance of materials, the quality of recyclates, and the environmental performance of buildings and infrastructure as a whole is highly relevant. This clearly calls for attention to standardization and certification in any policy package.

6. **The long life of buildings and infrastructure poses limits with regard to resource efficiency improvements on the short term**. Buildings and infrastructure have a very long life time, often of 100 years or more. The modelling in this study was done for a time horizon of 2030. As indicated above, 'greening' expenditure on building and construction materials now already gives significant

environmental benefits, while over time constructing infrastructure that is more sustainable will lead to a sustainable infrastructure stock. We did further a qualitative scenario analysis was done (see TP6) that showed that the following technical improvement options are relevant, even though they only have impact on the long term

a. Design for repair, disassembly and recycling (particularly of buildings of buildings as a whole)
b. Ensuring a high adaptability/flexibility/functionality of design so that the building and infrastructure can have a long service life regardless of future developments.

The policy packages proposed in this report provide in principle no conflict with policies stimulating such long-term technical improvement options. There is however always a danger that policies will focus on the short-term wins. Furthermore, if minimum environmental or technical performance criteria in administrative or informative instruments focus too much on means rather than goals, lock-ins may occur that prevent these options from being stimulated.

6.2 Suggestions for further research

This study provided a thorough analysis of the options for realising a resource-efficient built environment in Europe. As with any complex study, not all problems could be solved and suggestions for further research remain. Notable topics include:

1. Impacts of policy instruments. This study entailed the analysis of the effects of policy instruments as inputs to modelling. It appeared that literature which quantifies the impact of policy instruments in a way that it can be input to modelling is scarce. More research that quantitatively analyses the effects of policy instruments is desirable.
2. Alignment of bottom-up and top-down data. This study is one of the few that has attempted to combine different sources of information and different data sets to analyse the environmental and economic implications of technical improvement options with regard to resource efficiency (i.e. LCA and EE IO / dynamic models). As shown by Table 6.1, such data sets in practice do not give exactly the same results, while in theory they should (as EE IO databases that underlie dynamic models can be seen as aggregated life cycle inventories). Aligning LCA and EE IO databases is another research question.
3. Analysing other domains. As shown by, a.o., the EIPRO study, the built environment is an area with high environmental impacts. The resources used in the built environment, however, tend to have relatively low life cycle impacts. The 2010 UNEP Resource panel study on environmental impacts of products and resources showed that fossil fuels and biotic materials are the materials with the highest environmental impacts. It is suggested to do similar studies as this one for e.g. the use of fossil fuels and biotic materials.
4. Detailing insight into costs and impacts of technical improvement options. Even a relatively large study as this one has had limitations in analysing in detail the costs and environmental benefits of technical improvement options. A structural analysis of such characteristics of technical improvement options is relevant.

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Annex 1: Description of technical improvement options

Technical improvement options	Description of technical improvement option	Description of products involved
1. Design for deconstruction: adhesive flooring	**This technical improvement option is based on a change from adhesive fixing (e.g. using types of glue) to tactile fixing of flooring. It will allow for faster, more flexible and more extensive reuse of carpets. It requires changes from the construction sector, whereas carpet producers need not make major changes to their product.**	**Tufted and needle felt carpets, prepared glues and other adhesives**
2. Increase durability and service life: durable paint and flooring	**This technical improvement option is based on an extension of the average service life of paint and carpet flooring. The durability change of carpets is assumed to be from 7 to 9 years. This is done through reducing pile depth and fibre technology. The durability change of paints is assumed to be from 5 to 6 years. This can be achieved by changing the composition of the paint, anticipating different expectations from final users.**	**Tufted and needle felt carpets, paints based on aqueous or acrylic material**
3.Increased recycling of waste: increase in recycling share of asphalt, concrete, soil, PVC, float glass, carpet and plasterboard	**This technical improvement option is based on focused intensification of recycling efforts. It relates to the following materials and/ or applications: asphalt back into roads instead of landfilling, concrete and soil instead of landfilling, PVC at end of life instead of energy recovery, float glass at end of life, carpets at end of life, plasterboard at end of life. The change requires more stringent versions of policies already required under the Waste Framework Directive relating to construction and demolition waste.**	**Bitumen, gravel, crushed stone, tubes, plastic doors and windows, plastic sheets, float glass, carpets, plasterboards**
4. Increased renovation rate: energy efficiency improvements	**This technical improvement option is based on a partial extension of renovation of buildings ("partial renovation"), focusing on energy-efficiency measures. For details of modelling assumptions on renovation, see TP4. The policy options require no new instruments or products. Rather, authorities are asked to use the existing instruments they apply anyway in spatial planning and built environment, in such a way that renovation is stimulated over demolition and new construction. This entails more stringent evaluation criteria and planning directed on the long term use of buildings. A focus on public buildings is assumed.**	**Doors, windows, insulating glass, insulating sheets, insulating cladding paints, efficient boilers**
5.Increased use of recycled material: increase in amount of waste used in construction process	**This technical improvement option is based on the reuse of specific and typical construction waste.** **Three measures are defined. First, the use of demolition waste in road base and building fill. Uptake rate of this technical improvement option indicates he share of demolition waste that becomes a part of the road base. Second, the use of stockpiled fly ash/pulverised fuel ash (PFA) to replace cement in concrete applications. Finally, the mining of landfills as a source of secondary materials. It can be realised in relatively short time, setting minimum standards (e.g. the Ecodesign directive) and R&D support for landfill mining.**	**Gravel, crushed stone, cement, various metal ores**
6.Intensify use of buildings: more persons per m2	**This technical improvement option is based on the redesign of buildings in order to make more efficient use of floor space. It envisages the reduction of typical size of new housing (per dwelling) and offices (per occupant). The scenario requires a relatively great involvement of**	**The "construction material mix"[28]**

[28] paints, tubes, sanitary ware, doors, windows, roof elements, various construction elements, insulating glasses, ceramic sinks, (roofing) tiles, Portland cements, gypsum plasters, cement building blocks, ready mixed concrete, paper construction elements, natural stone, worked stone elements, bitumen rolls, slag wool, radiators, boilers, nails, tacks, screws, ventilators

Technical improvement options	Description of technical improvement option	Description of products involved
	policy. For residential purposes, allocation legislation that relates housing size to family size should be defined, using taxation as instrument. For offices, guidelines regulating maximum space per employee would be necessary.	
7.Reduce used land use: increase density of built environment	**This technical improvement option is based an overall increase of density of new developments in the built environment. It requires legislation on a spatial level above that of the actual building. Existing spatial planning and building permit systems to support development of compact cities and dense land use can be used. Implementation takes place on the local level. A supportive dissemination and research program could be helpful in this demanding societal change.**	**The "construction material mix"**
8.Reduce construction waste: reduce waste flow from construction	**This technical improvement option is based on the top of the waste reduction hierarchy: prevention. The reduction of amount of waste from construction is difficult, as the construction sector does not have economic incentives to reduce its waste flow. Reduction in the waste flow from construction sector requires implementation of policy measures additional to the current ones. For instance, the development of guidelines for construction waste minimization, education, guidelines to be used as criteria in procurement procedures etc.**	**The "construction material mix"**
9.Select materials with low impact: use materials with low environmental impact in construction	**This technical improvement option is based on the reduction of use of materials that have a high indirect raw material use. It defines three variations. First the use of lightweight timber construction instead of heavyweight masonry. Second, the increased production of products with lower impact as expressed by the Raw Material Equivalent of Eurostat. Third, the reduction of energy consumption of asphalt laying by moving from hot mix to warm mix asphalt. It requires a realistic but wide array of (policy) measures, such as updated ecolabel criteria, an operational definition of Gross Primary Production, new CEN standards, a LCA database that is compatible with BIM systems and the development of a harmonized assessment system at EU level.**	**Textiles, base metals, wood, LPG,**
10.Use materials more efficiently: produce more resource efficient products	**This technical improvement option is based on an increased production of more resource-efficient products. It relates closely to technical improvement option 9, but it focuses on more production instead of more use. Progress can be measured based on the information about current implementation of Environmental Protection Directives across the EU member states; differentiating between the group of countries with established EPD schemes (AT,FR,DE,SE,GB) and the group of countries with new EPD schemes (DK,FI,ES,IT,NL,PL,BE,PT).**	**The "construction material mix"**

Annex 2: Summary of technical improvement options, accompanying policies, and related administrative costs

No	Technical improvement option	Policies proposed	Administrative costs (Mio Euro)				Explanation
			Government		Business		
			Once off	Per annum	Once off	Per Annum	
1	Design for deconstruction (case focused on magnetic adhesive flooring)	Green public procurement Ecolabelling In due time: minimum standards via e.g. the Ecodesign directive	62,5			0	Total GPP implementation costs estimated at 100-150 Mio Euro once off in Europe. Efforts in de building sector may be at most half of this. Industry does not face different practices as regular procurement procedures so no additional administrative costs assumed. Ecolabel costs already included under 2
2	Increase durability and service life of products	Green public procurement	p.m.			0	GPP implementation costs already accounted for under 1). See further explanation under 1.
	(cases: asphalt, paint, flooring)	Including durability criteria in Ecolabels for paint and flooring	0,01		12,4	3	Criteria development at EU level at 25kEuro per product for 2 products. For business, we assume 200 companies applying, with 10 product lines each, with annually 1500 Euro ecolabel license fee and once-off 6200 Euro application and testing fees.
		In due time: minimum standards via e.g. the Ecodesign directive					Not feasible on the short term
3	Increase recycling of waste at end of life - Asphalt - Concrete - PVC - Float glass - Carpet - Plasterboard	More stringent versions of policies already required under the WFD to realise 70% recycling of C&D waste. It concerns mandatory administrative and financial instruments like: source separation; quality standards for secondary raw materials; re-use and recycling targets; landfill taxes This may require enhancement and subsequent enforcement of the 70% goal buy the EC	p.m.	p.m	p.m	p.m	Rough estimates of WFD implementation indicate some 500 Mio Euro administrative costs EU wide, of which some 100 Mio Euro could be allocated to C&D waste. These costs have to be made anyway, and it is not clear to see that implementing more stringent targets at national level would entail additional costs since the instruments are the same.
		Adjusting Ecolabels and GPP criteria to include recycled content	p.m.	p.m	p.m	p.m	Is already discussed under 5
4	Increase renovation rate	Use existing policies to stimulate renovation rather than demolition: - Spatial planning directed on the long term use of buildings - Focus on renovation in redevelopment plans of city quarters and public buildings	p.m.	p.m	p.m	p.m	The policy options require in no new instruments. Rather, authorities are asked to use the instruments they apply anyway in spatial planning and built environment, in such a way that renovation is stimulated over demolition and new construction.

No	Technical improvement option	Policies proposed	Administrative costs (Mio Euro)				Explanation
			Government		Business		
			Once off	Per annum	Once off	Per Annum	
		- More stringent evaluation criteria for getting demolition permits					
		Awareness campaign and best practice exchange	10				Similar to 3-4 network projects under EU FP7 or JPI Urban Europe
5	Increase use of recycled material (C&D waste, fly ash, landfill mining)	Developing or adjusting Ecolabel and GPP criteria so that they include demands for recycled content	0,01		12,4	3	Criteria development at EU level at 25 kEuro per product (cement and aggregates). Inclusion of more products hardly adds to costs. For business, we assume 200 companies applying, with 10 product lines each, with annually 1500 Euro ecolabel license fees and once off 6200 Euro application and testing fees.
		Green public procurement	p.m.	p.m	p.m	p.m	GPP implementation costs already accounted for under 1). See further explanation under 1.
		In due time: minimum standards via e.g. the Ecodesign directive					Questionable if this still is needed if the measures under 3) on increasing recycling rates are implemented.
		R&D support for landfill mining	2.5				Landfill mining is still in an experimental stage. Some interesting initiatives are currently co-funded by EFRO and national subsidy schemes. Some major Horizon 2020 projects suggested
6	Intensify use of buildings	Residential: allocation legislation that relates housing size to family size	p.m.	p.m	p.m	p.m	Politically probably not feasible; otherwise administrative costs around 1 ct per EU citizen
		Residential: gradually adjusting housing taxes on the basis of relation between family size and housing size (number of room)	p.m.	p.m	p.m	p.m	Countries have already complex housing taxing systems that are regularly updated; apart from difficult to estimate transition costs no annual costs can be foreseen.
		Offices: regulating maximum space per employee	p.m.	p.m	p.m	p.m	Politically questionable, otherwise administrative costs of less as 1% of office rental prices at stake. For small offices this may be higher.
		Offices, government: planning to use offices as efficient as possible.	p.m.	p.m	p.m	p.m	Implies planning at authorities about the use of their own office space, which happens anyway
7	Reduce land used by the built environment	Use existing spatial planning and building permit systems to support development of compact cities and dense land use.	p.m.	p.m	p.m	p.m	No additional administrative costs since existing instruments are used
		Implement a supportive dissemination and research program (compare ESPON)	50				This is probably a high-end estimate since it reflects the costs of ESPON, a knowledge development program much broader as needed in this case.
8	Reduce construction waste arising	Development of guidelines for construction waste minimization	1	p.m	p.m	p.m	Assumes a major project at EU level to consolidate best practice documents from member states and make some educational web-based tools available.
		Education and training	p.m.	p.m	p.m	p.m	Costs difficult to estimate. It must be assumed that industry employees will have education and training to catch up with best practice on a regular basis

No	Technical improvement option	Policies proposed	Administrative costs (Mio Euro)				Explanation
			Government		Business		
			Once off	Per annum	Once off	Per Annum	
		Making guidelines mandatory in building codes	p.m.	p.m	p.m	p.m	Is a very simple administrative adjustment
		Use guidelines as criteria in procurement procedures	p.m.	p.m	p.m	p.m	Is a very simple addition in what usually are very complicated procurement procedures and - documents
9	Select low impact material						
	a: Material level	Ecolabel criteria	1,25		61,25	75	Based on the extreme assumption that 50 building product categories with 10 product lines each made by 100 different companies (i.e. 50.000 applications) would be at stake, and that they all have to pay the highest fees under the EU ecolabel scheme (1500 Euro/pa license and 1200 Euro application fees once off. Testing costs neglected due to existing EPDs. Next to this 25 k costs for authorities and industry for criteria development per specific product.
		GPP	p.m.	p.m	p.m	p.m	GPP implementation costs already accounted for under 1). See further explanation under 1.
		Minimum legal standard	50	25-50			Based on the assumption 100 product groups would be regulated, which is much more as now under the Ecodesign Directive.
	b: Building level	A few dozen CEN standards	2		2		A similar number of standards had to be developed for the EPB Directive. Secretarial and meeting costs estimated at 4 Mio Euro, here split 50-50% between government and industry
		Development of an LCA-alike database that is compatible with BIM systems	4				Costs estimated on the basis of major LCA database development projects
		Development of a harmonized assessment system at EU level	6		6		Not clear, but this can easily become a long process and discussion, supported by significant research projects. Here set on 3 times the costs of developing CEN standards.
		Assessment and certification costs					Between 10 and 40 k for a 10.000 m2 building, to be renewed any 5 years. Is normally below 1% of annual renting costs. Absolute costs cannot be estimated since it is not clear for how many buildings BREEAM and LEED alike certifications would be done.
10	Use construction materials more efficiently		p.m.	p.m	p.m	p.m	Identical to option 9.a: more efficient production of construction materials leads to materials with lower impacts.
	TOTAL		**189,27**	**0**	**94,05**	**81**	

Source and underpinning: see TP5

Annex 3: Penetration rates of technical improvement options

A3.1: Uptake rates in the base year by EU member state

	1.1. Change from adhesive fixing to tactile fixing of flooring	2.1. Flooring: Increase carpet durability from 7 to 9 years through	2.2. Paint: Increase typical durability from 5 to 6 years	3.1. Recycle asphalt back into roads instead of landfilling	3.2. Recycle concrete and soil instead of landfilling	3.3. Recycle PVC at end of life instead of landfill or energy recovery	3.4. Recycle float glass at end of life instead of landfilling	3.5. Recycle carpet at end of life instead of landfilling	3.6. Recycle plasterboard at end of life instead of landfilling	4.1. Increase rate of take-up of renovation for energy-efficiency measures	5.1. Use recycled construction and demolition waste in road base and	5.2. Use stockpiled fly ash / pulverised fuel ash (PFA) to replace	5.3. Mine landfills and use as a source of secondary materials and	6.1. Reduce typical size of new housing (per dwelling) and offices (per occupant)	7.1. Increase density of new housing developments	8.1. Reduce amount of waste from construction	9.1. Use lightweight timber construction instead of heavyweight	9.2. Increased production of products with lower impact, decreased production of	9.3. Road asphalt: Reduce energy consumption of asphalt	10.1. Produce more resource-efficient products
Austria	0%	0%	0%	95%	92%	7%	5%	7%	5%	26%	92%	0%	0%	0%	0%	0%	7%	0%	0%	0%
Belgium	0%	0%	0%	65%	73%	3%	5%	7%	5%	26%	73%	0%	0%	0%	0%	0%	5%	0%	3%	0%
Bulgaria	0%	0%	0%	59%	61%	5%	5%	7%	5%	29%	61%	0%	0%	0%	0%	0%	4%	0%	4%	0%
Cyprus	0%	0%	0%	59%	0%	5%	5%	7%	5%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Czech Republic	0%	0%	0%	49%	55%	16%	5%	7%	5%	17%	55%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Denmark	0%	0%	0%	80%	82%	3%	5%	7%	65%	38%	82%	0%	0%	0%	0%	0%	8%	0%	7%	0%
Estonia	0%	0%	0%	59%	86%	5%	5%	7%	5%	17%	86%	0%	0%	0%	0%	0%	17%	0%	0%	0%
Finland	0%	0%	0%	80%	6%	5%	5%	7%	5%	38%	6%	0%	0%	0%	0%	0%	28%	0%	14%	0%
France	0%	0%	0%	45%	59%	2%	5%	7%	5%	26%	59%	0%	0%	0%	0%	0%	3%	0%	3%	0%
Germany	0%	0%	0%	84%	85%	9%	5%	7%	5%	26%	85%	0%	0%	0%	0%	0%	9%	0%	3%	0%
Greece	0%	0%	0%	0%	0%	5%	5%	7%	5%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hungary	0%	0%	0%	100%	53%	1%	5%	7%	5%	29%	53%	0%	0%	0%	0%	0%	4%	0%	0%	0%
Ireland	0%	0%	0%	40%	67%	5%	5%	7%	5%	26%	67%	0%	0%	0%	0%	0%	7%	0%	3%	0%
Italy	0%	0%	0%	20%	96%	3%	5%	7%	5%	47%	96%	0%	0%	0%	0%	0%	3%	0%	3%	0%
Latvia	0%	0%	0%	59%	91%	5%	5%	7%	5%	17%	91%	0%	0%	0%	0%	0%	23%	0%	4%	0%
Lithuania	0%	0%	0%	59%	73%	5%	5%	7%	5%	17%	73%	0%	0%	0%	0%	0%	22%	0%	4%	0%
Luxembourg	0%	0%	0%	100%	95%	5%	5%	7%	5%	26%	95%	0%	0%	0%	0%	0%	11%	0%	1%	0%
Malta	0%	0%	0%	59%	14%	5%	5%	7%	5%	47%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Netherlands	0%	0%	0%	98%	99%	6%	59%	7%	65%	26%	99%	0%	0%	0%	0%	0%	7%	0%	3%	0%
Poland	0%	0%	0%	0%	70%	4%	5%	7%	5%	17%	70%	0%	0%	0%	0%	0%	3%	0%	0%	0%
Portugal	0%	0%	0%	65%	47%	1%	5%	7%	5%	47%	47%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Romania	0%	0%	0%	87%	37%	1%	5%	7%	5%	29%	37%	0%	0%	0%	0%	0%	4%	0%	4%	0%
Slovakia	0%	0%	0%	59%	45%	2%	5%	7%	5%	17%	45%	0%	0%	0%	0%	0%	4%	0%	0%	0%
Slovenia	0%	0%	0%	50%	92%	5%	5%	7%	5%	29%	92%	0%	0%	0%	0%	0%	3%	0%	0%	0%
Spain	0%	0%	0%	83%	41%	4%	5%	7%	5%	47%	41%	0%	0%	0%	0%	0%	3%	0%	0%	0%
Sweden	0%	0%	0%	80%	77%	2%	5%	7%	65%	38%	77%	0%	0%	0%	0%	0%	31%	0%	7%	0%
United Kingdom	0%	0%	0%	45%	76%	7%	5%	9%	5%	26%	76%	0%	0%	0%	0%	0%	5%	0%	3%	0%

A3.2: Uptake rates assumed in the baseline scenario

technical improvement options	Current maximum cross-EU uptake rates	Current average EU uptake rates	Maximum technically feasible uptake rates	Uptake rates assumed in the LCI/LCA analysis	Uptake rates in the baseline scenario*	Assumptions of the baseline scenario
1. Design for deconstruction						
1.1. Change from adhesive fixing to tactile fixing of flooring	**0%**	**0%**	**80%**	**30%**	**15%**	**New construction products under the categories 'Design for deconstruction' and 'Increase durability and service life' represent a good investment for both households and firms. Their economic costs in the long-run are lower than the benefits. Due to economic reasons new products will gradually penetrate into the market and the penetration rate is assumed to be half of the one proposed in the LCI/LCA analysis from TP4. Analysis in TP4 has been performed under the assumption of implementation of voluntary agreements related to the use of new products which is not the case for all countries in the baseline.**
2. Increase durability and service life of products						
2.1. Flooring: Increase carpet durability from 7 to 9 years through reducing pile depth and fibre technology	**0%**	**0%**	**40%**[29]	**30%**	**15%**	**Durable carpets can only be used in a certain areas of the houses and offices, in particular I the hallways and corridors. This means that the market share of this type of flooring is relatively limited. The maximum market share is estimated to be 40% and represents the maximum feasible uptake rate.**
2.2. Paint: Increase typical durability from 5 to 6 years	**0%**	**0%**	**50%**	**40%**	**20%**	
3. Increase recycling of waste at end of life						
3.1. Recycle asphalt back into roads instead of landfilling	**100% (HU, LU)**	**60%**	**100%**	**100%**	**60% and higher**	
3.2. Recycle concrete and soil instead of landfilling	**99% (NL)**	**71%**	**99%**	**99%**	**71% and higher**	**It is assumed that the countries that are currently performing below EU average will reach the level of EU average by 2030, whereas countries that are currently performing above the EU average level will improve their current uptake levels with 0.5% of their current rates per year until they reach the current best practice level in EU.**
3.3. Recycle PVC at end of life instead of landfill or energy recovery	**30% (UK)**	**5%**	**60%**	**30%**	**5% and higher**	

[29] Stakeholders found this uptake maximum to be possibly over-optimistic, but the 40% uptake remained in the calculations

technical improvement options	Current maximum cross-EU uptake rates	Current average EU uptake rates	Maximum technically feasible uptake rates	Uptake rates assumed in the LCI/LCA analysis	Uptake rates in the baseline scenario*	Assumptions of the baseline scenario
3.4. Recycle float glass at end of life instead of landfilling	**60% (NL)**	**8%**	**45%**	**60%**	**8% and higher**	**Even though recycling of float glass in NL is 60% this uptake rate is not achievable in other EU countries due to large differences in construction process and legislation. The maximum technical feasible penetration rate has been set to 45% after receiving written comments from the stakeholder 'Glass For Europe'.**
3.5. Recycle carpet at end of life instead of landfilling	**30% (NL)**	**7%**	**70%**	**30%**	**7% and higher**	
3.6. Recycle plasterboard at end of life instead of landfilling	**65% (DK)**	**9%**	**70%**	**65%**	**9% and higher**	
<u>4. Increase renovation rate</u>						
4.1. Increase rate of take-up of renovation for energy-efficiency measures	**3% per annum (IT,GR,ES)**	**3% per annum**	**4% per annum**	**4% per annum**	**2% per annum and higher**	**It is assumed that the countries that are currently performing below EU average will reach the level of EU average by 2030, whereas countries that are currently performing above the EU average level will maintain their levels. It is assumed that the rate of energy-related renovations increases by 1% from a current average of approximately 2% (ECI, 2012) to approximately 3% (i.e. a 50% increase). (As the renovation rate is difficult to estimate; it is important to note that the 1% increase is not pegged to the existing rate; it is solely linked to the stock size.) Benefits in the use stage are summed over the 15-year period from 2016 to 2030.This technical improvement options concerns partial renovation of the buildings that is related to energy efficiency. The possible uptake rate is assumed to be one percentage point higher than the uptake rate in TP4.**
<u>5. Increase use of recycled material</u>						
5.1. Use recycled construction and demolition waste in road base and building fill	**99% (NL)**	**71%**	**99%**	**99%**	**71% and higher**	**It is assumed that the countries that are currently performing below EU average will reach the level of EU average by 2030, whereas countries that are currently performing above the EU average level will improve their current uptake levels with 0.5% of their current rates per year until they reach the current best practice level in EU. Construction and demolition waste in this option excludes glass to prevent conflicts with option 3.4**
5.2. Use stockpiled fly ash / pulverised fuel ash (PFA) to replace cement in concrete applications or as grout/aggregate	**0%**	**0%**	**10%**	**10%**	**0%**	**The baseline penetration of this technical improvement option is set to zero. Given that it is not economically profitable; its penetration requires implementation of a certain set of policies.**
5.3. Mine landfills and use as a source of secondary materials and energy	**0%**	**0%**	**10 out of 147 landfill mines can be used**	**2 out of 147 landfill mines**	**0%**	**The baseline penetration of this technical improvement option is set to zero. Given that it is not economically profitable; its penetration requires implementation of a certain set of policies. It is possible that in a more gradual approach a higher share than 10 landfill mines could be assumed.**

technical improvement options	Current maximum cross-EU uptake rates	Current average EU uptake rates	Maximum technically feasible uptake rates	Uptake rates assumed in the LCI/LCA analysis	Uptake rates in the baseline scenario*	Assumptions of the baseline scenario
				can be used		**There is only a few existing studies that investigate the potential of landfill mines. We have to be careful with our assumptions and try not to overestimate their potential. As a results of expert brainstorming meeting we have decided that give the necessary investments the potential number of landfill mines can be increased by factor of five.**
6. Intensify use of buildings						
6.1. Reduce typical size of new housing (per dwelling) and offices (per occupant)	**0%**	**0%**	**5% reduction in total floor area**	**5% reduction in total floor area**	**0%**	**Current trend goes in the direction of increase in the size of housing. Given the recent economic and housing market crises we make an assumption that there will be no change in the size of typical new house and/or office in the baseline.**
7. Reduce land used by the built environment (intensification)						
7.1. Increase density of new housing developments	**0%**	**0%**	**5% reduction in total floor area**	**5% reduction in total floor area**	**0%**	**Current trend goes in the direction of increase in the size of housing. Given the recent economic and housing market crises we make an assumption that there will be no change in the size of typical new house and/or office in the baseline.**
8. Reduce construction waste arising						
8.1. Reduce amount of waste from construction	**0%**	**0%**	**67%**	**50%**	**0%**	**Construction sector does not have economic incentives to reduce its waste flow. Reduction in the waste flow from construction sector requires implementation of policy measures additional to the current ones.**
9. Select materials with low impact						
9.1. Use lightweight timber construction instead of heavyweight masonry	**30% (SE)**	**5%**	**40%**	**40%**	**5% and higher**	**It is assumed that the countries that are currently performing below EU average will reach the level of EU average by 2030, whereas countries that are currently performing above the EU average level will improve their current uptake levels with 0.5% of their current rates per year until they reach the current best practice level in EU.**
9.2. Increased production of products with lower impact, decreased production of higher impact products	**0%**	**0%**	**20%**	**10%**	**0%**	**The uptake rates in the baseline are assumed to be zero.**
9.3. Road asphalt: Reduce energy consumption of asphalt laying by	**14% (FI)**	**3%**	**90%**	**90%**	**3% and higher**	**It is assumed that the countries that are currently performing below EU average will reach the level of EU average by 2030, whereas countries that are currently performing above the EU average level will improve their current uptake levels with 0.5% of their current rates per year until they**

technical improvement options	Current maximum cross-EU uptake rates	Current average EU uptake rates	Maximum technically feasible uptake rates	Uptake rates assumed in the LCI/LCA analysis	Uptake rates in the baseline scenario*	Assumptions of the baseline scenario
moving from hot mix to warm mix asphalt						**reach the current best practice level in EU.**
10. Use construction materials more efficiently						
10.1. Produce more resource-efficient products	**0%**	**0%**	**30% of products become 25% more resource efficient, 70% of products become 5% more efficient**	**30% of products become 25% more resource efficient**	**0%**	**The uptake rates in the baseline are assumed to be zero.**

*The values shown for uptake rates in the baseline scenario are sometimes already surpassed by some countries. In those cases all countries reach the baseline value except when the current uptake rate is already higher.

A3.3: Scenario-specific penetration rates of the technical improvement measures by 2030

Technical improvements	'Best practice uptake of technical improvements'		'Policy package with voluntary implementation of instruments'		'Policy package with mandatory implementation of instruments'	
	Penetration rates by 2030 across all EU member states	Assumptions used for calculation	Penetration rates by 2030 across all EU member states	Assumptions used for calculation	Penetration rates by 2030 across all EU member states	Assumptions used for calculation
1.Design for deconstruction: adhesive flooring	1.1 Flooring:15%	We assume that the countries reach the best practise uptake in the baseline scenario.	1.1 Flooring:30%	Analysis in TP4: Given that this new product saves money and time for the users, its uptake can be quite significant. Uptake is based on expert judgment.	1.1 Flooring:80%	Mandatory implementation of policy measures will result in maximum physically possible penetration rate which is lower than 100%.
2. Increase durability and service life: durable paint and flooring	2.1 Flooring:15% 2.2 Paint: 20%	We assume that the countries reach the best practise uptake in the baseline scenario.	2.1 Flooring:30% 2.2 Paint: 40%	Analysis in TP4: The uptake is considered reasonable in the TP4 authors' option. Higher uptake for flooring can be difficult since hard-wearing carpet tiles are most suitable in corridors, walkways and alike. Higher uptake for paint is not specified because durable paints are not needed for surfaces that are frequently repainted. Uptake rates are calculated on the basis of expert judgment.	2.1 Flooring:40% 2.2 Paint: 50%	Mandatory implementation of policy measures will result in maximum physically possible penetration rate
3.Increased recycling of waste: increase in recycling share of asphalt, concrete, soil, PVC, float glass, carpet and plasterboard	3.1 Road asphalt: 100% 3.2 Concrete and soil: 99% 3.3 PVC: 30% 3.4 Float glass: 30% 3.5 Carpet: 30% 3.6 Plasterboard: 65%	Analysis in TP4: Road asphalt: best practise achieved in Luxemburg Concrete and soil: best practise achieved in the Netherlands PVC: evidence from UK on increase in recycling of municipal waste Float glass: Best practice in the Netherlands is higher (59%) but stakeholders argued this is achieved under conditions that cannot be replicated in most EU Member states	3.1 Road asphalt: 80% 3.2 Concrete and soil: 85% 3.3 PVC: 30% 3.4 Float glass: 20% 3.5 Carpet: 20% 3.6 Plasterboard: 30%	Voluntary implementation of policy instruments ensures that all EU countries will reach the level of uptake rates halfway between the current EU average and 'Mandatory' scenario.	3.1 Road asphalt: 100% 3.2 Concrete and soil: 99% 3.3 PVC: 60% 3.4 Float glass: 45% 3.5 Carpet: 70% 3.6 Plasterboard: 70%	Introduction of landfill ban in combination with other supporting measures results in maximum possible recycling of waste flow.

Technical improvements	**'Best practice uptake of technical improvements'**		**'Policy package with voluntary implementation of instruments'**		**'Policy package with mandatory implementation of instruments'**	
	Penetration rates by 2030 across all EU member states	**Assumptions used for calculation**	**Penetration rates by 2030 across all EU member states**	**Assumptions used for calculation**	**Penetration rates by 2030 across all EU member states**	**Assumptions used for calculation**
		Carpet: best practise achieved in the Netherlands Plasterboard: best practise achieved in Denmark				
4. Increased renovation rate: energy efficiency improvements	4.1 Rate of energy-related innovations to 3% per annum	Analysis in TP4: Current average annual renovation rate across EU countries is 2%. An increase of 50% to 3% per year is assumed to be reasonable. Estimations are based on expert judgement.	4.1 Rate of energy-related innovations to 2.5% per annum	Voluntary implementation of policy instruments results in lower renovation rate as compared to the mandatory implementation of policy instruments in combination with subsidies	4.1 Rate of energy-related innovations to 4% per annum	The uptake is based on the PE data on current annual renovation rates under the assumption that all renovations will improve energy efficiency of buildings.
5.Increased use of recycled material: increase in amount of waste used in construction process	5.1 Recycled construction and demolition waste: 99% 5.2 Use of stockpiled fly ash: 0% 5.3 Use of land fill mines: 0%	We assume that the countries reach the best practise uptake in the baseline scenario.	For countries below the average EU-level: 5.1 Recycled construction and demolition waste: 71% 5.2 Use of stockpiled fly ash: 5% 5.3 Mine landfills: 2 out of 147 is suitable for landfill mining	Analysis in TP4: best practise achieved in the Netherlands. Uptake for fly ash cannot be higher due to physical reasons. Dutch study estimates are used for landfill mining (see van der Zee, Achterkamp and de Visser, 2003).	5.1 Recycled construction and demolition waste: 99% 5.2 Use of stockpiled fly ash: 10% 5.3 Mine landfills: 10 out of 147 is suitable for landfill mining	With additional investments in showcases and inventory of landfill mines it is possible to boost the penetration rates related to their use for construction.
6.Intensify use of buildings: more persons per m2	6.1 0% reduction in total floor area	We assume that the countries reach the best practise uptake in the baseline scenario.	6.1 0.5% reduction in total floor area	Voluntary policy instruments result in relatively low reduction in floor area	6.1 5% reduction in total floor area	Analysis in TP4: existing upward trend of average flooring area trend must be overcome with this measure. Only applied to new-build construction. Uptake rate is based on expert judgment.
7.Reduce used land use: increase density	7.1 0% reduction in total floor area	We assume that the countries reach the best practise uptake in the baseline scenario.	7.1 0.5% reduction in total floor area	Voluntary policy instruments result in relatively low reduction in floor area	7.1 1% reduction in total floor area	Analysis in TP4: existing upward of average flooring area trend must be overcome with this measure. Only applied to new-build construction. Uptake rate is based on expert judgment.

Technical improvements	**'Best practice uptake of technical improvements'**		**'Policy package with voluntary implementation of instruments'**		**'Policy package with mandatory implementation of instruments'**	
	Penetration rates by 2030 across all EU member states	**Assumptions used for calculation**	**Penetration rates by 2030 across all EU member states**	**Assumptions used for calculation**	**Penetration rates by 2030 across all EU member states**	**Assumptions used for calculation**
8.Reduce construction waste: reduce waste flow from construction	8.1 0% reduction in waste flow	We assume that the countries reach the best practise uptake in the baseline scenario.	8.1 50% reduction in waste flow	Analysis in TP4: best practise achieved in UK	8.1 67% reduction in waste flow	Policy mix is more stringent then 'Best practice' scenario
9.Select materials with low impact: use materials with low environmental impact in construction	9.1 Use timber instead of masonry: 30% 9.2 Construction products: 0% 9.3 Moving from hot mix to warm mix asphalt: 14%	We assume that the countries reach the best practise uptake in the baseline scenario.	9.1 Use timber instead of masonry: 20% 9.2 Construction products: 5% 9.3 Moving from hot mix to warm mix asphalt: 40%	Analysis in TP4: For timber best practise in the Nordic countries is assumed to be almost achieved. The use timber is only relevant for the Northern European countries. For asphalt we use outcomes of the research paper from the University of Nebraska. For other construction products we assume that some progress in the direction of the 'Mandatory' scenario is made, with a penetration rate of 5%	9.1 Use timber instead of masonry: 40% 9.2 Construction products: 20% 9.3 Moving from hot mix to warm mix asphalt: 90%	Policy mix is more stringent then 'Best practice' scenario and leads to higher effects. For 9.2 we use analysis in TP4: For other construction products as a whole we use evidence from EEA study (EEA, 2010).
10.Use materials more efficiently: produce more resource efficient products	10.1 15% of the products become 25% more resource efficient	We assume that the countries reach the best practise uptake in the baseline scenario which is an uptake of 15%.	10.1 30% of the products become 25% more resource efficient	Analysis in TP4: on the basis of expert judgement.	10.1 30% of the products become 25% more resource efficient, 70% of the products become 5% more resource efficient	Policy mix is more stringent then 'Best practice' scenario and leads to higher effects.

Annex 4: Assumptions and input with regard to financial parameters

A4.1: Administrative costs per scenario

The administrative and implementation costs for the government and industry were estimated in Topical Paper 5 and, based on the penetration rates, specified per scenario in in Topical paper 6. The administrative costs per scenario used in the modelling are provided below.

Table A4.1: Overview administrative costs for scenario "Best practice uptake of technical improvements" (in Million Euro per annum once-off or annual costs)

Best practice uptake of technical improvements						
		Government once-off	Government annual	Business once-off	Business annual	Assumptions
1	Design for deconstruction	62.5				Green public procurement and Ecolabelling
2	Increase durability and service life of products	1.1	-	12.5	3	
3	Increase recycling at end of life	-	-			Green public procurement and Ecolabelling
4	Increase renovation rate	10				
5	Increase use of recycled material	2.6	-	12.5	3	Awareness campaign.
6	Intensify use of buildings					Green public procurement and Ecolabelling. R&D support for landfill mining.
7	Reduce land used by the built environment	50				
8	Reduce construction waste arising	1				Implementation of dissemination and research program.
9	Select low impact material	63.3	25	69.3	75	Guidelines for waste minimization.
10	Use construction materials more efficiently					Ecolabelling, Green public procurement, minimum legal standard, a few dozen CEN standards, development of LCA-alike database compatible with BIM and development of harmonized assessment system at EU level.
	total	190.4	25	94.2	81	

Table A4.2: Overview of administrative costs for scenario "Policy package with voluntary implementation of instruments" (in Million Euro per annum once-off or annual costs)

Policy package with voluntary implementation of instruments						
		Government once-off	Government annual	Business once-off	Business annual	Assumptions
1	Design for deconstruction	62.5				Similar to "Best practice uptake"
2	Increase durability and service life of products	1.1	-	12.5	3	Similar to "Best practice uptake"
3	Increase recycling at end of life	-	-			
4	Increase renovation rate	10				Similar to "Best practice uptake"
5	Increase use of recycled material	2.6	-	12.5	3	Similar to "Best practice uptake"
6	Intensify use of buildings					
7	Reduce land used by the built environment	-				No implementation of dissemination and research program assumed.
8	Reduce construction waste arising	1				Similar to "Best practice uptake"
9	Select low impact material	63.3	25	69.3	75	Similar to "Best practice uptake"
10	Use construction materials more efficiently					
	total	140.4	25	94.2	81	

Table A4.3: Overview of administrative costs for scenario "Policy package with mandatory implementation of instruments" (in Million Euro once-off or annual costs per annum)

Policy package with mandatory implementation of instruments						
		Government once-off	**Government annual**	**Business once-off**	**Business annual**	**Assumptions**
1	**Design for deconstruction**	**63**	**0.01**	**0.4**	**0.1**	**In addition the Ecodesign directive is introduced. We assume 200 duty tests are required for paint and asphalt. Every four years new models are introduced which will require duty testing as well.**
2	**Increase durability and service life of products**	**1.1**	**-**	**19.9**	**6**	**Twice the number of test required compared to policy package "Best practice uptake". Testing costs for ecolabelling have overlap of 25% with Ecodesign directive testing costs.**
3	**Increase recycling at end of life**	**-**	**-**			
4	**Increase renovation rate**	**10**				**Similar to "Best practice uptake"**
5	**Increase use of recycled material**	**2.6**	**-**	**12.5**	**3**	**Similar to "Best practice uptake"**
6	**Intensify use of buildings**					
7	**Reduce land used by the built environment**	**50**				**Similar to "Best practice uptake"**
8	**Reduce construction waste arising**	**1**				**Similar to "Best practice uptake"**
9	**Select low impact material**	**64.5**	**50**	**130.5**	**150**	**Twice the number of test needed compared to the voluntary policy package, both for the introduction of Ecolabelling as well as minimum legal standards.**
10	**Use construction materials more efficiently**					
	total	**192.2**	**50.01**	**163.3**	**159.1**	

Table A4.4: Overview of administrative costs for scenario "Environmental tax reform a" (in Million Euro once-off or annual costs per annum)

Environmental tax reform						
		government once-off	annual	business once-off	annual	assumptions
1	**Design for deconstruction**	**62.5**				**Similar to voluntary policy package.**
2	**Increase durability and service life of products**	**1.1**	**-**	**12.5**	**3.0**	**Similar to voluntary policy package.**
3	**Increase recycling at end of life**	**39.3**	**11.5**	**-**	**-**	**Similar to voluntary policy package. Additional ad-valorem resource use tax on primary construction materials. In Ireland this was 1.2 million once-off and 350,000 annually. In another case in China it was implemented budget neutral. We assume that the costs in Ireland are halfway between no costs and the bag levy case.**
4	**Increase renovation rate**	**10.0**				**Similar to voluntary policy package.**
5	**Increase use of recycled material**	**2.6**	**-**	**12.5**	**3.0**	**Similar to voluntary policy package. Additional ad-valorem resource use tax on primary construction materials. Costs overlap with policy measure 3**
6	**Intensify use of buildings**					**Similar to voluntary policy package.**
7	**Reduce land used by the built environment**	**-**				**Similar to voluntary package. Increase in property taxes. This can be done through existing infrastructure.**
8	**Reduce construction waste arising**	**1.0**				**Similar to voluntary policy package. Additional ad-valorem resource use tax on primary construction materials. Costs overlap with policy measure 3**
9	**Select low impact material**	**63.3**	**25**	**69.3**	**75**	**Similar to voluntary policy package. Additional ad-valorem resource use tax on primary construction materials. Costs overlap with policy measure 3**
10	**Use construction materials more efficiently**					**Similar to voluntary policy package. Additional ad-valorem resource use tax on primary construction materials. Costs overlap with policy measure 3**
	total	**179.7**	**36.5**	**94.2**	**81**	

A4.2: Technical implementation costs per scenario

The basic implementation costs for technical improvement options have already been estimated in Table 3.4 in TP6. These are valid for the uptake rates assumed in the LCAs in TP4 and had to be re-scaled to the penetration rates in each scenario. This was done in Table 3.1 in TP6, replicated below.

Table A.4.5: Technical implementation costs in million in Euro, average annual costs 2013-in 2030

		Best practice	**Voluntary policy package**	**Mandatory policy package**	**Environmental tax reform (ETR)**
01.1	Flooring	0		0	0
02.1	Flooring	0		0	0
02.2	Paint	0		0	0
03.1	Road asphalt	797	567	797	567
03.2	Concrete and soil	481	276	481	276
03.3	PVC	315	315	315	315
03.4	Float glass	0		0	0
03.5	Carpet	29	16	80	16
03.6	Plasterboard	0		0	0
04.1	Rate of energy-related innovations	0		0	0
05.1	Recycled construction and demolition waste	0		0	0
05.2	Use of stockpiled fly ash	0		0	0
05.3	Mine landfills: 2 out of 147 is suitable for landfill mining	0	1,084	5,422	1,084
06.1	reduction in total floor area	0		0	0
07.1	reduction in total floor area	0		0	0
08.1	Reduction in waste flow	0		0	0
09.1	Use of timber instead of masonry	0		0	0
09.2	Construction products	0		0	0
09.3	Moving from hot mix to warm mix asphalt	0		0	0
10.1	Products become more resource efficient	0		0	0
Total	Total costs	0		0	0

Annex 5: Description of EXIOMOD

A5.1 Model overview

EXIOMOD combines the main structure of traditional CGE analysis with the innovative elements of semi-endogenous growth and adaptive expectations under the framework of Dynamic General Equilibrium. All main behavioural parameters of the model have been estimated econometrically based on the available data.

The model incorporates the representation of 43 main countries of the world. It includes an individual representation of all EU-27 countries and candidate member states. It also includes the largest emitters such as US, Japan, Russia, Brazil, India and China. The EXIOMOD model is a dynamic, recursive over time, model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and adaptive expectations.

EXIOMOD combines economic, environmental and social domains in an efficient and flexible way:

1. Social effects: includes the representation of three education levels, ten occupation types and households grouped into five income classes. One can trace the effects of specific policy on income redistribution and unemployment.
2. Economic effects: the model captures both direct and indirect (wide-economic and rebound) effects of policy measures. EXIOMOD allows for calculation of detailed sectoral impacts at the level of 129 economic sectors.
3. Environmental effects: the model includes representation of 28 types GHG and non-GHG emissions, different types of waste, land use (15 types) and use of material resources (171 types).

A5.2: Geographical coverage of EXIOMOD

The model incorporates the representation of 43 main countries of the world. It includes an individual representation of all EU-27 countries and candidate member states. It also includes the largest emitters such as US, Japan, Russia, Brazil, India and China. Countries which are not represented separately in EXIOMOD are grouped together into the rest of the world “country” with its separate technology, production, consumption and trade.

Table A5.1: Country list

Countries represented in EXIOMOD
EU-27 (each country separately)
United States
Japan
China
Canada
South Korea
Brazil
India
Mexico
Russia
Australia
Switzerland
Norway
Turkey
Taiwan
Indonesia
South Africa
Rest of the world

A5.3: Underlying database of EXIOMOD: EXIOPOL and CREEA projects

The project EXIOPOL (A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis) had as a key goal to produce a Multi-Regional Environmentally Extended Supply and Use Table (MR EE SUT) for the whole world. The EXIOPOL database (EXIOBASE) has a unique detail and covers 30 emissions, around resource extractions, given specifically for 130 sectors and products by 43 countries making up 95% of global GDP, plus a Rest of World. A follow-up project of 3.5 Mio Euro under the EU's FP7 program, called Compiling and Refining Environmental and Economic Accounts (CREEA), will expand this database with improved extensions for water, land use and other resources, but above all to create an additional layer with physical information in the (economic) SUT in the EXIOPOL database (in short: EXIOBASE). For the first time this will produce a global, integrated Multi Regional Environmentally Extended Economic and Physical Supply and Use Table (MR EE E&PSUT).

In EXIOPOL project, the following steps were taken

1. Harmonizing and detailing SUT
   a. Gathering SUT from the EU-27 via Eurostat, and other SUT and IOT from 16 other countries (covering in total 95% of the global GDP). Gap filling of missing European SUT via 'same country assumption'. Converting IOT into SUT by assuming a diagonal Supply table.
   b. Constructing Use tables in basic prices via reversed engineering
   c. Harmonizing and detailing SUT with auxiliary data from FAO and a European AgriSAMS for agriculture, the EIA database for energy carriers and electricity, various resource databases for resources, etc.

2. Harmonizing and estimating extensions
   a. Allocating available resource extraction data (e.g. FAOSTAT, Aquastat) to industry sectors
   b. Allocating the International Energy Agency database for 60 energy carriers to sectors of use. Estimating emissions on the basis of energy and other activity data and TNOs TEAM model

3. Linking the country SUT via trade
    a. Splitting of Import Use tables and allocating imports to countries of exports using UN COMTRADE trade shares
    b. Confronting the resulting implicit exports with exports in the SUT, adjusting differences and rebalancing via RUGs GRAS procedure

A5.4: Integrated impact assessment of policy measures

Sustainability is a complex issue which develops among social, economic and environmental domains. Modern impact assessment tools should be capable of assessing the impact of a particular policy measure or a combination of policy measures on all three dimensions of sustainability. EXIOMOD combines these three domains in an efficient and flexible way:

1. Social effects: includes the representation of three education levels and households grouped into five income classes. One can trace the effects of specific policy on income redistribution and allocation of negative impacts of local pollutants between various income groups. Effect of employment and unemployment by three education types and ten occupations can be evaluated.
2. Economic effects: the model captures both direct and indirect (wide-economic and rebound) effects of policy measures. It assesses policy impacts on GDP, consumption, production, investment etc. EXIOMOD allows for calculation of detailed sectoral impacts at the level of 129 economic sectors.
3. Environmental effects: the model includes representation of all GHG and non-GHG emissions, different types of waste, land use and use of material resources.

EXIOMOD permits two-way linkages between social, economic and environmental pillars of sustainability by allowing these three dimensions to interact and influence each other.

A5.5: General framework of the model

Traditional computable general equilibrium (CGE) models as well as macro-models have ignored uncertainty, and the possibility to go beyond the rational behaviour of households and proper treatment of expectations. Most of them also treat technological progress as exogenous to the model which makes it difficult to use such models for long-term policy analysis. EXIOMOD combines the main structure of traditional CGE analysis with the innovative elements of adaptive expectations and semi-endogenous growth under the framework of Dynamic General Equilibrium. All main behavioural equations of the model have been estimated econometrically based on the available time-series data.

The use of CGE as a main structure of EXIOMOD allows for:

- Capturing intra-regional and inter-regional effects
- Full representation of inter-sectoral spill-overs
- Efficient incorporation of all main resource constraints
- Proper treatment of unemployment and under-utilization of capital stock

By combining various methodological approaches EXIOMOD framework allows for:

- Dynamic analysis with endogenous investment decisions and development of capital stock, human capital and RTD stock
- Addressing uncertainty and provide confidence interval for policy affects by means by formal sensitivity analysis
- Incorporation of uncertainty and irrationality into the behaviour of economic agents via adaptive expectations
- Semi-endogenous technological progress

A5.6: Main structure of EXIOMOD

Computable General Equilibrium (CGE) framework is the basis of EXIOMOD. This framework takes as a basis the notion of the Walrasian equilibrium. Walrasian equilibrium is one of the foundations of the modern micro economics theory.
CGE models are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. A model consists of (a) equations describing model variables and (b) a database (usually very detailed) consistent with the model equations.

The model equations tend to be neo-classical in spirit, assuming cost-minimizing behaviour by producers, average-cost pricing, and household demands based on optimizing behaviour. A CGE model database consists of tables of transaction values and elasticities: dimensionless parameters that capture behavioural response. The database is presented as a social accounting matrix (SAM). It covers the whole economy of a country, and distinguishes a number of sectors, commodities, primary factors and types of households.

CGE models utilize the notion of the aggregate economic agent. They represent the behaviour of the whole population group or of the whole industrial sector as the behaviour of one single aggregate agent. It is further assumed that the behaviour of each such aggregate agent is driven by certain optimization criteria such as maximization of utility or minimization of costs.

The EXIOMOD model includes the representation of the micro-economic behaviour of the following economic agents: several types of households differentiated by 5 income quintiles, production sectors differentiated by 129 classification categories developed in EXIOPOL project; investment agent; federal government and external trade sector.

A5.7: Households and labour market

Each household group in the EXIOMOD model consists of the individuals differentiated by three types of education levels and ten types of professions. The composition of households is based on the extensive socio-economic dataset.

Behaviour of the households is based on the utility-maximization principle. Household's utility is associated with the level and structure of its consumption. Each household spends its consumption budget on services and goods in order to maximize its satisfaction from the chosen consumption bundle.

Households have substitution possibilities between different consumption commodities. They can substitute consumption of transport for the consumption of other goods and services. They are also able to substitute between their consumption of electricity and other energy. The inclusion of substitution possibilities is important for a realistic representation of the consumption decisions of the households and better assessment of the welfare and economic effects of transport and energy policies. Households in the EXIOMOD model receive their income in the form of wages, capital rent, unemployment benefits and other transfers from the federal government.

The level of the unemployment benefits, received by the household, depends upon the level of unemployment associated with the particular education level and occupation type of the individuals within the household. The unemployment in the EXIOMOD is modelled according to the search-and-matching approach, which explains the existence of frictional unemployment in the country. The main idea behind this approach is that there exists a mismatch between the available vacancies and the unemployed labour. It takes firms and individuals some time to find the right

vacancy/employee, which results in the frictional unemployment. The level of this type of unemployment varies between the education levels and occupation types.
The levels of the wages earned in different sectors of the economy by individuals with different education levels and occupation types are determined by the national-level bargaining process between the sector-specific trade union and the firms within this sector. Firms share their profits partially with their employees by paying them wages, which are higher than their marginal product of labour.

A5.8: Production sectors and trade

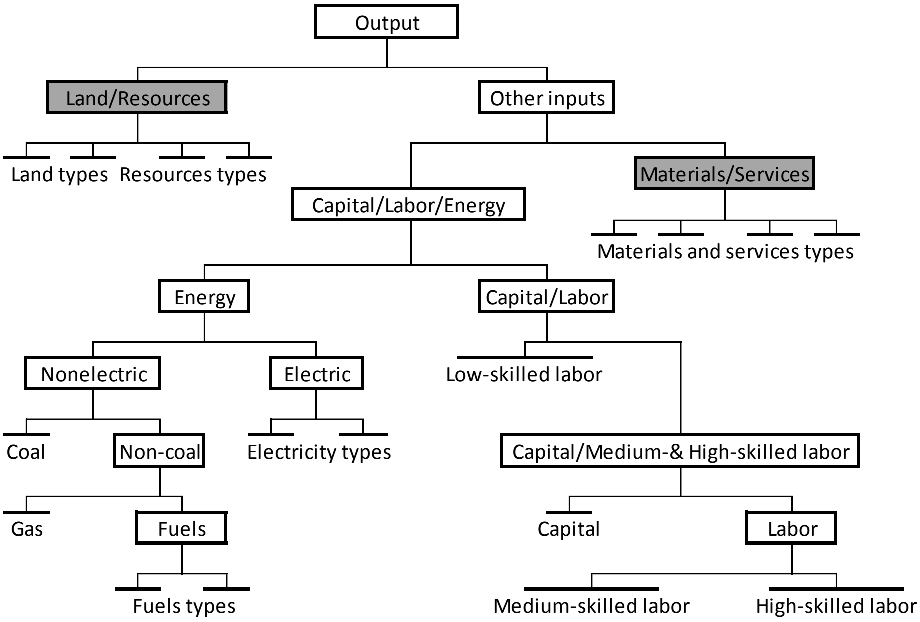
Behaviour of the sectors is based on the minimization of the production costs for a given output level under the sector's technological constraint. Production costs of each sector in the EXIOMOD model include labour costs by type of labour, capital costs and the costs of intermediate inputs. The sector's technological constraint describes the production technology of each sector. It provides information on how many of different units of labour, capital and of the 129 commodities and services, traded in the economy, are necessary for the production of one unit of the composite sectoral output.

In accordance with their production technology, sectors have substitution possibilities between different intermediate inputs and production factors. They can substitute between the use of different education types and between different occupations within each education type. They are also able to substitute between their consumption of electricity and other energy types such as gas, coal, oil and refined oil. Existence of the technological substitution possibilities is an important feature of the production process and cannot be neglected while modelling sectoral production.

Each sector in the economy may produce more than one type of commodity and the combination of these different commodities corresponds to the sectoral composite output. Production output of each sector can be either delivered to the domestic market or exported. Each sector determines the shares of its outputs, sold domestically and exported, based on the profit maximization principle. It takes into account the relative prices of the same type of commodities in its own country and abroad.

An Armington assumption on international trade is adopted in the model. According to this assumption the commodities produced by the domestic sectors for the consumption inside the country and for the consumption outside of it have different specifications.

Figure A5.1: Production structure of sectors in EXIOMOD



A5.9: Market equilibrium and investments

The equilibrium prices of all commodities and capital are defined by the market equilibrium conditions. Under the market equilibrium the sum of demands for a particular commodity is equal to the sum of its supplies. Due to the existence of unemployment and wage bargaining on the labour market, it is in disequilibrium. The level of the wages is determined by the bargaining process between the trade unions and firms. It depends positively upon the probability to find a new job and the firms' profits.

The model incorporates the representation of investment and savings decisions of the economic agents. Savings in the economy are made by households, government and the rest of the world. The total savings accumulated at each period of time are invested into accumulation of the sector-specific physical capital, which is not mobile between the sectors. The stock of this capital at each period of time is equal to the last period stock minus depreciation plus the new capital accumulated during the previous period of time.

The total investment into the sector-specific capital stock is spent on buying different types of capital goods such as machinery, equipment and buildings. The concrete mixture of different capital goods used for physical investments is determined by the maximization of the utility of the investment agent. This is an artificial national economic agent responsible for buying capital goods for physical investments in all the domestic sectors.

A5.10: Federal government

The EXIOMOD model incorporates the representation of the federal government. The governmental sector collects taxes, pays subsidies and makes transfers to households, production sectors and to the rest of the world. The federal government consumes a number of commodities, where the optimal governmental demand is determined according to the maximization of the governmental consumption utility function. The model incorporates the governmental budget constraint. According to this constraint the total governmental tax revenues are spend on subsidies, transfers, governmental savings and consumption.

Finally, the model includes the trade balance constraint, according to which the value of the country's exports plus the governmental transfers to the rest of the world are equal to the value of the country's imports.

A5.11: Environmental effects and welfare function

All production and consumption activities in the EXIOMOD model are associated with emissions and environmental damage. This is in particular true for the transportation. The model incorporates the representation of all major greenhouse gas and non-greenhouse gas emissions. Emissions in the EXIOMOD model are associated either with the use of different energy types by firms and households or with the overall level of the firms' outputs.

Environmental quality is one of the main factors of the households' utility function. Changes in the levels of emissions have a direct impact upon the utilities of the households. Different income classes in the model are influenced differently by the changes in emission levels of various pollutants. Local pollutants have more impact upon the poor household groups, who live closer to the industrial sites and areas with dense traffic. The evaluation of emissions by each household group depends upon its willingness-to-pay. It is assumed that the willingness-to-pay is closely correlated with the income of the household. Rich households put a higher value to the emissions then the poor ones. The willingness-to-pay of the households is determined endogenously in the EXIOMOD model and influences their respective welfare function. The welfare of each household type (population group) in the EXIOMOD model is calculated as the equivalent variation measure and depends upon consumption of commodities and the level of emissions.

A5.12: Dynamic features

The EXIOMOD model is a dynamic, recursive over time, model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and adaptive expectations. A recursive dynamic structure composed of a sequence of several temporary equilibriums. The first equilibrium in the sequence is given by the benchmark year. In each time period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period. The equilibriums are connected to each other through capital accumulation. Thus, the endogenous determination of investment behaviour is essential for the dynamic part of the model. Investment and capital accumulation in year t depend on expected rates of return for year t+1, which are determined by actual returns on capital in year t.

A5.13: Endogenous technological progress and growth

The general structure of the EXIOMOD extends to include endogenous growth elements such as technological progress and human capital accumulation. Specifically, the specification of endogenous growth in the model is based on models of economic growth and catch-up that are widely used in the literature on a leader-follower context of economic development. In this framework, productivity growth is generated through own innovations, knowledge spill-overs and technology adoption (catching-up).

The greater this distance and the higher the absorptive capacity, the greater is the potential for growth through technology transfer. The basic framework results in short-run growth rates being endogenous and long-run relative productivity levels being endogenous (but constant), implying that long-run growth rates converge.

These properties imply that we can classify the growth equation as a semi-endogenous growth model. Productivity relative to the frontier is endogenous. Still, the model remains realistic in that it maintains the long-run stability properties of neo-classical growth theory.

A5.14: Other issues

Treatment of resources and environmental effects
EXIOMOD incorporates the representation of all major environmental effects related to production and consumption choices of households and firms. The model includes all main types of GHG and non-GHG emissions, waste and waste water, land use changes and deforestation. In case of waste it also incorporates the modelling of the treatment of waste and recycling by type of waste.

Integration of physical and monetary data
Integration of physical and monetary data allows one to take proper account on the physical restrictions on consumption and production activities as well as to provide a full analysis of sustainability issues. EXIOMOD database includes both monetary and physical units in a consistent way and allows for their integration in a unified modelling framework. Physical dimension provides the representation of all main resource constraints in the global economy.

Uncertainty and non-rational behaviour
Uncertainty is included in EXIOMOD is addressed in two separate ways. First one is related to the representation of expectations of consumers and producers in the model. They are treated using adaptive expectations framework where the economic agents adjust their behaviour according the past realizations of their expectations. The framework of adaptive expectation is flexible enough to allow for some non-rational and stochastic elements in it such a hysteric expectations for example or group-related behaviour. This can potentially be useful for modelling of penetration of new technologies and behavioural changes of consumers over time.

Econometric nature of the model
All main behavioural equations of the model are estimated econometrically on the time-series data from EU KLEMS, international trade data and other relevant time-series data. These behavioural equations include: (1) production functions of groups of sectors including the substitution possibilities between production inputs; (2) semi-endogenous growth of total factor productivity; (3) international trade part with gravity framework and (4) unemployment modelling with logistic wage curve.

Main dimensions of the model: sectors and commodities, factors of production, types of emissions, energy use, physical inputs, land and water use

Table A5.2 Sectors/commodities in EXIOMOD

N	Name of production sector	Extended NACE code
1	Cultivation of paddy rice	p01.a
2	Cultivation of wheat	p01.b
3	Cultivation of cereal grains nec	p01.c
4	Cultivation of vegetables, fruit, nuts	p01.d
5	Cultivation of oil seeds	p01.e
6	Cultivation of sugar cane, sugar beet	p01.f
7	Cultivation of plant-based fibres	p01.g
8	Cultivation of crops nec	p01.h
9	Cattle farming	p01.i
10	Pigs farming	p01.j
11	Poultry farming	p01.k
12	Meat animals nec	p01.l
13	Animal products nec	p01.m
14	Raw milk	p01.n
15	Wool, silk-worm cocoons	p01.o
16	Forestry, logging and related service activities (02)	p02
17	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	p05
18	Mining of coal and lignite; extraction of peat (10)	p10
19	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	p11.a
20	Extraction of natural gas and services related to natural gas extraction, excluding surveying	p11.b
21	Extraction, liquefaction, and regasification of other petroleum and gaseous materials	p11.c
22	Mining of uranium and thorium ores (12)	p12
23	Mining of iron ores	p13.1
24	Mining of copper ores and concentrates	p13.20.11
25	Mining of nickel ores and concentrates	p13.20.12
26	Mining of aluminium ores and concentrates	p13.20.13
27	Mining of precious metal ores and concentrates	p13.20.14
28	Mining of lead, zinc and tin ores and concentrates	p13.20.15
29	Mining of other non-ferrous metal ores and concentrates	p13.20.16
30	Quarrying of stone	p14.1
31	Quarrying of sand and clay	p14.2
32	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	p14.3
33	Processing of meat cattle	p15.a
34	Processing of meat pigs	p15.b
35	Processing of meat poultry	p15.c
36	Production of meat products nec	p15.d
37	Processing vegetable oils and fats	p15.e
38	Processing of dairy products	p15.f
39	Processed rice	p15.g
40	Sugar refining	p15.h
41	Processing of Food products nec	p15.i

42	Manufacture of beverages	p15.j
43	Manufacture of fish products	p15.k
44	Manufacture of tobacco products (16)	p16
45	Manufacture of textiles (17)	p17
46	Manufacture of wearing apparel; dressing and dyeing of fur (18)	p18
47	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	p19
48	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	p20
49	Manufacture of pulp, paper and paper products (21)	p21
50	Publishing, printing and reproduction of recorded media (22)	p22
51	Manufacture of coke oven products	p23.1
52	Manufacture of motor spirit (gasoline)	p23.20.a
53	Manufacture of kerosene, including kerosene type jet fuel	p23.20.b
54	Manufacture of gas oils	p23.20.c
55	Manufacture of fuel oils n.e.c.	p23.20.d
56	Manufacture of petroleum gases and other gaseous hydrocarbons, except natural gas	p23.20.e
57	Manufacture of other petroleum products	p23.20.f
58	Processing of nuclear fuel	p23.3
59	Manufacture of chemicals and chemical products (24)	p24
60	Manufacture of rubber and plastic products (25)	p25
61	Manufacture of glass and glass products	p26.a
62	Manufacture of ceramic goods	p26.b
63	Manufacture of bricks, tiles and construction products, in baked clay	p26.c
64	Manufacture of cement, lime and plaster	p26.d
65	Manufacture of other non-metallic mineral products n.e.c.	p26.e
66	Manufacture of basic iron and steel and of ferro-alloys and first products thereof	p27.a
67	Precious metals production	p27.41
68	Aluminium production	p27.42
69	Lead, zinc and tin production	p27.43
70	Copper production	p27.44
71	Other non-ferrous metal production	p27.45
72	Casting of metals	p27.5
73	Manufacture of fabricated metal products, except machinery and equipment (28)	p28
74	Manufacture of machinery and equipment n.e.c. (29)	p29
75	Manufacture of office machinery and computers (30)	p30
76	Manufacture of electrical machinery and apparatus n.e.c. (31)	p31
77	Manufacture of radio, television and communication equipment and apparatus (32)	p32
78	Manufacture of medical, precision and optical instruments, watches and clocks (33)	p33
79	Manufacture of motor vehicles, trailers and semi-trailers (34)	p34
80	Manufacture of other transport equipment (35)	p35
81	Manufacture of furniture; manufacturing n.e.c. (36)	p36
82	Recycling of metal waste and scrap	p37.1
83	Recycling of non-metal waste and scrap	p37.2

84	Production of electricity by coal	p40.11.a
85	Production of electricity by gas	p40.11.b
86	Production of electricity by nuclear	p40.11.c
87	Production of electricity by hydro	p40.11.d
88	Production of electricity by wind	p40.11.e
89	Production of electricity nec, including biomass and waste	p40.11.f
90	Transmission of electricity	p40.12
91	Distribution and trade of electricity	p40.13
92	Manufacture of gas; distribution of gaseous fuels through mains	p40.2
93	Steam and hot water supply	p40.3
94	Collection, purification and distribution of water (41)	p41
95	Construction (45)	p45
96	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	p50.a
97	Retail sale of automotive fuel	p50.b
98	Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	p51
99	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	p52
100	Hotels and restaurants (55)	p55
101	Transport via railways	p60.1
102	Other land transport	p60.2
103	Transport via pipelines	p60.3
104	Sea and coastal water transport	p61.1
105	Inland water transport	p61.2
106	Air transport (62)	p62
107	Supporting and auxiliary transport activities; activities of travel agencies (63)	p63
108	Post and telecommunications (64)	p64
109	Financial intermediation, except insurance and pension funding (65)	p65
110	Insurance and pension funding, except compulsory social security (66)	p66
111	Activities auxiliary to financial intermediation (67)	p67
112	Real estate activities (70)	p70
113	Renting of machinery and equipment without operator and of personal and household goods (71)	p71
114	Computer and related activities (72)	p72
115	Research and development (73)	p73
116	Other business activities (74)	p74
117	Public administration and defence; compulsory social security (75)	p75
118	Education (80)	p80
119	Health and social work (85)	p85
120	Collection and treatment of sewage	p90.01
121	Collection of waste	p90.02.a
122	Incineration of waste	p90.02.b
123	Landfill of waste	p90.02.c
124	Sanitation, remediation and similar activities	p90.03
125	Activities of membership organisation n.e.c. (91)	p91
126	Recreational, cultural and sporting activities (92)	p92

127	Other service activities (93)	p93
128	Private households with employed persons (95)	p95
129	Extra-territorial organizations and bodies	p99

Table A5.3: Types of physical extractions represented in EXIOMOD including land use, water use and material use

Extraction Type Id	*Extraction Type Name*
1	Land Use - Arable Land - rice
2	Land Use - Arable Land - wheat
3	Land Use - Arable Land - other cereals
4	Land Use - Arable Land - roots and tubers
5	Land Use - Arable Land - sugar crops
6	Land Use - Arable Land - pulses
7	Land Use - Arable Land - nuts
8	Land Use - Arable Land - oil crops
9	Land Use - Arable Land - vegetables
10	Land Use - Arable Land - fruits
11	Land Use - Arable Land - fibres
12	Land Use - Arable Land - other crops
13	Land Use - Arable Land - fodder crops
14	Land Use - Permanent Pasture
15	Land Use - Forest Area

Table A5.4: Types of factor inputs in EXIOMOD

Factor Input Type Code	*Factor Input Type Name*
w02	Other net taxes on production
w03.a	Compensation of employees; Low-skilled
w03.b	Compensation of employees; Medium-skilled
w03.c	Compensation of employees; High-skilled
w04.a	Operating surplus: Consumption of fixed capital
w04.b	Operating surplus: Rents on land
w04.c	Operating surplus: Royalties on resources
w04.d	Operating surplus: Remaining net operating surplus
z01	Compensation of Employees; wages & salaries
z02	Comp of Emp; employers social contributions
z03	Employed persons
z04.a	Employment hours: Low-skilled
z04.b	Employment hours: Medium-skilled
z04.c	Employment hours: High-skilled
z05	Fixed capital formation
z06	Fixed capital stock

Table A5.5: Representation of physical inputs and outputs in EXIOMOD including energy, materials, water and biomass

Physical Type Id	*Physical Type Name*
1	Gross Energy Use - Anthracite
2	Gross Energy Use - Coking Coal
3	Gross Energy Use - Other Bituminous Coal
4	Gross Energy Use - Sub-Bituminous Coal

5	Gross Energy Use - Lignite/Brown Coal
6	Gross Energy Use - Patent Fuel
7	Gross Energy Use - Coke Oven Coke
8	Gross Energy Use - BKB/Peat Briquettes
9	Gross Energy Use - Coke Oven Gas
10	Gross Energy Use - Blast Furnace Gas
11	Gross Energy Use - Industrial Waste
12	Gross Energy Use - Municipal Waste (Renew)
13	Gross Energy Use - Municipal Waste (Non-Renew)
14	Gross Energy Use - Primary Solid Biomass
15	Gross Energy Use - Biogas
16	Gross Energy Use - Other Liquid Biofuels
17	Gross Energy Use - Natural Gas
18	Gross Energy Use - Crude Oil
19	Gross Energy Use - Natural Gas Liquids
20	Gross Energy Use - Refinery Feedstocks
21	Gross Energy Use - Additives/Blending Components
22	Gross Energy Use - Refinery Gas
23	Gross Energy Use - Liquefied Petroleum Gases (LPG)
24	Gross Energy Use - Motor Gasoline
25	Gross Energy Use - Gasoline Type Jet Fuel
26	Gross Energy Use - Kerosene Type Jet Fuel
27	Gross Energy Use - Kerosene
28	Gross Energy Use - Gas/Diesel Oil
29	Gross Energy Use - Residual Fuel Oil
30	Gross Energy Use - White Spirit & SBP
31	Gross Energy Use - Lubricants
32	Gross Energy Use - Bitumen
33	Gross Energy Use - Petroleum Coke
34	Gross Energy Use - Non-specified Petroleum Products
35	Gross Energy Use - Hydro
36	Gross Energy Use - Geothermal
37	Gross Energy Use - Solar Photovoltaics
38	Gross Energy Use - Solar Thermal
39	Gross Energy Use - Wind
40	Gross Energy Use - Electricity
41	Gross Energy Use - Heat
42	Gross Energy Use - Aviation Gasoline
43	Gross Energy Use - Naphtha
44	Gross Energy Use - Paraffin Waxes
45	Gross Energy Use - Nuclear
46	Gross Energy Use - Other Hydrocarbons
47	Gross Energy Use - Peat
48	Gross Energy Use - Charcoal
49	Gross Energy Use - Gas Works Gas
50	Gross Energy Use - Oxygen Steel Furnace Gas
51	Gross Energy Use - Ethane
52	Gross Energy Use - Tide, Wave and Ocean
53	Gross Energy Use - Coal Tar
54	Gross Energy Use - Other Sources
55	Gross Energy Use - Gas Coke
56	Gross Energy Use - Biogasoline
57	Gross Energy Supply - Lignite/Brown Coal
58	Gross Energy Supply - Peat
59	Gross Energy Supply - Coke Oven Coke
60	Gross Energy Supply - Coal Tar

61	Gross Energy Supply - Coke Oven Gas
62	Gross Energy Supply - Blast Furnace Gas
63	Gross Energy Supply - Industrial Waste
64	Gross Energy Supply - Municipal Waste (Renew)
65	Gross Energy Supply - Municipal Waste (Non-Renew)
66	Gross Energy Supply - Primary Solid Biomass
67	Gross Energy Supply - Biogas
68	Gross Energy Supply - Other Liquid Biofuels
69	Gross Energy Supply - Natural Gas
70	Gross Energy Supply - Crude Oil
71	Gross Energy Supply - Natural Gas Liquids
72	Gross Energy Supply - Refinery Gas
73	Gross Energy Supply - Liquefied Petroleum Gases (LPG)
74	Gross Energy Supply - Motor Gasoline
75	Gross Energy Supply - Kerosene Type Jet Fuel
76	Gross Energy Supply - Kerosene
77	Gross Energy Supply - Gas/Diesel Oil
78	Gross Energy Supply - Residual Fuel Oil
79	Gross Energy Supply - Lubricants
80	Gross Energy Supply - Bitumen
81	Gross Energy Supply - Petroleum Coke
82	Gross Energy Supply - Non-specified Petroleum Products
83	Gross Energy Supply - Hydro
84	Gross Energy Supply - Geothermal
85	Gross Energy Supply - Solar Photovoltaics
86	Gross Energy Supply - Solar Thermal
87	Gross Energy Supply - Wind
88	Gross Energy Supply - Electricity
89	Gross Energy Supply - Heat
90	Gross Energy Supply - Dissipative Energy Losses
91	Gross Energy Supply - Sub-Bituminous Coal
92	Gross Energy Supply - Patent Fuel
93	Gross Energy Supply - Naphtha
94	Gross Energy Supply - White Spirit & SBP
95	Gross Energy Supply - Nuclear
96	Gross Energy Supply - Other Bituminous Coal
97	Gross Energy Supply - BKB/Peat Briquettes
98	Gross Energy Supply - Other Hydrocarbons
99	Gross Energy Supply - Charcoal
100	Gross Energy Supply - Coking Coal
101	Gross Energy Supply - Gas Works Gas
102	Gross Energy Supply - Biodiesels
103	Gross Energy Supply - Refinery Feedstocks
104	Gross Energy Supply - Additives/Blending Components
105	Gross Energy Supply - Aviation Gasoline
106	Gross Energy Supply - Paraffin Waxes
107	Gross Energy Supply - Oxygen Steel Furnace Gas
108	Gross Energy Supply - Gasoline Type Jet Fuel
109	Gross Energy Supply - Biogasoline
110	Gross Energy Supply - Tide, Wave and Ocean
111	Gross Energy Supply - Ethane
112	Gross Energy Supply - Other Sources
113	Gross Energy Supply - Gas Coke
114	Gross Energy Supply - Anthracite
115	Net Energy Use - Total
116	Emission-relevant Energy Use - Anthracite

117	Emission-relevant Energy Use - Coking Coal
118	Emission-relevant Energy Use - Other Bituminous Coal
119	Emission-relevant Energy Use - Sub-Bituminous Coal
120	Emission-relevant Energy Use - Lignite/Brown Coal
121	Emission-relevant Energy Use - Patent Fuel
122	Emission-relevant Energy Use - Coke Oven Coke
123	Emission-relevant Energy Use - BKB/Peat Briquettes
124	Emission-relevant Energy Use - Coke Oven Gas
125	Emission-relevant Energy Use - Blast Furnace Gas
126	Emission-relevant Energy Use - Industrial Waste
127	Emission-relevant Energy Use - Municipal Waste (Renew)
128	Emission-relevant Energy Use - Municipal Waste (Non-Renew)
129	Emission-relevant Energy Use - Primary Solid Biomass
130	Emission-relevant Energy Use - Biogas
131	Emission-relevant Energy Use - Other Liquid Biofuels
132	Emission-relevant Energy Use - Natural Gas
133	Emission-relevant Energy Use - Crude Oil
134	Emission-relevant Energy Use - Natural Gas Liquids
135	Emission-relevant Energy Use - Refinery Feedstocks
136	Emission-relevant Energy Use - Additives/Blending Components
137	Emission-relevant Energy Use - Refinery Gas
138	Emission-relevant Energy Use - Liquefied Petroleum Gases (LPG)
139	Emission-relevant Energy Use - Motor Gasoline
140	Emission-relevant Energy Use - Gasoline Type Jet Fuel
141	Emission-relevant Energy Use - Kerosene Type Jet Fuel
142	Emission-relevant Energy Use - Kerosene
143	Emission-relevant Energy Use - Gas/Diesel Oil
144	Emission-relevant Energy Use - Residual Fuel Oil
145	Emission-relevant Energy Use - Lubricants
146	Emission-relevant Energy Use - Petroleum Coke
147	Emission-relevant Energy Use - Non-specified Petroleum Products
148	Emission-relevant Energy Use - Aviation Gasoline
149	Emission-relevant Energy Use - Other Hydrocarbons
150	Emission-relevant Energy Use - Peat
151	Emission-relevant Energy Use - Charcoal
152	Emission-relevant Energy Use - Gas Works Gas
153	Emission-relevant Energy Use - Naphtha
154	Emission-relevant Energy Use - Oxygen Steel Furnace Gas
155	Emission-relevant Energy Use - Ethane
156	Emission-relevant Energy Use - Bitumen
157	Emission-relevant Energy Use - Coal Tar
158	Emission-relevant Energy Use - Gas Coke
159	Domestic Extraction Used - Biomass - Primary Crops - rice
160	Domestic Extraction Used - Biomass - Primary Crops - wheat
161	Domestic Extraction Used - Biomass - Primary Crops - other cereals
162	Domestic Extraction Used - Biomass - Primary Crops - roots and tubers
163	Domestic Extraction Used - Biomass - Primary Crops - sugar crops
164	Domestic Extraction Used - Biomass - Primary Crops - pulses
165	Domestic Extraction Used - Biomass - Primary Crops - nuts
166	Domestic Extraction Used - Biomass - Primary Crops - oil crops
167	Domestic Extraction Used - Biomass - Primary Crops - vegetables
168	Domestic Extraction Used - Biomass - Primary Crops - fruits
169	Domestic Extraction Used - Biomass - Primary Crops - fibres
170	Domestic Extraction Used - Biomass - Primary Crops - other crops
171	Domestic Extraction Used - Biomass - Crop Residues - straw
172	Domestic Extraction Used - Biomass - Crop Residues - other crop

	residues
173	Domestic Extraction Used - Biomass - Fodder Crops - fodder crops
174	Domestic Extraction Used - Biomass - Fodder Crops - biomass harvested from grasslands
175	Domestic Extraction Used - Biomass - Grazed Biomass - grazing
176	Domestic Extraction Used - Biomass - Wood - timber
177	Domestic Extraction Used - Biomass - Wood - other extractions
178	Domestic Extraction Used - Biomass - Animals - marine fish
179	Domestic Extraction Used - Biomass - Animals - inland water fish
180	Domestic Extraction Used - Biomass - Animals - other aquatic animals
181	Domestic Extraction Used - Biomass - Animals - hunting
182	Domestic Extraction Used - Metal Ores - iron ores
183	Domestic Extraction Used - Metal Ores - bauxite and aluminium ores
184	Domestic Extraction Used - Metal Ores - copper ores
185	Domestic Extraction Used - Metal Ores - lead ores
186	Domestic Extraction Used - Metal Ores - nickel ores
187	Domestic Extraction Used - Metal Ores - tin ores
188	Domestic Extraction Used - Metal Ores - uranium and thorium ores
189	Domestic Extraction Used - Metal Ores - zinc ores
190	Domestic Extraction Used - Metal Ores - precious metal ores
191	Domestic Extraction Used - Metal Ores - other metal ores
192	Domestic Extraction Used - Non-Metallic Minerals - chemical and fertilizer minerals
193	Domestic Extraction Used - Non-Metallic Minerals - clays and kaolin
194	Domestic Extraction Used - Non-Metallic Minerals - limestone, gypsum, chalk, dolomite
195	Domestic Extraction Used - Non-Metallic Minerals - salt
196	Domestic Extraction Used - Non-Metallic Minerals - slate
197	Domestic Extraction Used - Non-Metallic Minerals - other industrial minerals
198	Domestic Extraction Used - Non-Metallic Minerals - building stones
199	Domestic Extraction Used - Non-Metallic Minerals - gravel and sand
200	Domestic Extraction Used - Non-Metallic Minerals - other construction materials
201	Domestic Extraction Used - Fossil Energy Carriers - hard coal
202	Domestic Extraction Used - Fossil Energy Carriers - lignite/brown coal
203	Domestic Extraction Used - Fossil Energy Carriers - crude oil
204	Domestic Extraction Used - Fossil Energy Carriers - natural gas
205	Domestic Extraction Used - Fossil Energy Carriers - natural gas liquids
206	Domestic Extraction Used - Fossil Energy Carriers - peat for energy use
207	Unused Domestic Extraction - Biomass - Primary Crops - rice
208	Unused Domestic Extraction - Biomass - Primary Crops - wheat
209	Unused Domestic Extraction - Biomass - Primary Crops - other cereals
210	Unused Domestic Extraction - Biomass - Primary Crops - roots and tubers
211	Unused Domestic Extraction - Biomass - Primary Crops - sugar crops
212	Unused Domestic Extraction - Biomass - Primary Crops - pulses
213	Unused Domestic Extraction - Biomass - Primary Crops - nuts
214	Unused Domestic Extraction - Biomass - Primary Crops - oil crops
215	Unused Domestic Extraction - Biomass - Primary Crops - vegetables
216	Unused Domestic Extraction - Biomass - Primary Crops - fruits
217	Unused Domestic Extraction - Biomass - Primary Crops - fibres
218	Unused Domestic Extraction - Biomass - Primary Crops - other crops
219	Unused Domestic Extraction - Biomass - Crop Residues - straw
220	Unused Domestic Extraction - Biomass - Crop Residues - other crop residues

221	Unused Domestic Extraction - Biomass - Fodder Crops - fodder crops
222	Unused Domestic Extraction - Biomass - Fodder Crops - biomass harvested from grasslands
223	Unused Domestic Extraction - Biomass - Grazed Biomass - grazing
224	Unused Domestic Extraction - Biomass - Wood - timber
225	Unused Domestic Extraction - Biomass - Wood - other extractions
226	Unused Domestic Extraction - Biomass - Animals - marine fish
227	Unused Domestic Extraction - Biomass - Animals - inland water fish
228	Unused Domestic Extraction - Biomass - Animals - other aquatic animals
229	Unused Domestic Extraction - Biomass - Animals - hunting
230	Unused Domestic Extraction - Metal Ores - iron ores
231	Unused Domestic Extraction - Metal Ores - bauxite and aluminium ores
232	Unused Domestic Extraction - Metal Ores - copper ores
233	Unused Domestic Extraction - Metal Ores - lead ores
234	Unused Domestic Extraction - Metal Ores - nickel ores
235	Unused Domestic Extraction - Metal Ores - tin ores
236	Unused Domestic Extraction - Metal Ores - uranium and thorium ores
237	Unused Domestic Extraction - Metal Ores - zinc ores
238	Unused Domestic Extraction - Metal Ores - precious metal ores
239	Unused Domestic Extraction - Metal Ores - other metal ores
240	Unused Domestic Extraction - Non-Metallic Minerals - chemical and fertilizer minerals
241	Unused Domestic Extraction - Non-Metallic Minerals - clays and kaolin
242	Unused Domestic Extraction - Non-Metallic Minerals - limestone, gypsum, chalk, dolomite
243	Unused Domestic Extraction - Non-Metallic Minerals - salt
244	Unused Domestic Extraction - Non-Metallic Minerals - slate
245	Unused Domestic Extraction - Non-Metallic Minerals - other industrial minerals
246	Unused Domestic Extraction - Non-Metallic Minerals - building stones
247	Unused Domestic Extraction - Non-Metallic Minerals - gravel and sand
248	Unused Domestic Extraction - Non-Metallic Minerals - other construction materials
249	Unused Domestic Extraction - Fossil Energy Carriers - hard coal
250	Unused Domestic Extraction - Fossil Energy Carriers - lignite/brown coal
251	Unused Domestic Extraction - Fossil Energy Carriers - crude oil
252	Unused Domestic Extraction - Fossil Energy Carriers - natural gas
253	Unused Domestic Extraction - Fossil Energy Carriers - natural gas liquids
254	Unused Domestic Extraction - Fossil Energy Carriers - peat for energy use
255	Water Consumption Blue - Agriculture - rice
256	Water Consumption Blue - Agriculture - wheat
257	Water Consumption Blue - Agriculture - other cereals
258	Water Consumption Blue - Agriculture - roots and tubers
259	Water Consumption Blue - Agriculture - sugar crops
260	Water Consumption Blue - Agriculture - pulses
261	Water Consumption Blue - Agriculture - nuts
262	Water Consumption Blue - Agriculture - oil crops
263	Water Consumption Blue - Agriculture - vegetables
264	Water Consumption Blue - Agriculture - fruits
265	Water Consumption Blue - Agriculture - fibres
266	Water Consumption Blue - Agriculture - other crops
267	Water Consumption Blue - Agriculture - fodder crops
268	Water Consumption Green - Agriculture - rice
269	Water Consumption Green - Agriculture - wheat
270	Water Consumption Green - Agriculture - other cereals

271	Water Consumption Green - Agriculture - roots and tubers
272	Water Consumption Green - Agriculture - sugar crops
273	Water Consumption Green - Agriculture - pulses
274	Water Consumption Green - Agriculture - nuts
275	Water Consumption Green - Agriculture - oil crops
276	Water Consumption Green - Agriculture - vegetables
277	Water Consumption Green - Agriculture - fruits
278	Water Consumption Green - Agriculture - fibres
279	Water Consumption Green - Agriculture - other crops
280	Water Consumption Green - Agriculture - fodder crops
281	Water Consumption Total - Livestock - dairy cattle
282	Water Consumption Total - Livestock - nondairy cattle
283	Water Consumption Total - Livestock - pigs
284	Water Consumption Total - Livestock - sheep
285	Water Consumption Total - Livestock - goats
286	Water Consumption Total - Livestock - buffaloes
287	Water Consumption Total - Livestock - camels
288	Water Consumption Total - Livestock - horses
289	Water Consumption Total - Livestock - chicken
290	Water Consumption Total - Livestock - turkeys
291	Water Consumption Total - Livestock - ducks
292	Water Consumption Total - Livestock - geese
293	Water Consumption Total - Manufacturing - food products, beverages and tobacco
294	Water Consumption Total - Manufacturing - textiles and textile products
295	Water Consumption Total - Manufacturing - pulp, paper, publishing and printing
296	Water Consumption Total - Manufacturing - chemicals, man-made fibres
297	Water Consumption Total - Manufacturing - non-metallic, mineral products
298	Water Consumption Total - Manufacturing - basic metals and fabrication of metals
299	Water Consumption Total - Domestic - domestic Water Consumption Total
300	Water Consumption Total - Electricity - tower
301	Water Consumption Total - Electricity - once-through
302	N loads - Biomass - Primary Crops - Rice
303	N loads - Biomass - Primary Crops - Wheat
304	N loads - Biomass - Primary Crops - Other cereals
305	N loads - Biomass - Primary Crops - Roots and tubers
306	N loads - Biomass - Primary Crops - Sugar crops
307	N loads - Biomass - Primary Crops - Pulses
308	N loads - Biomass - Primary Crops - Nuts
309	N loads - Biomass - Primary Crops - Oil crops
310	N loads - Biomass - Primary Crops - Vegetables
311	N loads - Biomass - Primary Crops - Fruits
312	N loads - Biomass - Primary Crops - Fibres
313	N loads - Biomass - Primary Crops - Other crops
314	N loads - Biomass - Fodder Crops - Fodder Crops
315	N loads - Biomass - Grazed Biomass - Permanent Pasture
316	P loads - Biomass - Primary Crops - Rice
317	P loads - Biomass - Primary Crops - Wheat
318	P loads - Biomass - Primary Crops - Other cereals
319	P loads - Biomass - Primary Crops - Roots and tubers
320	P loads - Biomass - Primary Crops - Sugar crops
321	P loads - Biomass - Primary Crops - Pulses

322	P loads - Biomass - Primary Crops - Nuts
323	P loads - Biomass - Primary Crops - Oil crops
324	P loads - Biomass - Primary Crops - Vegetables
325	P loads - Biomass - Primary Crops - Fruits
326	P loads - Biomass - Primary Crops - Fibres
327	P loads - Biomass - Primary Crops - Other crops
328	P loads - Biomass - Fodder Crops - Fodder Crops
329	P loads - Biomass - Grazed Biomass - Permanent Pasture

Table A5.6 GHG and non-GHG emissions represented in EXIOMOD

Emission type	***Discharge***
CO2	air
N2O	air
CH4	air
HFCs	air
PFCs	air
SF6	air
NOX	air
SOx	air
NH3	air
NMVOC	air
CO	air
CFCs	air
HCFCs	air
Pb	air
Cd	air
Hg	air
As	air
Cr	air
Cu	air
Ni	air
Se	air
Zn	air
Aldrin	air
Chlordane	air
Chlordecone	air
Dieldrin	air
Endrin	air
Heptachlor	air
Hexabr.-biph.	air
Mirex	air
Toxaphene	air
HCH	air
DDT	air
PCB	air
dioxin	air

PM10	air
BaP	air
Benzene	air
1,3 Butadiene	air
Formaldehyde	air
N	water
P	water
BOD	water
N	soil
P	soil
Cd	soil
Cu	soil
Zn	soil
Pb	soil
Hg	soil
Cr	soil
Ni	soil
PM2.5	air
Furans	air
Benzo-[a]-pyrene (PAHs)	air
PBDEs	air