Material Efficiency & Resource Conservation

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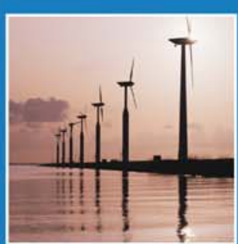
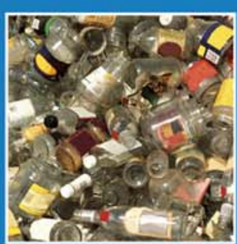
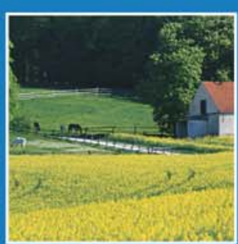
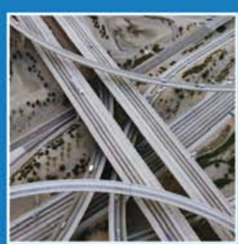
Indicators / Bottom-Up Models and Scenarios

Executive Summary

Executive Summary of Task 6 within the framework of the „Material Efficiency and Resource Conservation“ (MaRess) Project

Resource Efficiency Paper 6.6

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Umwelt Bundes Amt
For our Environment

Indicators / Bottom-Up Models and Scenarios

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Part II outlines the results of Task 6.2.

PART I – Summary report of Task 6.1

Material Use Indicators for Measuring Resource Productivity and Environmental Impacts

Authors: Stefan Bringezu, Helmut Schütz

Executive Summary

The German government intended to assess the applicability of macro indicators measuring the use of resources by the German economy and requested suggestions for further use and development. In a broader context, this relates to the development of a national programme for sustainable resource management, which is, for instance, requested by the EU´s Thematic Strategy for Sustainable Use of Natural Resources. More specifically, the existing monitoring of progress towards sustainability in pursuit of the national strategy for sustainable development should be improved, through widening the scope of the raw material productivity indicator used so far.

The material flow accounting concepts of ESTAT and OECD provide a stepwise extension of indicators for resource use and resource productivity. Direct Material Input (DMI) and Domestic Material Consumption (DMC) build the basis; however, they do not account for indirect flows of imports and exports, nor consider unused extraction, thus missing the foreign dimension and the full extent of primary resource extraction. DMI and DMC can be accounted as raw material equivalents (RME) that accounts for indirect flows of used extraction thus leaving out unused extraction. The most comprehensive indicators accounting for the total global primary material requirements for production and consumption, i.e. including both used and unused extraction, account for Total Material Requirement (TMR) and Total Material Consumption (TMC).

Furthermore, the European Commission aims at developing indicators to account for environmental impacts associated with resource use, so as to be able to monitor progress towards double-decoupling which is a central issue in the Thematic Strategy on the Sustainable Use of Natural Resources.

The workshop brought experts and representatives of data users, data providers from research, and statistical offices together. Different approaches and positions were highlighted and discussed regarding basic methodological issues and interpretability of derived indicators. A mind map exercise worked out basic requirements of an ideal resource use indicator as seen by users, providers or statisticians. An interactive session on requirements for German official reporting and need for improvement put the focus further on the interest of the German government how to proceed with monitoring resource use and resource productivity.

Among the users of data and indicators there was a general tendency to go for RME first and then for TMR/TMC which was regarded as most comprehensive indicator.

Also impact related indicators received some attention of users. However, there was no clear attitude towards changing the current headline indicator in the short term.

Providers from research institutes confirmed their background for indicators work, with a general tendency – like users - to go for RME in the short term and for TMR/TMC in the longer run by following a modular approach and add up unused extraction to RME, while being open towards further research on resource use impact indicators.

Statisticians were in favour of the RME indicator and showed interest for TMR/TMC as well as for an impact related resource use indicator.

Apart from that, some critical open issues concerning the conceptual foundation of the different indicators were identified which require further discussion and harmonisation.

PART II – Summary report of Task 6.2

Bottom-Up Impact Analysis Model

Authors: Thomas Hanke, Ole Soukup, Peter Viebahn, Manfred Fischedick

1 Concept of the Model

1.1 Goals and remit

The aim of Task 6.2 was to analyse how policy approaches for increasing resource efficiency affect the resource balance, using the example of a chosen category of need, and to find out how successfully these approaches have been implemented. This study contains three levels of investigation:

- By developing and using an exemplary *bottom-up impact analysis model,* we seek to determine the direct and indirect effects of a policy mix identified by Task 3 (Innovative resource policy approaches to design framework conditions), 4 (Innovative resource policy approaches at the microscopic level: instruments and approaches close to companies) and 12 (Consumer and customer-oriented approaches to increase resource efficiency). In other words, our aim is to perform a “net” assessment of the resource flows resulting from various policy approaches. This method enables us to identify not only direct interactions, but also trade-offs and synergistic effects between measures under consideration.
- In addition to the impact on the resource area, interactions with other socio-political objectives (in particular, climate protection targets) should also be analysed simultaneously. In view of climate policy regulations in Germany and the European Union, for instance, we must ask ourselves whether measures to reduce resource flows are consistent with the reduction targets for greenhouse gas emissions. Other environmental impact areas on the emissions side include summer smog, the acidification of soils and bodies of water, and fine dust pollution, which can be determined using a *life cycle assessment model*.
- By applying and transferring the scenario analysis established in the energy sector, it was also possible to model the impact of various resource policy approaches in the same category of need, and to compare their impacts and how they differ. By modelling not only the actual situation, but also the development on a time line up to 2050, we were simultaneously able to analyse *long-term effects*. These effects are particularly relevant when the impact of resource efficiency measures apply to a period of several decades.

The ultimate aim was, then, to analyse whether the experiences gained in modelling the chosen category of need and the devised method can be applied to other categories of need. This part of the analysis is explored in Paper 6.1 “*Applicability of the bot-*

tom-up impact analysis model to other categories of need.” This paper shows that the model developed here is applicable to other categories of need under two conditions: first, measurable indicators must be available to enable the impact of policy instruments to be portrayed; second, a technical model for calculating changes to the chosen indicators with regard to the scenario over a specific time period must be operational for the respective category of need. In the category of need “mobility and transport”, for instance, this condition is met by the TREMOD model, developed by ifeu Heidelberg for the German Federal Environment Agency (see ifeu 2010).

1.2 The category of need “warm living space” as an element of the category of need “building and living”

The sub-category of need “warm living space” within the category of need “building and living” was chosen. In accordance with the definition adopted here, this category of need comprises the demand for “warm living space” in Germany. “Warm living space” can be achieved using heating systems based on fossil fuels and renewable energies, using electric heating based on fossil fuel-fired electricity or renewables, or by optimising the energy situation of buildings (for example, heat insulation). In addition to the housing stock, new constructions and demolitions by 2050 will also be considered.

This category of need was selected for a number of reasons:

- The category of need “building and living” is a hot spot area with regard to the direct and indirect overall material expenditure involved in domestic sectoral production (Acosta-Fernandez et al. 2009). If, in addition, the consumption of energetic resources is analysed, the crucial importance of the category of need “warm living space” becomes apparent.
- Despite the considerable importance of the area of buildings to the question of resources, efficiency strategies have so far been explored only rather rudimentarily. In this paper, therefore, energy saving strategies and the resulting demand for insulating materials will be compared for the first time.
- Until now, measures taken to save energy and emissions in the area of buildings implicitly assume that there will be no negative trade-offs. Whether, for example, the impact of energy saving measures will perhaps be cancelled out by the energy required to produce the insulating materials can be assessed relatively easily by making a rough estimate. Less obvious, however, are the interactions ultimately resulting from energy- and process-related emissions with regard to various environmental impacts, which often depend primarily on the design of the process chains under consideration. This will be specifically investigated for the first time here by coupling a building energy model to a material flow model.
- In particular, due to the high expenditure of non-energetic resources required in the category of need “warm living space”, it is also interesting to analyse the trade-offs

between energy- and emission-driven strategies and more resource efficiency-driven strategies.

- Last but not least, Wuppertal Institute has developed a bottom-up method for the energy flows relevant to this area, implemented in the stock-exchange building model *HEAT*.

1.3 The bottom-up impact analysis model “warm living space”

The bottom-up impact analysis model “warm living space” described below was developed to meet the targets outlined above. Fig. 1 shows the various modules contained in the model.

Module 1: Modelling the category of need “warm living space” using *HEAT*

The purpose of the EDP system *HEAT* (Household Energy and Appliances modelling Tool) is to balance and monitor energy and emissions in the household sector. In addition to a differentiated household appliances side to determine power requirements, the system also contains a structural element-specific modelling of the building stock in Germany on the heat side. The system can be adjusted to regional and data requirements, and is able to differentiate between a maximum of 64 types of building.

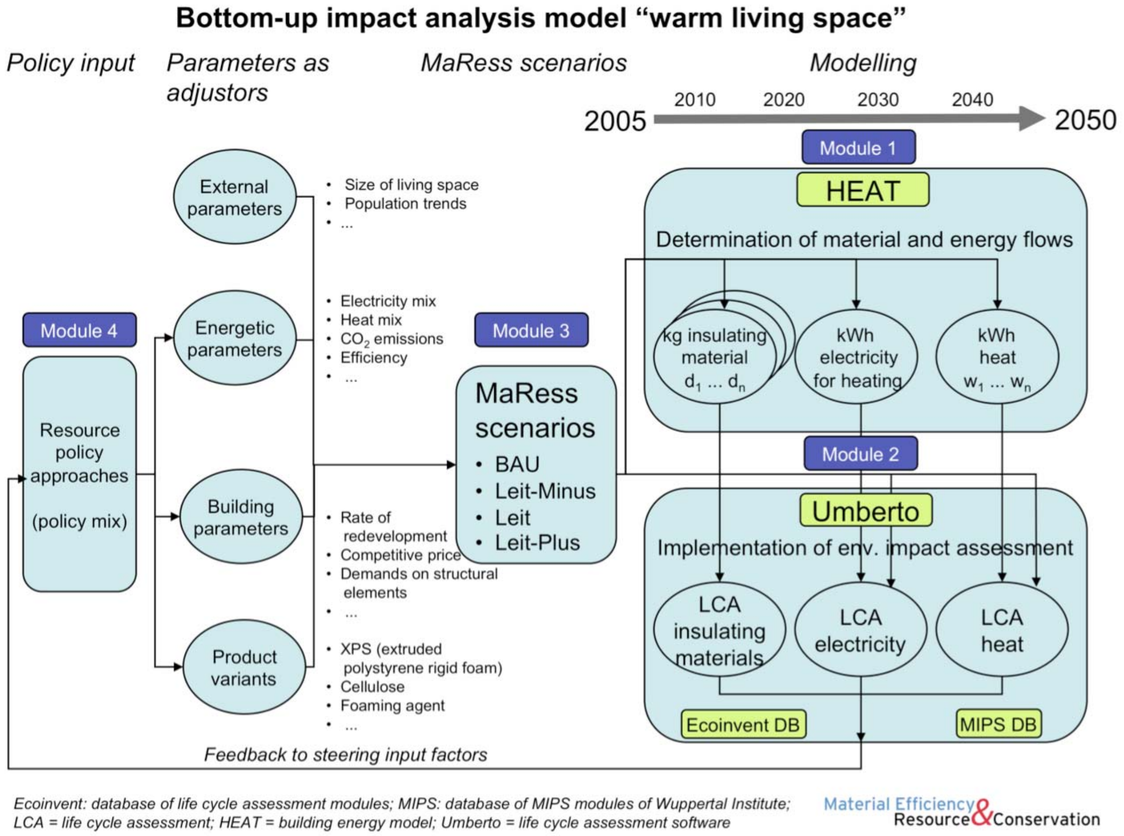
Within this technology model, the development of the final energy demand for the housing sector, divided into energy types, will be modelled for a long-term period up to 2050 for various scenarios, derived from resource policy regulations. At the same time, the direct demand for insulating materials will be determined, whereby the predicted requirements of heat transfer coefficients of building envelopes, for example, are assessed in the calculation of insulating material quantities. The whole building stock in Germany, including new constructions and demolitions, is considered for the years 2005, 2010, 2020, 2030, 2040 and 2050.

Module 2: Environmental impact analysis

The annual quantities of insulating materials used and the annual use of final energy in heating systems in the total building stock computed by *HEAT* are then entered into material and energy flow models, created using the software Umberto. To determine their environmental impacts, life cycle assessments are created in line with (DIN 2006a,b).

The results of these assessments finally undergo an environmental impact assessment, enabling an ecological overall assessment of materials and quantities of energy used to be made with the help of various environmental impact indicators, taking the respective upstream supply chains into consideration. We use the CML method (Guinée et al. 2002: 63ff), applied by a wide range of international users, which is characterised by its coverage of a multitude of impacts of various environmental media. These include impact categories on the emissions side and the input side.

Fig. 1: Model concept for the category of need “warm living space”



Source: Author’s design

On the emissions side, the following impact categories are assessed: eutrophication, acidification, stratospheric ozone depletion, freshwater sediment ecotoxicity, sedimentary marine water ecotoxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photo-oxidant formation, climate change, ionising radiation and human toxicity.

On the resource side, the following impact categories are assessed: *depletion of abiotic resources* and *land use.* The resource indicator captures the extraction of mineral raw materials and fossil fuels. On the basis of its relation between annual extraction and resource potential (“ultimate reserves”), its depletion potential is determined and converted to the reference resource antimony during characterisation.

These two indicators on the resource side provide information on the strain placed on energy, material and land resources by the product system, whereby 284 elementary flows of the “resource” category are assessed. The depletion potential, however, does not take into account the total quantity of abiotic and biotic resources used. To this end, we must also capture the “ecological rucksack” via indicators MIPS or TMR (one of the main categories of MIPS which is to be captured long-term at the economic level, too, as a key indicator of OECD, ESTAT and DESTATIS). Since, however, it is not possible at present to carry out a consistent assessment including both life cycle assessment indicators and MIPS indicators (see need for research in Section 4), the life cycle assessment indicators are used here for the time being. In a sensitivity analysis, material intensities are additionally computed using MIPS in one case.

Module 3: MaRess scenarios

Modelling within HEAT and Umberto is based on the definition and design of various “MaRess scenarios”. In the long-term perspective, these describe potential development paths to reduce energy demand (and hence energetic resources) in the private building sector. The scenarios cover a range from low to very high depths of (policy) intervention. Initially, they are oriented towards the instrument of energy modelling, since we have decades of experience and specific policy regulations or memorandums of understanding on this (see Section 2).

Module 4: Policy mix and influence parameters

Drivers for the various scenarios are relevant influence parameters resulting from the policy mix of a resource policy. These variables, also called “adjustors”, determine the range of scenarios, showing a spectrum of potential developments up to 2050. These include

- *External parameters*: Framework indicators which reflect a general economic or social development, and are equally applicable to all scenarios, are combined under the general non-energetic drivers. They also include demographic trends and the associated development of living space, the development of structural element standards (since the quality of the respective standards within the scenarios are not varied, only their market shares), as well as the impact of accompanying measures on redevelopment rates.
- *Energetic parameters:* Assumptions were made on the development of the electricity mix and the heat mix in the benchmark years for all MaRess scenarios. In the material flow model, the respective electricity mix is taken as a basis for the direct power requirements for manufacturing insulating materials and the use of electricity for heating purposes. The heat mix is incorporated into the assessment of heat and hot water generation in households.
- *Building parameters*: In addition to the assumptions directly concerning energy scenarios, further assumptions were made for each scenario with regard to modelling the respective energy consumptions in the housing sector. These assumptions included the expected rate of redevelopment in the housing stock, the demands on the quality of structural elements and competitive prices related to the costs of redevelopment measures.
- *Product variants*: As sensitivity analyses, a variation of the insulating material and the composition of the foaming agents required for manufacturing the insulating material XPS was modelled. With the product variants, it will generally be possible in future to take into account expected changes in production processes (resulting,

for example, from technical innovations, the reduction of materials and energy used or the replacement of individual products by substitute materials).

Throughout the course of various impact indicators, the policy mix Module 4 is finally fed information about the degree to which the targets of original policy approaches have been achieved. It is then possible to adjust and optimise policy approaches if the targets are not met, and to adapt the MaRess scenarios accordingly.

2 Definition and Implementation of the MaRess scenarios

2.1 Starting point: policy mix

Basic idea of the planned modelling

The original aim of modelling the scenarios was to build on one of the policy mixes identified by Task 3, 4 and 12 and, in particular, to integrate resource policy measures into the scenarios or to develop our own specific resource scenarios. The best practice of creating scenarios known from energy modelling served here as the methodical basis. The key elements are:

- *Target orientation*: Definition of a long-term objective consisting of one or more target values – prominent examples are the energy scenarios that have been generated for years and which, in variant E1 of the Lead Scenario 2008 (BMU 2008), for example, focus on the target of achieving an 80% reduction in energy-related CO_2 emissions by 2050;
- *Scenario arrays*: Development of a large number of long-term scenarios which create development paths to achieve the target values set or which show how, and the extent to which, targets have not been met. Such scenarios usually range from little intervention (business-as-usual path) to deep intervention (with consequences to the point of changing the system).

To develop policy instruments, several coordination meetings and joint workshops took place between Modelling Task 5 (Quantitative and qualitative analysis of the economic effects of an accelerated resource efficiency strategy) and 6, as well as Policy Task 3, 4 and 12. In a nutshell, however, none of the resource policy approaches identified by the Policy Task can be directly applied to the modelled area concerning the redevelopment of residential buildings. The only two instruments identified as relevant would have been the taxation of construction materials (Task 3) and the resource certificate for buildings (Task 12). The former, however, takes only primary building materials into account, whilst insulating materials are modelled in Task 6.2; the latter was discarded due to major uncertainties regarding the values to be applied. It became evident that there is still need for further research concerning the connection of the scenario development to material flow modelling with the specification of housing-related instruments.

Even if quantifiable instruments were available, however, the challenge, from a technical point of view, is to be able to model them in material flow models. As mentioned above, integrating resource indicators into life cycle assessments constitutes another important research approach.

Alternative modelling approach chosen

Due to the difficulties in defining specific resource targets, and the instruments to achieve them, existing climate policy targets and scenarios were reverted to. In established scenarios from this sector, such as variant E1 of the Lead Scenario 2008 (BMU 2008), a limitation of energy-related CO_2 emissions in Germany to 40% by 2020 compared to 1990 and to 80% by 2050 is generally modelled. These targets are often even more ambitious in more recent scenarios. For instance, a figure of -91% by 2050 is given in the innovation scenario according to the Öko-Institut and Prognos (2009). Even if these scenarios do not include specific resource targets, they are nevertheless of great relevance to the targets pursued in MaRess:

- Due to the energy demand in the power, heat and transport sectors, a large quantity of finite energetic resources (primary energy) is used. It therefore appears to be extremely relevant to consider these sectors, not only for climate policy, but also for resource policy (and security policy) reasons;
- until now, no assessments had been made of possible trade-offs between energy savings and the total consumption of raw materials. By coupling a building energy model to a material flow model, we now have the opportunity to analyse this specifically for the first time.

Against this background, the MaRess scenarios for the category of need "warm living space", based on the respective energy scenarios, will be described in the following section.

2.2 Narrative description of the MaRess scenarios

The *Lead Study 2008* by the German Federal Ministry for the Environment, Nature Conversation and Nuclear Safety served as a basis for creating the scenarios. The Lead Study is based on the target-oriented *Lead Scenario 2008,* which shows how energy-related CO_2 emissions in Germany can be reduced by approximately 20% by 2050 compared to the 1990 value (BMU 2008). It specifies the interim targets set by the German government for 2020, laid down in the resolutions of the German government, applicable laws and the regulations of the EU Commission. They concern stipulations on the reduction of CO_2 emissions, the increase of energy productivity and the contribution of renewable energies, triggering a structural change in energy supply. The heat mix in the household sector and the national average electricity mix from the energy scenarios are used for modelling purposes in Task 6.2.

The economic data and other underlying data (for example, population trends, household sizes) upon which all scenarios of the Lead Study are based were slightly adjusted. In particular, the economic data was revised downwards due to the economic crisis. Modelling in *HEAT* and top-down modelling in Task 5 are both based on the same adjusted data.

The *MaRess BAU* scenario

To show how the *Lead Scenario 2008* contributes to climate protection and resource targets, it is advisable to model a reference development first. Since in the *Lead Study 2008* target-oriented scenarios were devised that were not compared to such a reference development, we first had to devise our own business-as-usual scenario (BAU). To achieve this, we used the reference scenarios from the World Energy Outlook (IER et al. 2009) and the WWF study “Modell Deutschland” (Öko-Institut and Prognos 2009).

The *MaRess Leit-Minus* scenario

The *MaRess Leit-Minus* scenario corresponds to the *Defizitszenario D1* contained in the *Lead Study 2008*. On the one hand, it is assumed here that use of renewable energies will be expanded as intended, that is, that the quantity of power and heat generated in absolute quantities remains the same as in the *Lead Scenario 2008*. On the other hand, however, it is assumed that the package of measures to increase efficiency and to expand combined heat and power will have a lower impact. Consequently, the demand for energy increases, which is why the share of renewable energies declines in relative terms.

The MaRess Leit scenario

The *MaRess Leit* scenario corresponds to the Lead Scenario 2008, described above.

The *MaRess Leit-Plus* scenario

MaRess Leit-Plus differs to *MaRess Leit* in that the efforts to improve efficiency in the category of need “warm living space” have been *heightened* by further reducing the demand for heat energy. The simplified heat mix composition was kept constant, meaning that both fossil and renewable heat transfer media decrease in absolute terms.

2.3 Details of scenario interventions on the demand side and their drivers in *HEAT*

Complementary to the basic assumptions on the energetic side, further influence factors or drivers (see Module 4) were set in the MaRess scenarios to implement efficiency measures in the housing sector. These were used to model the demand side in *HEAT,* and are outlined in Tab. 1.

Tab. 1: Scenario-specific summary of influence factors in the area of buildings

Scenarios				
Influence factors	***MaRess BAU***	***MaRess Leit-Minus***	***MaRess Leit***	***MaRess Leit-Plus***
Objectives **• Lead Study 2008** **• Other**	a. Final energy b. Renewables	a. Final energy b. Renewables	a. Final energy b. Renewables	--- --- Result-oriented complete redevelopment whilst tapping the full potential of renewable energies from the Lead Scenario
Lead indicators at the effective energy level (building efficiency)				
Redevelopment rate	Residuum up to < 0.7% p.a. Current rate of redevelopment in the implementation of thermo-technical measures to the building envelope	Residuum up to < 0.7% p.a.	Residuum < 1.5% p.a. Promotion of accompanying measures (energy consulting, energy performance certificate, Reconstruction Loan Corporation (KfW))	< 2.5% p.a. Maximum implementation (complete redevelopment)
Competitive price		Residuum up to < 4.4 ct/kWh	Residuum up to < 6.7 ct/kWh	8.8 ct/kWh Oriented to future price trend of energy sources
Amortisation expectation		< 4 years Expected profit from household investments	< 10 years Average expectation of profit (banking practice)	< 15-20 years Oriented to life cycles of structural element renewals
Demands on structural elements (old buildings)	EnEV 2009 (Energy Saving Ordinance)	EnEV 2009	-15% HT’ (average heating heat requirements) (based on EnEV 2009)	Gradual tightening from 2020 to 2050 to passive house
New buildings up to 2020 2020-2050		Residuum -15% HT’	Residuum -80% HT’	-80% HT’ Passive house
Lead indicator(s) at the final energy level (heating system mix/efficiency)				
Potential renewable energies	SPECIFICATION of reference development	SPECIFICATION from the Lead Scenario (D1 reduced efficiency)	14.8% of the demand for heat in 2020 (excluding heat flow)	Absolute values from the Lead Scenario
Technical progress (specifically degree of utilisation)	BAU	BAU	BAU	BAU

Source: Author’s compilation

3 Modelling Results and Conclusions

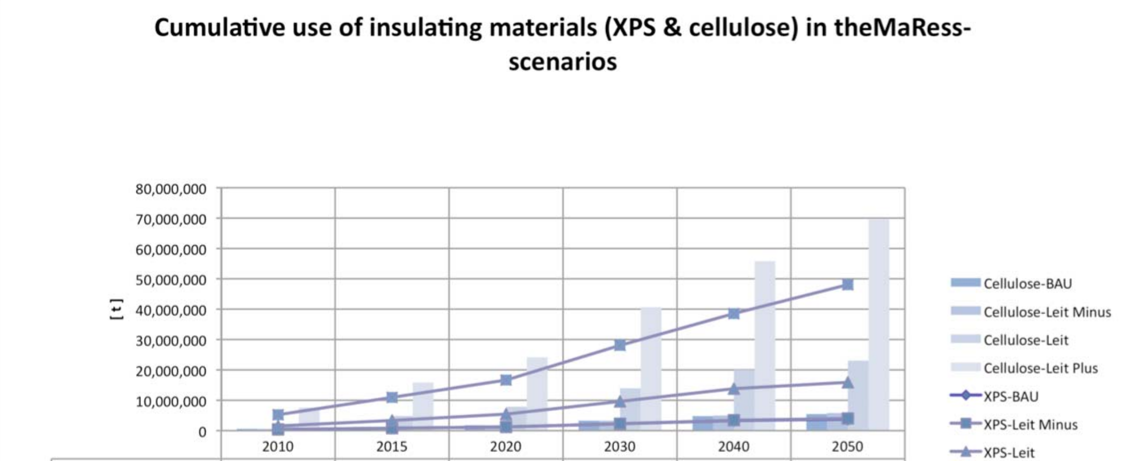
Modelling in Task 6.2 revealed a plethora of new findings. The three key results on the methodological side are

- the development of the bottom-up impact analysis model and its exemplary application to the category of need “warm living space”,
- a trade-off analysis, conducted for the first time, between increasing efficiency, resource consumption and emission impacts, and
- the expansion of “pure” energy scenarios by resource policy analyses, made possible by this analysis.

The key result of the model analysis is that the additional expenditure for insulating materials is overcompensated in almost all environmental impact categories due to considerable savings on building heating only both the resource and the emissions side. Essentially, no trade-offs are perceptible, and the percentage contribution of insulating materials to the environmental impact indicators is low.

Fig. 2 shows the development of the cumulative use of insulating material in the four MaRess scenarios (in the base case, we used the insulating material XPS, portrayed as a line). The increasing demand for insulating materials associated with ever deeper intervention based on policy stipulations is clearly visible, particularly in the *MaRess Plus* scenario.

Fig. 2: Cumulative use of insulating materials (XPS and cellulose) in the MaRess scenarios *MaRess BAU, MaRess Leit-Minus, MaRess Leit* and *MaRess Leit-Plus*

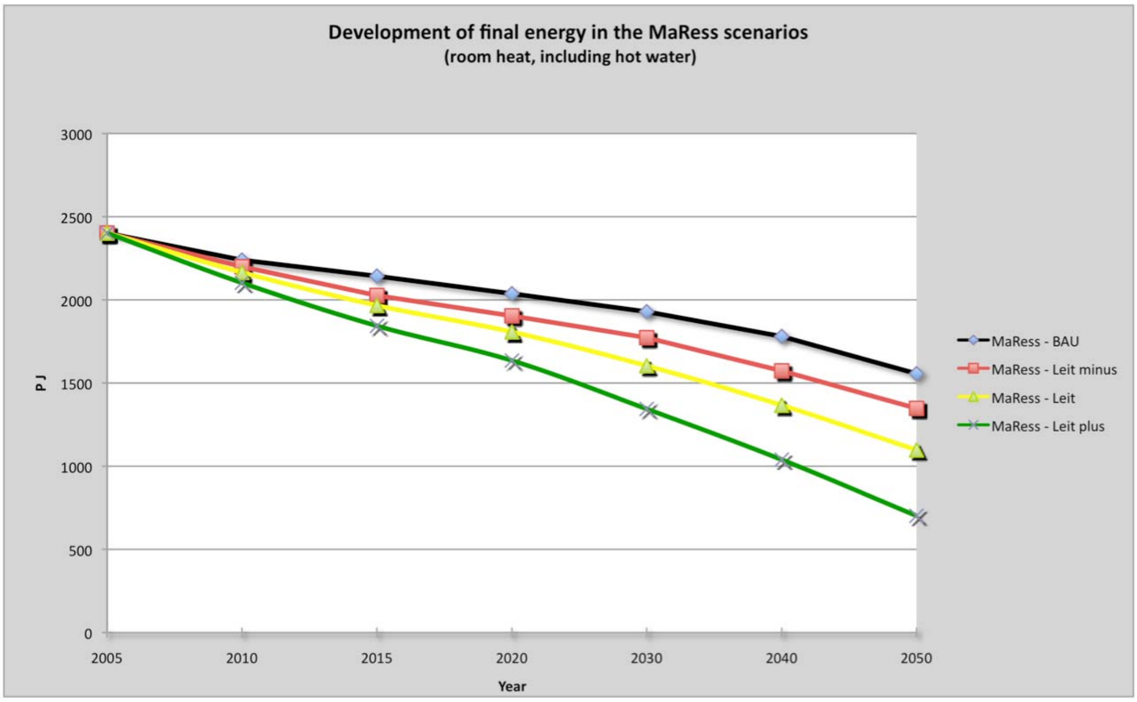


	2010	2015	2020	2030	2040	2050
Cellulose-BAU	589,690	1,179,380	1,769,070	3,285,415	4,801,760	5,468,529
Cellulose-Leit Minus	589,690	1,179,380	1,769,070	3,285,415	4,970,243	5,805,495
Cellulose-Leit	2,223,041	4,850,272	7,881,692	13,944,532	20,007,372	23,041,920
Cellulose-Leit Plus	7,580,105	15,849,310	24,118,515	40,656,925	55,817,134	69,599,143
XPS-BAU	407,128	814,256	1,221,383	2,268,283	3,315,183	3,775,527
XPS-Leit Minus	407,128	814,256	1,221,383	2,268,283	3,431,505	4,008,171
XPS-Leit	1,534,810	3,348,676	5,441,599	9,627,444	13,813,289	15,908,371
XPS-Leit Plus	5,233,380	10,942,521	16,651,662	28,069,945	38,536,705	48,051,940

Source: Author’s model calculations

Fig. 3 shows the reduction in final energy (room heat, including hot water) resulting from the use of insulating materials. In the business-as-usual path (*MaRess BAU*), a 35% reduction by 2050 is possible. In the *MaRess Leit-Plus* scenario*,* the quality of redevelopment measures (gradual intensification of the redevelopment of old buildings to passive house standard) has a particular impact on the demand for effective energy, leading to consistent reductions in effective energy, final energy and emissions in connection with the use of renewable energies. The enforced saving strategy leads to effective energy savings of 1,250 PJ and final energy savings of approximately 1,700 PJ, or 70%.

Fig. 3: Comparison of the demand for final energy in the MaRess scenarios *BAU*, *Leit-Minus*, *Leit* and *Leit-Plus* for room heat and hot water up to 2050

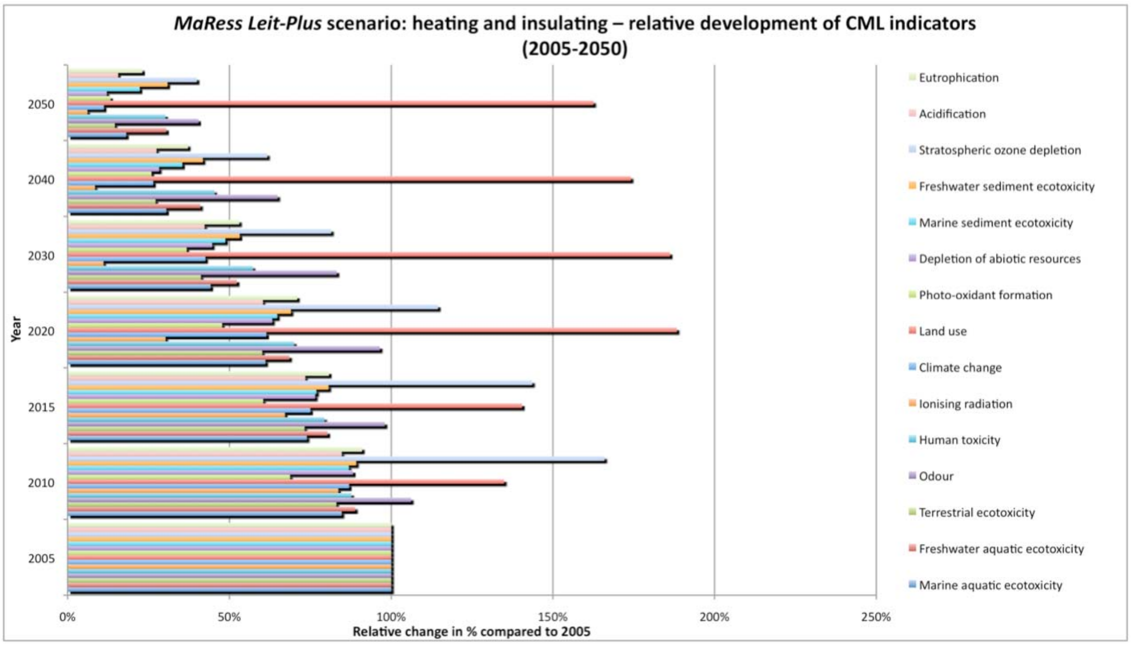


Source: Author's model calculations

If we compare the development of environmental impacts along the four scenarios, it becomes evident that, even in the reference case – the *MaRess BAU* scenario – a continuous, but moderate net decline of 30-50% by 2050 compared to 2005 can be observed in all of the impact category indicators considered. As expected, this decline increases steadily the more resource and climate policy is accelerated, and reaches a net reduction of 70-90% in the same period in the *MaRess Leit-Plus* scenario (see Fig. 4).

Here, however, (and also in the *MaRess Leit* scenario not shown here) initially opposing developments can be observed in three environmental impact categories: the two impact categories “*odour”* and “*stratospheric ozone depletion”* increase up to 2010, and only then decrease analogously to the other categories. The impact category “*land use”* increases up to 2020, and only then drops (slightly).

Fig. 4: Relative development of environmental impact indicators in the *MaRess Leit-Plus* scenario



Source: Author’s model calculations

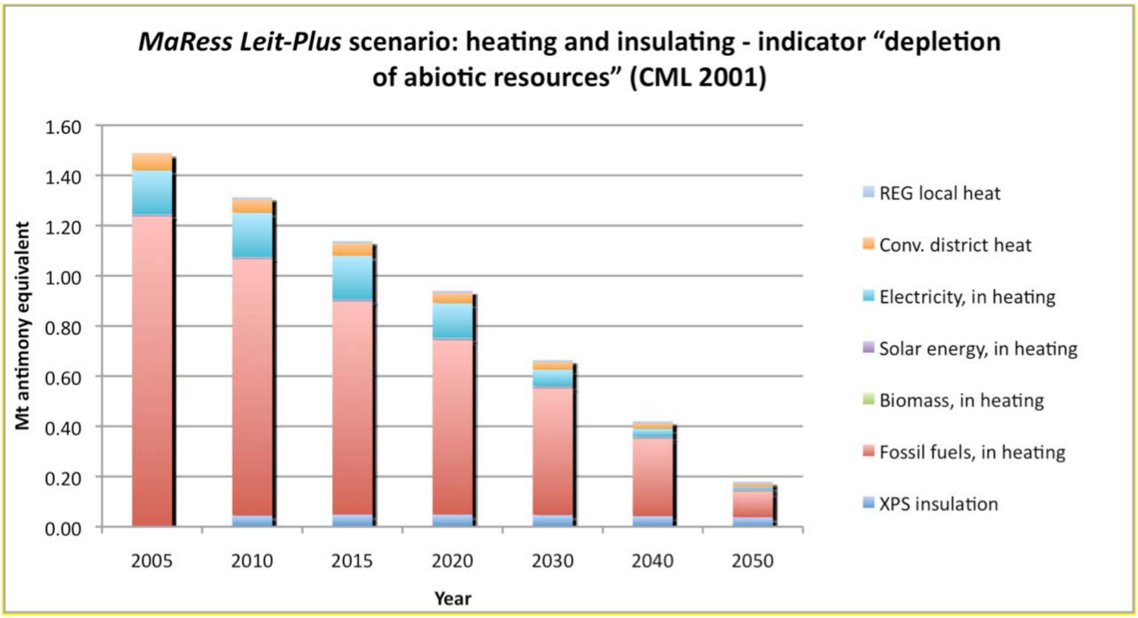
This is due to the following developments:

- The indicator “odour”, dominated by fossil fuels, initially exceeds the value of the base year due to increasing proportions of biomass in the electricity mix and regenerative local heat, but falls below it by 2050, as a result of savings in fossil fuel heat energy. The increased use of biomass can also impact on the particulate air pollution which is not captured separately here, but is included in the indicator “human toxicity”.
- The indicator “stratospheric ozone depletion”, dominated essentially by the use of fossil fuel-fired heating, also increases initially by over 50% of the value of the base year 2005, due to additional process-related emissions in the manufacture of XPS insulating materials. This effect is compensated as early as from 2030 due to savings in fossil heat energy caused by insulation. In the further course of time, the impact drops considerably by around 60% of the reference value by 2050.
- The rise in the indicator “land use” is also a result of the increased use of biomass heating in the heat mix. Due to the increased use of biomass in pellet and firewood heating, this is the only indicator that is higher in 2050 than the base value of 2005. However, this development must be seen independently from efficiency measures, since it is based on scenario assumptions on covering the remaining need for heat by renewable energies. Since, in the event of the growing need for forest biomass

and restricted domestic potential, increased competitive usages can be expected with material uses and increasing import dependencies, the Lead Scenario of the BMU should be reviewed on the basis of a comprehensive biomass concept, taking domestic and foreign land use into consideration.

It can also be seen from Fig. 4 that the impact indicator “depletion of abiotic resources” will drop continually, despite the extensive use of insulating materials. In a detailed analysis, Fig. 5 shows which processes contribute to the depletion of natural resources, in turn using the example of the *MaRess Leit-Plus* scenario. According to this, the share of XPS insulating material is very low: 3% in 2010 and 10% in 2050. The impact results primarily from the use of fossil sources of energy for heating purposes.

Fig. 5: Absolute development of the environmental impact indicator “depletion of abiotic resources” in the *MaRess Leit-Plus* scenario

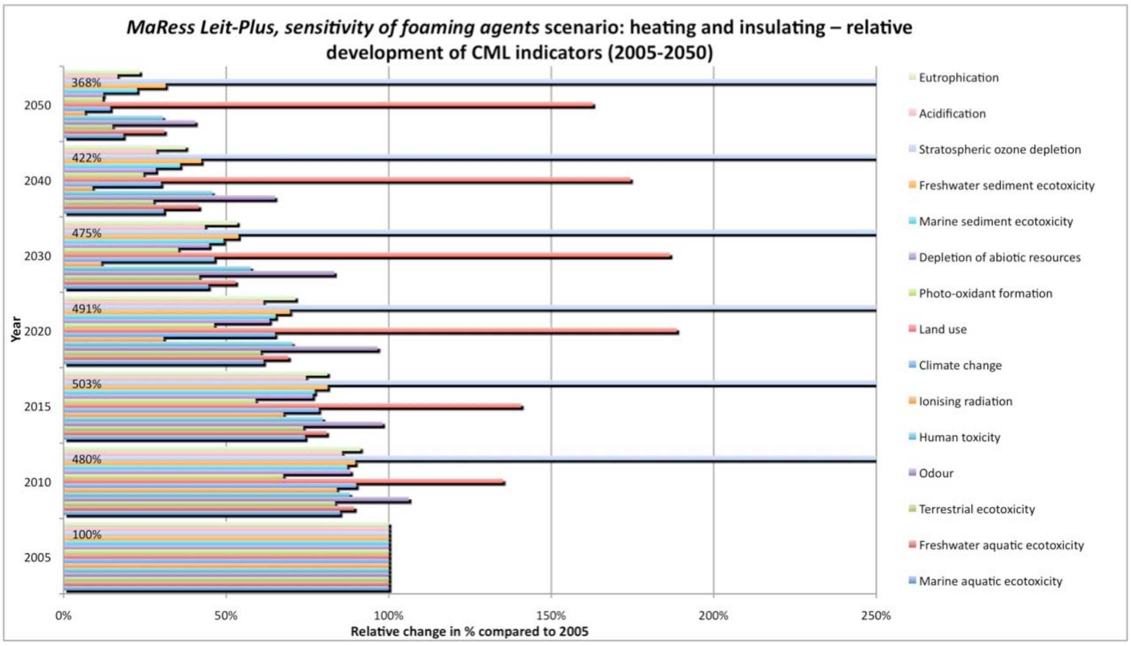


Source: Author’s model calculations

The choice of foaming agent in the foamed XPS insulating materials is important (see Fig. 6): it was assumed for the base analysis that 90-96% of the XPS used in Germany was foamed using CO_2, whilst the remainder was foamed in equal parts by the fluorocarbons HFC-134a and HFC-152a. Since this proportion may differ considerably in other countries, in a sensitivity analysis a foaming agent composition of 50% CO_2 and 25% each of HFC-134a and HFC-152a was assumed. In the final result, this leads to a considerable trade-off with regard to the impact category “stratospheric ozone depletion” (the impact of insulation exceeds the relief caused by the 500% energy savings in 2015, and decreases to 368% in 2050) and to a perceptible, yet not very considerable impact on the greenhouse potential.

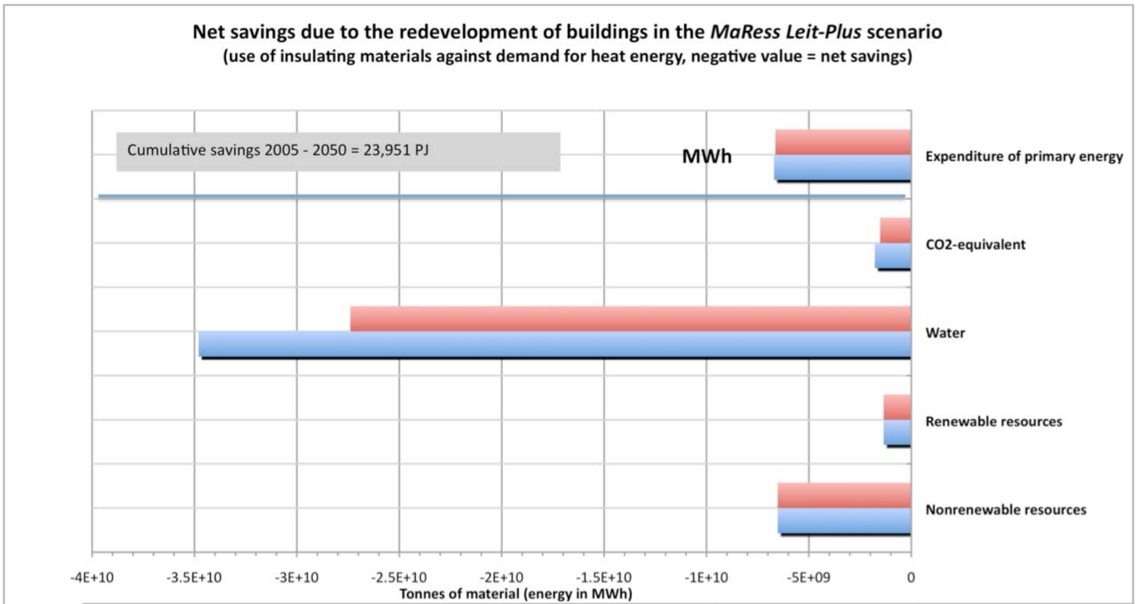
In the second sensitivity analysis, the alternative insulating material cellulose (made of recovered paper) was used. As seen above in Fig. 2, there is a considerable additional consumption of cellulose compared with XPS – with the same heat insulating standard. This is because XPS has a substantially lower density than cellulose. The results of the life cycle assessment show, however, that even the already small proportions of insulating materials in the impact indicators decrease yet further.

Fig. 6: Relative development of CML indicators in the *MaRess Leit-Plus (sensitivity of foaming agents)* scenario – values between 250 and 500% are cut off



Source: Author’s model calculations

Fig. 7: Results of the trade-off analysis (use of resources versus savings) of the insulating material variants XPS and cellulose



	Nonrenewable resources	Renewable resources	Water	CO2-equivalent	Expenditure of primary energy
XPS	-6522521333	-1350429185	-27389684153	-1521791597	-6,637,855,394
Cellulose	-6524117169	-1350429185	-34803888107	-1782416129	-6,704,123,783

Source: Author's model calculations

If, in addition to the impact indicators from the life cycle assessment, the resource indicator set MIPS is taken into consideration, it becomes evident that XPS and cellulose insulation have a comparative impact on the material intensity. The cumulative net impact from the use of insulating materials compared with the savings from heat energy is portrayed in Fig. 7. They include an estimate of the balances of primary energy expenditure, greenhouse gas emissions and the need for water, biotic and abiotic raw materials. The negative indicator values show that, due to the impact of insulating materials and the associated considerable reduction in heat energy, the additional consumption of material is overcompensated by savings in both cases. In summary, ambitious insulating material strategies using not only XPS, but also cellulose, make a considerable contribution to both material efficiency and emission reduction targets with regard to all of the factors analysed in this Task.

In general, competitive situations can arise in the use of wood-based insulating materials. According to Fig. 2, in the case of cellulose, however, even with a complete redevelopment by 2050 exclusively on the basis of this insulating material, an average annual expenditure of around 1.2 million tonnes of recovered paper must be assumed. This value equates to approximately 8% of the quantity of domestic recovered paper in 2007, which amounted to 15.4 million tonnes (VDP 2010). In a realistic insulating material mix, competitive usages with the manufacture of recycled paper and indirect competition for space for forest resources are therefore assessed as low, but should nevertheless be investigated when devising an insulating material strategy.

Since energy resources make up a considerable share in the environmental impact of the category of need “warm living space”, it was nevertheless possible in the first step to model in detail energy and climate policy approaches in connection with resource policy (in particular with regard to building insulation). This constitutes a considerable expansion of previous “pure” energy scenarios, which do not focus on the resource side, and generally consider only greenhouse gas emissions on the emissions side.

4 Policy Recommendations and Need for Research

The results presented here lead to the following policy recommendations:

- The energy savings and efficiency strategies modelled in the MaRess scenarios, based on the BMU Lead Scenario 2008, should be implemented promptly. Relevant policy guidelines would have a positive effect on virtually all environmental impact categories, in particular the consumption of material resources and almost all emissions indicators.
- The increased consumption of land arising (indirectly) from the increase in biomass heating plants should be taken into consideration when implementing a renewable energy strategy. To this end, a comprehensive biomass strategy is required that takes into account the use for food, materials and energy, and the domestic and foreign use of space.
- Due to the considerable trade-off arising when XPS insulating material is not foamed using CO_2, but using fluorocarbons (HFC), a further reduction of HFC in insulating materials should be supported in industrial policy. Whilst in Germany, CO_2 is already predominantly used (a proportion of 90-96% was assumed), this concerns insulating materials manufactured, in particular, in other EU Member States.
- The impact on resources in the manufacture of insulating materials and building materials in general should be analysed in depth, and included in industrial policy instruments.
- Efforts should be made to develop a standardisable assessment approach that couples life cycle assessment methods currently being developed to comprehensive material resource indicators. In addition, current, harmonised, reviewed and continuable datasets should be made available.

In addition, a series of research aspects was derived following the analysis of the unanswered questions that arose during the implementation of the project. These aspects ought to be explored in a possible follow-up project with adequate resources.

Technology model *HEAT*

- *Modelling building stock*: In addition to our examination of insulating materials in the framework of energy-saving redevelopment measures, a change in the actual building stock should be modelled. This includes the options of demolition, new construction or recycling. Other materials besides insulation, such as replacing windows, should be taken into consideration. Such a work step necessitates the assessment of the material flows used to build the 44 different house types, as well as an assessment of future material flows arising from new constructions and demolitions. In this Task, we can build on the work from MaRess Task 4.4, in which considerations were made for three exemplary house types.

- *Expansion of HEAT*: Expansion of the MaRess building type model by the estate type approach to enable renewable energies to be included more effectively (consideration of many decentralised plants, including local grids and hot water storage tanks).
- *Consideration of climate change*: In future, assumptions should be made on the extent to which climate change will impact on the need for heat and air conditioning in buildings, which, if possible, should be included in the model calculations.

Bottom-up modelling

- *Quantification*: Political scientists should methodically quantify policy approaches or more advanced instruments. The aim should be to have the ability to assess the short-, medium- and long-term effects of identified policy measures on a time line up to 2050. At the same time, one or more target indicators should be developed that can be modelled into long-term scenarios.
- *Other categories of need*: The devised approach could be transferred to other categories of need (for example, mobility, nutrition or consumption). To this end, relevant “technology models”, such as that available for the category of need “warm living space” in the form of the *HEAT* model, would have to be used or developed. For the category of need “mobility”, it would make sense, for instance, to couple it to ifeu’s TREMOD model.
- *Renewables and consumption of resources*: Trade-offs between raising efficiency, consumption of resources and the impact of emissions were calculated in Task 6.2. Building on the model approach developed, the expansion of renewable energies in accordance with the *Lead Study,* and its impact on the consumption of resources should be computed. In particular, the scenarios of the *Lead Study* with regard to total demand for land for all biomass consumptions in Germany should be reviewed.
- *Scenario update*: The MaRess scenarios are based on scenarios from the Lead Study 2008. Following the publication of the new *Lead Study 2010,* the MaRess scenarios should be updated accordingly.

Bottom-up versus top-down modelling

- The model results from bottom-up modelling should be aligned with the results of the top-down computation carried out in parallel by modellers in Task 5. This step could no longer be carried out in Task 6.2, due to time limitations. Using an example (such as the *MaRess Leit* scenario), it should be investigated whether appreciable deviations exist between the two model approaches and, if so, what causes them. It should be explored whether the results could be optimised using a hybrid model. Data from the top-down model could then be applied to the bottom-up model if it does not contain its own life cycle assessment data, or if the quality of such data is inadequate.

Life cycle assessments and resource indicators

- *Coupling life cycle assessments to MIPS*: The life cycle assessment (LCA) method has not yet been fully developed. For one, there is no capture and assessment of the abiotic and biotic use of resources. For this purpose, the MIPS method, for instance, was developed. This method is a variant of the LCA that focuses on the input side and comprehensively captures the use of primary material. One of the main indicators of the MIPS concept – the TMR – is also used at the macroeconomic level and, following improvements to data availability, is to be used long-term as the headline indicator (ESTAT, OECD).

  The system boundaries and allocation rules of LCA and MIPS are very similar. Nonetheless, several deviations should be harmonised in future. On the one hand, various international databases with life cycle assessment modules have been developed over a number of years (such as the ecoinvent database used here). According to the life cycle assessment method, these are oriented to emissions caused by products or services, and partially capture selected substance flows on the input side, up to the extraction of raw materials (with the indicator “depletion of abiotic resources”). On the other hand, the method used in MIPS focuses on considering the whole resource flows of a product. Both approaches have already been combined in a plethora of single studies (including in MaRess 1), whereby key indicators, such as greenhouse gas emissions, are combined with MI categories such as land use. However, there is no harmonisation in the area of previous standard life cycle assessment software packages.

  For this reason, the two approaches must be coupled and the resource categories considered in the MIPS concept should, ideally, be added to the life cycle assessment instrument. This requires an input in the LCA discussion at international and national level, for example, via the UNEP/SETAC International Life Cycle Initiative or the German Life Cycle Inventory network.

- *Expansion of existing life cycle assessment* software: In line with the first point, the MIPS method must also be harmonised with life cycle assessments with regard to software technology. Here, it would make sense to add the MIPS approach to existing software products and databases, with the assistance of software developers (for example, ifu Hamburg for the software Umberto). Discussions have already been held with the providers.

- *Further development of resource indicators*: There is still a need for methodological research in many of the established environmental impact categories. For instance, with regard to the impact category “use of raw materials”, discussions on a suitable raw material indicator have not yet been concluded. Indicator sets such as MIPS to capture the extraction of primary material from the natural environment across the life cycle is a possible solution in this case. The suitability and security of direction of such solutions should be discussed and enhanced within a differentiation process. To this end, an international workshop under the leadership of the Wuppertal Institute has already been held within the scope of the MaRess project.
- *Expansion of data inventories*:
  - Data inventories on the use of raw materials should be updated and harmonised (alignment of assumptions, data and system boundaries) and dynamised (projection to 2025 and 2050).
  - Equally, a series of life cycle assessment data inventories (for example, geothermal power plants, fossil fuel-fired combined heat and power plants) should be updated and harmonised; resource indicators should be integrated into new and updated datasets; collaboration with the German Life Cycle Inventory network would also be of interest here.
  - The stock-taking of resource-intensive infrastructures should be advanced further; the expansion of stock and recycling options (“urban mining”) should be examined using different long-term scenarios.
  - Process chain modelling within life cycle assessments should be further advanced to be able to take dynamic changes in the process chain into consideration more easily and comprehensively (for example, changed material compositions or energy demands in all stages of production).

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