Bridging macroeconomic and bottom up energy models — the case of efficiency in industry

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Abstract

Energy demand and supply projections for a country are generally based on one of two types of models: macroeconomic models or bottom-up models for several sectors. Both types of models are essential for future energy policy design and ex ante evaluation of energy and material efficiency strategies. However, both types have their strengths and limitations. The solution to this dilemma is to link both model types and run them iteratively in order to benefit from their strengths and advantages and avoid their limitations. This paper focuses on one essential element of a hybrid energy model system: the data transformation of industrial production data from a macroeconomic model to an industrial sectoral bottom up model of an existing hybrid energy model system. Making use of this 'transformation module', the information of the macro model is converted into physical units as input for the bottom-up models operating as a "hard-link" between the two model types. This paper reports on energy-intensive industries such as metal production, pulp, paper, and printing, or non-metallic minerals, taking into account material efficiency improvements as well as material substitution and, hence, this aspect of indirect energy efficiency improvements.

Introduction

Extensive discussions in energy science and energy policy communities about the perspectives, feasibility and impacts of future energy demand and supply can often be traced back to the different types of energy models used and their results. Detailed techno-economic (or process-oriented) models of industrials branches can simulate the market penetration and related cost changes of new energy technologies or policies with a certain degree of technical detail (which is why they are called "bottom-up" models), but they cannot project the corresponding economic and social impacts and costs for society. The bottom-up models are able to simulate technical developments in the final energy sectors and the conversion sector in great detail (some of them also optimise electricity generation) including related investments and changing energy and operation costs. However, as stringent policy scenarios may substantially change industrial structures, employment, income and prices, the bottom up models cannot calculate these economic implications.

On the other hand, macroeconomic models (also called top-down models) can simulate sector-specific future energy demand and supply including the impacts on economic growth, employment, prices or foreign trade, but not at the detailed level of specific technologies, their market penetration, or sectoral or technology-oriented policies. The macroeconomic models are used to deliver energy demand and supply projections using a consistent set of data of economic, structural, and demographic developments which reflect assumed general policy framework conditions and calculate economic impacts of particular energy policy scenarios compared to a reference scenario. Their disadvantages are: limited possibilities to simulate future increases

in energy and material efficiency or intra-industrial structural changes due to technological innovations.

This paper focuses on one essential element of a hybrid energy model system: the data transformation from a macroeconomic model to sectoral bottom up models of an existing hybrid energy model system that was developed by Schade, Jochem et al. 2009 (see Figure 1). With the 'transformation module', the information of the macro model (such as economic and demographic data, income growth, gross value added of industrial or service sectors, development of households, price developments) should be converted into physical units as input for the bottom-up models (e.g. tonnes of oxygen or electric steel, cement, paper, or office area) operating as a 'hard-link' between the macroeconomic and sectoral bottom up models.

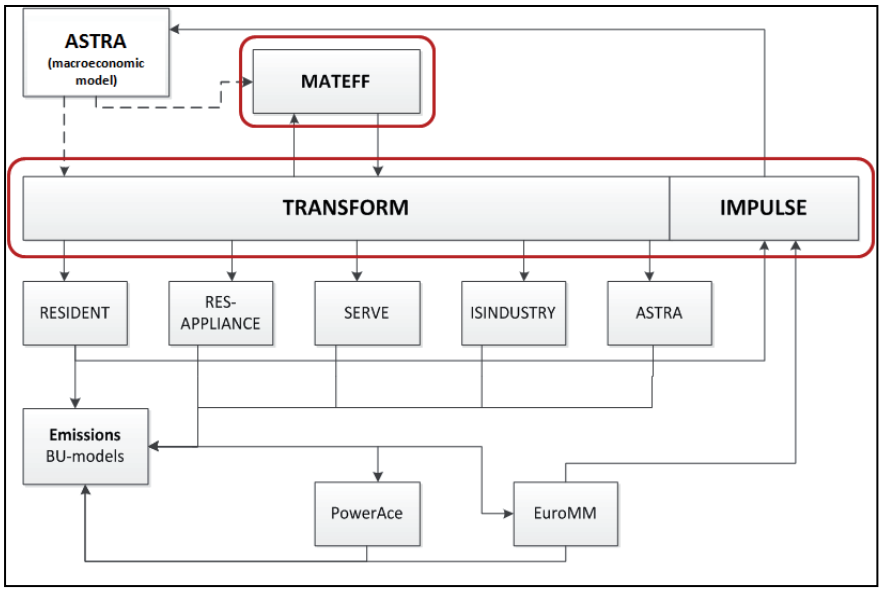
In addition, the 'transformation module' (TRANSFORM) includes a separate 'material efficiency module' (MATEFF) simulating technological and demand changes of energy-intensive basic products. The model is going to handle the reduced demand for industrial basic products due to improved material qualities, improved design, intensified recycling or substitution of basic materials by other materials (Jochem et al., 2007; Schade et al. 2009). In the final step, the 'feedback module' (IMPULSE) inducts the results of the bottom-up models back into the macroeconomic model (e.g. additional investments, reduced energy costs, changed operating costs, and programme costs of policies) in order to allow the analysis of the economic impacts at the macro level.

Energy modelling approaches – state-of-the-art

Every modelling approach abstracts to a certain degree from reality using stylized facts, statistical average figures, past trends as well as other assumptions. Consequently, energy models represent a more or less simplified picture of the real energy system and the real economy; at best they provide a good approximation of today's reality and of possible future situations. Nevertheless, it would be impossible to answer very specific questions on energy technologies or economic implications without making some cut backs and approximations, with an uncertain reliability on quantitative figures used by these models. A large diversity of modelling approaches has been developed over time depending on their target group, intended use, regional coverage, conceptual framework, the available data and resources, and disciplines of the analysts.

Obviously, both types of energy models, top-down and bottom-up, have specific advantages and limitations, of which modellers, users of the results, and policymakers are, however, often not sufficiently aware. Bottom-up models are generally constructed and used by engineers, natural scientists, and energy supply companies, whereas top-down models tend to be developed and used by economists and public administrations. The understanding of the two approaches has increased substantially over the last decade (Böhringer, 1998; Böhringer and Rutherford, 2006, 2008; Hourcade et al., 2006) and there have already been attempts to combine both approaches in one hybrid energy model system (e.g. Jochem et al., 2007; Schade et al., 2009; Catenazzi, 2009). Recent or current projections and studies of energy demand and supply using energy models (E3Mlab, 2007; BFE, 2007; WWF, 2009; IEA, 2010; Prognos, 2011) are not just made for routine decisions by decision makers in administrations or large energy companies; they also increasingly serve as a scientifically derived information basis for societal debate among governments, energy companies, trade associations, and NGOs.

Top-down energy models try to depict the economy as a whole on a national or regional level and to assess the aggregated effects of energy and/or climate change policies in monetary units. Currently, macroeconomic energy models are often used to evaluate the economic costs and environmental economic effects of general energy or climate policy instruments, such as energy or CO_2 taxes or surcharges, emission trading schemes (ETS), feed-in tariffs of renewable energies, etc. (Bataille, 2005).



Source: Jochem/Barker et al. 2007.

Figure 1: Example of a hybrid energy model system, used for 29 European countries and climate change policy scenarios 2005 to 2050.

Table 1: Top-Down versus Bottom-up Modelling.

Model type	Advantages	Disadvantages
Conventional top-down energy model	• feedback loops to welfare, employment, and economic growth • higher consistency of results at macro level	• lack of technological and policy detail • delivery of rather generalized results • inadequate indication of technological progress, innovations, barriers to energy efficiency, etc. • underestimation of non-monetary constraints • tendency to trend extrapolation
Conventional bottom-up energy model	• high degree of technological and policy detail • plausible technology and innovation development • detailed evaluation of technology-specific policies	• (very) high data requirements • no/incomplete picture of macro-economic impacts • no consideration of programme costs

Source: own research.

In the past, conventional top-down energy models considered technology developments mainly in the context of price-based policies (taxes, surcharges, or investment subsidies) and regulatory policies (technical standards, bans, and technological targets). In current top-down modelling approaches, efforts are made to extend the energy demand forecasting framework of the existing models to include technological and economic feedbacks (Löschel, 2002; Böhringer and Löschel, 2006) as well as non-price policies (technical standards, norms, etc.; Worrell et al., 2004). Four main types of top-down models have been identified: input-output models (Nathani et al., 2006; Mayer, 2007; United Nations, 1999; Eurostat, 2008), econometric models (Camecon, 2011), computable general equilibrium models (Capros et al., 1996a, 1996b; Bernard and Vielle, 2008, the GTAP model consortium, or the World Bank models) and system dynamics (Forrester, 1958, 1962, 1971, 1980; Schade, 2004; Krail and Schade, 2010; de Vries et al., 1999; Russ and Criqui, 2007).

The main characteristic of a conventional bottom-up energy model is its relatively high degree of technological detail (compared to top-down energy models), used to assess future energy demand and supply. In contrast to top-down models, bottom-up models use a business economics approach for the economic evaluation of the technologies simulated. They usually cannot consider macroeconomic impacts of energy or climate policies or related investments. They do not consider transaction costs which are implicitly covered by top-down models. Their technological detail and transparency considering technological progress and the diffusion of new energy technologies make bottom-up energy models unsuitable for very long-term energy demand and supply projections in technology areas with re-investment cycles of less than 20 years (e.g. future generations of a new technology may be quite different from its present type). Additionally, most bottom-up models limit their investment and cost calculations to the conversion sector and cross cutting technologies in the final energy sectors if it comes to energy efficiency options. This fact is often overlooked and leads to questionable conclusions in cases of scenario comparisons and model comparisons. The following main types of bottom-up models have been identified: partial equilibrium models (Enerdata, 2011; IEA, 2011; E3Mlab, 2007), optimisation models (Seebregts et al., 2002; Loulou et al., 2004; Schade et al., 2009), simulation models (Mundaca and Neij, 2009; Yao and OrAn, 2010), multi-agent models (Sensfuss, 2008; Sensfuss et al., 2008; Weidlich and Veit, 2008)

Linking the results of process-based models and macroeconomic models

Between the 1970s and the 1990s many debates about the quality of energy demand projections and the related impacts on the economy and society could be observed at international conferences, energy symposia, or seminars. There was inadequate understanding of the strengths, weaknesses, and limitations of the top-down and bottom-up models used by the different disciplinary communities, but with the increasing interdisciplinary competence of energy research teams over the last decade there has also been a growing demand to combine the two approaches. Despite the fact that these models are essential for future energy policy design, they will always be associated with certain strengths and weaknesses as they are only models and designed for a specific use (see Table 1).

To overcome the above mentioned weaknesses and limitations of conventional top-down and bottom-up energy models, energy modelling is currently moving in the direction of hybrid energy modelling systems combining at least one macroeconomic approach with at least one bottom-up approach. The simplest form of linking top-down and bottom-up approaches, also called 'soft linking', is the manual transfer of data, parameters and coefficients. If this transfer is further evolved using automatic routines, a 'hard link' is established between the different models. The next step for connecting top-down and bottom-up models is to apply partial model elements (top-down or bottom-up) in their modelling counterparts (Catenazzi, 2009; Hourcade et al., 2006; Bataille, 2005; Kumbaroglu and Madlener, 2001; Jochem et al., 2007). Challenges facing hybrid energy modelling include, amongst others, the need to keep such combined model systems theoretically consistent and empirically valid without constructing huge models that are incomputable. Additionally, the endogenous consideration of structural change (intersectoral as well as intrasectoral) and technological progress are important issues that require further attention/research.

Presently, linking the two types of models is often limited to manually transferring a few major drivers and investment figures of bottom-up models to macroeconomic models. Data transformation modules between the two types of models are important in policy scenarios because macroeconomic models cannot simulate detailed technological innovations in the energy field by definition due to their focus on technological developments. Similarly, bottom-up models cannot simulate the macroeconomic impacts of new energy technologies. The challenge presently facing energy demand and supply modelling is the need to link these two 'worlds'. What is needed is the ability to simulate the projected futures in both types of models consistently which may induce the need for one or two iterative runs between the two types of models in policy scenarios that deviate substantially from a reference scenario (e.g. a climate change scenario with substantial reductions of greenhouse gas emissions during the next few decades, assuming substantial increases in energy and material efficiency and intensive use of renewable energies).

Transformation of data and results between the two types of models

This section describes a work-in-progress hard link of a hybrid energy model system based on the ADAM project (Adaptation and Mitigation Strategies): a European energy model (Jochem et al., 2007), which will connect several process-oriented, bottom-up models for individual final energy sectors and conversion sectors on the one hand with a macroeconomic simulation model on the other hand in both directions (see Figure 1). The model system combines a macroeconomic model (ASTRA), with a set of bottom-up models for the four final energy sectors (industry, services, transport and the residential sector which has been split into buildings and electrical appliances). The drivers of energy demand needed by the several bottom-up models are projected by the macroeconomic model ASTRA as for e.g. GDP, population, income per capita, production values of the individual branches in industry and the service sector. This hybrid system has been applied to project the energy demand and supply of 29 European countries up to the year 2050 in various scenarios (Jochem et al., 2007; Schade et al. 2009). As describing all bottom-up models of the hybrid energy model system would exceed the scope of this paper, the authors focus only on the 'transformation module' of this model system for the case of industry.

The TRANSFORM module translates monetary production data of basic goods industries into physical production. It also should incorporate improvements in material efficiency and material substitution and saturation by the MATEFF submodule; a bottom-up model for simulating those effects on basic products such as steel, cement, non-ferrous metals, paper, glass, etc. Finally, the IMPULSE module of this hybrid model system collects all data of the bottom-up models on investments, changing operating cost (including energy cost), and the programme costs, stemming from the policies assumed in a particular scenario. (Jochem et al., 2007; Schade et al., 2009). To relate the specific energy demand of basic materials to their physical production and not to monetary production data (such as gross value added or net production) is very important in order to arrive at realistic and transparent results in energy demand projections of basic product industries.

THE 'TRANSFORMATION MODULE' (TRANSFORM) REGARDING THE INDUSTRIAL SECTOR

The TRANSFORM module converts production (for energy-intensive bulk products) given in monetary units (such as net production or gross value added) into physical units (e.g. tonnes), however the TRANSFORM module is still under methodological development and improvement. Establishing a relation of the energy-intensive basic industrial products to the economic unit of gross value added or net production delivered by the top-down models is a challenge due to the following reasons:

- Past or future increases in gross value added may not be only caused by increases in production but also due to quality improvements (e.g. high quality steel, complex co-polymers) or additional services (e.g. delivery of concrete instead of cement, or support of planning or maintenance of machinery) of the related industrial sector. It is important, therefore, to relate the specific energy demand of those basic materials to their physical production and not to economic values such as gross or net production values in order to arrive at realistic and transparent results in energy demand projections.
- Changes in the quality of basic industrial products or improved design or less primary wastes in manufacturing may also induce reduced demand for the basic materials: For instance, beer bottles produced 30 years ago were 30 % heavier than those made today. Increased recycling of paper, paper board, copper, aluminium etc. may also reduce energy demand. This can be considered in bottom-up modelling.
- Finally, (partial) substitution of raw materials may reduce the energy demand of basic industrial products such as steel furnace slakes in cement production or bio-based fibres or starch in the production of chemical fibres and polymers. These technical options which result in the decreased production of energy-intensive basic materials will be considered in the MATEFF module.

Transforming industrial economic production values in physical units

The first step when turning the economic production units from macroeconomic models into physical units is to analyse past production statistics. Generally, one observes that the growth of bulk products in physical terms is smaller than in terms of gross value added or net production of the branch considered indicating a trend towards higher material qualities and additional product accompanying services. The relation between the two growth rates varies among basic industrial products over time. There are many reasons for these differences such as saturation processes in highly industrialised countries, changes in the recycling rates of the specific energy-intensive basic product, slow or fast market diffusion of a new high quality product which may also depend on growing or shrinking exports (e.g. more construction steel imported from Central European countries or emerging countries, or shrinking primary aluminium production in most European countries).

The TRANSFORM module transforms the development of the gross value added by certain energy-intensive branches of EU-27 plus Norway and Switzerland (extensions for Turkey are under development) from 2008 to 2035 into physical units

(Jochem et al., 2007, 2008). At present, the module covers the following branches (according to the sectoral definitions used in the energy balances of EUROSTAT) and their related energy-intensive products, which add up to nine basic industrial products as first candidates for the methodological development covering different aspects such as intra- and inter-product group substitution, long or close supply chain to the end product, and scarcely or intensively tradable basic products:

- iron and steel industry: oxygen steel and electric steel,
- non metallic minerals: cement, flat glass, container glass, other glass,
- non ferrous metals: primary and secondary aluminium,
- pulp and paper: paper,
- chemicals: chlorine.

Extensions to further industrial products are planned in the next few years when the methodological questions of the hard link are more developed. Besides information on the development of the gross value added (GVA) of the energy-intensive branches listed, the TRANSFORM module will also use data on the population, per capita income of a country, foreign trade (tradable intermediate and final products). The MATEFF submodel is expected to deliver future domestic material usage and demand, accordingly; i.e. material efficiency assumptions, recycling trends, and past and future trends of changes towards higher quality products, quality improvements (trends towards higher value added). Finally, the expansion of product-related services in selected industries have to be considered (especially capital goods) influencing the relation between growth of GVA and physical production.

The methodology currently used in the TRANSFORM module is still quite simple. Depending on the basic product and some statistical and literature analysis, a choice is made among the various possible drivers and potential influencing factors (population, gross value added, changing recycling rates, better material qualities, etc.) to make an educated guess at the correlation between the driver selected and the production of the bulk product. After its finalisation, the TRANSFORM module will consist of different approaches including econometric, technological-econometric and partial analytical approaches as well as expert estimates. Trends of increasing gross value added in relation to physical units produced may also include changes in foreign trade and therefore can partially explain changes in domestic production. This is going to be treated econometrically.

Trend estimates of per capita production of "old" basic products (per capita saturation)
The basic drivers for this calculation method are the estimated development of the population in EU-27, and Switzerland and Norway, as well as the development of the per capita demand for these basic products in the past decades and assumptions about the future per capita demand and production. The plausibility of the projected future production of the basic products is based on considering past trends in absolute terms and additional knowledge about future changes in the developments of the demand for the product considered (e.g. flat glass and triple glazing). The basic products calculated using this method are crude steel (including the substitution of electric steel by oxygen steel) and aluminium (including the substitution of primary by secondary aluminium) (Jochem et al., 2007; Schade et al., 2009).

Stringent correlation method
If foreign trade patterns of the basic product considered change substantially or if there seems to be no direct link to domestic per capita consumption, the relation is applied between production in economic units of the industrial branch and in physical units of the basic product. This relation is derived taken from historical past long-term time series. If this relation changes over time, expert interviews can be used to estimate an appropriate relation for the future which may also depend on increasing shares of high quality products or on intra-industrial structural change in the respective branch (e.g. cement in non-metallic minerals which also include lime, bricks, glass and ceramics, concrete products, or quarry stones). Basic products calculated using this method are flat glass, container glass and other glass.

Multi-parameter calculation method (example: paper)
This method tries to consider several trends which may be important for the production of basic products. It is particularly useful if the basic product is only part of a large spectrum of products like ethylene in the basic chemicals industry, or paper in the pulp and paper industry that often incorporates printing and publishing as an economic branch. Based on the example of paper production in the EU-27, and Norway and Switzerland, physical production is calculated using a multi-parameter calculation method which simulates the major material inputs by using the following parameters (paper production is based on wood (cellulose), recycled paper and additives):

- production and net import of pulpwood (in metric tonnes),
- net imports of pulp (in metric tonnes) as many countries import substantial quantities of mechanical or chemical pulp from forest-rich countries,
- estimated quotas of recycled paper that may amount to more than 80% in some countries and
- quotas of inserted additives (in metric tonnes).

Considering material efficiency (MATEFF)

As the final energy demand of those basic products amounts to a substantial share in total industrial energy demand, the question of additional material efficiency due to better material properties, improved construction and design, increased recycling rates or material substitution and organisational measures such as pooling (car sharing, renting of durable products) is handled by the technology-oriented, bottom-up tool MATEFF. MATEFF will take into account recent changes in competitiveness in materials and basic industrial products (reflected in material quality and design improvements, lower rates of waste production, higher recycling rates at the end user level, the growing demand for carbon footprints of consumer producing industries, innovative production technologies and materials and intensive research activities in material science) and material, and raw material substitution with less

specific energy demand (e.g. natural fibres or starch instead of petrochemicals). The structure of this material efficiency model is very similar to the existing bottom-up sectoral energy models.

Playing back to the macro model (IMPULSE)

Additional policy efforts in energy and material efficiency as well as in renewable energies imply substitution of energy use by increasing capital investments and related indirect employment effects. However, since some of the renewable energies or efficiency strategies may not be as profitable as conventional energy carriers and may also induce programme costs for governments or industry (e.g. technical standard regulations, information and training programmes), one of the essential questions for climate change policy is the impact of mitigation on the economy. Macroeconomic models have the ability to calculate those impacts, but they cannot generate the detailed information about investments, changing energy and operating costs or the programme costs for national or regional governments. These data can be calculated by bottom-up models of the residential, tertiary, industrial, transport, and energy conversion sector, but these process-oriented models are unable to calculate the impact the sum of all these changes has on the economy as a whole. Therefore, a module was developed (IMPULSE) to collate all the additional investments of all the final energy sectors and the energy conversion sector, all the changing energy and other operating costs, and also the programme costs for the governments involved in the particular climate change scenario (Schade et al., 2009).

The four types of cost data implemented in the IMPULSE module are (Schade et al., 2009):

- additional investments in all energy using and converting technologies of all sectors,
- avoided adaptation investments to limit atmospheric CO_2 concentration,
- changes in energy and operating costs in all sectors, and
- the sum of all programme costs related to the additional energy, material efficiency, and climate change policies in all sectors (differentiated as subsidies and as administration costs).

These data from the IMPULSE module are fed back into the macroeconomic model ASTRA, a simulation model in order to calculate the impacts on economic growth, product prices, foreign trade and net employment (Schade et al., 2009). The results were reported in Schade et al. (2009); a second loop using the new macroeconomic results as input for the bottom-up models via the TRANSFORM module was not conducted due to time restrictions of the ADAM project which had to be finished by July 2009.

SELECTED RESULTS

The preceding section described the development and future improvements of two modules used to complement a hybrid energy model (linking a top-down energy model and several bottom-up models). This section reports on the production data of some energy-intensive basic products of a reference scenario transmitted by the TRANSFORM module as energy drivers to the sectoral industrial bottom-up. The boundary conditions which are used as a starting point for the projections have to be defined first for a specific scenario setting, including population, gross value added of industry and the relevant industrial branches in a detailed structure (see Table 2). The depicted reference scenario is aimed at reflecting a rather probable electricity demand development with rather 'likely' economic and demographic developments. For this model framework the financial and economic crisis has also been taken into account.

Some of the European countries, which produced certain basic products in the year 2000, do not produce these products today or are expected to close down their production during the next 25 years (e.g. mercury cell based chlorine). In cases of possible substitution of secondary and primary basic products, the share of secondary material is increasing (e.g. crude steel and aluminium) which has a substantially reducing effect on final energy demand and a net positive effect on electricity demand (see Table 5). Chlorine production by membranes is increasing heavily due to increasing demand for chlorine, but also due to closed down capacities of mercury production cells and declining production capacities in diaphragm cells (see Table 4).

While glass, aluminium, and chlorine production is likely to increase in terms of physical production, other products are projected to stagnate (e.g. EU 15 for total crude steel). At a first glance, these structural changes or stagnation trends reduce the overall energy productivity of industry and, hence, curve down final energy demand of industry, not caused by improved energy efficiency, but due to these various effects in the production of bulk products. Assuming that these trends indicate higher value added, more material efficiency and substitution, more recycling of used materials would not take place within the next 20 years, energy demand would be 10 % higher for the European Union 15 than assumed in this scenario (described in Table 3).

One might disagree with some of the projected production figures (see Table 3 and 4). But the objective of this subsec-

Table 2: Development of selected main indicators for the reference scenario.

Country	Indicator	Unit	2010	2015	2025	2035
European Union 15	Population	in 1000	398,000	404,000	412,000	416,000
European Union NMS			103,000	103,000	102,000	99,000
European Union 15	GVA	billion euro	10,000	10,000	12,000	15,000
European Union NMS			700	800	1,000	1,600

Source: IREES, 2012.

Table 3: Development of basic products of energy-intensive industries in 1,000 tonnes, EU-27, Reference Scenario 2000–2035 (rounded).

Country	Branche	Product	Unit	2000	2008	2015	2020	2030	2035
European Union 15	Iron and steel	Oxygen steel	1000 to	84,451	89,381	89,000	85,000	80,000	77,000
European Union NMS				14,587	16,198	16,000	16,000	15,000	15,000
European Union 15	Iron and steel	Electric steel	1000 to	62,938	70,924	77,000	82,000	84,000	86,000
European Union NMS				5,449	6,848	7,300	7,600	7,600	7,700
European Union 15	Non-ferrous metals	Aluminum, primary	1000 to	1,937	2,300	2,400	2,300	2,200	2,100
European Union NMS				203	210	210	210	210	210
European Union 15	Non-ferrous metas	Aluminum, secondary	1000 to	2,058	2,378	2,500	2,700	2,800	2,900
European Union NMS				80	100	100	100	100	200
European Union 15	Pulp and paper	Paper	1000 to	83,214	85,457	87,000	89,000	90,000	92,000
European Union NMS				6,706	8,021	8,600	9,000	9,300	9,500
European Union 15	Non-metallic minerals	Container glass	1000 to	17,973	18,789	20,000	21,000	22,000	23,000
European Union NMS				2,152	2,453	2,700	3,100	3,500	3,700
European Union 15	Non-metallic minerals	Flat glass	1000 to	7,442	8,034	8,500	6,900	9,300	9,500
European Union NMS				2,022	2,178	2,500	2,900	3,200	3,600
European Union 15	Non-metallic minerals	Other glass	1000 to	3,842	4,118	4,300	4,500	4,500	4,700
European Union NMS				634	681	800	900	1000	1100
European Union 15	Non-metallic minerals	Cement Grinding	1000 to	180,762	196,147	206,000	212,000	219,000	224,000
European Union NMS				33,752	39,071	46,000	50,000	53,000	56,000

Source: IREES 2012

Table 4: Development of basic products of energy-intensive industries in 1,000 tonnes, EU-27, Reference Scenario 2000–2035 (rounded).

Country	Branche	Product	Unit	2000	2008	2015	2020	2030	2035
EU27	Chemicals	Chlorine, diaphragma	1000 to	2,107	1,632	1,400	1,400	1,300	1,200
EU27	Chemicals	Chlorine, membrane	1000 to	2,797	5,114	5,700	8,000	8,000	8,000
EU27	Chemicals	Chlorine, mercury	1000 to	5,156	3,808	2,500	0	0	0
EU27	Chemicals	Chlorine, total	1000 to	10,060	10,554	9,700	9,300	9,300	9,300

Source: IREES 2012

tion was to show the results of hard links such as the TRANSFORM/MATEFF module and how production trends (and related energy demand) vary among the various basic products and among European countries due to their available natural resources (including recycled wastes), electricity prices (primary aluminium), changing recycling rates and foreign trade of secondary raw materials (e.g. steel scrap) and other influences such as material substitution and material efficiency. This methodological setting offers the opportunity to make the main drivers of industrial energy demand much more transparent by explicitly enumerating figures of projected amounts of produced bulk materials of basic goods industries.

Conclusions and outlook

Hybrid model systems begin to further the understanding of the advantages and limitations of the existing bottom-up or top-down energy models and also improve the consultation process of the energy analysts for decision-makers in governments, international institutions (e.g. IEA, UNEP) and large energy supply companies as well as energy technology producers.

While the energy models on both levels (bottom-up and top-down) are further improved by more detailed structures, more empirically based equations and adding multi-agent aspects, the progress of the development of hard links of the two modelling levels is of crucial interest. Starting from this challenge the following conclusions can be drawn:

Connecting conversion modules like the work-in-progress TRANSFORM module, which transforms economic drivers into physical production units with the MATEFF submodule, and which will incorporate the material efficiency and material substitution effects on the production of basic products, is a good example of establishing a hard link between the top-down models and their framework conditions on the one hand and bottom-up models on the other hand. The model system planned will manage to bridge the gap between the economic and physical units of energy-intensive industries. The varying

Table 5: Total and Industry Electricity Demand (EU15, NMS), 2010–2035.

Country	Fuel	Branche	Unit	2010	2015	2025	2035
European Union 15	Electricity	Total	1000 GWh	2,555	2,600	2,600	2,700
European Union NMS				306	320	350	370
Industry							
European Union 15	Electricity	Iron and steel	1000 GWh	100	100	100	100
European Union NMS				12	13	13	13
European Union 15	Electricity	Non-ferrous metals	1000 GWh	61	64	63	60
European Union NMS				6	6	6	6
European Union 15	Electricity	Paper and printing	1000 GWh	117	110	105	100
European Union NMS				8	9	9	10
European Union 15	Electricity	Non-metallic minerals	1000 GWh	66	66	65	70
European Union NMS				10	10	12	13
European Union 15	Electricity	Chemical industry	1000 GWh	166	170	175	190
European Union NMS				17	20	20	30
European Union 15	Electricity	Engineering and other metals	1000 GWh	134	140	150	170
European Union NMS				20	20	30	35
European Union 15	Electricity	Food, drink and tobacco	1000 GWh	94	95	100	110
European Union NMS				10	10	15	15
European Union 15	Electricity	Other non-classified	1000 GWh	192	190	190	200
European Union NMS				19	20	25	30

Source: IREES 2012

recycling rates in the cases of glass, recovered paper or scrap metals for instance cannot be handled by the macro-models.

Based on physical production trends and possible developments of the basic products' specific energy demand, the energy intensity figures for the related industrials branches of the macroeconomic projections can be checked for plausibility and corrected, if necessary. Another advantage of the results of a hard link is the substantiated and transparent explanation of inter- and intra-industrial structural changes in the industry of a country considered. Furthermore, changes in production technologies, changes in foreign trade of the product considered, or demographic changes in the countries considered can be mirrored in a quite transparent manner.

These improvements, advantages and new features of hard links result in an energy modelling system which supports the quality and transparency of assumptions and intermediate results for providing scientifically-founded information and advice for energy policy or climate policy. By calculating and comparing different scenario results, the impacts of various policy instruments and of accelerated innovations on the energy demand of energy-intensive industries are simulated in a transparent manner as well. Closeness to possible future developments is achieved by considering specific energy demands of individual industrial sectors as well as the development of material demand as one of the drivers of industrial energy demand.

In the near future transformation modules should intensify the interaction between process-oriented models and macroeconomic models by implementing computer-based hard links. Examples are: (1) the development of living areas in the residential sector derived from relationships of demographic variables, income per capita, and other preferences of private households; (2) the mileage of cars, trucks, ship, or public transport depending on demographic variables, per capita income, foreign trade and industrial production, and inter-industrial structural change. In addition, the different impacts on material substitution or material efficiency in energy-intensive industries will be modelled in more detail based on numeric factors and relationships. In this context, export/import rates and detailed recycling rates and potentials of the different basic products will be taken into consideration for all European countries.

In the more distant future, differentiation of the company size (e.g. small, medium, big) will allow to treat the influences of barriers and supporting factors of energy efficiency measurements more adequately. This would improve the transparency of the relations between potentials, obstacles, and impacts of sector- or technology-oriented policies depending on company size. The progress expected will lead to a more adequate and transparent simulations and projections of sector- and technology-oriented policies by governments and trade associations and to more reliable information about the impacts of these policies at the economic and societal level.

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