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Abstract

The aim of this study is to develop a method for how to soft-link a Computable General Equilibrium (CGE) model with a energy system model. The central research question is how the interaction between modellers and models can, both qualitatively and quantitatively, enable and facilitate a transparent energy and climate policy decision-making process at the national level. The paper describes this development in detail, and presents and discusses the results of the soft-linking methodology applied to a climate scenario. Important similarities and differences between two Swedish models, i.e. EMEC (a CGE model) and TIMES-Sweden (an energy system model), are identified. These findings are used to develop a robust and transparent method to translate simulation results between the two models, resulting in intermediate 'translation models' between EMEC and TIMES-Sweden. EMEC provides demand input to TIMES, while TIMES provides feedback on the energy efficiency parameters, the energy mix, and the prices of electricity and heat. These 'translations' can also be used stand-alone to feed into other energy system models. The presented soft-linking process demonstrates the importance of linking an energy system model with a macroeconomic model when studying energy and climate policy. With the same exogenous parameters, the soft-linking between the models results in a new picture of the economy and the energy system in 2035 compared with the corresponding model results in the absence of soft-linking. The study also leads to a better understanding of how the models can interact while preserving the respective models' strengths, to give an improved picture of both the flows in the economy and the impact of energy policy instruments.

JEL classification code: C68, D58, Q43

Keywords: Soft-linking, Computable General equilibrium, TIMES/MARKAL, Climate policy, Energy policy

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Sammanfattning

Syftet med denna studie är att utveckla en metod för hur en allmänjämviktsmodell (CGE-modell) och en energisystemmodell kan länkas samman via en så kallad mjuk länk. Till skillnad från hårdlänkning där två modeller optimeras under samma funktion, så används modellerna vid mjuklänkning individuellt i en iterativ process till dess att konvergens i centrala parametrar har uppnåtts. Den centrala forskningsfrågan är hur interaktionen mellan modellerna kan bidra till att såväl kvalitativt som kvantitativt förbättra det beslutsunderlag som modellerna bidrar till. Denna artikel beskriver mjuklänkningsprocessen i detalj och presenterar och diskuterar resultat från metoden applicerat på ett klimatscenario.

Intressanta skillnader och likheter har identifierats mellan de två svenska modellerna EMEC (en CGE-modell) och TIMES-Sweden (en energisystemmodell). Resultaten används för att utveckla en robust och transparent metod för att översätta simuleringsresultat mellan de två modellerna vilket har resulterat i översättningsmodeller mellan EMEC och TIMES-Sweden. EMEC förser TIMES-Sweden med efterfrågeförändringar, medan TIMES-Sweden återkopplar till EMEC med resultat gällande energieffektiviseringsparametrar, energisammansättning och pris på el och värme. Dessa översättningsmodeller kan även användas fristående för att mata in i andra energisystemmodeller.

Mjuklänkningsmetoden som presenteras visar på vikten av att återkoppla modellresultat mellan energisystemmodellen med den makroekonomiska modellen när man studerar energi- och klimatpolitik. Med samma exogena parametrar resulterar mjuklänkningsmetoden mellan modellerna i nya resultat gällande effekter på ekonomin och energisystemet år 2035 jämfört med resultaten från de enskilda modellerna i avsaknad av mjuklänkning. Studien leder också till en bättre förståelse för hur modellerna kan interagera samtidigt som respektive modellernas styrkor bibehålls. Därmed förbättras beskrivningen av effekterna på ekonomi och energisystemet av energi- och klimatpolitiska styrmedel.

1 Background

The transition to a low carbon economy will take decades, have severe impacts on future energy systems and is likely to affect the entire economy. Energy systems depend both on the availability of energy sources and the derived demand for energy-intensive goods (e.g. steel and paper) and energy services (e.g. transportation and space heating). Low carbon development is also likely to affect the interaction between different sectors. For instance, it may increase the competition for some resources, e.g. biomass, both within the energy sector but also between the energy sector and other sectors using biomass. The competition for energy commodities between sectors can be captured with so-called energy systems models, which provide a technology-detailed description of the energy system and capture important interactions within the energy system from a bottom-up (BU) perspective (thus often referred to as BU models). There is also competition for other resources such as physical capital and labour. This makes it important to address the interaction of the energy system with the rest of the economy. The entire economy can be modelled by using macroeconomic models, e.g. computable general equilibrium (CGE) models, which provide a consistent description of how the different economic sectors interact with each other employing a top-down (TD) approach (typically referred to as TD models).

Many models have incorporated features of both bottom-up and top-down models, which from a strict point of view makes the division into BU and TD somewhat misleading. However, these concepts are well established and go beyond differences in model structure. Even though the model approaches are converging, both are important since they answer different questions. BU models, with their more detailed representation of technology, are better suited to identify technical potentials and financial costs and savings. TD models, with their more detailed representation of the broader economic activity, are better suited to identify costs in terms of higher or lower economic growth (IPCC, 1996).

Due to the different coverage, partial versus general, and different logics, the BU and TD models may lead to rather different estimates of e.g. the cost of climate polices, as noted by Wilson and Swischer (1993) and IPCC (1996) already two decades ago. The divergent model results from the two model types in terms of policy implications, and the strong interactions between the energy system and the rest of the economy are the reason why the emphasis in climate modelling has been on using a combination of top-down and bottom-up methods (IPCC, 1996). Böhringer and Rutherford (2009) classify the various approaches to link these two model types into three categories: i) connection of existing large-scale BU and TD models with soft-linking; ii) addition of one model type (BU or TD) with a simplified representation of the other (sometimes referred to as hybrid models, illustrated in Böhringer, 1998; Hourcade et al., 2006); and iii) a direct combination of BU and TD properties by specifying the equilibrium model as a 'Mixed Complementary Problem' (MCP) (further elaborated in Cottle and Pang, 1992; Rutherford, 1995; Böhringer and Rutherford, 2005). The two latter categories are often referred to as hard-linking approaches.

There are some comparisons between soft- and hard-linking in the literature. Wene (1996), for example, summarizes the advantages of hard-linking with the words productivity, uniqueness and control, while he describes the advantages of soft-linking with the words practicality, transparency and learning. Bauer et al. (2007) compare soft- and hard-linking approaches when coupling macroeconomic growth models and energy system models. They conclude that sound coupling of macroeconomic growth models and energy system models requires a hard-linking approach since simultaneous equilibrium at the energy and capital market cannot be guaranteed in the soft-linking approach. In spite of this, though, they emphasize that more system complexity can be represented in the soft-link than in the hard-link approach.

When models are soft-linked, the macroeconomic model and the energy system model operate together in an iterative process until convergence in central parameters are achieved, e.g. price and quantity parameters (Kumbaroĝlu and Madlener, 2003). A soft-linking approach takes advantage of the strengths of both models, i.e. the CGE models have a strong focus on sector interactions and general equilibrium effects while the energy system models capture changes in energy carriers and offer a detailed description of available technology options and energy potentials for each energy carrier. Critics have raised the concern that there may be difficulties in achieving consistency between the two model approaches since the differences in terms of structure and methodology can be significant (Böhringer and Rutherford, 2009). In hard-linking, BU- and TD-related characteristics are highly integrated into one model and solved in a simultaneous optimization, unlike the iterative process of model outputs when soft-linking is applied. The hard-linking often implies a simplified description of either the BU or the TD dimension, in contrast to soft-linking, where also relatively large-scale models are kept more or less intact (e.g. Bauer et al., 2007; Böhringer and Rutherford, 2009). For example, Remme and Blesl (2006) create a hard link between TIMES (TIMES-MACRO) and a one-sector general equilibrium model. These types of studies are useful when looking at the global picture where the regional details are subordinate. However, when having a national focus the details in both modelling approaches are valuable. In a national model, the most important industries will be described in detail, something which cannot be done in global models.

When looking at the national level with detailed knowledge about the specifics of the energy system and the economy, an energy system model provides different insights compared with a macroeconomic model. This disparity between modelling results is described in Fortes et al. (2013), who compare climate policy implications from a bottom-up energy system model (TIMES_PT) and a top-down computable general equilibrium model (GEM-E3_PT). This work illustrates the fact that the two model approaches have been developed to capture different mechanisms of a future energy system, and that both are important building blocks for policy analysis at the national level. Hybrid models, where one modelling type is simplified, might not be sufficient to capture changes in a future energy system. We have therefore chosen to focus on soft-linking models, in part since examples on hard-linking of a detailed energy system model with a detailed macroeconomic model are missing in the scientific literature. The reasons for this are both the difficulty in solving the two model optimizations simultaneously and the complexity in identifying non-overlapping features to link. There are several examples of national studies on climate policy and some of these apply soft-linking. Martinsen (2011) introduces technology learning in a national CGE model by soft-linking it with a national MARKAL model. Schäfer and Jacoby (2006) give another example of soft-linking, in which the macroeconomic EPPA model (based on GTAP4E) is linked with the MARKAL model of transport technology. This soft-linking procedure was to a large extent characterized as 'one way' in that the MARKAL model mostly generated changes into the EPPA model concerning transport demand. Common for these studies is that they focus on the results rather than the linking itself and that the iteration part is limited.

Messner and Schrattenholzer (2000) describe an automated soft-linking between an energy supply model (MESSAGE) and a macroeconomic model (MACRO). The paper gives an extensive description of the overall linkage but does not provide any details regarding the linking process between sectors, which is crucial at the national level. Overall, the existing literature does not provide a comprehensive assessment of the specific challenges involved in achieving transparent soft-linking. In practice, the specific measures taken to achieve transparency and consistency across models are critically important. It is thus useful to document the measures necessary for models to communicate better, in particular since the separate (TD and BU) models typically have not been designed to facilitate linking with other types of models. The greater need for communicating the process of – and the challenges involved in – model integration efforts is emphasized also by Kragt et al. (2013). They conclude:

> "We encourage modellers to not only report the final projects, but describe the creation of new knowledge and theory during the integrative modelling process. Communicating positive and negative experiences with integrated model development to the wider scientific community will enable others to learn from past experiences and avoid mistakes." (p. 329)

The aim of the present paper is to develop a method for how to soft-link a national CGE model to a national energy system model, which enables an improved and transparent national energy and climate policy decision process. The developed method for soft-linking is based on two Swedish models: EMEC (a CGE model) and TIMES-Sweden (an energy system model). The choice of these is motivated by the fact that they (in particular EMEC) have in recent years played an important role in the Swedish government's decision-making process (e.g. climate taxation policy evaluation). Moreover, the Swedish Energy Agency applies both TD (i.e. EMEC) and BU modelling in its development of long-term scenarios for the energy system, but so far there has been a lack of explicit links between these two modelling approaches and therefore also a lack of transparency and learning.

Supporting the aim of a transparent process and to, as far as possible, retain the benefits of each model, the soft-linking approach is considered preferable for the purpose of this paper. A soft-linking procedure also benefits from the fact that each of the two models is controlled by a modeller who is an expert of the particular model and within the particular research field that the model is based on. The central research question is how the interaction between modellers and models can, both qualitatively and quantitatively, improve the present decision-making process. The underlying philosophy has been to develop a method allowing the models to interact in a transparent manner while at the same time maintaining each model's strengths. This paper describes this development in detail and presents and discusses results of the developed soft-linking methodology applied to a climate scenario. It draws conclusions with regards to both the developed methodology and its potential application for improved decision support. The focus is more on identifying important challenges of soft-linking and discussing ways to manage these than on developing original features.

The paper is organized as follows: Section 2 identifies and discusses a general soft-linking process on what and how to link. In Section 3, this process is applied to the specific case of EMEC and TIMES-Sweden. Section 4 presents the resulting soft-linking methodology. In Section 5, the developed soft-linking method is applied to a scenario analysis where the outcomes from running the models stand-alone are compared with the outcomes from iterating between the models using the soft-linking approach. Finally, our findings are summarized and discussed in Section 6.

2 Identifying what to link – general concerns

In order to define a soft-linking process, we have to identify what to link, hence identify the 'connection points'. A connection point can be thought of as the specific variable in one of the models that should communicate with a certain variable or parameter in the other model. Before identifying the connection points, a mutual understanding of the differences and similarities between the modelling approaches has to be derived. Differences in 'values and language' are one of the challenges encountered in interdisciplinary research projects, as pointed out by Kragt et al. (2013). Previous studies, such as Wene (1996) and Messner and Schrattenholzer (2000), have presented a generic soft-linking approach. Our point of departure is instead two existing models, which will be used to illustrate the details of the soft-linking process, with an emphasis on the working process to facilitate the soft-linking. This will first be examined in general terms and then applied to the chosen models.

2.1 Similarities and differences in model structures

When identifying the differences and similarities between EMEC and TIMES-Sweden, the identified steps outlined by Wene (1996) are applied.

1. **Identifying basic differences between the models:** In addition to the different modelling approaches, TD versus BU, the main difference between the two models concerns the types of flows that are represented in each model. While the energy system model focuses on physical flows of energy (in energy units), materials (in mass or volume), emissions (in mass), certificates (in number) and taxes (in monetary terms), the CGE model represents flows of energy, materials, capital and labour in monetary terms, as well as emissions in metric tonnes. In the process of identifying differences between the models, we dealt with questions like how to map sectors and variables in one model to sectors and variables in the other, what does it mean that a sector is growing in one model compared with the corresponding sector growth in the other model, and what can be done when sectors do not match?
2. **Identifying overlaps:** A sectoral comparison enables a better understanding of the aspects of the sectoral development captured by each model and, thus, the identification of analytic overlaps.
3. **Identifying and deciding upon common exogenous variables:** The exogenous assumptions are normally defined within a scenario. Since the baseline assumptions typically have a major impact on the result, it is important that the exogenous assumptions are harmonized between the two models. Typical assumptions in both of the models are import fuel prices and included energy and climate policy instruments.

2.2 Identifying connection points

Wene (1996) describes the importance of finding common measuring points (CMP), i.e. where the macroeconomic model and the energy system model can communicate. He suggests that the reference energy system framework be used to identify the CMPs. We have chosen to instead use the phrase 'connection points'. These can be different in each direction and not constant hubs. When comparing the structure of CGE models and energy system models, respectively, many cross-couplings will most likely appear. Full consistency between existing models is not likely to be achieved since the models typically are based on different statistical sources (e.g. energy statistics versus national accounts) that are not directly comparable and sometimes overlap. This is what Wene (1996) refers to as 'soft-linking noise'. In addition, the two models' analytical concepts represent different aspects of sector development (e.g. energy composition versus economic growth). These differences will make it practically impossible to identify exact translation points as model results from one model may be incorporated directly into the other. To address this, we have chosen to let the connection points be 'direction specific' and to have different translation methods in different sets of connections points. 'Direction specific' here means looking at each direction separately, starting with the direction of the CGE and thus incorporating the CGE-results into the energy system model and vice versa.

3 Identifying what to link – Application EMEC and TIMES-Sweden

In our case, both the CGE model and the energy system model have been developed to analyse energy and climate policy implications. Below is a brief description of the two models.

3.1 The models

ENVIRONMENTAL MEDIUM TERM ECONOMIC MODEL (EMEC)

EMEC is a static (CGE) model of the Swedish economy developed and maintained by the National Institute of Economic Research (NIER) for analysis of the interaction between the economy and the environment (Östblom and Berg, 2006).

The EMEC model includes 26 industries and 33 composite commodities including seven energy commodities. There is also a public sector producing a single commodity. Produced goods and services are exported and used together with imports to create composite commodities for domestic use. Composite commodities are used as inputs by industries and for capital formation. In addition, households consume composite commodities and there are 26 consumer commodities. Production requires primary factors (i.e. two kinds of labour and capital) as well as inputs of materials, transports and energy. Households maximize utility subject to an income restriction, firms maximize profit subject to resource restrictions, the provision of public services is subject to a budget constraint and the foreign sector's import and export activities are governed by an exogenously given trade balance.

The model differs from many other CGE models by having a detailed description of the energy use, environmental economic instruments as well as emissions. In the model, household spending and business activity cause pollution. The model calculates emissions of carbon dioxide, sulphur dioxide, nitrogen oxides and particulate matter (PM 10 and PM 2.5) from stationary and mobile sources of emissions, but also emissions from industrial processes. Households' and industries' use of energy is subject to energy and environmental taxes (a carbon tax and a sulphur tax). The tax rates are calibrated to the base year, which enables a correct representation of tax exemptions for various industries. The sectors included in the EU emissions trading system (EU ETS) buy carbon allowances at a given (exogenous) price.

TIMES-SWEDEN

TIMES-Sweden is an energy system model based on the TIMES. TIMES is an energy-economic model generator for local, national or multi regional energy systems, and provides a technology-rich basis for calculating energy dynamics over a long-term, multi-period time horizon. TIMES is developed within ETSAP[1], and the TIMES-based models are usually applied to the analysis of the entire energy sector, but may also be applied to detailed studies of a single sector (Loulou et al., 2005). The TIMES models minimize the total discounted system cost over the modelled time-horizon to meet a given demand of useful energy. The main structure of TIMES-Sweden was designed within the NEEDS and RES2020 projects, and has since been further developed. The model has, for example, been used to analyse ancillary benefits of climate policy in Krook-Riekkola et al. (2011), and more recently to compare different impacts of climate policy instruments on Swedish district heating in Krook-Riekkola and Söderholm (2013).

TIMES-Sweden covers the Swedish energy system divided into six main sectors (Electricity and heat, Industry, Agriculture, Commercial, Residential and Transport), based on the structure of Eurostat. Each sector includes 60 different 'demand segments' that drive the model. Examples of these demand segments are: demand for iron and steel in the industry sector (in million tonnes), demand for space heating in multi-family dwellings in the residential sector, and demand for short-distance travel in the transport sector (in vehicles in million person-km). The industry sector is represented by a detailed reference energy system including various process steps and material flows.

3.2 Similarities and differences between EMEC and TIMES-Sweden

IDENTIFYING BASIC SIMILARITIES BETWEEN THE MODELS

Even though the two models have different scientific bases, they both assume cost-minimizing behaviour by producers and household demands based on optimizing behaviour. These similarities facilitate the exchange of data between the models.

[1] The Energy Technology Systems Analysis Program (ETSAP) is an implementing agreement of the International Energy Agency (IEA), see www.iea-etsap.org.

IDENTIFYING BASIC DIFFERNECES BETWEEN THE MODELS

An important difference between the models is within the industry and sector breakdown. This will be further discussed in subsection 3.3. In addition to the general differences between CGE models and energy system models described above, the most important differences between EMEC and TIMES-Sweden are described in Table 1.

Table 1. Basic differences between EMEC and TIMES-Sweden.

	EMEC	TIMES
How prices are treated	Prices are normalized to the base year value at current prices. Only relative price changes are modelled.	Prices are normalized to a base year. Energy carriers with an exogenous price have a specified price for each time period. Fuels traded in the global market are assumed to vary over time according to official sources.
How energy conversion technologies are described	Continuous production functions (Constant Elasticity of Substitution specifications), where substitution elasticities are key parameters.	Discrete processes / techniques with pre-defined technological (efficiency, availability etc.) and economic (capital, operating costs etc.) parameters. Parameters vary over time to capture technology development.
Time dimension	Static	Dynamic

IDENTIFYING OVERLAPS

While both models simulate the electricity mix and the energy demand for each sector in the economy, this is the main strength of an energy systems model. TIMES-Sweden will therefore be the governing model for these variables. However, it is important that despite the fact that TIMES-Sweden will be the governing model, the general equilibrium effects of a policy intervention must continue to affect the energy demand through a change in the assumed demand of energy services, materials and transports. How results from TIMES are implemented into EMEC and vice versa is further discussed below.

IDENTIFYING AND DECIDING UPON COMMON EXOGENOUS VARIABLES

Before starting the soft-linking iteration, the scenarios will be defined with a focus on common exogenous variables. Both models have exogenously defined import fuel prices, and the existing energy and climate policies are incorporated into both models. Fossil fuel prices and taxes were therefore straightforward to harmonize, whereas since the definition of biomass differed substantially between the models biomass prices could not be harmonized.

3.3 Identifying connections points

The recognition that different sets of connection points are needed depending on which direction the information is being transferred during the iteration process resulted in two different mappings of the connection points – one when transferring information from EMEC to TIMES-Sweden and another when transferring information from TIMES-Sweden to EMEC. Both mappings are presented in detail in Appendix A. The mapping of the sectors will always need to be model unique, and requires a good understanding of both models. Two examples are provided below relating to the treatment of the pharmaceutical industry and representation of transports.

The pharmaceutical industry is modelled as a separate sector in EMEC, while it forms one part of the chemical industry in TIMES-Sweden. The distinction in EMEC has been made since the pharmaceutical industry constitutes a relatively large share of the aggregated chemical industry in economic terms. On the other hand, due to the low energy intensity of the sector, in TIMES-Sweden, the pharmaceutical industry constitutes just a small part of the sector 'other chemicals'. This means that an increase in economic growth in the pharmaceutical industry is not likely to have a significant impact on the energy use in the sector 'other chemicals' (in TIMES-Sweden). Thus, aggregating the growth levels from the two sectors in EMEC and matching this with the sector 'other chemicals' in TIMES-Sweden could result in a misleading demand assumption in TIMES-Sweden. The energy composition in 'other chemicals' from TIMES-Sweden can still be assumed to represent the energy mix in both the pharmaceutical industry and the chemical industry in EMEC. The resulting connection points is that 'the chemical industry' from EMEC will be used as input demand growth input to TIMES-Sweden, while the change in energy use (mix and amount) in the 'other chemical' sector from TIMES-Sweden will be used as input to both the pharmaceutical industry and the chemical industry in EMEC. Despite the complexity of the chemical industry, a straightforward procedure is possible to implement by applying different connection points at different stages of the iteration.

A more difficult issue arose when comparing the representation of transports, which is the sector where the two models differ the most. In EMEC, a significant part of transports is allocated to the transportation sectors, but transports are also part of other production sectors and of private consumption. In these latter cases, transport demand is represented by the demand for fuels. Transportation in TIMES-Sweden is instead split into different segments, based on both type of transport (freight or passenger) and type of vehicle (air, train, bus etc.).

4 Identifying the soft-linking process

The aim of this section is to define a soft-linking process for how the information can be transferred from one model to the other at each connection point, emphasizing the need for different methods at different connection points. This methodological pragmatism has been motivated both due to differences in sector breakdown between the models and because of fundamental differences in the relationship between the energy demand and the economic development across different commodities. Each section first identifies what aspects the receiving model is missing or treating in a simplified manner. This gives what types of information the other model can provide in order to improve the overall modelling objective. These findings are used to develop a robust and transparent method to translate simulation results between the two models, resulting in intermediate ‘translation models’ between EMEC and TIMES-Sweden.

4.1 Translation model – EMEC to TIMES-Sweden

Energy system models are not well suited to address changes in demand due to economic growth. The EMEC model will therefore be the provider of this information to TIMES-Sweden. Even in cases when there is no iteration between EMEC and TIMES-Sweden, the demand is often either directly or indirectly taken from a macroeconomic model. When the units are different, a conversion between the economic development (from the macroeconomic model) and useful demand (in the energy system model) is needed. Manne and Wene (1992) calculate the demand endogenously within MARKAL-MACRO based on four factors: aggregate rate of economic growth, the autonomous energy efficiency increase (AEEI), the elasticity of price energy substitution (ESUB) and the change in energy price. Messner and Schrattenholzer (2000) base their method on pre-defined translations in the so called ‘Scenario generator’, either as a one-way feedback into MESSAGE when running the model stand-alone or in an iteration loop when MESSAGE and MACRO are soft-linked. The ‘Scenario generator’ is described in Gritsevskii (1996). Kypreos and Van Regemorter (2006) use GEM-E3 (a recursive dynamic European CGE model) to generate the exogenous demand projection to a European TIMES model. In their analysis, useful energy demand projections per region and sector depend on the change of a specified demand driver (either population, GDP or a combination of the two), demand elasticity (□ j), price change, price elasticity (□ j), and a price-independent demand change due to autonomous energy efficiency improvement (AEEI). They argue that much of what is normally put into AEEI is already included in the European TIMES model (which shares the structure of TIMES-Sweden). Using an AEEI factor can therefore lead to double counting. This is especially the case with energy-intensive industries, which in the TIMES model have a detailed structure with several process steps. Similar reasoning applies for cars and buildings, which over time in the model will be replaced with new technologies. Higher marginal energy prices will result in more energy-efficient technologies being chosen. Kypreos and Van Regemorter (2006) also argue that for some demand segments, an AEEI factor is still relevant to use. This is especially relevant for aggregated sectors, like chemistry, where one can assume structural changes over time. They also emphasize that the AEEI can be seen as lifestyle changes that are independent of energy prices. These changes can for example be represented by a shift from cars to public transportation. By assuming an AEEI close or equal to zero, Kypreos and Van Regemorter (2006) derive a relationship between useful energy demand projections (EUr,t,j) per region (r) and sector (j) supplied to the European TIMES model, and the growth of the drivers (drgrrj) and evolution of prices (pgrrj) taken from GEM-E3. The relationship is seen in Equation (1), were □ j is the demand elasticity and □ j the price elasticity for demand segment j.

$$EU_{r,t,j} = EU_{r,0,j} \cdot \left(\prod_{\tau=1}^{\tau=t}(1 + drgr_{r,j})\right)^{\alpha_j} \cdot \left(\prod_{\tau=1}^{\tau=t}(1 + pgr_{r,j})\right)^{\varepsilon_j} \quad (1)$$

In the iterative process in our specific case, the changes in sectoral production levels in EMEC are converted into changes in demand as specified in TIMES-Sweden. Kypreos and Van Regemorter (2006) conclude that further research is needed on nation-specific correlation between economic growth and useful demand. This was confirmed by communication with representatives of the Swedish Energy Agency. The focus has instead been on identifying which parameters and variables are important to include, while the equations have been kept very simple.

All demand segments cannot be treated in the same way and there are cases where no relationship exists between change in demand of a certain commodity (input to TIMES-Sweden) and economic growth (from EMEC). No relationship between demand and growth holds for demand segments where the price elasticity is close to zero. Different approaches for translating the output from EMEC into usable input in TIMES-Sweden include: i) a direct approach based on the specific sector commodity, ii) an indirect approach based on an economic development in an alternative sector, and iii) an assumption of no connections and instead based on other sources. The approach used and the corresponding sector in EMEC are listed in Appendix A for each demand segment in TIMES-Sweden.

In the direct approach, each demand segment in TIMES-Sweden is mapped to the specific sector in EMEC. Thus, a historical relationship between gross production in monetary terms from the national account and production of the corresponding commodity in mass or volume gathered from the branch associations is identified for each demand segment. The relationship between the yearly change of each demand segment and the yearly change in gross production in monetary terms of the corresponding sector in EMEC can now be defined by Equation (2). This should be considered an initial approach; the relationship is more complex and further research is needed but this is outside the scope of this study.

$$TC_{t,i,j} = TC_{0,i,j} \cdot \left(\prod_{\tau=1}^{\tau=t}(\beta_j \cdot drgr_{t,i,j})\right) \quad (2)$$

where the TIMES commodity TCt,i,j is the exogenous demand of a specific commodity or product in physical terms in TIMES-Sweden, in year t, iteration i and demand segment j, and drgrt,i,j is the annual change in gross production in monetary terms of iteration i and branch j, from the EMEC model. The conversion parameter βj, presented in Table 2, is based on the historical correlation between demand of a commodity j in physical units as described in TIMES-Sweden (TCt,j) and the corresponding sector growth in monetary units according to the national accounts (drgrt,j).

Table 2. Conversion parameters

Segment in TIMES	Identified sector in EMEC	Conversion parameter
Iron*	Iron and Steel industry	0.992
Steel (IIS)	Iron and Steel industry	1.002
Aluminium(IAL)	Metal industry	0.996
Copper (ICU)	Metal industry	1.047
Cement (ICM)	Mineral industry	1.000
Paper (IPH, IPL)	Pulp and paper industry	1.007
Pulp*	Pulp and paper industry	1.002
Freight transport road	Road freight transport	0.995
Freight transport train	Rail transport	1.020
Navigation	Sea transport	0.983
Passenger City Busses (TBU)	Passenger road transport	0.979
Passenger Intercity Busses (TBI)	Passenger road transport	0.979
Passengers City Train (TTL)	Rail transport	1.008
Passengers Train (TTP)	Rail transport	1.008

*Iron and pulp are produced and consumed within the optimization in TIMES-Sweden.

Not all demand segments in TIMES-Sweden are described with detailed technological information. These segments are represented by an aggregate production function, e.g. energy consumption within 'other industries', where total demand for energy is used as exogenous input in the TIMES model. The above approach is therefore not applicable. For these segments, different conversion methods are used depending on the type of scenario. In the reference scenario, the historical relationship between total energy use and gross production in monetary terms is used, while in the alternative scenarios the EMEC result with respect to change in aggregate energy demand for each of these sectors is used without any modification. This iteration process is, for example, used for the agricultural sector.

The second approach was used when estimating the car transport demand for households. In EMEC, household car transport demand is modelled as demand for petrol and diesel while TIMES-Sweden calculates the demand for energy given a certain demand for travelled distance in passenger kilometres. 'Road transport by cars' is in TIMES-Sweden split into long and short distance. In order to estimate the change in demand for 'Road transport by cars' (TCt,j), the income change (igrj) and change in price of petrol (pgrj) from EMEC were used; see Equation 3. The price elasticity (□ j) and income elasticity (μj) are based on VTI (2006) and SIKA (2002).

$$TC_{t,j} = TC_{0,j} \cdot \left(\prod_{\tau=1}^{\tau=t} (1 + igr_{r,j}) \right)^{\mu_j} \cdot \left(\prod_{\tau=1}^{\tau=t} (1 + pgr_{r,j}) \right)^{\varepsilon_j} \qquad (3)$$

Finally, the third approach is applied when demand is decoupled from economic development. One example of this is demand for space heating, which is assumed to mainly depend on population and on change in the number of persons per household. Demands of this type will therefore not be affected by the iteration in the reference scenario. In the alternative scenarios, the demand for space heating will be changed according to changes in the housing commodity, which in the EMEC model includes both energy and rents.

4.2 Translation model – TIMES to EMEC

Due to their broader focus, CGE models are unable to explicitly address the following three aspects of the energy system: i) changes in energy intensity due to introduction of new technologies, ii) changes in the energy-mix following changes in energy demand, and iii) changes in electricity and heating prices due to competition of limited energy commodities between and within sectors. These are aspects that energy system models are design to target.

ENERGY INTENSITY

The information about total energy use per sector given by TIMES-Sweden should be incorporated into the economic model in such a way that the general equilibrium effect of the policy change is not modified. By introducing a new restriction, i.e. Equation (4), in the EMEC model, the resulting technical improvement found in the TIMES model is now transformed into the EMEC model without making the total energy use exogenous. The technical efficiency parameter, which is normally exogenously given in the EMEC model, is now endogenously changed until the ratio between total energy use and total production is as given by the TIMES model.

$$EE_{i,2}/YE_{i,2} = ET_{i,1}/YT_{i,1} \tag{4}$$

where EEi,2 is total energy used in sector i, iteration 2, in EMEC, YEi,2 is the gross production in sector i, iteration 2, in EMEC, ETi,1 is the total energy used in segment i, iteration 1, in TIMES-Sweden, and YTi,1 is total production in segment i, iteration 1, in TIMES-Sweden (which is equal to YEi,1).

ENERGY MIX

In EMEC the energy mix (the share of different energy carriers) for each sector will be completely determined by the results from TIMES-Sweden. To facilitate the transformation of results between TIMES and EMEC, the production function in the soft-linked version of EMEC has been changed so that the elasticity between the different energy products in each sector is set to zero, i.e. the energy branch is assumed to be represented by a so-called Leontief structure (with fixed input coefficients).

ENERGY PRICES

Electricity and heating prices are endogenous in both models. EMEC describes the electricity and heat production with two aggregated production functions, and it is not able to describe changes in the technology mix that arise in different scenarios. TIMES-Sweden, on the other hand, describes power production in detail. The electricity and heating prices are therefore chosen to follow the results from TIMES-Sweden. In order to implement these price changes in EMEC, the price of capital in the power sectors is affected exogenously by a ‘mark-up’, which makes capital more or less expensive than in other sectors. This mark-up is adjusted until the electricity price is equal in both models.

The prices of fossil fuels are, through exogenous assumptions about the world market prices of crude oil, coal and natural gas, the same in both models. The prices of biomass, however, are not harmonized due to the large differences in the definitions of biofuels in the two models.

4.3 Deciding where to start

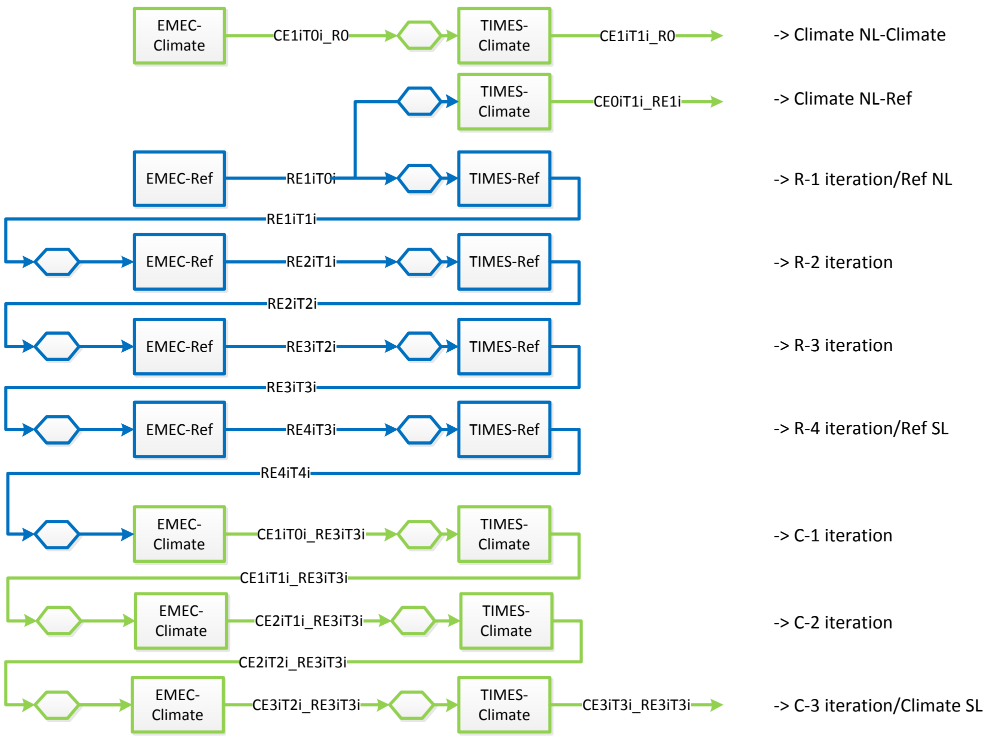
In the presented soft-linking process, both models are dependent on inputs from the other model. Yet, one model has to start the iteration. To run the EMEC model, it is not necessary to include information from an energy systems model like TIMES-Sweden, while the TIMES model needs demand assumptions from a macroeconomic model like EMEC. When EMEC is used to produce the Swedish official projections of sector growth, we choose to start the iteration with EMEC.

5 Applying the developed soft-linking methodology

This section presents results from a scenario analysis. Specifically, we compare the outcomes of a reference scenario with a climate policy scenario in which higher prices of carbon dioxide have been implemented, with and without the soft-linking method. The iteration between the two models is described in Figure 1.

In EMEC, the reference scenario describes a possible outcome for the Swedish economy and energy demand in the long run. The reference scenario in this paper is based on NIER (2012) with one exception: the energy efficiency parameters in EMEC are in this study not exactly in line with the official scenario in NIER. These parameters are instead determined by soft-linking the two models. In the climate scenario, the CO2 tax is assumed to increase by fifty percent and the CO2 price within EU ETS is increased from 16 to 30 €/ tonne CO2 in 2020 and stays at this level to the end of the modelling period (in 2035).

Figure 1. Iteration scheme between EMEC and TIMES-Sweden.



Note: The first letter indicates the set of scenario assumption used, i.e. reference scenario or climate scenario. The second letter indicates the model (EMEC or TIMES-Sweden), followed by the number of iterations (xi is iteration No. x). NL indicates No Linking, whereas SL indicates Soft-Linking. Hexagon boxes illustrate translation models.

Wene (1999) proposes the use of stop parameters, which we only applied as indicative numbers. Our approach includes a larger exchange of parameters between the models compared with his MARKAL-MACRO approach, which implies that it most likely was easier to find convergence between their models compared with ours. Still, our results show convergence for most of the variables, with a few exceptions.

It is important to note that the purpose of this study has been to develop an operative methodology rather than to produce scenario results. The results presented below should therefore primarily be seen as an illustration of the dynamics of the soft-linking methodology, and of how each model's results are affected in this process. Thus, the focus lies on the differences in results with or without the soft-linking.

5.1 Output from translation models- resulting demand and energy mix

In the presentation of the energy demand, from the translation model between EMEC and TIMES, the focus has been on the change in energy-intensive industrial sectors. The reason is that these sectors have high energy consumption and are therefore sensitive to changes in climate policy, and thus are the sectors most likely to be affected by the soft-linking process.

The ‘energy mix’ is the resulting final energy consumption from TIMES-Sweden, specified individually for each industrial sector (iron and steel, pulp and paper etc.) and for each transportation segment (freight, public, private etc.). Electricity and district heating are reported separately. Remaining sectors are grouped into households, the commercial and service sector, and agriculture-fishery-forestry.

THE REFERENCE SCENARIO

The iteration process starts with EMEC. The EMEC results are fed into the translation models described in Section 4, resulting in a set of demands that are used as inputs to TIMES-Sweden. Figure 2 shows how the resulting energy demand in 2035 for the energy-intensive industrial sectors changes with the soft-linking iterations for both the reference scenario and the climate scenario (the latter is to be described in the next section). Demand in 2005 is shown for comparison. In general, the first iteration resulted in a significant change in the structure of the economy, which in turn affected the energy use. This is illustrated in Figure 2 for six different energy-intensive goods. The models adapt to each other already in the second reference iteration (R-2 iteration), and thereafter only smaller changes are made, and the models converge. However, full convergence could not be achieved.

The lower demand in energy-intensive industries, after the iteration process, can be explained by: i) a higher electricity price from the TIMES-Sweden model compared with running the EMEC model alone, together with ii) TIMES-Sweden assuming fewer technology options in the energy-intensive industries to reduce their energy demand compared with EMEC, which assumes changes in energy demand based on substitution elasticities. Higher electricity prices and lower substitution possibilities imply increased production costs and a decreased demand for energy-intensive goods as their relative price increases.

Furthermore, soft-linking reinforces the trend towards higher increased demand for transport and services. When production moves from capital- and energy-intensive industries with relatively high labour productivity towards transport and service with lower productivity, GDP growth decreases compared with the reference scenario without the soft-linking. As a result, total energy demand decreases.

The energy mix changes during the iteration process despite the fact that this mix is solely determined by the TIMES-Sweden model. This is due to the decrease in the overall energy demand. A change can be seen in most sectors except in the iron and steel sector and chemical industry. The reason is that the alternatives are more limited in those sectors. The decrease in energy demand following the soft-linking iteration results in a decrease in final energy consumption of electricity, gas and coal (in PJ), while only marginal changes in the use other energy commodities are found.

THE CLIMATE SCENARIO

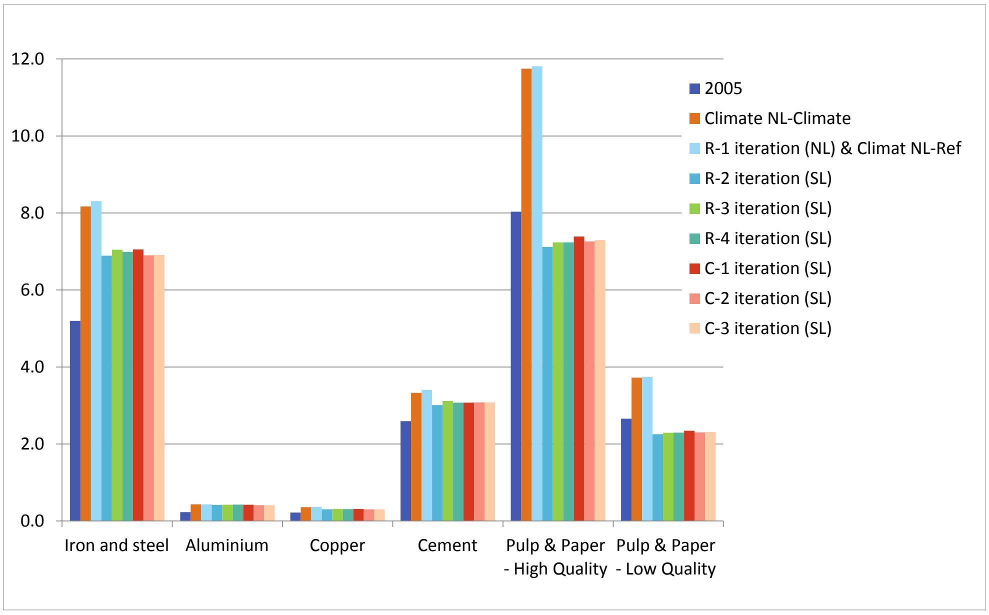
The climate scenario is analysed based on three different starting points (see Figure 1): a non-linked reference scenario (Climate NL-Ref), a non-linked climate scenario (Climate NL-Climate) and a soft-linked scenario (C-* iteration). In the latter case, when the soft-linked reference scenario is the starting point of the climate scenario iterations, the number of iterations does not affect the production level from EMEC to any greater extent. Hence, the differences between C-1 and C-3, seen in Figure 2, are small compared with the difference seen between R-1 and R-2. The results of the

EMEC model have already adjusted to mimic TIMES-Sweden's behaviour in the reference scenario. Since the increases in the carbon tax and the EU ETS price only affect the TIMES-Sweden resulting electricity price in Sweden to a smaller extent, the differences between the two methods regarding the economic development are not so extensive.

When comparing the energy mix from TIMES-Sweden with and without soft-linking, the energy mixes in the iron and steel industry and chemical industry, respectively change only marginally, while the changes in the other industries are similar as for the references scenario. Like in the reference case, the lower final energy demand in the soft-linking case results in lower use of gas and coal, but the decrease in coal is much smaller and the decrease in natural gas is much higher. The reason is that there is less coal and more natural gas in the climate scenario compared with the reference scenario.

Figure 2. Development of energy demand input to TIMES-Sweden for the energy-intensive industry for the iterations.

Yearly demand in 2035 of six different energy-intensive goods is presented in Mtonne (y-axis), as input to TIMES-Sweden, for each iteration and with two different scenarios (reference versus climate policy scenario). As a comparison, the demand in 2005 is included.



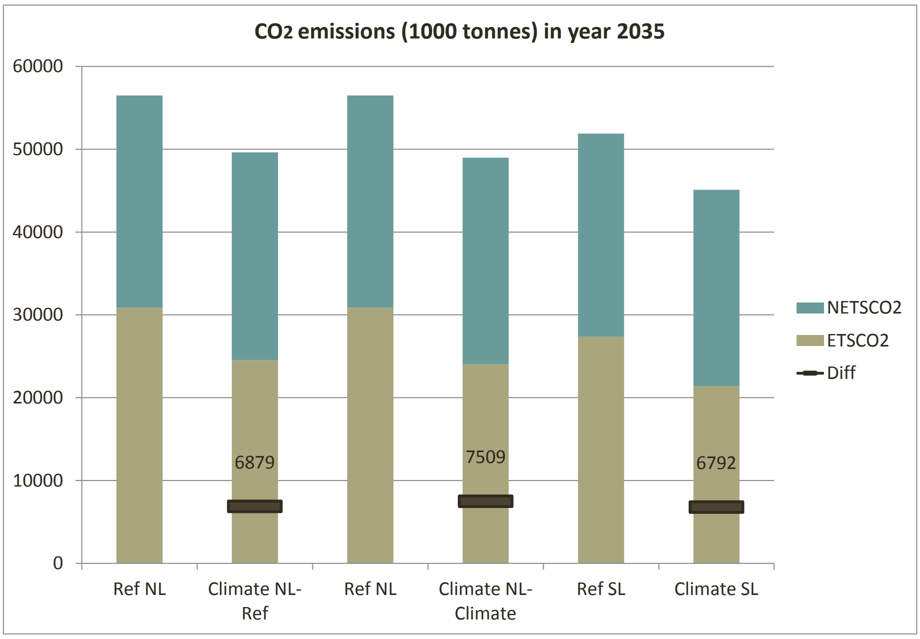
Note: NL= no linking, SL= soft-linking, R= reference scenario, C=climate scenario. Figure 1 gives further understanding on how the iterations are executed.

5.2 Policy impact – resulting CO_2 emissions

In order to test if the changes in the results from introducing the soft-linking process had a policy impact, we looked at the resulting CO2 emissions from TIMES-Sweden in 2035 (Figure 3). The results clearly show that the amount of CO2 is significantly lower in the scenarios with soft-linking than in the scenario without soft-linking (Ref NL vs. Ref SL, Climate NL vs. Climate SL). This is partly a result of lower demand for energy services in the soft-linked scenario. The relative change in CO2 emissions between the reference scenario and the climate scenarios, black mark in Figure 3, is almost the same with and without linking when starting from a non-linked climate scenario in EMEC – 'Climate NL-climate' compared with 'SL-Climate' – while the absolute difference is greater without linking. If demand instead is based on EMEC's reference scenario, the relative difference is greater – 'climate NL-ref' compared with the 'climate SL' – while the absolute difference is almost the same. If the sectors included in the EU-ETS (ETSCO2) are analysed separately from the sectors not included (NETSCO2), the results indicate a greater variation between the different methodologies. If the scenario would involve the consequences of introducing a CO2 cap, the differences between introducing the soft-linking method is likely to be greater since the absolute CO2 level is significantly lower when soft-linking the models.

Previous studies with EMEC and TIMES-Sweden show a strong link between CO2 reduction and reduction in other emissions (Östblom and Samakovlis, 2007; Krook-Riekkola et al., 2011), indicating that the soft-linking process also could have a non-negligible impact on the non-CO2 emissions.

Figure 3. Carbon emissions in (1000 tonnes) in 2035.



Note: 'Diff' represents the emission reduction in the climate scenario vs. the reference scenario.

5.3 Lessons learned from the iteration process

The biggest challenge and uncertainty in the soft-linking iteration is the price information from TIMES-Sweden to EMEC. We found the price change between the base year (2008) and end year (2035) to be exaggerated. The main explanation for this is that all costs are not represented in the base years. The standard use of TIMES-Sweden is to compare the resulting prices from different scenarios – different sets of assumptions. In contrast, in the soft-linking process the price difference between two years, within one scenario, is compared. The reason this is problematic is that the calculated price in the first modelling years does not include all costs.[2] The optimization solves for the lowest total cost, but when the base years are fixed there is no need to include those cost figures when the model is used for scenario analysis. Moreover, which price to pick from the TIMES model is not obvious. TIMES-Sweden calculates a shadow price for each time step and for each sector and each commodity that uses electricity, while EMEC only has one electricity price (but different taxes depending on the sector). The price issue was not fully resolved during this exercise, and hence needs further investigation.

During the present work, future improvements of the models to facilitate the soft-linking process were identified. For example, the information on the electricity technology mix from TIMES-Sweden to EMEC could be to disaggregate the electricity and district heating sectors in EMEC. This would in fact result in a hybrid version of the EMEC model. In the current version of EMEC, electricity is described using only a continuous aggregate production function, in which adaptation occurs gradually when input prices change. This is in contrast to TIMES-Sweden, where each electricity-generation technology is described in detail and changes over time are discontinuous on the basis of a cost-minimization problem. The change would imply that the electricity sector from the national accounts is divided into two main sectors: one 'power-generating sector', to which the cost for electricity and heat production is allocated, and one 'transformation and distribution sector', to which transformation and distribution of power as well as the overhead costs and sales organizations are allocated. Electricity and heat production would then be described by the various available technologies for power generation, e.g. hydro, nuclear, wind, biomass CHP, gas CHP and gas conventional. Despite this increased level of detail, EMEC will not be able to model the energy at the same level of detail and precision as TIMES-Sweden. To develop EMEC into a hybrid model would improve the analysis when running the model stand-alone, but it would also improve the process of transforming information from TIMES-Sweden to EMEC. A soft-link with the hybrid model would more accurately describe the investment demand in the economy since a disaggregation of the power sector will indicate the link between different power technologies and the demand for capital investments.

Total energy demand in EMEC was affected indirectly by changing the energy efficiency parameter by using information from the TIMES model. In order to facilitate the transformation of results from TIMES-Sweden to EMEC regarding the demand for different energy carriers, the EMEC model was altered to directly incorporate the TIMES-Sweden result. Since the economic feedback into TIMES-Sweden goes through the demand projections that also are exogenous inputs when running the model stand-alone, there is no critical need to modify the structure of TIMES-Sweden. Nevertheless, the definition of sectors in TIMES-Sweden could be modified to better reflect the sector structure in EMEC to improve the translation model.

There are some possible changes in TIMES-Sweden that could be implemented to improve the soft-linking procedure. One important change could be to redefine the operating and maintenance costs in the model from a definition based on a single economic cost to one based on number of working hours required and wages per

[2] The evolution of the energy commodities over time is possible to capture with the model, since the base year is calibrated to the energy statistics and includes all energy flows. Hence the energy mix and level will still be accurate to compare between two different years.

hour. In this way, possible competition for labour is captured and wage changes resulting from the EMEC model could be linked to increased maintenance costs.

By applying the developed soft-linking methodology, the results change significantly both regarding demand and energy mix. The difference between the reference and climate scenarios makes it clear that assumptions that previously where looked upon as static between different scenarios need to be reflected in the scenario assumptions even when the models are used stand-alone. For TIMES-Sweden, this implies that the climate policy assumptions should be reflected in the demand assumptions. In EMEC, scenario specific energy mixes and levels could be used to adjust the reference and alternative scenarios and thereby improve the description of the future economy and energy system even though there is no complete soft-linking between the models.

6 Conclusions and discussion

In the present work, important similarities and differences between EMEC (a CGE model) and TIMES-Sweden (an energy system model) have been identified. These findings were used to develop a robust and transparent method to translate simulation results between the two models, resulting in intermediate 'translation models' between EMEC and TIMES-Sweden. Soft-linking the energy parameters for each sector in EMEC and synchronizing them to TIMES-Sweden's results has been done by altering i) the energy efficiency parameters in each sector, ii) the energy mix in each sector and iii) the price of electricity and heat. The translation can also be used stand-alone to feed other energy system models. Finally, the proposed soft-linking process was tested and evaluated.

When comparing the results, the soft-linking methodology showed a new picture of the economy's energy use compared with the model results without soft-linking. The first iteration resulted in a significant change in the structure of the economy, which in turn affects the energy use. The subsequent iterations only resulted in minor changes; hence the results of the two models converged. The change in demand assumptions, due to the iteration with the EMEC model, affects the outcome from TIMES-Sweden with respect to both the energy mix and the quantity of final energy demand in each of the sectors. The results indicate that it is essential that the impacts of the analysed policy on the economy are reflected in the demand assumptions in TIMES. When running TIMES-Sweden stand-alone, the demand assumptions are generally taken from a variety of official sources for which the underlying assumptions are usually difficult to assess. By instead using the economic output from EMEC directly into the translation model, the process becomes more transparent and consistent.

Changes in investment flows, due to large structural changes in the energy system are aspects that cannot be captured in a satisfactory way in the proposed soft-linking methodology. In the presence of a major restructuring of the economy, e.g. caused by a radical reduction in the use of fossil fuels, investment flows would most likely change substantially and affect the overall investment requirements and in turn give rise to significant general equilibrium effects. The resulting investments from the energy system model might therefore not be feasible since there is no link between investment demand and the rest of the economy. Macroeconomic models, on the other hand, face difficulties in capturing the entrances of new technologies and fuels. By adjusting the electricity and heat price, some of the changes in investments flows are captured in the presented soft-linking methodology.

The disadvantage of the soft-linking approach is that the process is relatively time consuming. Although we facilitated the process by introducing intermediate translation models, each of the iterations requires a certain amount of manual adjusting. We estimate that each iteration round takes up to one working day, given that the whole system is rigged for a specific scenario. Repeating the iteration with scenario assumptions goes much faster. The time required is reasonable and, above all, the extra amount of time required will also give a certain amount of manual quality control.

One of the largest challenges with the soft-linking methodology has been the conversion between actual levels and rates of change. This arises due to the differences in scope of the two models, where EMEC considers monetary units while TIMES-Sweden mostly covers physical units. The representations of prices also differ, where EMEC considers relative prices while TIMES-Sweden's prices are provided at absolute levels. How to synchronize the electricity price is another challenge, which is an important component in the calibration of the reference scenario in EMEC.

The soft-linking process presented in this paper shows the importance of linking an energy system model with a macroeconomic model when studying energy and climate policy. With the same exogenous parameters, soft-linking between the models results in a new picture of the economy and the energy system in 2035 compared with the model results without soft-linking. As in Labandeira et al. (2009), we did not achieve full convergence between the model results. However, the soft-linking minimized the differences between the model results in a transparent and consistent manner, and we believe that the assessment gives a consistent picture of the Swedish economy and energy system. Thus, soft-linking EMEC and TIMES-Sweden is likely to improve the present Swedish decision-making process.

The present study has led to a better understanding of how the models can interact while preserving their respective strengths, to give an improved picture of both the flows in the economy and the impact of energy policy instruments. The work process of developing the soft-linking methodology has been characterized by integrity, trust, and mutual respect between team members – all three identified by Parker et al. (2002) and McIntosh et al. (2008) as important factors in interdisciplinary projects to achieve successful integration and communication between team members. By working closely together with the soft-linking method, a mutual understanding of each other's discipline has arisen. These insights are useful both when soft-linking the models and when running them separately.

Further research is needed on the relationship between macroeconomic outputs and national demand projections.

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Appendix A

Table A1. Identified connection points – direction EMEC to TIMES-Sweden.

EMEC results are first translated into yearly percentage change in demand, and thereafter calculated into yearly demand (in the specific unit). Three different translation methods are used: i) a direct approach based on the specific sector commodity (Dir-A), ii) an indirect approach based on an alternative sector economic development (InDir-A), and iii) assume no connections (N-C).

TIMES Demand segment *Some include several segments, those are separated with "/"*	**Projection is based on EMEC sector**	**Translation method**	**Unit**
Commercial Sector (COM) *Both Public and Private*			
Refrigeration (COM)	Average value between Service and Public Sector	InDir-A	PJ
Cooking (COM)	Average value between Service and Public Sector	InDir-A	PJ
Lighting (COM)	Average value between Service and Public Sector	InDir-A	PJ
Public Lighting (COM)	Average value between Service and Public Sector	InDir-A	PJ
Space Cooling Small/Large (COM)	Average value between Service and Public Sector	InDir-A	PJ
Space Heating Small/Large (COM)	Average value between Service and Public Sector	InDir-A	PJ
Warm Water Small/Large (COM)	Average value between Service and Public Sector	InDir-A	PJ
Other Electric (COM)	Average value between Service and Public Sector	InDir-A	PJ
Other Energy (COM)	-	N-C	PJ
Industry Sector (IND)			
Aluminium Demand	Mineral products - applied on aluminium productions	Dir-A	Mton
Copper Demand	Non-iron metal industry- applied on copper productions *)	Dir-A	Mton
Iron Demand	Iron and steel industry - applied on iron productions	Dir-A	Mton
Steel Demand	Iron and steel industry- applied on steel productions	Dir-A	Mton
Other Non-Ferrous Metals Demand	Non-Ferrous metal industries	InDir-A	PJ
Ammonia Demand	Average value between Chemistry and Pharmaceutical industry	InDir-A	Mton
Chlorine Demand	Average value between Chemistry and Pharmaceutical industry	InDir-A	Mton
Other Chemicals Demand	Average value between Chemistry and Pharmaceutical industry	InDir-A	PJ
Mineral products : Cement/Lime/ Glass Hollow/Glass flat/ Other non-metallic mineral products	Mineral products	InDir-A	Mton/PJ
High/Low Quality Paper Demand	Pulp, paper and printing	Dir-A	Mton
Other Industries	Average value between Mining, Other industries, Engineering, Water and sewage and Construction	InDir-A	PJ
Non Energy Consumption – Chemicals	Average value between Chemistry and Pharmaceutical industry	InDir-A	PJ
Non Energy Consumption – Others	-	N-C	PJ

Residential Sector (RSD)			
Cloth Drying (RSD)	Household electricity	InDir-A	PJ
Cloth Washing (RSD)	Household electricity	InDir-A	PJ
Dish Washing (RSD)	Household electricity	InDir-A	PJ
Refrigeration (RSD)	Household electricity	InDir-A	PJ
Lighting (RSD)	Household electricity	InDir-A	PJ
Other Electric (RSD)	Household electricity	InDir-A	PJ
Space Cooling – Multifamily/Single-family-rural/ Single-family-urban and Existing/New (RSD)	-	N-C	PJ
Space Heating – Multifamily/Single-family-rural/ Single-family-urban and Existing/New (RSD)	-	N-C	PJ
Warm Water Heating – Multifamily/Single-family-rural/ Single-family-urban and Existing/New (RSD)	-	N-C	PJ
Other Energy (RSD)	-	N-C	PJ
Transport Sector (TRA)			
Aviation International/ Generic	-	N-C	PJ
Navigation Generic/ Generic Bunker	Navigation freight transport	Dir-A	PJ
Road Bus Intercity/Urban	Public Transportation	Dir-A	Million Pkm
Road Car Long/Short Distance	Household	InDir-A	Million Pkm
Road Motorcycle	Household	InDir-A	Million Pkm
Road Freight	Road Freight transport	Dir-A	Million Tkm
Rail Freight	Rail transport	Dir-A	Million Tkm
Rail Passengers Light/Heavy	Rail transport	Dir-A	Million Pkm
Other Segments			
Agriculture, Fishery and Forestry (AGR)	Average value between Agriculture, Fishery and Forestry	InDir-A	PJ
Non specified (according to Eurostat)	-	N-C	PJ

*) The copper demand is temporarily defined to follow the growth of the iron- and steel industry. The reason is that the historical relationship between copper production and economic growth is not continuous. In Sweden, the copper industry is represented by few production sites. Over the past fifteen years there have been several expansions of existing sites, which is the reason for the increases seen in the statistics rather than yearly economic growth. If the years 2005 and 2009 are removed in the statistics, a correlation between copper and steel production can be seen. However, further research is needed.

Table A2. Identified connection points – direction TIMES-Sweden to EMEC.

When transferring information about energy use and energy prices from TIMES-Sweden to EMEC, the TIMES-Sweden results are translated into EMEC as yearly percentage change.

EMEC sector	Projections on energy use is based on TIMES Demand segment
Agriculture	Agriculture, Fishery and Forestry
Fishery	Agriculture, Fishery and Forestry
Forestry	Agriculture, Fishery and Forestry
Mining	'Other Industries'
Other industries	'Other Industries'
Mineral products	Sum of Cement, Lime, Glass hollow, Glass flat and Other non-metallic mineral products.
Pulp and paper mills	Sum of Pulp and paper industry
Drug industries	Sum of Ammonia, Chlorine and Other Chemicals
Other chemical industries	Sum of Ammonia, Chlorine and Other Chemicals
Iron & steel industries	Iron and Steel industry
Non-iron metal industries	Sum of Aluminium, Copper and Other Non-Ferrous Metals
Engineering	'Other Industries'
Petroleum refineries	No Connection
Electricity supply	Electrical generation
Hot water supply	District heat production
Gas distribution	No Connection
Water and sewage	'Other Industries'
Construction	'Other Industries'
Rail road transports	Sum of Rail transports
Road goods transports	Sum of Road freight transports
Road passenger transports	Sum of Bus transport
Sea transports	Sum of Navigations
Air transports	Sum of Aviation
Other transports	Commercial sector (includes also public)
Services	Commercial sector (includes also public)
Real estate	Commercial sector (includes also public)
Public sector	Commercial sector (includes also public)
Households	Residential sector and Transport fuels from passenger cars and motorcycles

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