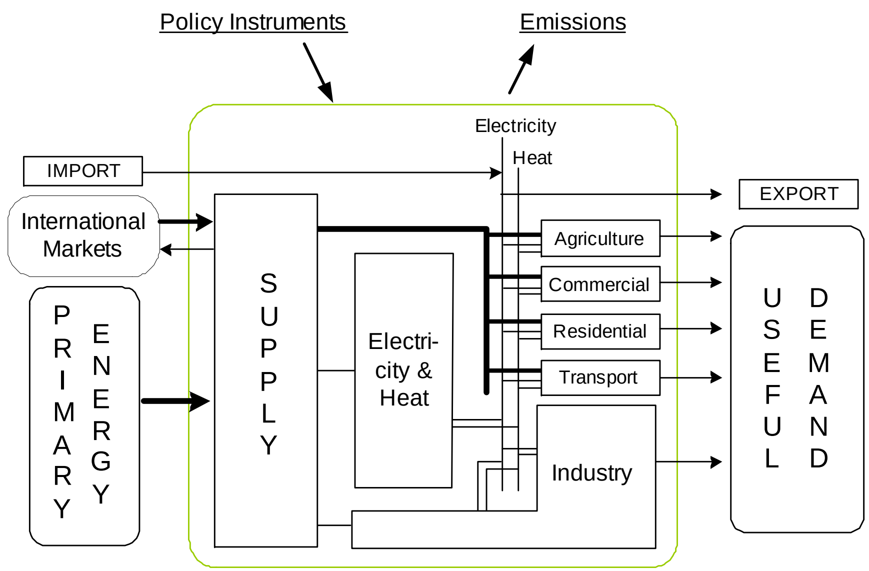
TIMES-SWEDEN

by Anna Krook-Riekkola, Erik Sandberg and Jonas Forsberg

TIMES-Sweden is an energy system model covering all parts of the Swedish energy system. TIMES-Sweden is based on the TIMES model generator. TIMES is an acronym for The Integrated MARKAL-EFOM System and is developed within ETSAP[1]. The main characteristics are common for all models based on the TIMES model generator, while the assumed data and how they are connected are unique for the specific model (some data are shared between models). TIMES-Sweden shares the main structure with EU-TIMES (e.g. Simoes, 2013), deriving from the same model. Yet EU-TIMES includes all EU Member states plus Norway and Switzerland, while TIMES-Sweden focuses on the Swedish energy system. This section is divided as follows: Firstly, the model characteristics are described in contrast to other models (both TIMES in general and TIMES-Sweden specifically). Secondly, each of the main assumptions are described (TIMES in general). Thirdly, the main data sources are described (TIMES-Sweden specific). Finally, some examples of results are presented (TIMES-Sweden specific).



The model is being further developed within the frameworks of ongoing projects, which this project will benefit from. The pulp and paper industry is updated to follow the schematic shown in Figure 1 , and the forestry industry and biomass flows are being updated according to Figure 2.

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[1] The Energy Technology Systems Analysis Program (ETSAP) is an implementing agreement of the International Energy Agency (IEA). It is a platform for exchanging experiences within the energy system analysis field and for discussing ways to improve common tools. www.iea-etsap.org/web/index.asp

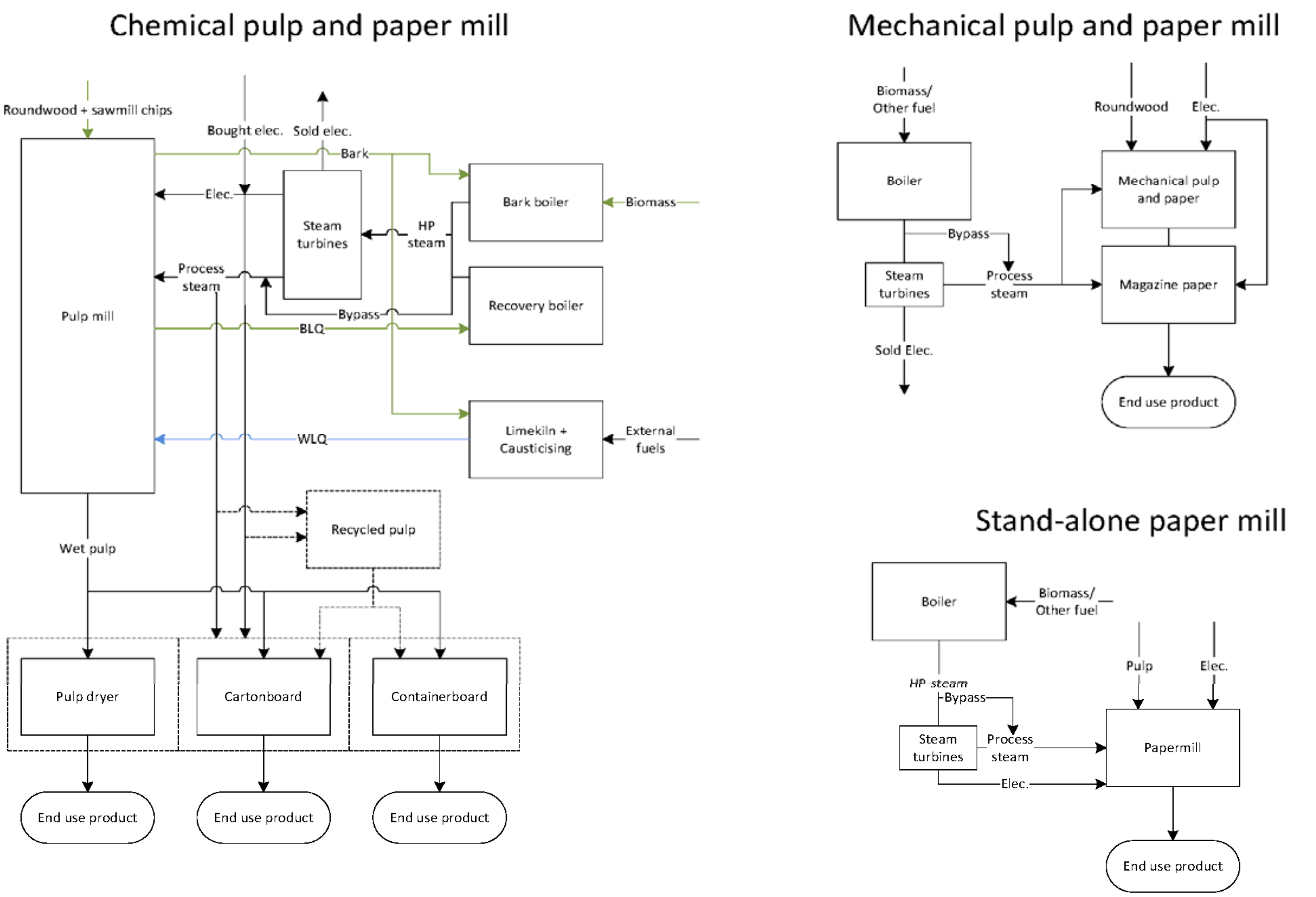

Figure 1:Pulp and paper industry.

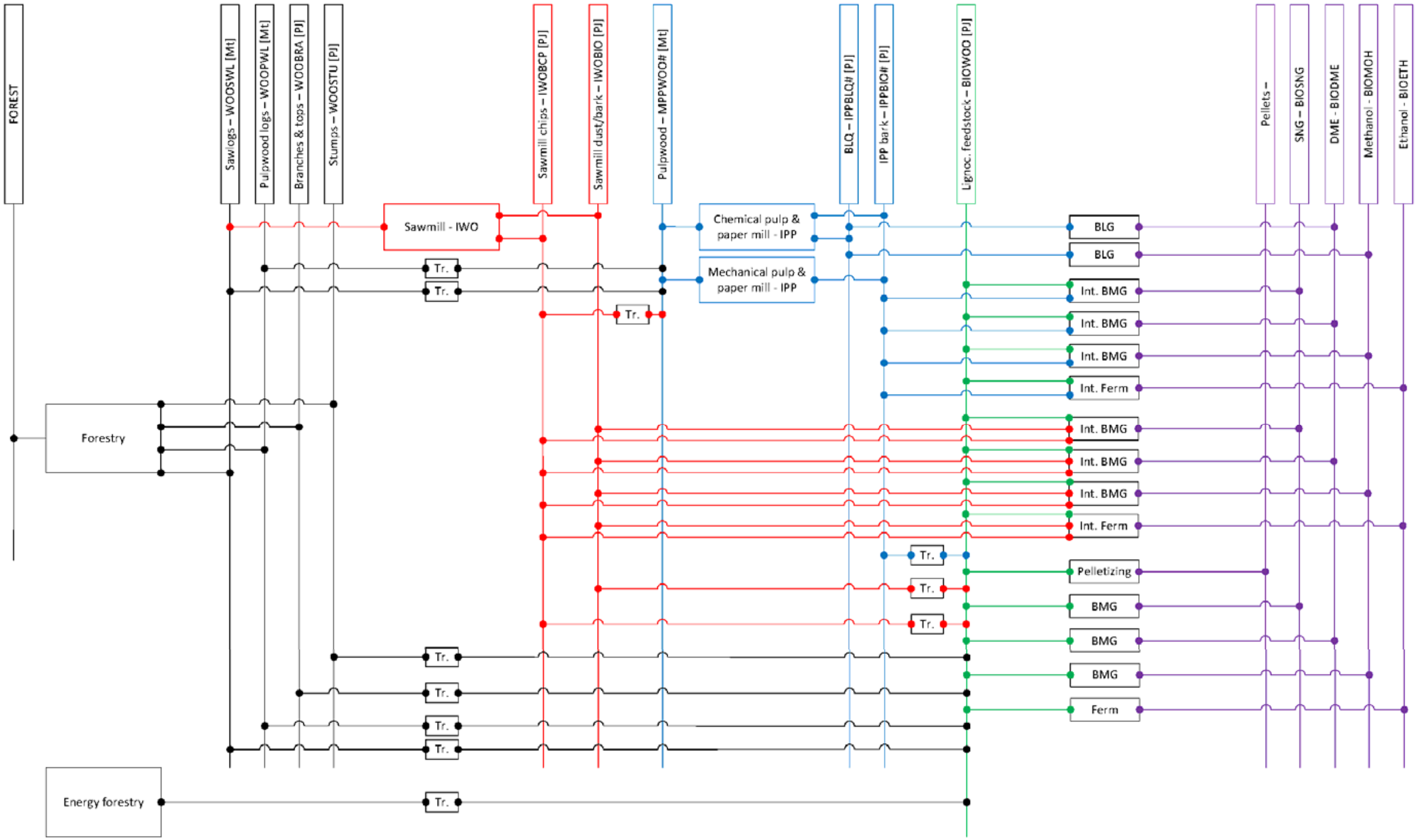

Figure 2: Forestry industry and biomass flows.

1 Model characteristics

There are many ways of categorising energy models. This section is based on chapter 5 in Krook Riekkola (2015) and uses different ways of categorising models in order to describe the model. Some characteristics are common for all TIMES models and some are specific for TIMES-Sweden.

Energy systems model: Energy system models when the model includes several sectors, unlike sector models that focus of the interaction within one sector/one part of the energy system. This facilitates that analysis of competition of secondary energy carrier, such as electricity and district heating, and limited resources, such as biomass.

Optimisation model: A TIMES model 'compute[s] a partial equilibrium on energy markets'. Or more specifically, the model computes both the flows of each energy carrier and each material as well as their price for each time period and at every stage of the energy system. The described energy system usually includes primary energy forms, secondary energy forms and energy services. Mathematically, the model minimises the total system cost, i.e., the objective is to minimise the discounted total cost of the system over the entire modelling period. All cost components are appropriately discounted to a specific year. (Loulou et al., 2005).

Bottom-up model: In the past there was an explicit distinction between bottom-up models and top-down models. Bottom-up models were 'technology rich' models describing the technology system based on details knowledge about the system, which in the result were being aggregated. In contrast, top-down 'economic' models used aggregated statistical data in order to show trends in the details. Today the differences are less distinct (IPPC, 1996; p.13). Many economic models have incorporated detailed information about the power system by technology (bottom-up features) and many national energy system models start from aggregated statistical data that have been broken down into sub-systems (top-down features). TIMES-based models have the possibility to apply price elasticity, which is based on rough historical trends. This is more similar to a classic historical top-down approach than a bottom-up approach.

Technology rich: The model fundamentally calculates the optimal allocation of energy carriers and mix of technologies. At present the TIMES-Sweden database contains 746 different end-use technologies to meet 90 different end-uses. The database also includes 157 different CHP technologies (industrial, district heating and small-scale), 93 other power plants and 120 heat plants. In addition, there are 135 mining and trade processes and more than 600 different processes that contain both physical industrial processes (i.e. blast oxygen furnace) and 'artificial' conversion processes in which the name of the energy carrier is changed. Artificial processes make it possible to trace sector fuels and thereby facilitate the allocating taxes and subsidies at sector level and facilitate a transparent result analysis.

Energy-economic: Both economic and technical aspects are considered in the model, and both parts are important for the result. The objective function is typically to minimise the total system cost over the entire time horizon and, thus, the optimisation seeks to find the optimal mix of technologies to create the given amount of demand at the lowest cost. The choice between technologies and processes will therefore be determined by the fuel costs, delivery costs and techno-economic parameters of the technologies.

Partial equilibrium: The model calculates the equilibrium between demand and supply of energy. It considers only part of the economy to attain equilibrium and is thereby defined as a partial equilibrium model. Since TIMES-Sweden contains both supply and demand sectors, the model is able to capture the competition of energy carrier within and between sectors. As a consequence, the final energy consumption, presented in the statistics, is an output of the model. There is also a possibility to include a demand elasticity, which allows the demand to decrease if the price of meeting the given demand is very high. However, the model does not include the competition between spending money on energy related services/goods compared with spending money on other services/goods, which is the case for a general equilibrium model.

Dynamic: The model is dynamic when the objective is to identify the development of the energy system over time, thus the objective function is to minimise the cost over the entire time horizon. The decisions in one time period will have an impact on the subsequent time-periods. This is unlike a static model, which gives a photo-snap of the situation.

Perfect foresight: The objective function minimises the discounted total system cost over the entire studied time horizon, thus assuming full information over time and between sectors, and hence all information about future prices, policies and technologies is known for everyone from year one.

Time dimension: The time dimension is flexible in TIMES, with respect to last year in the model (time horizon), length of each period (time step) and division within each period (time granularity). Time step and time granularity can vary over the modelling period. The first modelling years – when much information is available – can for example be split by weeks and applying 1 year as time step, while later years – when the uncertainty is larger – can be split by season and applying 5-10 years as time step. In TIMES-Sweden, each year is divided into 12 time-slices based on four seasons which are divided into day, night and a daily peak hour (i.e. 4x3 time-slices). The present version of TIMES-Sweden has data until 2050, but this can easily be extended.

Regional coverage: The regional coverage is defined by the system boundary and is unique for each model. TIMES-Sweden focuses on Sweden with aggregated national data. Some larger industries are divided into local sites, such as the iron and steel industry. One could consider dividing some sectors into regions instead of national data, like the demand for space heating, where the heating profile over the year differs depending on where the demand is located.

2 Main assumptions

A typical TIMES model consist of five different types of assumptions: energy service demand, primary resource potential, policy settings, techno-economic parameters and environmental parameters. Common for all assumptions is that they can differ between scenarios and that figures can be given for each time period as well as for each time step.

Energy service demand: The energy service demand is driving the model and can be defined by a demand profile to represent variations in demand throughout the year. The choice of demand segments will depend on the system boundary. The demand is not restricted to energy demand. In the case of modelling the entire energy system, the demand is typically defined as services or products. Examples of demand segments include demand for steel in Mtonnes (the industry sector), demand for space heating in multi-family buildings (the residential sector) and demand for short distance travels in vehicles in million person-km (the transport sector). The demand projection for each demand category are defined for each year during the model time horizon, and are typically based on official figures or calculated based on key drivers. Driver-based demand projections can either be calculated outside the model or within the model, but always outside of the optimisation. Population, GDP, GDP per capita, sector GDP, number of households and people per household are all examples of drivers. The drivers are externally obtained, either from other models or accepted sources. The drivers can easily be changed between scenarios (Loulou et al., 2005). In addition there is a demand elasticity feature in TIMES that can make the demand respond to price changes or other changing conditions between the reference scenario and an alternative scenario.

Primary resource potential: Limited energy and material resources can be defined by multi-stepped supply curves for each time period as well as cumulative potential over time. The latter is useful when endogenously modelling the annual use of oil reserves. The number of steps in the supply curve is flexible; each step represents how much is available at a certain cost. The resource potential also includes restrictions on import and export of energy commodities and materials.

Techno-economic parameters: Technologies or processes are nodes with defined input and output in which commodities are transformed into new commodities. This holds for all processes except, import, mining and resource processes (which only have output) and export processes (which only have input). Technologies can be divided into existing technologies, base-year technologies and technologies available for the model to choose from. All technologies can be defined by techno parameters such as efficiency (can be defined per activity as well as per commodity), availability (defined annual and/or time step), and contribution to peak equation. Examples of economic parameters are investment costs, fixed and variable operation and maintenance cost, taxes and subsidies (can be defined per activity as well as per commodity). All parameters can be changed over time to account for technology learning. Technology learning is based on the assumption that cost and/or energy efficiency can improve over time as a result of performing research (learning-by-researching) and by using the technology (learning by doing).

Environmental parameters: There is a possibility to define emissions, which are treated similarly as energy flows, as commodities in TIMES. In addition, so-called permits can be defined, which can register the use of or the production/emission of commodities. Permits, for example, can be applied on water use, land use and/or keep track on the use of renewable energy uses or energy-efficiency measures. Emissions and permits can be measured in weight, volume, number or whatever makes sense. Like energy and demand commodities, emissions and permits can be defined as input and output to processes and can be included in boundary equations.

Policy settings: The policy definition will differ between scenarios. The technology richness of TIMES makes it possible to define taxes, substitutes, markets and targets at technology level, thus facilitating the analysis of micro measures such as technology portfolios, targeted subsidies to groups of technologies and white certificates. When applying a micro level policy across sectors, it is crucial that all sectors have the same level of details – the model can obviously not capture aspects that are not represented. The inclusion of the entire energy system enables analysis of broader policy targets such as environmental and energy taxes, climate targets and permit trading systems (green electricity certificate systems and EU ETS). All taxes, subsidies and targets can be implemented at commodity, technology and/or sector level. Policies can also target the attitude to specific technologies, e.g. the future installed capacity of nuclear power. The main policies introduced in the TIMES-Sweden reference scenario are energy and environmental taxes, the EU ETS scheme (exogenously given prices) and the electricity certificate market to promote electricity from renewable energy sources (endogenously by defining quotas).

3 Main data sources

The model is being continuously updated, thus below only provide information on typical sources.

Time dimension: The base year in TIMES-Sweden, 2000, is calibrated to have an energy balance in line with existing statistics. Year 2005 and 2010 are adjusted to represent the statistics (e.g. Eurostat, Statistics Sweden and the Swedish Energy Agency), but without the intention to fully replicate the past.

Demand projections: The demand projection takes as a starting point the existing demand in year 2000. Existing demand is based on statistics from e.g. Eurostat, Statistics Sweden and the Swedish Energy Agency (SEA). Demand estimates for the past are continuously updated when statistics are made available. Projection drivers were originally derived from GEM-E3[2], a European CGE model, and have been individually adjusted when the projections diverged too much from the statistics of past years (2001, 2005 and 2010). The drivers have in a recent study instead been linked to the EMEC, a Swedish

[2] GEM-E3 is an acronym for General Equilibrium Model for Economy - Energy - Environment. More information is available at: https://ec.europa.eu/jrc/en/gem-e3/

CGE model; see Paper VI. However, more research is needed with respect to the correlation between economic growth and demand growth at a Swedish level. The demand projections for space heating in new buildings are mainly based on the Swedish building standards (e.g. SNBH 2009; 2014) and projections of building volume. Household electricity and service electricity, in residential and commercial sectors, are assumed to have a moderate annual increase of 0.245 %, which is low compared with older studies, however, following the trend over the last twenty years (e.g. SEA, 2013a).

Energy balance: Base year data are based on Eurostat data that are validated and when needed updated with official national statistics. The main sources for the energy data in TIMES-Sweden are Statistics Sweden, the Swedish Energy Agency and Nordel[3].

Technology database: The database contains techno-economic assumptions about future technologies for each sector. It was originally created within the international cooperation of the NEEDS project[4] and thereafter further improved in the RES2020 project[5] (e.g. RES2020 2007; 2009). The database has since been updated when improved data have been identified and in cases of inconsistencies. ELFORSK reports (i.e. Hansson et al., 2007; Nyström et al., 2011) have been used for the electricity sector, but cost data were first modified when the data originated from a different year compared with the other technology costs in the model database. Heat and cooling technologies are to some extent updated based on Pardo et al. (2012b). The investment cost of the various technologies develops over time with respect to both the 'value of money' (due to inflation accrued and exchange rate) and material and construction costs (especially steel prices), e.g. the Chemical Engineering Plant Cost Index (CEPCI). All these parameters need to be considered when comparing different sources. In an optimisation model, it is usually more important that the relative costs of different technologies are correctly described than that the absolute costs are correct. Cogeneration and conventional thermal power plants were in the original database separate technologies, even though cogeneration can be considered an application of a conventional plant. A harmonisation of cogeneration and conventional thermal power plants has been implemented in the model, based on expert knowledge.

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[3] Nordel was a body for co-operation between the transmission system operators in Denmark, Finland, Iceland, Norway and Sweden. It was founded in 1963 and closed in 2009 when the operational tasks were transferred to the European Network of Transmission System Operators for Electricity (ENTSO-E).

[4] 'New Energy Externalities Development for Sustainability' (NEEDS) was a research project of the European Commission in the context of the 6th Framework Programme, Research Stream 2a 'Modelling internalisation strategies, including scenario building'. Website: www.needs-project.org.

[5] 'Monitoring and evaluating the RES directives implementation in EU27 and policy recommendation for 2020' (RES2020) was funded by the Intelligent Energy Europe research programme. Website: www.cres.gr/res2020.

Resources: Hydro power availabilities are based on historical data, adjusted for wet/dry hydrological years (main source: Nordel 1997-2008). Herland (2005), Government Offices of Sweden (2007), Börjesson (2007, 2015) and Ericsson and Börjesson (2008) are used as the main sources for biomass potential. Swedish National Grid (2008) is used as the main source of annual wind potential. The wind profile is based on Blomqvist et al. (2008) and Martinez-Anido et al. (2013). The model includes an assumption of added investments in the national grid in order to facilitate a large expansion of wind power. The cost assumptions are based on Södergren & Barr (2011), but tailored to a linear programming format. Wind power between 10-20 TWh requires grid investments of 96 MEuro per TWh, and above 20 TWh requires grid investments at 145 MEuro per TWh. All national grid investments are assumed to have a life-time of 40 years.

Emissions: RAINS model[6] is the main database for emissions factors in the European TIMES as well as in TIMES-Sweden. From the database, emission factors for energy commodities and technologies were derived (within the two European projects NEED and RES2020). These emissions factors have, within the ancillary benefit study presented in Paper-V, been updated in TIMES-Sweden based on available national emission factors. Main Swedish sources: Boström et al. (2004), SEPA (2008; 2009) and Statistics Sweden (2008).

Fuel prices: The International Energy Agency (IEA) and SEA (2013b) are the main source for fossil fuels. The Swedish Energy Agency and personal contacts are the main source for biofuels, solid biomass and municipal waste.

Policy assumptions: Environmental and fuel taxes are derived from the Swedish Tax Agency (2008a, 2008b, 2012) and the SEA (2011a). Biofuels are not taxed today, but following Kågeson (2007) there is an assumption in the model that biofuels will have energy taxes in line with other transport fuels from 2015 and onwards. ETS prices are derived from IEA's 4D and 2D scenarios. The Swedish green certificate system is modelled endogenously to meet the quotas outlined by the SEA (2007, 2011b).

[6] RAINS stands for Regional Air Pollution INformation and Simulation and is a model developed by IIASA for 'integrated assessment of alternative strategies to reduce acid deposition in Europe and Asia'.

4 Policy analysis based on TIMES-Sweden

2016

- Provided input to the governmental Cross-Party Committee on Environmental Objectives proposals to tighten up climate policy in Sweden (SOU 2016:21 and SOU 2016:47). Two-step modeling runs for climate mitigation scenarios using TIMES-Sweden, first with the aim to define an overall long-term target, and second to define intermediate targets. (2015-2016).

2015

- Swedish National Board of Housing, Building and Planning (SNBH, 2015). Förslag till svensk tillämpning av nära-nollenergibyggnader. Definition av energiprestanda och kvantitativ riktlinje. Boverket rapport 2015:26.
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2011

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5 Projects developing and/or applying TIMES-Sweden (to be updated)

2015-2018 Högt uppsatta mål för förnyelsebar energi – Fokus på biomassans roll hos slutanvändaren (Strategisk energisystemforskning/Energimyndigheten).

2015-2018 TIMES-Sweden kompetensbyggande (Strategisk energisystemforskning/ Energimyndigheten).

2015-2016 Policy analysis: Swedish Climate target for 2050. (Miljömålsberedningen/Swedish government)

2015 Policy analysis: Assessing the impacts of Swedish building measures (Boverket).

2014-2016 Biomassa - systemmodeller och målkonflikter (Fjärrsyn).

2014-2016 Policy- och scenarioanalys i en ny modellmiljö: en applikation av TIMES-EMEC (Energimyndigheten).

2014 Studera klimat- och förnybarhetsmål (Konjunkturinstitutet).

2011-2013 Fjärrvärmen och de långsiktiga klimatmålen: En analys av olika styrmedel och styrmedelskombinationer, (Fjärrsyn).

2012-2013 Samhällsekonomisk analys av fjärrvärme: Fjärrvärmens samhällsekonomiska nytta i energisystemet idag och i framtiden (Fjärrsyn).

2012 Energianalys av den svenska järn- och stålindustrin i TIMES, (Energimyndigheten).

2011-2012 Mjuklänkning mellan EMEC och TIMES-Sweden (Energimyndigheten).

2006-2009 RES2020 (Monitoring and Evaluation of the RES directives implementation in EU27 and policy recommendations for 2020), (Intelligent Energy for Europe Project).

2004-2009 NEEDS (New Energy Externalities Developments for Sustainability), (EU Sixth Framework Programme Integrated Project).

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