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Renewable energy in Austria: Modeling possible development trends until 2020

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Abstract

This paper reports on the recently completed Austrian research project "Renewable energy in Austria: Modeling possible development trends until 2020". The project investigated possible economic, social and ecological effects of a substantially increased use of renewable energy sources in Austria. Together with stakeholders and experts, three different scenarios were defined, specifying possible development trends of renewable energy in Austria. The scenarios were simulated for the period 2006 - 2020, using the newly developed integrated environment–energy–economy model "e3.at". The model is parameterized econometrically, and integrates an input-output model with an energy and a material model.

This paper introduces the model "e3.at" and describes the development and the simulation outcomes of the three scenarios. The modeling results indicate that increasing the share of renewable energy sources in total energy use is an important but not sufficient way towards a sustainable energy system in Austria. A substantial increase in energy efficiency and a reduction of residential energy consumption also form important cornerstones of a sustainable energy policy.

Keywords: renewable energy, macro-econometric modeling, input-output model

1 Introduction

Renewable energy plays an important role in Austria for reducing the dependency on imported fossil fuels and to support the reduction of greenhouse gases. This role will grow within the next years due to the fact that the current share of renewables of about 20% of the whole energy mix has to increase to 34% by 2020 in order to fulfill EU targets. In this respect, it is important to estimate and quantify the effects of an intensified use of renewable energy for the supply of heat and power on the environment, economy and society.

The project "Renewable energy in Austria: Modeling possible development trends until 2020" (Stocker et al., 2008) investigated potential economic, employment and environmental effects of an increasing use of renewable energy resources for heat and power generation for the case of Austria. More specifically, the integrated environment-energy-economy model "e3.at" was used to simulate different renewable energy technology (RET) scenarios with a focus on renewable energy use in Austria until 2020.

In order to analyze the research questions posed, the project comprised two main blocks: the development of the simulation model "e3.at" which integrates energy, economic and environmental aspects in one single and consistent modeling framework, and its application within a participatory scenario modeling process. After the creation of the simulation model and the development of the scenarios, the scenarios had to be implemented into the model. The outcome of the scenario simulation is a quantitative estimation of the effects of the diffusion of different renewable energies and related technologies.

The process of scenario modeling (from the development of scenarios to the dissemination of the modeling results) integrates participative elements. A stakeholder and expert group of 30 people was formed, actively accompanying the project by means of bilateral discussions and participation in workshops. In total, four workshops were held with the objective of presenting and discussing the set-up and functioning of the simulation model and to elaborate the scenarios. Thanks to these discussions, valuable inputs and helpful suggestions were received and considered in the project work. Thus, the research results are not only built upon the work of researchers, but also integrate knowledge, expertise and preferences of stakeholders.

The paper introduces the integrated model "e3.at" (chapter 2) and describes the scenarios (chapter 3). Based on the simulation results (chapter 4) we derive some conclusions in chapter 5.

2 The Integrated Environment – Energy – Economy Model „e3.at"

In this chapter we will briefly introduce the integrated environment – energy – economy model e3.at (for a detailed description see Großmann et al., 2008) which was used within the project to analyze different scenarios aiming at resource use reductions. The model integrates an input-output model with an energy and a material model in order to show the manifold relationships between economy and environment. Furthermore, “e3.at” has a soft link to the world model GINFORS[1] to illustrate the effects of international trade on the Austrian economy. It is an econometric model for Austria built in the style of the German model PANTA RHEI[2]. However, the Austrian model is not a copy of the German model, but rather uses general construction principles that are also valid for other countries, and is then adapted to Austrian conditions and circumstances. The general features of the model will be presented in the next sub-section, followed by a short description of the model structure and components.

2.1 General properties

“e3.at” is a multi-sector model that permits the illustration of structural change and as such is able to recognize particular burdens on certain industries. This fact is important for the design of a social reconciliation and supporting measures to offset these burdens. The transition to a sustainable development can thereby be arranged with consideration of social and economic compatibility.

The model also illustrates the interdependencies of environment and economy, which allows not only the analysis of effects on economic growth and employment, but also on resource use and CO_2 emissions. The integration of the environmental and socio-economic systems with their various linkages and feedbacks is needed to appropriately assist policy-makers in their decisions for suitable strategies to tackle the most challenging environmental and socio-economic problems.

The model “e3.at” is based on the philosophy that agents are acting on imperfect markets under conditions of bounded rationality. The application of econometric methods facilitates an empirically validated parameterization of the model. As an empirically validated model it is able to produce reliable baseline forecasts, which, confronted with environmental and economic targets, allow the calculation of sustainability gaps.

The construction of the model follows two principles: bottom–up modeling and full integration—both typical characteristics of the INFORUM philosophy (Almon, 1991). Bottom–up means that all 57 sectors of the Austrian economy are modeled in great detail. Macroeconomic variables such as GDP, disposable income or the consumer price index are calculated by explicit aggregation. Full integration implies complex modeling, which simultaneously depicts inter-industry connections and the generation, distribution, redistribution, and use of income for the demand of goods. It further depicts the influence of the economy on the environment, as well as the short-term effects of the change in use of the environment on economic performance.

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1 The GINFORS model is documented in Meyer et al. (2007) and Meyer et al. (2008).

2 PANTA RHEI has been used for many simulations of suggested policies (see for example Meyer, 2001; Meyer and Welfens, 2001; Lutz et al., 2005) as well as for the evaluation of implemented policies such as the ecological tax reform in Germany (Bach et al., 2002). Furthermore, PANTA RHEI was a central part of several studies seeking sustainability strategies for Germany (Spangenberg, 2003; Coenen and Grunwald, 2003; Keimel et al., 2004; Bockermann et al., 2005).

The disaggregated structure of the model is necessary because the linkage between the economy and the environment requires a detailed production structure. With regard to data, time series of input–output tables are consistently linked with time series of a full system of national accounts (SNA).

2.2 Overview of the model structure

The model "e3.at" illustrates the interdependencies of the energy system, environment and economy, which not only allows the analysis of effects on economic growth and employment, but also on resource and energy use, as well as on CO_2 emissions. Figure 1 provides a first impression of the structure of the model, which comprises the following components:

- an economic model, consisting of an input-output model, the system of national accounts (SNA), and the labor market;
- an energy model, illustrating the relationship between economic development, energy use and CO_2 emissions. It comprises energy demand, transformation and supply;
- a resource model, allocating the domestic and imported material inputs to those sectors responsible for the material extraction; and finally
- "e3.at" has a soft link to a world model to illustrate the effects of foreign trade on the Austrian economy.

The model serves as a basis for quantifying the effects of different scenarios of a more ambitious use of renewable energy in Austria.

Figure 1

In the following we describe the economic model, the material model and the energy model, respectively.

2.3 The economic model

The economic model shows a very high degree of endogenization, while tax rates and labor supply are exogenous. As already said, sectoral exports and import prices are taken from GINFORS, but they are endogenous to that system. The high degree of endogenization leads to the advantage of the effects calculated in simulations being complete.

In addition to the usual interdependencies of the circular flow of income, e3.at depicts the interdependencies of prices and volumes as well as of prices and wages. The model is non-linear, due to the many multiplicative connections of variables in definitions and many behavioral equations estimated in double logarithms.

It is a dynamic model because of the capital stock adjustment and the lags in behavioral equations. The nonlinearity, combined with the interdependency of the system requires an iterative solution procedure which is given with the Gauss–Seidel algorithm. The dynamic structure allows a year-by-year solution for a longer time path.

The core of the economic model is an input–output model, which shows the interdependencies of all industries and is also important for linking the economic model with the material and energy model. Figure 2 shows the structure of the input-output model.

Figure 2

Within the input-output model demand determines production. First, the model specifies the final demand categories at purchasers' prices. Then they are transformed to final demand categories at basic prices. In particular, this requires the exclusion of net commodity taxes and the re-distribution of trade and transport margins. Based on the Leontief-Inverse the gross production at basic prices is then calculated as a function of final demand.

Yet, the demand is also explained within the system, since all demand variables depend on relative prices. Prices, in turn, are given by the unit costs of the firms using the mark-up hypothesis, typical for oligopolistic markets. Profits and unit costs for every sector are given by definition. Together with the import price of the specific good, the unit costs determine producer prices, a calculation which is carried out for each of the demand components (intermediate consumption, gross fixed capital formation, final consumption expenditures by households and government, exports) and for each of the 57 products. Thus, firms set their prices depending on their costs and the prices of competing imports. Demand reacts to price signals and in turn determines production as indicated above.

Obviously, the e3.at model includes both demand and supply elements and is not only demand-driven like general IO models. Besides the usual interdependencies of the circular flow of income, the model shows the interdependencies of prices and volumes as well as those of prices and wages.

The SNA is also part of the model and is consistently linked with the input-output system. It calculates the aggregate variables and the income redistribution between government, households, firms and the rest of the world. It covers production, primary distribution of income, secondary distribution of income, use of income, change in net worth, and financial accounts. The behavioral equations of this system explain its expenditures; the revenues are given by definition. The government's budget, including fiscal policy and the social security system, is endogenously depicted. The detail of this system allows identifying the expenditures and revenues of the social security system, so that it can be linked to the labor market and other parts of the model.

The labor market consists of an aggregated and a disaggregated part. Figure 3 depicts the structure of this model block.

Figure 3

In the aggregated part, the demographic development determines the macro-economic labor supply. Unemployment is given by definition, subtracting the aggregated labor demand from the exogenous labor supply.

In the disaggregated part, for each of the 57 production sectors, the labor demand is explained by gross production and the real costs of labor per capita in that sector, as well as by a time trend.

A macro wage rate is calculated in a function, which forecasts the result of the bargaining process between the unions and the firms: Macroeconomic labor productivity, the deflator for aggregate consumption and the situation on the labor market determine the macro wage rate, which in turn explains – besides some sector-specific variables - the sectoral wage rate. Adding the social security contributions yields the labor costs per capita.

The data base of the labor model additionally consists of the average weekly working time, of labor volume as well as of the employees' qualifications. It is assumed that the structure of employee qualification in each sector remains constant for the whole simulation period. In order to gain reliable statements, detailed modeling would be required, which however could not be carried out in the course of this project.

2.4 The material model

The material input model calculates the direct material inputs (DMI) according to the "Eurostat guide on economy-wide material flow accounts" (EUROSTAT 2001). The DMI comprises "the flow of natural resource commodities that enter the industrial economy for further processing. Included in this category are grains used by a food processor, petroleum sent to a refinery, metals used by a manufacturer, and logs taken to a mill" (Adriaanse et al. 1997, p. 8).

As can be seen from Table 1, the material model differentiates 12 material categories that are part of three material groups (biomass, minerals, and fossil fuels). The model covers the extraction in Austria as well as those import materials induced in other countries by Austrian imports. The material data was provided by a EUROSTAT time series from 1970 to 2001 (EUROSTAT, IFF, 2004).

Table 1

Domestic material extractions (in tons) are linked to the extracting production sector. The direct physical material imports are driven by the imports in monetary terms measured in constant prices. It is assumed that the development of material extraction and of economic variables is proportional.

The modeling of the effects of material savings considers the following process levels (see Figure 4): At the extraction level (1) no savings are possible. This means that the production value and extraction of material develop proportionally. The extractor delivers either to final consumption (2) or to the first process level (3). In both cases material savings are possible due to increased efficiency. Goods produced by the first process level are used by the final consumption (4) as well as by other process levels (5). In summary, there are various interdependencies affecting the material extraction.

Figure 4

If the comparison of the historical development of the production value and material consumption showed that the production value was higher than material consumption, an increased material productivity was assumed and the input coefficients (in constant prices) in the baseline scenario were adapted. In addition, it is possible to change the input coefficients in the scenarios.

The design of the material model allows considering not only the direct changes of material use but also the indirect ones which take place because of the various interdependencies between the different sectors. These indirect effects induced by structural change of the input–output coefficients, and the change of the structure of final demand, which are both endogenous, are very important for the structure of physical inputs.

2.5 The energy model

The energy model describes the interrelations between economic developments, energy consumption and CO_2 emissions. On the one hand, the variables of the input-output model influence the primary energy use. On the other hand, the expenditure for energy consumption has a direct impact on economic variables.

Since final energy usually cannot be provided directly to the consumer, the transformation sector converts indigenous (primary) energy to final energy consumption. Primary energy commodities are extracted or captured directly from natural resources such as crude oil, hard coal, natural gas, or water. In contrast to secondary energy (e.g. electricity), they are not converted by physical and/or chemical processes. Partly, primary energy is transformed directly into final energy. The used primary energy required, can be won in Austria or be imported from abroad. Also, part of the domestic production can be exported. Furthermore, final energy is provided by transformation of primary energy carriers to secondary energy (e.g. electricity and heat), where, however, large transformation losses may occur.

An adequate energy model must therefore be able to consider primary and secondary sources of energy, the final energy as well as losses of the energy conversion. In addition, the differentiation of a multiplicity of sources of energy and a sufficiently deep sector disaggregation are necessary.

The database of the energy model is the energy balance in physical units drawn by Statistik Austria which has been available for each year from 1970 onwards. The CO_2 emissions, which are connected with the primary energy use via fixed emission factors, are provided be the Austrian Federal Agency.

Energy price data were obtained both from national sources (e.g. E-Control[3], Austrian Energy Agency 2004) and the International Energy Agency (IEA 2007). IEA provides prices with and without taxes (consumption and value added tax for selected energy sources. In order to ensure the comparability of the data, all prices refer to Terajoule (TJ).

[3] http://www.e-control.at/portal/page/portal/ECONTROL_HOME/OKO/ZAHLEN_DATEN_FAKTEN/OEKOSTROMMENGEN/Gesamt/Archiv

2.5.1 Forward projection of the energy balances

The energy balance of the Statistik Austria that differentiates 37 energy sources and 21 industries is the starting point for the construction of the energy model. First, the energy balance is aggregated to 17 sources that comprise fossil fuels and renewable energy forms (see blue cells in the following figure).

Figure 5

Regarding the structure (see Figure 6), the energy balance comprises three main parts: energy supply, transformation and demand. This structure holds for all energy sources considered.

Figure 6

Starting with the energy supply, domestic energy production plus imports and stocks minus exports yields *gross domestic consumption*. The supply is determined by definition from the transformation and final energy demand.

The transformation sector comprises the conversion of primary forms of energy to secondary or final energy. The transformation output is the result of this transformation process. In the transformation process the plants do not only require primary energy (i.e. the transformation input) but also energy to operate the plants.

The total energy demand is the sum of the uses for transformation input, use within the energy sector for needs other than transformation, any losses between the points of production of the energy commodities and their final use, and the final consumption. A number of fuels may also be used for *non-energy purposes*. An example is the transformation of fossil fuels (oil, natural gas and coke-oven byproducts) and biomass carbon to synthetic organic products. Thus, the final consumption consists of the non-energy and energy uses.

In order to determine the energy balances for all 17 energy sources in the forecasting period, first the final energy consumption of the 21 economic sectors (given by the energy balance) has to be calculated, followed by the determination of transformation output and input. The gross domestic consumption is by definition determined on the demand side. Finally, the imported energy goods are calculated as residuals from the gross domestic consumption, the stocks, the exports and the domestic production.

In a first step, for each of the 17 sources final energy consumption for the regarded 21 industries was projected with the growth rates of real production. For this purpose, the 57 economic sectors of the input-output model are allocated to the 21 industries that are captured in the energy model. The final energy demand of the 21 economic sectors is explained - if no better information is present - for all the energy sources together.

Figure 7

Logarithmic estimation only enters the real production of the respective economic sectors, since no correlation to the price relations and therefore also no substitution possibilities between the sources of energy were found. The development of the total energy demand of a sector then determines the growth of final energy demand for each energy source and economic sector.

For the sectors “iron and steel“ and “private households“ more detailed information is available so that the final energy consumption can be estimated separately for each energy source. The estimation is based on real production, average energy prices as well as on technological trends and learning curves.

The final energy consumption (electricity and heat) of private households is modeled subject to the development of real consumption expenditures for electricity, natural gas and other fuels. The demand for heat of private households is a function of the use of coal, crude oil products, natural gas, and solar heating, district heating, energy from heat pumps, firewood, pellets and waste wood.

Apart from the oil products the remaining sources of energy for the heat production of the private households are estimated. The heat demand from oil products (fuel oil) is residually determined, i.e. it results from the difference of the entire energetic final demand of the households, the electricity demand as well as the heat demand of the remaining sources of energy.

Final energy consumption for each energy source respectively is the sum of the final energy demands over all 21 economic sectors:

$$EEV_{i,ET}[t] = EEV_{i,ET}[t-1] \cdot \frac{ebtl_i[t]}{ebtl_i[t-1]}$$
$$EEV_{ET}[t] = \sum_{i=1}^{21} EEV_{i,ET}[t] \qquad (1)$$

$EEV_{i,ET}$ ... final energy consumption of the energy source $_{ET}$ and the industry i

(ET = 1, ..., 17, i = 1, ..., 21)

$ebtl_i$ … total final energy demand of the respective industry (i = 1, ..., 21)

Total final energy consumption EEV_{ET} implies, in principle, the transformation output $UA_{j,\ ET}$. For the subsequent years the transformation output is determined by projecting the relationship between transformation output and final consumption from the year 2005. It is assumed that the transformation output and the final energy consumption are directly proportional to each other. The transformation output is differentiated according to the individual converters (coking plant, blast furnace, refinery, power stations, cogeneration plants, heating stations and gas production). The transformation output of oil and photovoltaic is modeled as a function of the transformation input, since a direct relationship exists. The transformation input is identical to the transformation output. The energy sources "gas", "water", "geothermal heat", "solar heat", "wind", "energy from heat pumps", "firewood", "wood fuel" and "biofuels" have by definition no transformation output.

$$UA_{j,ET}[t+1] = EEV_{ET}[t+1] \cdot \frac{UA_{j,ET}[2005]}{EEV_{ET}[2005]} \cdot 100$$

$$UA_{ET}[t+1] = \sum_{j=1}^{7} UA_{j,ET}[t+1] \qquad (2)$$

UA_j: transformation output of plants (j = 1, 2, …, 7)

EEV_{ET}: total final energy consumption over all industries

The transformation output results from converting or using primary energy (for heating or power). The output depends on the used amount of primary energy and of technology. The technological coefficient is assumed to be constant, so that the transformation input can be calculated as:

$$UE_{j,ET}[t+1] = UA_{j,ET}[t+1] \cdot \frac{UE_{j,ET}[2005]}{UA_{j,ET}[2005]} \cdot 100$$

$$UE_{ET}[t+1] = \sum_{j=1}^{7} UE_{j,ET}[t+1] \qquad (3)$$

In general, it is assumed that under normal conditions the power and heat output develops proportionally (in the ratio of 1:1), i.e. if the entire final energy demand increases, the change in production of power and heat develops equally. In the scenarios the transformation input of the energy sources, with given final energy demand, can be varied so that the power to heat ratio can be changed.

Figure 8

Domestic production, changes in stocks and the non-energy uses are constant. Transport losses and own use of the energy sector are modeled subject to the size of use of the respective energy source, so that they grow proportionally. Energy exports depend on the economic exports.

Gross domestic energy consumption can by definition be calculated either from the supply or demand perspective. On the demand side, gross domestic energy consumption is determined by the transformation input minus transformation output plus the use within the energy sector, plus non-energy use, plus transport losses and final energy use. On the supply side, gross domestic energy consumption consists of domestic energy production plus imports and stocks minus exports.

In this modeling framework, gross domestic consumption of energy is calculated from the demand side perspective (see Figure 9).

Figure 9

After determining gross domestic energy consumption, imports can be calculated as residuals (see Figures 9 and 10). A change of the energy imports influences the economic imports in the input-output model. An increased demand of oil, for instance, augments on the one hand the amount of imports and, on the other hand, affects the price, which again causes further reactions. The energy supply is determined by definition.

Figure 10

2.5.2 Forward projection of energy prices

The determination of the energy prices follows the duality of the selected modeling approach: On the one hand, energy prices have to be seized correctly in the energy model. On the other hand, production price indices in the concept of basic prices have to be adapted in the economic model in order to correctly record the developments in the energy model.

For the economic development the production price indices are crucial. Due to the information that the input-output model provides, the cost structure for the sector "energy and services of the energy industry" is well-known. It contains the costs for intermediate demand, capital use in the form of depreciations and labor costs. Further cost components are the net taxes on goods and net production taxes.

In the energy model the development of the prices is determined on the basis of scenario assumptions and "learning curves": These assumptions are based on various studies. The source for import prices of the fossil sources of energy is the IEA World Energy Outlook (IEA, 2007). The price history for large and small consumers follows the growth rates of the respective sources of energy.

For calculating the changes in the input coefficients of the energy industry, the energy balance is the basis. In the transformation sector the lines for power plants (KW) and combined heat and power plants (KWK) do not only deliver the input of the different energy sources ($EB_{KW\&KWK,EC,t}$), but also the sum of the used energy sources ($EB_{KW\&KWK,t}$). From these components it is possible to determine the ratio of use:

$$EC-Ratio = \frac{EB_{KW\&KWK,EC,t}}{EB_{KW\&KWK,t}} \qquad (4)$$

For the changed inputs of coal and gas during the power generation thereby a connection to the input-output table can be determined: The price-adjusted input coefficient $AR_{Gas\&coal,energy\ sector,t}$ is defined as the ratio of price-adjusted intermediate flows to price-adjusted production and determines the necessary amount of electricity.

Accordingly, the input coefficient $AR_{Gas\&coal,energy\ sector,t}$ decreases proportionally when the portion of fossil energy sources on power generation declines. The consequence of additional inputs of renewable energies – with unchanged electricity consumption – thereby leads to savings in inputs and thus *ceteris paribus* to a reduction of the basic prices.

So far, only one part of the changes of the cost structure of the energy industry is captured. In addition, we have to differentiate renewable energies as (1) renewable energies that use biofuels (fire wood, wood pellets, combustible wastes, fermentation gas, etc.) and (2) renewable energies that do not (solar, water, wind etc.). For both cases it is true that an increasing use implies that additional production capacity has to be generated.

Investments have to be made which are included in the cost accounting of the firms by the size of the consumption of fixed capital.

The size of the investments depends on the costs per installed capacity unit (in kW) and the operating time (in h). While renewable energies that are based on regenerating raw materials can be operated continuously, power stations that are based on wind and solar energy are dependent on the weather situation. Accordingly, for each energy source an investment path is computed, which entails a change in the depreciation. Thereby, it is assumed that the investments in renewable energies are additive and added to the "usual" investments in the energy sector. Hence it follows that the depreciations in the cost calculation of the energy supply industry rise and thus accelerates the development of prices.

In the first case additional costs (e.g. for the use of fuels) must be added. A higher use of fuels implies proportional changes in the input coefficients of the cost structure to the ratio of use in the energy balance. Depending on the energy source, the wood industry, the chemical industry or agriculture increase their portion on the cost structure of the energy industry.

In the second case the situation is more difficult: For wind, water and solar energy no intermediate deliveries arise in the cost structure of the energy industry since no costs emerge. From this it cannot be concluded, however, that the electricity tariff reduces, as long as the depreciations for, e.g., photovoltaic systems are smaller than the savings of fossil energy sources.

In both cases the renewable energies are fed into the electricity grid. The grid operator ("distribution") pays the feed-in compensation to the renewable power producers. The power distribution companies record the costs of the electricity feed-in to the grid into their cost calculations. Since the feed-in compensation per kWh for renewable energies is usually clearly higher than for conventionally produced energy the input coefficient AR[energy][energy] increases.

Due to the missing decomposition of the energy sector (production and distribution of energy cannot be divided) the portion of renewable energy shifted within the energy sector is not known. Thus, a proper allocation has to use assumptions. In the following it is postulated that this sector internal flow increases by twice the savings of fossil energy resources. This hypothesis stems from the consideration that each renewable energy (except for water and fuel wood) is at least twice as expensive as conventionally produced energy. From this, it follows that the price changes are all the more underestimated the higher the feed-in compensation is. Especially strong is the underestimation in the case of photovoltaics.

Concerning the labor costs we assume a constant development, due to missing information.

Figure 11 provides an overview of the connections between the economic and the energy model. Furthermore, the price effects of a higher use of renewable energies are summarized. At a first glance, the figure conveys that the use of renewable energy leads to augmenting prices. However, it has to be considered that increasing prices for fossil fuels may cause an overall decelerated price development. The beneficiary of a particular energy source is thus dependent on the assumptions about the energy prices in the scenarios.

Figure 11

Furthermore, it has to be noted that the prices for final consumption are based on the purchaser price principle, i.e. current taxes etc. still positively affect the development of the purchaser prices. In addition, the energy sector can include additional criteria – e.g. the development of the price for electricity at the stock exchange – and, accordingly, further mark-ups into the price setting. This is not the case in the modeling; rather a constant relationship between unit costs and production prices is assumed.

Finally, the consequences of the CO_2 emission trading are included in a simplified way. The energy industry pays the costs of the CO_2 certificates – the arising payment stream is accordingly booked in the SNA – and allocates these costs equally, in a way that all the production prices increase, however without additional profits in the energy industry.

2.5.3 Feedbacks between the energy model and the economic model

The feedbacks that exist between the economic model and the energy model are illustrated in Figure 12. The economic and the energy imports and/or exports of fossil and renewable energy resources mutually influence each other in their development. A quantitative increase of the imported energy resources such as coal or gas, equally causes a rise in the amount of the price-adjusted imported goods of the economic model. The fossil sources of energy such as coal, gas and oil can be added directly to the economic goods imported. Firewood, however, is only one part (approx. 4 %) of the imported goods of the commodity group "forest products".

Figure 12

A similar logic applies to the exports. However, here the imported economic goods determine the energy exports (i.e. the exports of the energy balance). The reason lies in the structure of the model. It is assumed that Austria’s exports depend on the world import demand. This is given by the world trade model GINFORS. The size of the exports depends on the market shares, which change by the competitiveness of the regarded country.

Changes in industry-specific final energy demand also affect the intermediate flows of the “industry energy and services of the energy supply" as well as the associated transformation input of primary energy (coal, crude oil, natural gas, etc.) for the production of the secondary energy (district heating, electricity). Changes in the transformation input and, concomitantly, the transformation output of secondary energy in the respective converters (coking plant, refinery, heating plants etc.) lead to a changed cost structure (see previous remarks).

The change in final energy demand must be integrated into the intermediate consumption matrix accordingly. This is realized by projecting the input coefficients with the quantitative change of the assigned energy sources used for power and heat generation.

3 The RET Scenarios

Based on the experience of the project "ARTEMIS" (see Kowalski et al., 2006; Madlener et al. 2007; Kowalski et al., 2008, www.project-artemis.net), scenarios were defined to specify how an increased share of renewable energy may look like. Together with stakeholders and experts of energy technology and policy, altogether three scenarios were worked out, illustrating different pathways to promote renewable energy and analyzed in comparison to a Business as Usual (BAU) scenario. The BAU scenario reflects the policy situation of 2005. Comparing the BAU scenario with the RET scenarios allows us to recognize effects of changes induced by the scenario design.

The scenarios focus on heat and power generation. They neither refer to the transport sector nor to measures to improve efficiency in the manufacturing industries or the thermal reconstruction of buildings. However, energy efficiency improvements are considered in the BAU scenario.

3.1 The Scenario "Improve strengths" - STA (short-term oriented)

The scenario "Improve strengths" (STA) is based on those technologies which have low actual heat or power costs and are able to promptly expand their capacities. Thus, "Improve strengths" primarily focuses on the extension of wind power and small hydropower for power generation, as well as on pellets for heat generation. All these technologies have good chances of further implementation in Austria. Concerning the security of supply, the scenario is supposed not to be able to significantly reduce energy imports, while the structure of supply will be more centrally organised.

Due to the limited capacity expansion with respect to hydropower, wind power and wood pellets, this scenario would result in relatively small CO_2 savings. The expansion of hydropower is limited due to environmental constraints. Missing areas with favorable wind conditions and lacking social acceptance restrict the further exploitation for wind power. For wood pellets a doubling of the capacity is assumed, but a higher expansion is limited due to increasing competition with the wood industry. For these reasons, also an increase of photovoltaics is assumed.

3.2 The Scenario "Biomassive" – BIO (middle-term oriented)

The scenario „Biomassive" (BIO) was designed due to the importance of biomass as an energy carrier for Austria and due to the fact that a comprehensive and sustainable use of the available biomass potentials is very likely (e.g. richness of forests, tradition, successful wood industry, technological know-how). These technologies, which have led to substantial capacity building over the last years and which hold great potential for further development, are extended the most. Principally, the use of solid biomass and biogas receives the strongest support, leading to a central structure of supply with a focus on heat generation.

The scenario is constructed to estimate the maximum biomass use within critical framework conditions. In this respect, additional biomass capacity, recycling capacity, land use conflicts with wood, paper and food industry, and biofuels as well as biomass imports have to be considered. As it was the case for the first scenario, the technological conditions for the implementation are also given. However, a strong expansion of biomass utilisation will require increasing imports of investment goods in order to offset missing short-term production capacity in Austria.

As a result, a significant reduction of CO_2 emissions in comparison to the BAU scenario can be expected. This reduction, however, is not possible without imports of biomass carriers and technological equipment.

3.3 The Scenario "Think of tomorrow" – DAM (long-term oriented)

On the one hand, the scenario "Think of tomorrow" (DAM) is based on a long-term investment strategy, which is provided by the promotion of costly but very promising future technologies (e.g. photovoltaics, geothermal energy). On the other hand, market-ready technologies with low land use requirements are furthered in order to distinguish this scenario from „Biomassive".

Thus, "Think of tomorrow" disregards the combustion and the gasification of biomass resources. On advice of the stakeholder group the power of the sun is used in the form of a massive expansion of photovoltaics. However, due to the still high investment costs of photovoltaics, the financing of this scenario would have to be strongly supported by the government, and require substantial subsidy funding.

In addition, it is not easily possible to create the necessary production capacity for solar cells in Austria, leading to additional imports of solar cells, which would incur a run-off of value added. If a similar behavior in other countries is assumed, then demand-driven price increases for solar cells are likely. Furthermore, the provision of the technology is very resource-intensive. Positive factors of this scenario are the exploitation of a sustainable energy source, the achievement of a significant CO_2 reduction and the decrease of fossil resource imports.

4 Results of scenario simulation

With respect to the economic development the BAU scenario as well as the RET scenarios are supposed to have positive effects. In the BAU scenario the gross domestic product (GDP) will increase by 2.1% p.a., in the RET scenarios this growth will even be higher. The scenarios substantially differ in the growth dynamic of investments. The scenario "Think of tomorrow" requires considerable investments which entail the strongest growth in GDP. As already mentioned, it has to be assumed, however, that not all solar cells can be produced domestically, implying that additional imports will reduce domestic economic growth.

The results for employment show that economic growth also leads to an increase in the number of employees. While in the BAU scenario 198,000 additional jobs can be created until 2020, this number is still higher in the three scenarios designed: In comparison to the BAU scenario the scenario "Think of tomorrow" leads to 19000 new jobs, in BIO about 15,000 and in STA about 10,000 additional people can be employed.

The composition of the final energy consumption according to energy sources develops very heterogeneously between the scenarios. The use of fuel oil is lower in BIO and in DAM than in STA. Especially in "Biomassive" the higher use of firewood in private households reduces the use of fuel oil significantly. In the scenario "Think of tomorrow" it is the generation of heat by solar energy which decreases the use of fuel oil.

The comparison of the shares of renewable energy in the course of time shows that in the BAU scenario the share between 2005 and 2020 decreases due to the missing extension of hydropower. In the RET scenarios this decrease can be stopped (see Figure 13).

Figure 13

The target to cover 34% of energy use by renewable energy cannot be met in neither of the scenarios (see Table 2). The highest share with 27.5% in 2020 can be expected in the scenario "Think of tomorrow". "Improve strengths" supposes that the share of the year 2005 can be kept, while in "Biomassive" even a slight decrease in percentage over time is possible.

By combining the assumptions of the different scenarios the overall share can be extended to 28.3%. Yet, it has to be noted that energy use will strongly increase until 2020 (see Table 2), so that despite the massive expansion of renewable energy additional heat and power consumption cannot be covered. A stabilization of energy use through efficiency gains and changes in consumption behavior could lead to an increase of the share to 37%.

The resulting CO_2 reduction is caused by the realized shares of renewable energy. It is true that in all scenarios the CO_2 emissions can be reduced compared to the BAU scenario, since fossil fuels can be substituted by renewable resources. An absolute reduction of CO_2 emissions over time is, however, not possible in neither of the scenarios (see Figure 14). Thus, with an exclusive expansion of renewable energy the respective EU regulation of reducing CO_2 emissions by 20% compared to 1990 will not be met.

Figure 14

Table 2

In summary, one can conclude that the scenarios developed do not provide a formula for success concerning the extension of renewable energy. There is no free lunch. The scenario „Improve strengths" features cost efficiency and competitiveness, but the expansion of wind and hydropower is limited and problematic from an environmental point of view. "Biomassive" is supposed to have high potential for political implementation, but suffers from land use conflicts and resource scarcity. The scenario "Think of tomorrow", in turn, is able to achieve a high augmentation of renewable energy and large CO_2 savings, but requires high investment costs.

Finally, it is obvious that there is no alternative to reducing energy consumption. Only if it is possible to stop its growth through huge efficiency gains and changes in behavior can renewable energy live up to the high expectations to contribute to reach a sustainable energy system.

5 Summary

In the course of the project the emphasis of the work was on the development of the simulation model, the design of the scenarios as well as on their simulation. The model "e3.at", which integrates energy, environmental and economic aspects in an integral and consistent way, is well-suited for illustrating the impacts of an increased portion of renewable energy technologies. The integration of the environmental and socio-economic systems with their various linkages and feedbacks is needed to appropriately assist policy-makers in their decisions for suitable strategies to tackle the most challenging environmental and socio-economic problems.

Through its participatory approach, the project fosters the intensive exchange of experience between researchers and actual users of the results from the political, economic and societal domain. This enables an illustration of the potential impacts of renewable energy resources which reflects actual stakeholders' concerns. Furthermore, the involvement of various actors (energy suppliers, NGOs, public administration etc.) with their different interests and values represents a crucial element of a democratic decision process towards a sustainable energy future. In this respect, the project contributes to the connection of science and practice by improving the dialogue between stakeholders and researchers and by enhancing the transparency of the modeling process.

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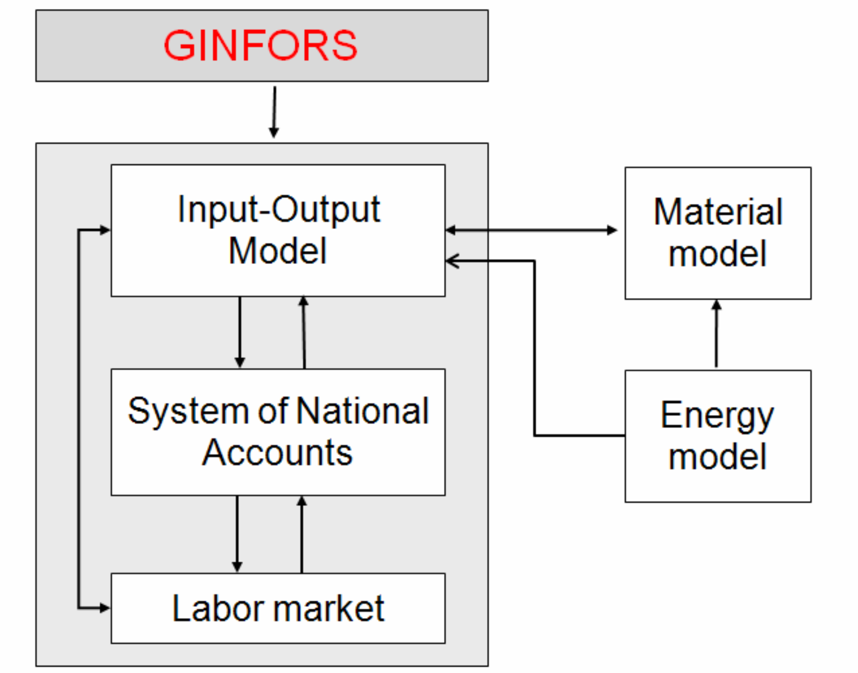
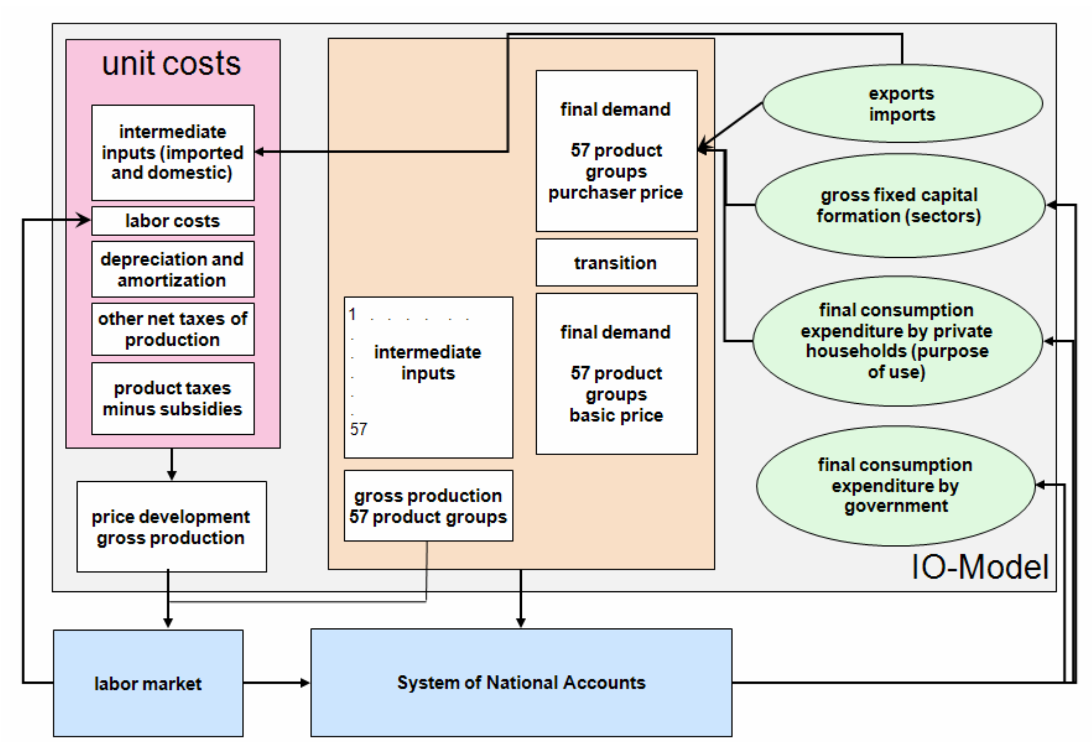
Tables and Figures:

Figure 1



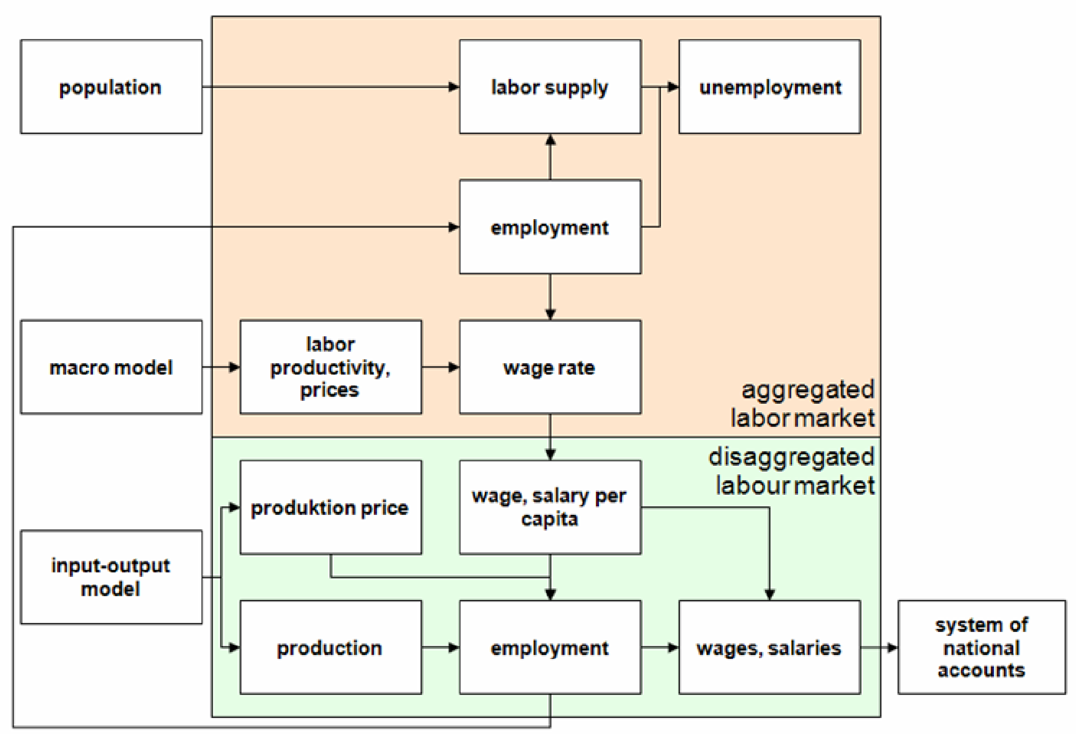
Structure of the model “e.3.at” (*Source: own illustration)*

Figure 2



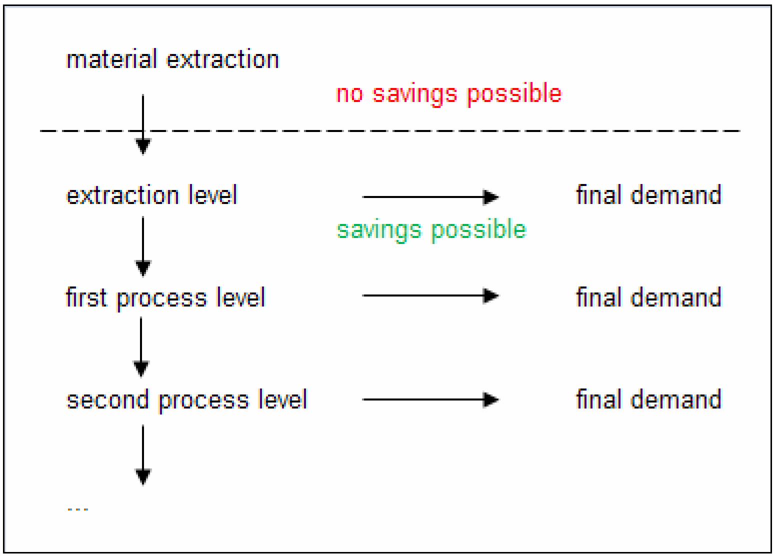
Structure of the input-output model (*Source: own illustration)*

Figure 3



Structure of the labor market (*Source: own illustration)*

Figure 4



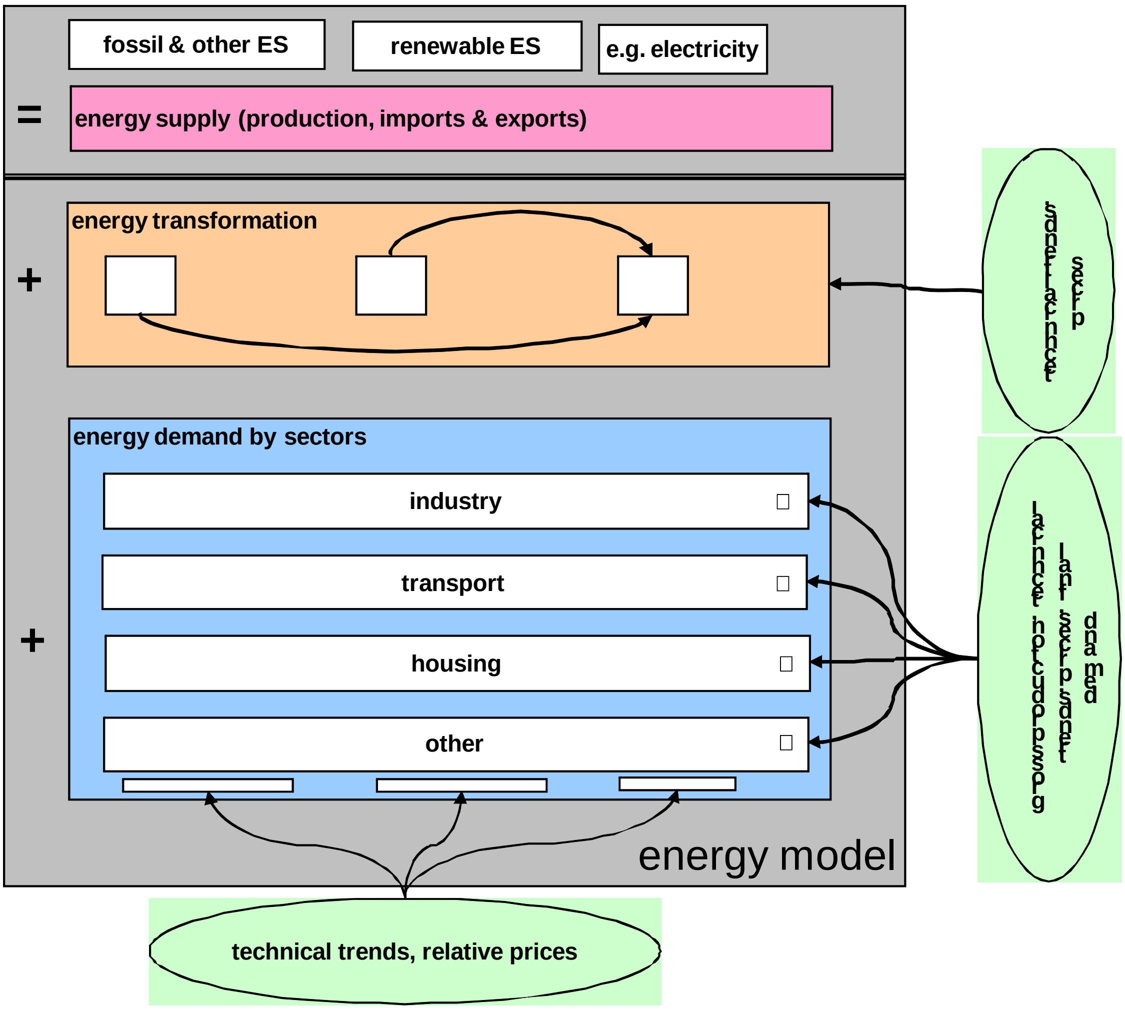
Potential material savings along the process chain (*Source: own illustration)*

Figure 5

ENERGY SOURCES								
coal	oil			gas	renewable			
	crude oil	*fuels*	*oil products*		*combustible waste*	*biogenous fuels*	*latent heat*	*other*
hard coal	crude oil	gasoline	paraffin	mixed gas	renewable wastes	leach	geothermal energy	fire wood
brown coal	other refinery	diesel	gasoil for heating	natural gas	non-renewable wastes	biogas	solar heating	pellets and wood waste
lignite briquette			light fuel oil		industrial waste	sewage gas	heat pump	photovoltaics
peat			liquid gas			landfill gas		hydro power
coke			other petroleum products			other biogenous		wind power
blast furnace gas			refinery gas					district heating
coke oven gas								electricity

Energy sources *(Source: own illustration)*

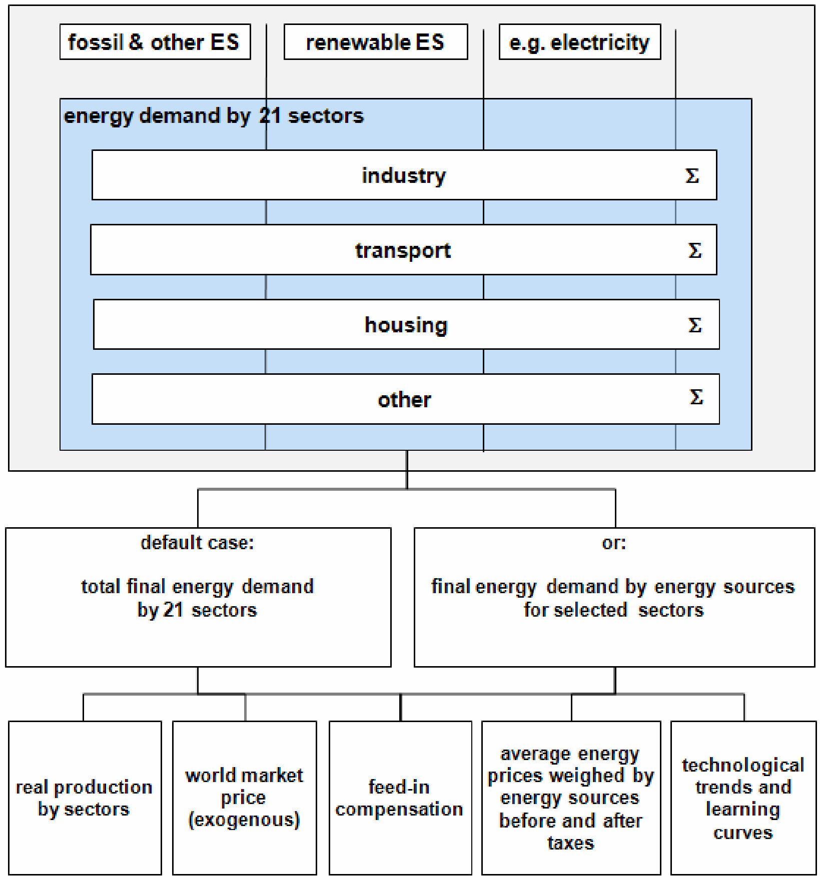
Figure 6



Note: ES: energy sources

Structure of the energy balance *(Source: own illustration)*

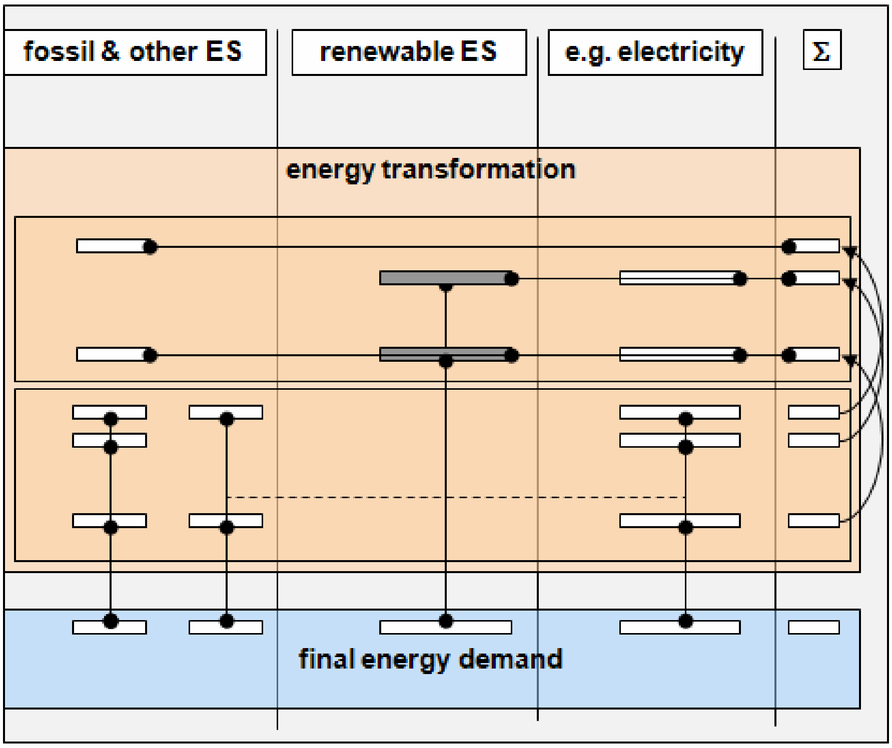
Figure 7



Note: ES: energy sources

Modeling final energy demand *(Source: own illustration)*

Figure 8



Note: ES: energy sources

Transformation of energy *(Source: own illustration)*

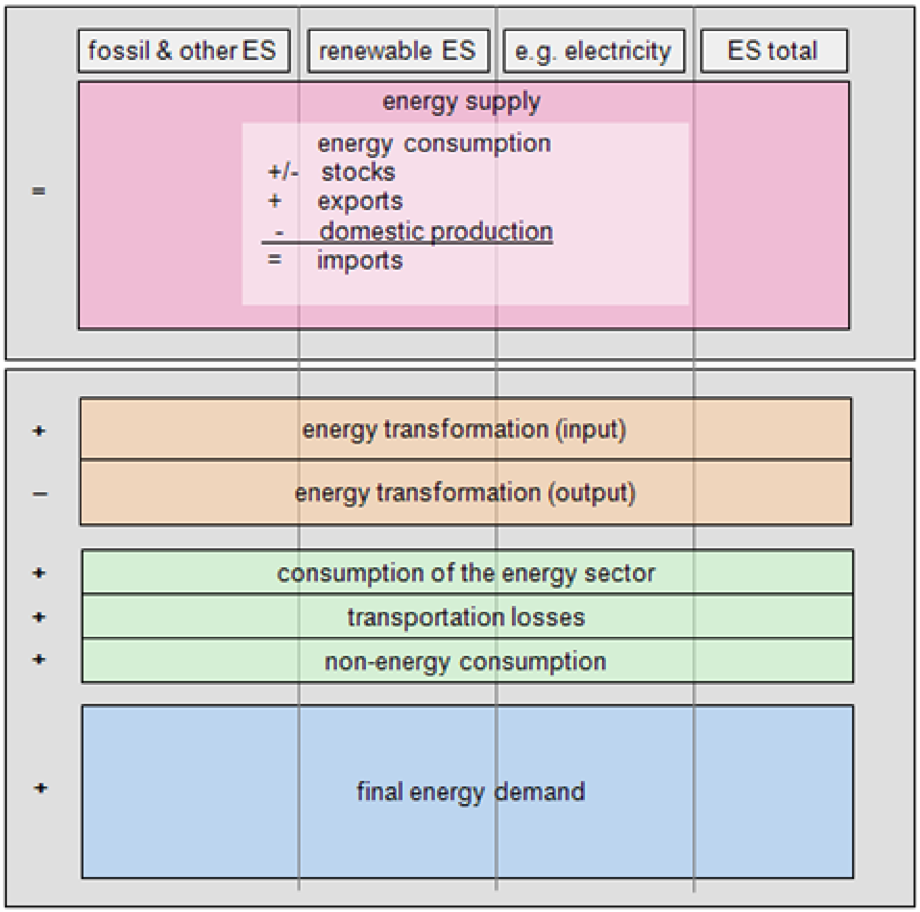
Figure 9

	energy transformation (input)
-	energy transformation (output)
+	consumption of the energy sector
+	transportation losses
+	non-energy consumption
+	final energy demand
=	gross domestic consumption

	gross domestic consumption
-	domestic energy production
+/-	changes in inventories
+	exports
=	imports

Balance equations

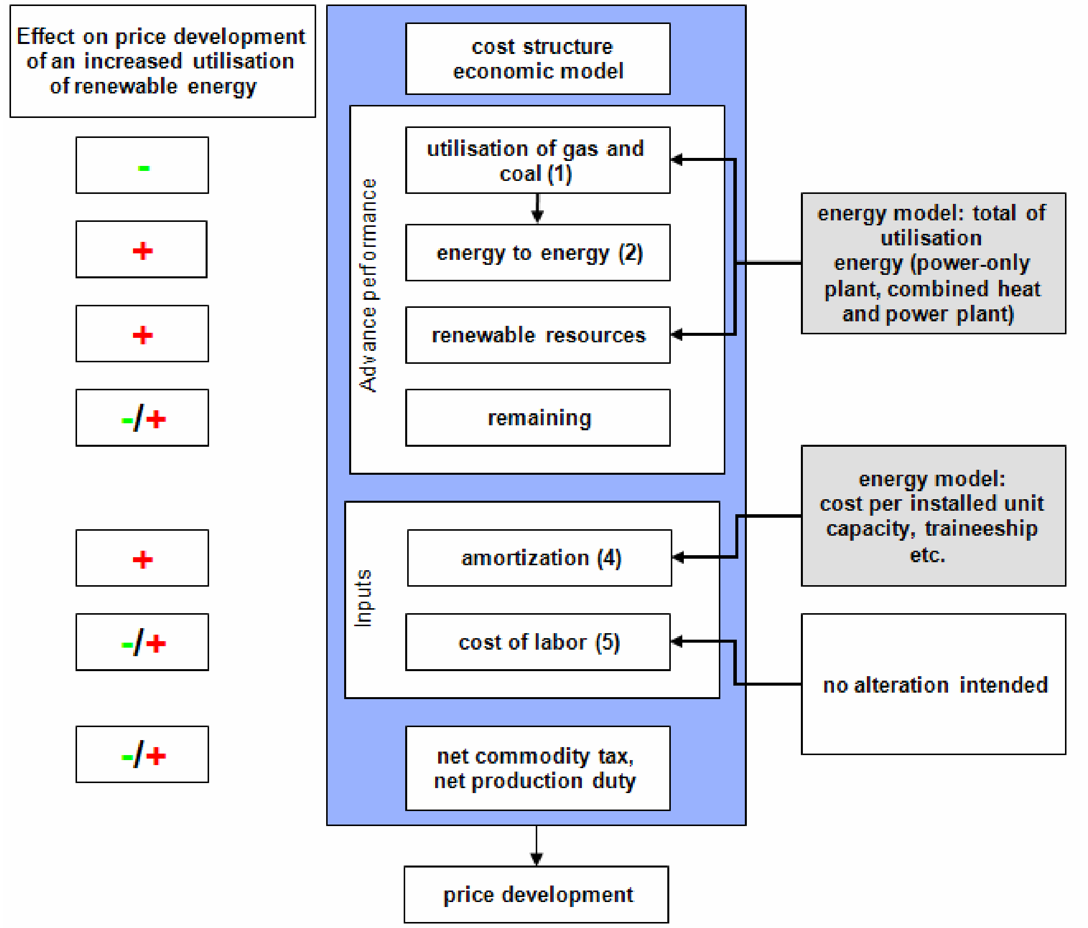
Figure 10



Note: ES: energy sources

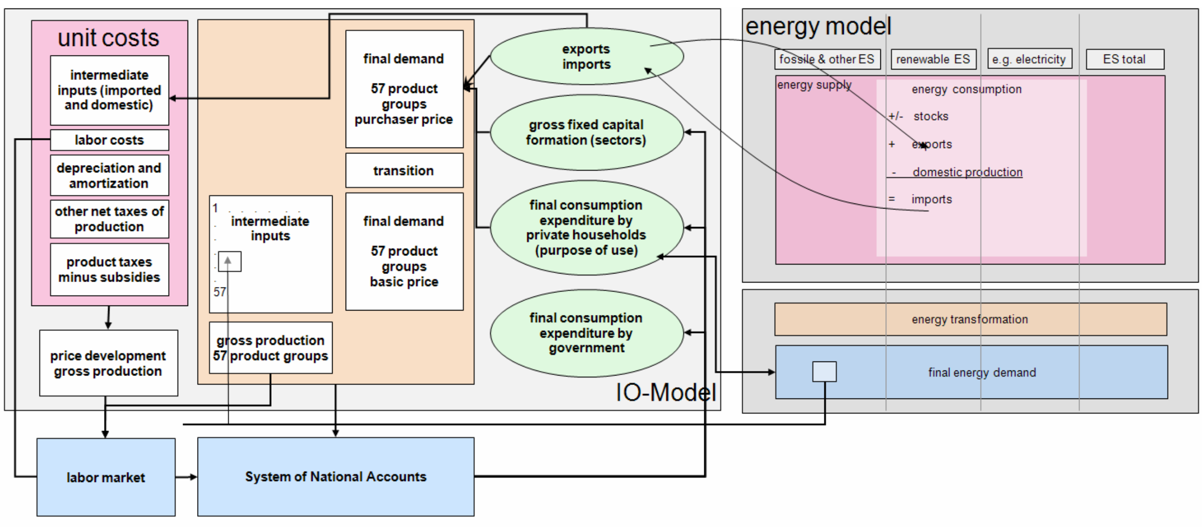
Calculation of energy supply (*Source: own illustration*)

Figure 11



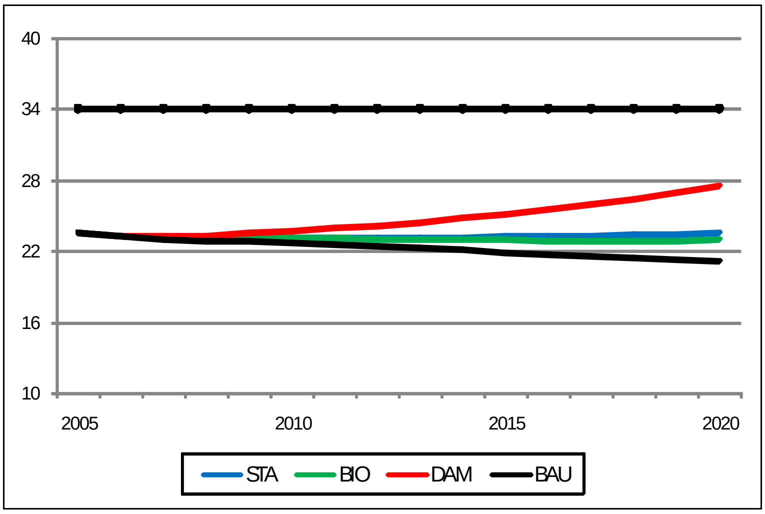
Modeling of the development of energy prices (*Source: own illustration)*

Figure 12



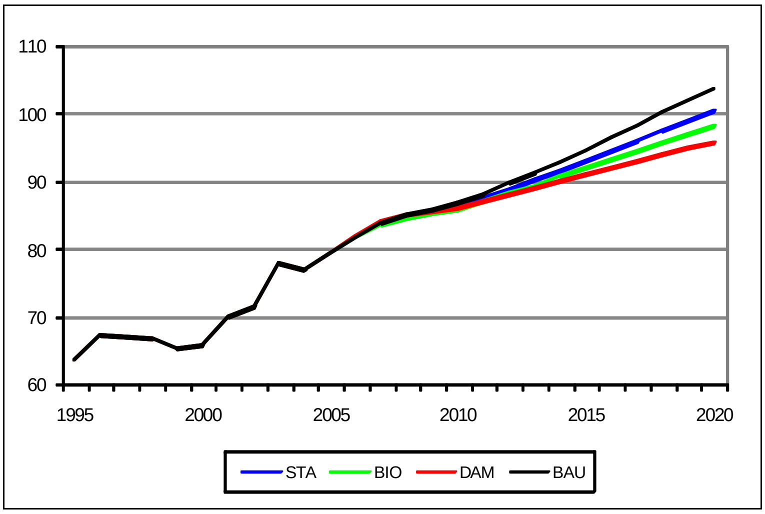
Feedbacks of energy model and economic model *(Source: own illustration)*

Figure 13



Share of renewable energy in final energy consumption (in %)
(*Source: own calculation)*

Figure 14



Development of CO_2 emissions (in million tons) (*Source: own calculation)*

Table 1

	Domestic extraction	Material imports
Biomass	food feed stock animals forestry non edible biomass	food feed stock animals forestry non edible biomass
Minerals	construction minerals industrial minerals ores	construction minerals industrial minerals ores
Fossil fuels	coal crude oil natural gas other fossils	coal crude oil natural gas other fossils

Overview of material inputs covered by the material model (*Source: own illustration)*

Table 2

	2005	**BAU 2020**	**STA 2020**	**BIO 2020**	**DAM 2020**	**TOTAL 2020**
Final energy consumption (total)	*1.105.190*	*1.448.683*	*1.451.472*	*1.452.544*	*1.453.400*	*1.453.400*
Transport losses, energy sector use	*62*	*62*	*62*	*62*	*62*	*62*
Transformation input (renewables)						
Hydro	129.150	137.028	142.194	137.028	137.028	142.194
Photovoltaics	51	1.364	22.670	22.670	82.216	82.216
Wind	4.781	12.331	22.235	12.331	22.235	22.235
Final energy consumption (renewables)						
Geothermal	259	351	353	354	354	354
Solar thermal	3.816	6.895	6.904	6.908	9.323	9.323
Heat pumps	4.976	7.125	7.161	7.174	7.200	7.200
Firewood	64.737	66.439	66.451	72.388	66.464	72.388
Combustible waste	10.615	13.957	13.972	13.981	13.981	13.981
Biofuels	16.139	20.500	20.514	20.516	20.529	20.529
Pellets, wood waste	25.954	40.232	40.317	40.336	40.389	40.336
Sum renewable energy in TJ	260.477	306.222	342.771	333.685	399.719	410.757
Share renewable energy in %	23,6	21,1	23,6	23,0	27,5	28,3

Share of renewable energy (in % and in TJ) (*Source: own calculation)*