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Authors' addresses:

Andrea Stocker
Sustainable Europe Research Institute (SERI)
Garnisongasse 7/21
1090 Vienna, Austria
E-mail: andrea.stocker@seri.at

Anett Großmann, Marc Ingo Wolter
Institute of Economic Structures Research (GWS)
Heinrichstrasse 30
49080 Osnabrück, Germany
E-mail: grossmann@gws-os.com, wolter@gws-os.com

Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 6
52074 Aachen, Germany
E-mail: RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 6, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.eonerc.rwth-aachen.de/fcn
E-mail: post_fcn@eonerc.rwth-aachen.de

Sustainable energy development in Austria until 2020: Insights from applying the integrated model "e3.at"

Andrea Stocker [a*], Anett Großmann [b], Reinhard Madlener [c], Marc Ingo Wolter [b]

[a] *Sustainable Europe Research Institute (SERI),*
Garnisongasse 7/21, 1090 Vienna, Austria

[b] *Institute of Economic Structures Research (GWS),*
Heinrichstrasse 30, 49080 Osnabrück, Germany

[c] *Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University,*
Mathieustrasse 6, 52074 Aachen, Germany

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Abstract

This paper reports on the Austrian research project "Renewable energy in Austria: Modeling possible development trends until 2020". The project investigated possible economic 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 for renewable energy in Austria. The scenarios were simulated for the period 2006–2020, using the integrated environment–energy–economy model "e3.at". The modeling results indicate that increasing the share of renewable energy sources in total energy use is an important but insufficient step towards achieving 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, scenario development

[*] Corresponding author. Phone: +43 (4352) 30 276, Fax: +43 (1) 969 07 28-17, *E-mail:* andrea.stocker@seri.at (A. Stocker).

1 Introduction

Renewable energy plays an important role in Austria for reducing the country's dependence on imported fossil fuels and for supporting the reduction of greenhouse gas emissions. This role will become more important within the next years due to the fact that the share of renewables – which amounts to about 24% of the entire final energy mix in 2005 – has to increase to 34% by 2020 in order to fulfill EU targets (CEC, 2009)[1]. In this respect, it is important to estimate and quantify the effects of an intensified use of renewable energy on the environment, the 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 in Austria. More specifically, the integrated environment–energy–economy model "e3.at" was developed and used to simulate different renewable energy technology (RET) scenarios with a focus on different developments of renewable energy use in Austria up to 2020. The scenarios were developed jointly with stakeholders and experts. The e3.at model enables a much deeper impact assessment of renewable energy policy than more conventional less integrated models.

The process of scenario modeling (from the development of scenarios up to the dissemination of the modeling results) integrates participative elements. A stakeholder and expert group of 30 people were 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 duly considered in the project work. Thus, the research results are not only built upon the work of researchers, but they also integrate the knowledge, the expertise and the

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[1] Besides the 34% goal, Austria also agreed within the EU Climate and Energy Package upon reducing greenhouse gas emissions in the non-ETS sectors by 16% with regard to the 2005 level; and reducing primary energy use by 20% compared with projected levels, to be achieved by improving energy efficiency (BMLFWU, 2010).

preferences of the major stakeholders, thus enriching the policy value and relevance of the research still further.

The remainder of this paper is organized as follows: Section 2 introduces the integrated model “e3.at” and Section 3 describes the scenarios. On the basis of the simulation results, reported in Section 4, we draw some policy implications in Section 5, and derive some conclusions from this analysis in Section 6.

2 The integrated environment–energy–economy model “e3.at”

In this section, we will briefly introduce the integrated environment–energy–economy model e3.at (for a detailed description see the Appendix and Großmann and Wolter, 2010), which was developed and applied within the project to analyze different scenarios aiming at increasing renewable energy use.

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

The model also illustrates the interdependencies between the environment and the economy, allowing not only for the analysis of economic growth and employment effects, but also the impact 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 energy policy-makers in their decisions on suitable strategies to tackle the most challenging environmental and socio-economic problems related to energy supply and use.

A major advantage of integrated modeling with e3.at is the representation of direct and indirect rebound effects (Sorell, 2010). Forcing renewable energy in Austria means increasing both economic activity and energy consumption. Moreover, the additional added value leads to an increased demand (e.g. for transport and other consumer goods). These effects can be calculated within e3.at.

The model is based on the philosophy that agents act in imperfect markets under conditions of bounded rationality (see, e.g. Rubinstein, 1998). 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 projections, which, when confronted with environmental and economic targets, allow for 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 each of the 57 sectors of the Austrian economy is 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 interindustry connections and the generation, distribution, redistribution, and use of income for consuming goods. It further depicts the influence of the economy on the environment, and vice versa.

The detailed 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 (IO) tables are consistently linked with time series of a full system of national accounts and balancing items (SNAB).

The core model of e3.at consists of an *economic model*, consisting of an input-output (IO) model, the SNAB, and the labor market; and an *energy model*, illustrating the relationship between economic development, energy use and CO_2 emissions. Additionally, the core model can be expanded by a *material model*, a *regional housing inventory model* and a *transportation model for private households* in order to show the manifold relationships between the economy, the energy system, and the environment. With the aim of displaying social and distributional impacts, the model was extended by 25 household groups according to their income and size of household. Furthermore, e3.at has a soft link to the world model GINFORS (Global INterindustry FORcasting System; see Meyer et al. 2007; Meyer et al., 2008; and Lutz et al., 2010), in order to illustrate the effects of international trade on the Austrian economy. Since in the reported project only the economic and the energy model components are used, we only describe these shortly in the following. For further information see the Appendix or Großmann and Wolter (2010).

Figure 1 provides a brief overview of the structure of the model. The *economic model* consists of an input-output (IO) model, the SNAB, and the labor market. It shows a very high degree of endogenization, although tax rates and labor supply are exogenous. As already stated, 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 and including also direct and indirect rebound effects.

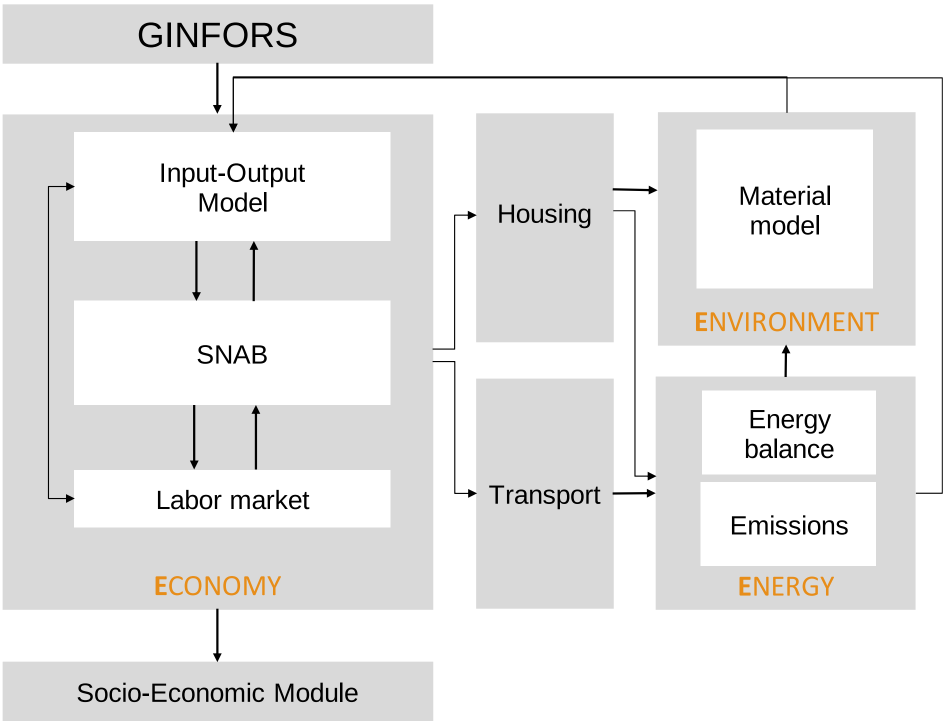

Figure 1 Structure of the e.3.at model

Source: own illustration

In addition to the usual interdependencies between the circular flow of income, e3.at depicts the interdependencies between prices and volumes as well as between 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 dynamic structure enables a year-by-year solution for a longer time path.

The core of the economic model is an *IO model*, which shows the interdependencies of all industries, and which is also important for linking the economic model with the material and the energy model.

The *SNAB* 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 and secondary distribution of income, use of income, acquisition of non-financial assets and accumulation accounts. The government's budget, including the tax system and the social security system, is endogenously determined. The detail of this system allows the identification of the expenditures and revenues of the social security system, so that the system can be linked to the labor market and other parts of the model.

The labor market consists of both an aggregated part and a part modeled in detail. In the aggregate part, the demographic development determines the macroeconomic labor supply. Unemployment is given by definition, subtracting aggregated labor demand from the exogenous labor supply.

In the part modeled in detail, 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.

The *energy model* describes the interrelations between economic development, energy consumption and CO_2 emissions. On the one hand, economic development influences primary energy use. On the other hand, expenditure for energy consumption has a direct impact on the economic variables.

Since final energy usually cannot be provided directly to the consumer, the transformation sector converts domestic and imported (primary) energy to final energy. Primary energy commodities are extracted or captured directly from natural resources, such as crude oil, hard coal, natural gas or renewable energy. 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 primary energy required can either be produced in Austria or 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, final energy, as well as losses occurring from energy conversion. In addition, the differentiation of a multiplicity of sources of energy and sufficiently detailed sector levels are necessary.

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

3 The RET scenarios

Hydropower and the biomass resources make a substantial contribution to energy supply in Austria, whereas all other renewables still play a minor role. Against the climate problem and dwindling fossil resources, it is necessary to produce useful energy in other ways than the combustion of oil, coal or natural gas. As already mentioned in the introduction, renewable energy sources are environmentally more friendly alternatives to fossil fuels and, therefore, should contribute much more to meet the energy needs of society. The question arises, which potential the renewables in Austria have, and which economic, ecological and social consequences their increased use may have.

Based on the experience gained in the project “ARTEMIS” (see Kowalski et al., 2006; Madlener et al., 2007; Kowalski et al., 2009; www.project-artemis.net), scenarios until 2020 were defined to specify how an increased share of renewable energy could look like. Together with stakeholders and experts in energy technology and policy, three scenarios were elaborated, illustrating different pathways to promoting renewable energy.

The RET scenarios were analyzed in comparison to a Business as Usual (BAU) scenario, which reflects the policy situation of 2005. This scenario serves as a reference scenario, showing the expected future development up to 2020, under the assumption that aside of already implemented measures no additional promotion of renewables takes place. Comparing the BAU scenario with the RET scenarios allows to recognize effects of changes induced by the scenario design.

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

The three alternative scenarios considered range from more centralized to decentralized technologies, from a focus on land-intensive to land-saving technologies, and from electricity to heat technologies. They also differ with respect to their feasibility in the short-, medium- and long-term as well as their investment costs and competitiveness.

In the following, the scenarios are described by presenting their general intention, their key technologies involved, the potentials of their promotion until 2020, their learning curves as well as their prices. The definition of the key parameters is based on a comprehensive literature review and on intensive discussions with stakeholders and experts.

In all scenarios we assume that the Austrian government is at least partly willing to bear the investment and credit risks of companies in the form of guarantees. This support is especially important for those technologies that are associated with high investment costs. The effects of misdirected investments can be significant even for large utilities. Therefore, it is implicitly assumed that the government is collaterizing half of the investment volume with guarantees. In the model simulation, it is implied that the income tax is increased to finance the guarantees. One advantage of this funding is that it has positive effects on distributive justice: Because of the tax progression, households with higher incomes pay more income or payroll taxes. However, their pro rata share of expenditures for energy is rather low. The opposite is true for households with low incomes.

3.1 Scenario “Improve Strengths” – IS (short-term oriented)

The scenario “Improve Strengths” (IS) is based on renewable energy technologies that have low actual heat or power generation costs and that 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 wood pellets for heat generation. All these technologies have good chances for further implementation in Austria, because they will further improve technological leadership and competitiveness (BMVIT, 2002; Bodenhöfer et al., 2004).

Just like biomass, hydropower is of great importance in Austria, too. Between 1980 and 2004, depending on weather conditions, between 60% and 74% of total electricity production was realized by (mainly large-scale) hydropower[2]. The potential of large-scale hydropower is mostly exhausted. Optimistic estimates of the remaining potential show that power production from large-scale hydropower could be increased further by some 4% until 2020. In absolute numbers, this is equivalent to an increase by about 5200 TJ until 2020 (compared to 124,711 TJ in 2005).

An important role in this scenario has the expansion of small-scale hydropower.[3] Currently, small-scale hydro accounts for some 4440 TJ (2005) of renewable electricity regulated by the Austrian Green Electricity Act (Ökostromgesetz), ranking second after wind power. The additional potential (until 2020) has been estimated to be about 7900 TJ (equivalent to an increase by 178%).

In the case of wind power an exploitation of the potential of currently (2005) 4780 TJ to more than 22,200 TJ (i.e. almost a quintupling) is assumed. Especially for wind power the potential rises with increasing technological know-how, as more and more surface areas can be used for wind power production, the installed capacity per m^2 rises with rising size of the plants, and full-load hours rise as well with increasing nacelle height (e.g. Haas et al., 2007).

Regarding heat and combined-heat-and-power (CHP) production the expansion of plants for using wood pellets and wood residues is forced more than in the other scenarios. For CHP plants the increase is 3000 TJ between 2005 and 2020, whereas the capacity of heat-only plants doubles (increase by 7500 TJ between 2005 and 2020). An expansion beyond this level is considered unlikely, given the increasing competition with the use of wood residues (esp. sawdust and shavings) in the particle board industry (Nemestothy, 2006). In other words, the

[2] Cf. www.eva.ac.at/(de)/enz/res-dat_strom.htm, accessed January 15, 2008.

[3] The distinction between large- and small-scale hydropower production in the model is done on the basis of the split in the energy balance between self-producing firms (so-called “Unternehmen mit Eigenanlagen”, UEA) and energy utilities (Energieversorgungsunternehmen, EVU).

limiting factor here is resource availability and not so much the timely construction of the plants.

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 and social acceptance constraints. Missing areas with favorable wind conditions as well as lacking social acceptance restrict the further exploitation for wind power as well. For wood pellet heating systems, a doubling of the capacity is assumed, but a higher expansion is limited due to increasing competition within the timber processing industry. For these reasons, an increase in photovoltaics is also assumed.

With regard to the electricity and heat generation costs, the IS scenario is favorable compared to the other two scenarios, at least in the initial phase. Due to the much higher oil and gas prices in this scenario, small hydropower plants and certain types of biomass plants can successfully compete with those based on fossil fuels. Also thanks to the promotion of green electricity, wind power shows relatively low investment and operating costs, and the cost of solar thermal collectors – at least in the decentralized supply of hot water – is no big obstacle any more. Table 1 summarizes the parameterization for the “Improve Strength” scenario.

Concerning the security of supply, the scenario is not expected to be able to significantly reduce energy imports, and the structure of supply will be centrally organized. In the IS scenario the supply of electricity (electricity to heat in a 3:1 ratio) is dominant. Electricity is produced mostly by small hydropower, wind power and photovoltaics, but also by nuclear power plants, and is structured more centrally. Heat is mainly provided in a localized manner through biomass district heating and combined heat and power (CHP) plants.

Although security of supply is supported by a diverse energy mix, electricity supply must be secured with other indigenous power generating capacity and electricity imports, since wind power is subject to strong fluctuations. The market for wood pellets is already an international one. Since Austria exports a high proportion of the wood pellet production, but also imports from other countries, it is not very easy to reduce the dependence on imports (although the transport costs generally account for a large fraction of the total fuel costs and are expected to rise further due to increasing transport distances).

Table 1: Quantitative description of the “Improve Strength” (IS) scenario

Key technologies	Capacity		Price (incl. learning curve)	
	in TJ, 2005	in TJ, 2020	in ct/kWh (unless stated otherwise), 2005	in ct/kWh (unless stated otherwise), 2020
Hydropower (power plants)	129,150	142,194	4.90	5.10
Photovoltaics (power plants)	51,000	22,810	65.14	37.54
Wind (power plants)	4781	22,235	7.75	6.73
Combustible waste (power plants)	3634	40,305	10.69	12.64
Biofuels (power plants)	10,879	13,525	11.27	11.67
Pellets, wood residues (power plants)	529,000	1057	3.26	5.01
Sum power plants	**149,024**	**242,125**		
Combustible waste (CHP)	4065	6384	10.69	12.64
Biofuels (CHP)	12,325	19,398	11.27	11.39
Pellets, wood residues (CHP)	1000	3998	3.26	5.01
Sum CHP	**17,390**	**29,780**		
Geothermal energy (heating plant)	562,000	867,000	8.15	8.76
Combustible waste (heating plant)	1976	3048	10.69	12.64
Biofuels (heating plant)	236,000	365,000	11.27	11.41
Pellets, wood residues (heating plant)	10,182	16,699	3.26	5.01
Sum heating plants	**12,956**	**20,979**		
Solar thermal (private households)	2285	4821	8.15	8.28
Firewood (private households)	59,532	59,532	37.05 €/m^3	56.98 €/ m^3
Pellets, wood residues (private households)	6603	14,079	3.26	5.01
Heat pump (private households)	688	1215	8.15	8.76
Sum private households	**69,108**	**79,647**		
Overall sum	**248,478**	**372,531**		

Source: own compilation

3.2 Scenario “Biomassive” – BIO (medium-term oriented)

The scenario “Biomassive” (BIO) was designed in light of 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. high share of forest land, tradition, successful timber industry, technological know-how). These technologies, where considerable experience has been gained in the last few decades, and which hold great potential for further development, are extended the most. In principle, the use of solid biomass and biogas receives the strongest governmental support, leading to a central structure of supply with a focus on heat generation.

Just like in the IS scenario, the focus lies also on the provision of electricity (electricity-to-heat ratio 3:1), yet the contribution of renewable heat production is the highest in this scenario. A major advantage of biomass is that it can be directly stored and is not as much subject to seasonal variations as wind and solar energy.

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 the timber, paper and pulp and food industries, and biofuels as well as biomass imports have to be considered. As was the case for the first scenario (“Improve Strengths”), the technological conditions for the implementation are also given. However, a strong expansion of biomass utilization will require increasing imports of investment goods in order to offset the missing production capacity in Austria.

Regarding security of supply, biomass for heat production should mainly be supplied from domestic sources, in order to reduce foreign dependence. It must be noted that the available domestic space for increased cultivation of biomass for energy purposes (energy crops) is limited and different users (wood industry, paper and pulp industry, food industry, agrofuels) compete for the raw material. It is generally expected that a shortage of domestic fuel supply will occur, leading to rising import shares.

With regard to the time horizon this scenario is medium-term oriented. Those technologies are used that are already widely disseminated, but that are relatively land-intensive and thus in competition with other land use options. Moreover, the cascadic use of biomass is fostered, aimed at yielding the maximum material and energetic use of biomass with a minimal input.

A central aim is the maximization of sustainable agricultural land use for energy crops and the extensive exploitation of the yield potential of the forest biomass for energy use (to the extent that this is economically viable).

The price development for the energy resources forced in this scenario is assumed to be modestly rising, since some biomass technologies are already available at relatively low cost, but the exploitation of the entire potential incurs high additional investment cost. Also, despite economies of scale and learning effects, higher prices can be expected due to resource scarcities. We assume that the price of wood logs, for instance, rises from €37 today to €57 per m^3 in 2020. For biofuels (stationary and transport use) we assume a moderate increase in price.

Concerning the expansion potentials it is assumed that biogenic fuels for power production increase from currently about 11,000 TJ to more than 45,000 TJ in 2020, and for heating plants from about 240 TJ to 390 TJ. In the private household sector the use of log wood increases from currently 59,500 TJ to 65,500 TJ in 2020. Note that the assumptions made about the expansion potentials for biofuels only address heat and power supply, as an investigation of the transport sector was deliberately excluded from the project. Implicitly, we take into account that the share of agricultural biofuels envisaged at the EU level has to be increased as well, even though this is not explicitly modeled. The assumed expansion paths, therefore, do not exploit the maximum available potentials, but do account for the resource competition with transport fuels.

With regard to the investment costs we made the following assumptions:

(1) The feed-in tariffs are reduced in line with the learning rates.

(2) The installation of additional capacity causes an investment volume of 3420 €/kW in 2006. The costs in the subsequent years diminish in line with the learning rates.

(3) The learning rate (per doubling of the global capacity for biogenic fuel) until 2010 is assumed to be 12.5% and from 2011–2020 10%.

(4) We assume that the capacity increases with 10% per annum on average.

(5) For simplicity, we assume that the plants are in permanent use (24 hrs a day, 7 days a week).

Table 2 summarizes the parameterization for the “Biomassive” scenario.

Table 2 Quantitative description of the "Biomassive" (BIO) Scenario

Key technologies	Capacity		Price (incl. learning curve)	
	in TJ, 2005	in TJ, 2020	in ct/kWh (unless stated otherwise), 2005	in ct/kWh (unless stated otherwise), 2020
Hydropower (power plants)	129,150	137,028	4.90	5.10
Photovoltaics (power plants)	51	22,810	65.14	37.54
Wind (power plants)	4781	12,331	7.75	7.13
Combustible waste (power plants)	3634	12,718	10.69	12.64
Biofuels (power plants)	10,879	45,445	11.27	10.26
Pellets, wood residues (power plants)	529	5864	3.26	5.01
Sum power plants	**149,024**	**236,195**		
Combustible waste (CHP)	4065	6384	10.69	12.64
Biofuels (CHP)	12,325	19,358	11.27	11.39
Pellets, wood residues (CHP)	1000	3998	3.26	5.01
Sum CHP	**17,390**	**29,740**		
Geothermal energy (heating plant)	562	867	8.15	8.76
Combustible waste (heating plant)	1976	3048	10.69	12.64
Biofuels (heating plant)	236	388	11.27	11.33
Pellets, wood residues (heating plant)	10,182	16,699	3.26	5.01
Sum heating plants	**12,956**	**21,002**		
Solar thermal (private households)	2285	4821	8.15	8.28
Firewood (private households)	59,532	65,485	37.05 €/m^3	56.98 €/m^3
Pellets, wood residues (private households)	6603	14,079	3.26	5.01
Heat pump (private households)	688	1215	8.15	8.76
Sum private households	**69,108**	**85,600**		
Overall sum	**248,478**	**372,537**		

Source: own compilation

3.3 Scenario "Think about Tomorrow" – TAT (long-term oriented)

On the one hand, the scenario "Think about Tomorrow" (TAT) 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 fostered in order to distinguish this scenario from the BIO scenario.

Thus, "TAT" disregards the combustion and the gasification of biomass resources. Following the advice of the stakeholder group, solar power is used in the form of a massive expansion of photovoltaics. Apart from large-scale hydropower, photovoltaics has the second-largest technical potential for renewable electricity generation in Austria (Kaltschmitt and Neubarth, 2000). We presume the most expensive growth path suggested in the literature (e.g. Fechner and Lugmaier, 2007), and an expansion to an installed capacity of 82,000 TJ until 2020, which constitutes a massive extension, as compared to today's PV production level of some modest 50 TJ (2005).

In order to model the significant expansion in this scenario reasonably well, we have made the following assumptions:

- The installation of additional capacity induces an investment volume of 4000 €/kW in 2006. The costs in the subsequent years diminish according to the learning rate.
- The learning rate from 2005 to 2010 is assumed at 20% (per doubling of worldwide PV capacity installed), while from 2011 to 2020 a lower learning rate of 12% applies. The feed-in tariffs develop in line with the learning rates.
- We assume that, globally, a doubling of installed capacity can be achieved every second year.
- Capacity expansion is done stepwise: 1000 TJ in 2006, 2000 TJ in 2007, 3000 TJ in 2008–2010, 4000 TJ in 2011, 5000 TJ each in 2012 and 2013, 6000 TJ in 2014 etc. Moreover, it is taken into account that the investment path cannot follow an exponential trajectory, since then an average growth of 64% per annum would be implied, which in the years 2015-2020 would result in major capacity jumps (2018: +12,000 TJ, 2019 +20,000 TJ, 2020 +32,000 TJ). Whether such a rapid capacity expansion is really feasible, i.e. whether

a sufficient amount of solar cells can actually be produced, transported and constructed, is uncertain. If capacity expansion remains constant for several years, *ceteris paribus* the required investments fall due to the learning rate. Only at the next jump in capacity expansion they rise again.

- It is assumed that the daily useable solar irradiation has a duration of 3 h on average. An installed unit can then produce 1050 kWh per year.

- We assume that a plant remains in operation for 20 years, implying that over the simulation period no plant is removed from the capital stock.

- It is assumed that the feed-in remuneration for a plant is constant over time (on average), i.e. the later one invests, the lower is the feed-in tariff granted. Therefore, the average feed-in tariff does not coincide with the feed-in tariff of the last unit installed.
- We assume further that the electricity produced in PV plants is used locally.

Due to the high investment costs involved, the financing of this scenario would have to be strongly supported by the government, and would require substantial subsidy funding.

This fact is related to high prices of the technology (the primary costs) and, at least initially, the lack of profitability. It is to be expected that the initially high prices decrease significantly in the long term. It is assumed that the feed-in tariff scheme is maintained until the year 2020 and private households participate in the financing through higher electricity prices. Furthermore, there will be considerable need for communication between policy-makers and utilities. Since the risks are substantial, investments at the assumed scale can hardly be sustained by new companies.

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 and the related diminution of domestic 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.

In addition to PV, geothermal electricity, solar thermal heat and wind power are forced as well. Specifically, geothermal energy currently only plays a minor role in Austria. Whereas in

2005 only two geothermal plants were in operation in Austria (Proidl, 2006), yielding 562 TJ, a capacity expansion to (the equivalence of) 1125 TJ of thermal energy is envisaged until 2020 (under present economic and geological framework conditions). The capacity of heat pumps is increased from 688 TJ in 2005 to 1215 TJ in 2020. Solar thermal capacity is increased from 2285 TJ in 2005 to 7232 TJ in 2020. For both geothermal energy and solar thermal energy we assume constant prices between 2005 and 2020. The assumptions about the expansion of wind power are the same as in the scenario “Improve Strengths”. Table 3 summarizes the parameterization for the scenario “Think about Tomorrow”.

The ratio of additional electricity and heat generation in this scenario is about 4.5-1, meaning that proportionally much electricity can be provided. Electricity generation, which is characterized by the key technologies of photovoltaics and wind power, is characterized by a central structure. Although solar thermal and geothermal energy will be stepped up, heat is still produced in large part by using biomass.

Regarding supply security, the recent past has shown that the growing electricity consumption could not be covered by increases in domestic power generation capacity. Therefore, Austria turned into a net importer of electricity in 2001. The additional development of local generation capacities can improve this situation in the future, but does not guarantee the supply security by itself. Overall, the supply security in this scenario is classified as high, as the long-term oriented technologies unfold their potential already in 2020.

Further positive factors of this scenario are the exploitation of a sustainable energy source, the achievement of significant CO_2 reductions, and the decrease in fossil fuel imports.

Table 3 Quantitative description of the "Think about Tomorrow" (TAT) Scenario

Key technologies	Capacity		Price (incl. learning curve)	
	in [TJ], 2005	in [TJ], 2020	in ct/kWh (unless stated otherwise), 2005	in ct/kWh (unless stated otherwise), 2020
Hydropower (power plants)	129,150	137,028	4.90	5.10
Photovoltaics (power plants)	51	82,722	65.14	32.33
Wind (power plants)	4781	22,235	7.75	6.73
Combustible waste (power plants)	3634	12,718	10.69	12.64
Biofuels (power plants)	10,879	13,525	11.27	11.67
Pellets, wood residues (power plants)	529	1057	3.26	5.01
Sum power plants	**149,024**	**269,285**		
Combustible waste (CHP)	4065	6384	10.69	12.64
Biofuels (CHP)	12,325	19,398	11.27	11.39
Pellets, wood residues (CHP)	1000	3998	3.26	5.01
Sum CHP	**17,390**	**29,780**		
Geothermal energy (heating plant)	562	1125	8.15	8.06
Combustible waste (heating plant)	1976	3048	10.69	12.64
Biofuels (heating plant)	236	365	11.27	11.41
Pellets, wood waste (heating plant)	10,182	16,699	3.26	5.01
Sum heating plants	**12,956**	**21,237**		
Solar thermal (private households)	2285	7232	8.15	.02
Firewood (private households)	59,532	59,532	37.05 €/m^3	56.98 €/m^3
Pellets, wood residues (private households)	6603	14,079	3.26	5.01
Heat pump (private households)	688	1215	8.15	8.06
Sum private households	**69,108**	**82,058**		
Overall sum	**248,478**	**402,360**		

Source: own compilation

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 (see Table 4). In the BAU scenario, the gross domestic product (GDP) increases by 2.1% p.a., while in the RET scenarios this growth is even higher. While consumption, exports and imports develop rather similarly in all scenarios, they substantially differ in the dynamics of investment growth. The TAT scenario requires considerable investments, which entail the strongest growth in GDP. The model assumes that a large part of the solar cells can actually be produced in Austria. If this is not the case, rising imports will slow down domestic economic growth. Economic growth also leads to an increase in employment. Whereas in the BAU scenario some 198,000 additional jobs can be created by 2020, this figure is still higher in the three RET scenarios envisaged: In comparison to the BAU scenario, the scenario “TAT” would lead to 19,000 new jobs, “BIO” to about 15,000, and “IS” to about 10,000 additional jobs per year.

The scenarios differ significantly in the pricing of the gross production of energy. Higher depreciation, due to higher investment and higher feed-in tariffs, influences the price. In the IS and the BIO scenarios, the price is 9.2% and 9.4% higher compared with the BAU scenario in 2020; in the TAT scenario, it is 23.3% higher. Concerning the TAT scenario, it is important to keep in mind the assumption that a shortage of solar cells would inflate the price even further.

The macroeconomic impacts of these price increases are minor, because, for example, the private consumption is only around 3.2% for electricity, gas and other fuels. In 2020, the price of the total household consumption in “Improve Strengths” and in “Biomassive” is by approximately 0.2% higher than in the BAU scenario. Prices in the scenario “Think about Tomorrow” are about 0.5% above those of the BAU scenario. The average price development of the total gross production increases by 0.36% in IS, 0.39% in BIO, and 0.9% in TAT.

Table 4 Components of gross domestic product (GDP), inflation-adjusted – average growth rates (5-year intervals)

	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020
Business as Usual					
GDP	2.94	1.45	2.26	1.96	2.20
Consumption private households	2.23	1.46	1.96	1.76	1.91
Consumption public sector	2.02	1.00	0.67	0.28	0.94
Investments	3.24	-0.22	2.33	1.69	1.96
Exports	9.74	5.65	6.14	5.26	4.99
Imports	7.44	5.37	5.52	4.76	4.67
Improve Strength					
GDP			2.33	1.99	2.19
Consumption private households			2.01	1.77	1.90
Consumption public sector			0.78	0.34	0.96
Investments			2.65	1.91	1.99
Exports			6.13	5.25	4.98
Imports			5.59	4.79	4.66
Biomassive					
GDP			2.35	1.99	2.20
Consumption private households			2.02	1.78	1.91
Consumption public sector			0.80	0.36	0.99
Investments			2.72	1.94	2.03
Exports			6.13	5.25	4.98
Imports			5.61	4.79	4.67
Think about Tomorrow					
GDP			2.46	1.99	2.15
Consumption private households			2.10	1.76	1.86
Consumption public sector			0.96	0.37	0.94
Investments			3.27	2.07	1.88
Exports			6.11	5.24	4.97
Imports			5.74	4.80	4.62

Source: own calculations

The composition of the final energy consumption[4] according to energy sources develops very heterogeneously between the scenarios. The use of heating oil is lower in “BIO” and in “TAT” than in “IS”. Especially in the BIO scenario, the higher use of firewood in private households reduces the use of fuel oil significantly. In the scenario “Think about Tomorrow”, it is the generation of heat by solar energy which decreases the use of heating oil.

A comparison of the shares of renewable energy over time shows that, in the BAU scenario, the share between 2005 and 2020 decreases, due to the lacking expansion of hydropower use. In the RET scenarios, this decrease can be stopped (see Figure 2).

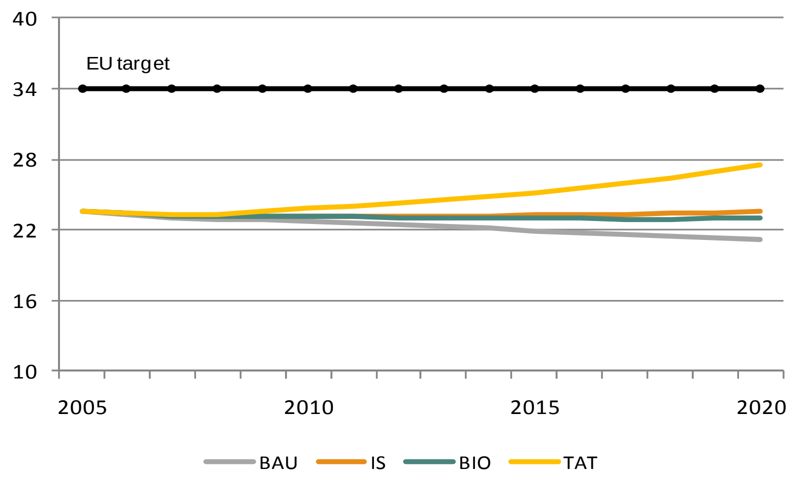

Figure 2 Share of renewable energy in final energy consumption (in %)

Source: own calculations

The Austrian energy policy target, i.e. to cover 34% of final energy consumption by renewable energy by 2020, cannot be met in any of the scenarios (see Table 5). The highest share with 27.5% in 2020 can be expected in the scenario “Think about tomorrow”. “Improve Strengths” supposes that the share for 2005 can be maintained, while in “Biomassive”, even a slight decrease in the percentage over time is possible.

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[4] Final energy consumption is the energy that households, industry, services, agriculture and the transport sector use.

Table 5 Share of renewable energy (in % and in TJ)

		BAU	IS	BIO	TAT	Total
	2005	**2020**	**2020**	**2020**	**2020**	**2020**
Final energy consumption (total)	*1,105,190*	*1,448,683*	*1,451,472*	*1,452,544*	*1,453,400*	*1,453,400*
Final energy consumption (renewables)						
Geothermal	259	351	353	354	354	354
Solar thermal	3816	6895	6904	6908	9323	9323
Heat pumps	4976	7125	7161	7174	7200	7200
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 residues	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

Note: The share of renewable energy is based on the EC definition (see CEC 2008/0016 (COD)).

Source: own calculations

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 up to 2020 (see row "Final energy consumption (total)" in Table 5), so that despite the massive expansion of renewable energy supply, additional heat and power consumption cannot be adequately covered (rebound effect). On the other hand, the Austrian Energy Strategy (BMWFJ, 2010) foresees that the level of final energy consumption is stabilized in 2020 at the 2005 level (ca. 1100 PJ). Such a stabilization (e.g. through efficiency gains and changes in consumption behavior) could lead to a situation where the share increases to 37%.

The resulting CO_2 reduction is caused by the realized shares of renewable energy. It is true that, in all RET scenarios, the CO_2 emissions can be reduced vis-a-vis the BAU scenario, since fossil fuels can be replaced by renewable energy sources.

In the TAT scenario, with its significant additional investments, at the beginning of the projection period there is even an increase in CO_2 emissions, due to the positive impact of the investments on the economic system. In other words, there are two countervailing forces. On the one hand, the increased use of photovoltaics leads to a reduction in the share of fossil fuels. On the other hand, the energy consumption rises due to the boost to the economy. Only when the investment volumes decrease relative to the installed capacity, the replacement effect of fossil fuels starts to dominate.

An absolute reduction of CO_2 emissions over time is, however, not possible in any of the RET scenarios (see Figure 3). Thus, with an exclusive expansion of renewable energy, the respective EU regulation of reducing CO_2 emissions until 2020 by 20% (compared to 1990 levels) will not be met[5]. Furthermore, the Austrian Kyoto target is clearly missed. It stipulates that the total greenhouse gas emissions have to be reduced by 13% between 2008 and 2012, relative to the base year 1990, when they amounted to 68.8 million tons of CO_2 equivalents. Since the e3.at model only accounts for CO_2, and not all greenhouse gases that are included in the Kyoto Protocol, the relevant CO_2 stabilization target of 1990 would be at 62.08 million tons of CO_2 (assuming that the share of CO_2 emissions in total greenhouse gas emissions is about 80%; see e.g. Umweltbundesamt, 2009). If the Austrian Kyoto target of -13% is referred to this amount only, the CO_2 reference value would be at about 54 million tons.

The three scenarios differ primarily with regard to their technology mixes. One commonality is the high growth of photovoltaics. Overall, for the assumptions made in scenario "Think about Tomorrow" the strongest expansion of renewables arises (with an additional contribution of almost 176,000 TJ between 2005 and 2020), which is primarily achieved by an increase in electrical energy (mainly PV). Consequently, also the CO_2 emission reductions are largest in this scenario.

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[5] The overall emission reduction goal of the EU Climate and Energy Package is a reduction of 20% below 1990 levels by 2020. This reduction should, on the one hand, be met through binding targets for emissions from sectors not included in EU Emissions Trading System (ETS), such as transport, buildings, agriculture and waste; on the other hand, through a reduction resulting from the ETS. While sectors in the ETS are regulated at the EU level, it will be the responsibility of the member states to define and implement policies and measures to limit emissions of "non-ETS sectors". The Austrian target for CO_2 emission reduction in the non-ETS sectors is minus 16% emissions with regard to the 2005 level (see BMWFJ, 2010).

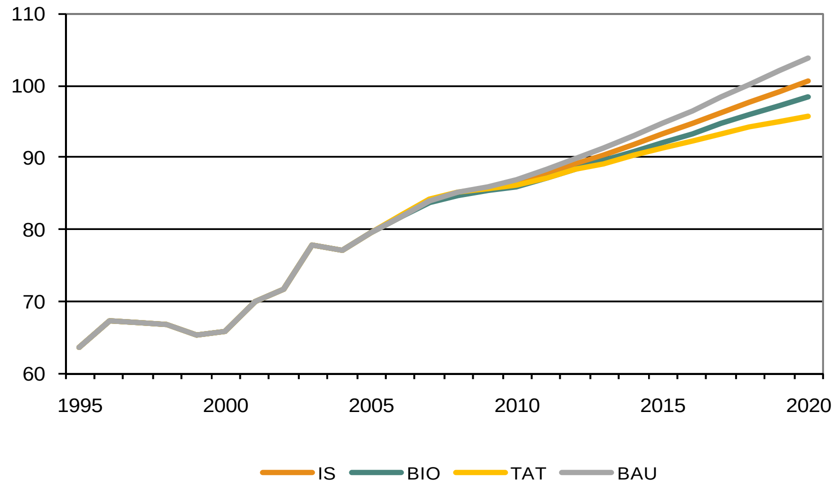

Figure 3 Development of CO_2 emissions (in million tons)

Source: own calculations

All scenarios have in common that they focus on electricity supply from power plants that do not make use of combined heat-and-power production (CHP). Although this does not lead to the most energy-efficient energy supply, several arguments can be put forward for this simplification. First, over the coming years the need for electricity is expected to rise faster than that for heat. Second, we did not find any sound evidence about how much capacity can actually be used by CHP. Finally, the framework conditions required for the use of heat from CHP is not always there.

A further important distinctive feature of the scenarios is the degree of centrality of energy supply. As an indicator we use the ratio between more centralized technologies (energy conversion facilities: power-only plants, CHP and heat-only plants) to the more decentralized technologies (solar thermal plants, heat pumps, logwood and wood pellet heating systems). The degree of centrality is assumed to rise further in the BAU scenario (see Figure 4). Only in the BIO scenario marked reductions in this indicator are realized. Nevertheless, also in this scenario the degree of centralization of energy supply rises.

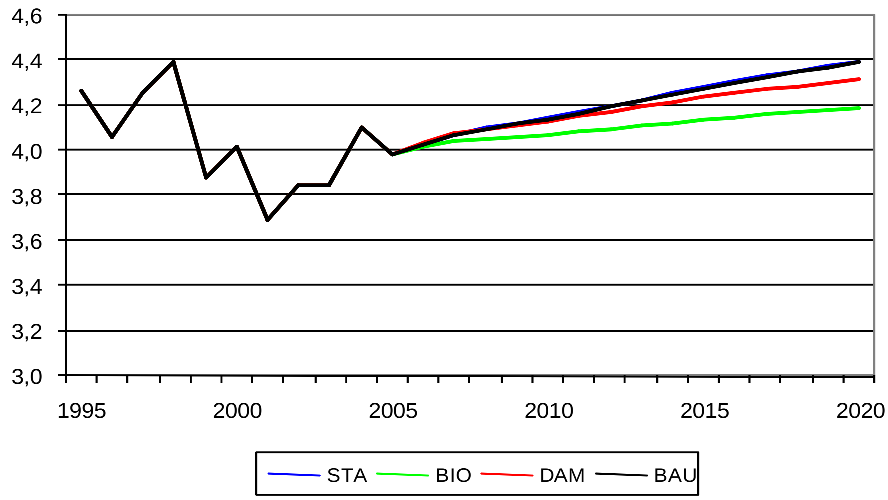

Figure 4 Centralized vs. decentralized technologies

Source: own calculations

In order to model supply security, total energy imports are used (measured in Terajoule, TJ). Also for this comparison none of the scenarios differs markedly from the general development path. Compared to the BAU scenario, the strongest decrease in imports takes place in the "Think about Tomorrow" Scenario, followed by "Biomassive" and "Improve Strength". This result was to be expected, as electricity production from PV depends on the number of solar irradiation hours and because a part of the biomass can be produced domestically, whereas fossil fuels have to be predominantly imported.

In summary, one can conclude that the RET scenarios do not provide a formula for success concerning the extension of renewable energy. In other words: There is no free lunch. The IS scenario features cost efficiency and competitiveness, but the expansion of wind and hydropower is limited and problematic from an environmental and social acceptance point of view. The BIO scenario is supposed to have a high potential for political implementation, but suffers from land-use conflicts and resource scarcity. The TAT scenario, 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 but to reduce energy consumption. Only if this can be achieved, for instance through huge efficiency gains and changes in behavior, can renewable energy live up to the high expectations placed on it for achieving a sustainable energy system in Austria.

5 Policy implications

Even though the share of renewable energies in gross energy consumption in Austria is relatively high (25% in 2007), about three quarters of domestic energy consumption are met by fossil fuels. Due to only modest fossil fuel resources, Austrian energy supply depends to about 70% on imports (Anderl et al., 2007). Hence a reduction of fossil fuel imports is an important goal in Austrian energy and climate policy. Massive expansion of renewable energy use can help to reduce import dependency.

The increasing scarcity of fossil fuels in the long run and the related rising oil prices seem to pave the way to a more intensive use of renewable energies. In order to achieve a breakthrough, however, suitable framework conditions and sustainable energy policy strategies have to be implemented.

Whereas the framework conditions in a few areas still seem to be insufficient (see, e.g. the revision of the Green Electricity Act), the commitments to an increased use of renewables are already definitive. The individual EU Member States, for example, have committed themselves in the Energy and Climate Agreement to ambitious goals for reducing greenhouse gases and to promote renewable energies until 2020. For Austria this results in an obligation to increase the share of renewables to 34% of the entire energy mix by 2020 (cf. EU Website "Energy Strategy for Europe"[6].

In the course of the envisaged increase it is important to estimate the expected impacts of the expansion of using the various renewable energy carriers (e.g. solid biomass, biogas, wind, solar thermal, and photovoltaics) on the environment, economy and society also quantitatively. The underlying research project was dedicated to such a quantification, by developing various expansion scenarios for renewable energy sources (RET scenarios) and to

[6] http://ec.europa.eu/energy/index_en.htm, accessed March 27, 2008)

simulate these with the integrated environment–energy–economic model e3.at developed ad hoc for this project.

By means of this new, integrated tool of analysis, political actors are offered a significantly improved decision-making framework, compared to the typically much less comprehensive standard analysis in this field. A major advantage of integrated modeling, in contrast to straightforward potential assessments, lies in the fact that the economic interdependencies are modeled in much more detail and complexity, and that the costs of measures are fully accounted for (i.e. any financial input in one part of the system needs to be funded in another part of the system and thus is effective also there). The investments in the expansion of renewable energy thus have an immediate impact on market prices.

The results provide insights as to which technologies, strategies and measures can help to achieve the increased use of renewable energy sources and also whether the resulting consequences are socially balanced, economically viable and ecologically beneficial.

The developments assumed in the various scenarios can also occur in a bundled manner. By deliberately focusing on differing policy objectives and technologies, it is possible to shed some light on the impact of specific aspects. For instance, the implications of an especially ambitious expansion of biomass energy can be contrasted with the enforcement of technologies that have no fuel needs and enormous long-term potentials. Nevertheless, Austria should exploit the potential of all renewable resources available, in order to reduce the dependency of fossil fuels and reach a high diversification of the energy mix. Besides the cost-effective technologies, such as hydropower and biomass, other sources that are more investment-intensive should also be supported now, in order to unfold their potentials.

The project results show clearly that an increase in the share of renewables is an important element of an “energy change”, but in itself is insufficient for reaching the energy and climate policy goals of Austria.

Whereas in a scenario dedicated to the expansion of renewables, a large part of the energy-saving potential can be foregone due to direct (larger living space, inefficient heating behavior etc.) and indirect or macroeconomic rebound (higher energy consumption due to economic growth induced by investments) effects, by *additional* attitude changes the entire potential could be exhausted. Only when a further increase in energy demand can be stopped by behavioral change, renewable energies can fulfill their ascribed role for achieving a sustainable energy system.

6 Summary and conclusion

In the course of the project, the emphasis of the work was on two main focus areas: first, the development of the simulation model e3.at and, second, its application within a participatory modeling process, in which RET scenarios were developed in close cooperation with stakeholders and experts.

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 the socio-economic system, with their various linkages and feedbacks, is needed in order to appropriately assist policy-makers in their decisions on suitable strategies to tackle the most challenging environmental and socio-economic problems in Austria.

The valuation of energy scenarios in an integrated model such as e3.at enables to consider a wide range of aspects of the energy system, and to link economic and energy impacts. Still, the complexity of the matter requires a concentration on selected aspects only. In the case of the research project described here, the focus was on the expansion of renewable energy use for electricity and heat. A widening of the scope to further aspects, e.g. the transport sector or increases in energy efficiency and energy consumer behavior, was not part of the project.

Furthermore, it has to be noted that even a very comprehensive model like e3.at is not able to provide information for a wide range of important aspects concerning the very ambitious use of renewable energy. For instance, for maintaining energy supply security, it is important to account for balancing energy. Our modeling accounts for the expansion of renewable energy use over a year, but does not account for the intra-day and intra-year availability of energy. Among the renewable energy sources, especially hydro power and biomass can contribute to the balancing of the system, both with respect to the total potential and also with respect to the possibility of energy storage and load shifting. Moreover, we have to keep in mind that an adequate infrastructure (e.g. power transmission and distribution grids and electric storage systems) has to be realized, which enables the exploitation of the renewable energy potentials. However, the costs of providing this infrastructure were excluded from the analysis.

From the results reported it becomes clear that achieving the Austrian target of a 34% share of renewable energy sources is not realistic on the basis of the scenarios calculated. Note, however, that the scenarios discussed focus exclusively on renewables and thus ignore other important components, such as energy retrofits of the dwelling stock or a more energy-efficient use of energy in private households. Also, the economic development and the behavior of energy consumers were not varied in the scenarios.

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 domains. 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 dialog between stakeholders and researchers and by enhancing the transparency of the modeling process.

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Appendix: The integrated environment–energy–economy model “e3.at”

The core of the macro-econometric model system e3.at consists of an economy model, including input-output tables, labor market data, and the system of national accounting and balancing items. Additional modules are an energy model, a material model, a transportation model, a regional housing inventory model and a model for international trade. In this annex, the model structure and components of the model e3.at are presented.

Furthermore, “e3.at” has a soft link to the world model GINFORS (Global INterindustry FORcasting System, see Meyer et al. 2007; Lutz et al., 2010), in order to illustrate the effects of international trade on the Austrian economy.

e3.at was recently extended by a regional housing inventory model (see Bohunovsky et al., 2010), showing the energy consumption of private households on a regional level. Differences in demographic and economic aspects, such as disposable income, on the level of federal states affect the demand for housing. Depending on the improvement of accommodation (including heating systems), the energy consumption and CO_2 emissions are influenced by changing energy sources and/or energy-efficient heating systems. e3.at also comprises a transportation module for private households. This enables the analysis of mobility and allows valuable insights about the effects of transport on total energy consumption and CO_2 emissions. However, since in the reported project these two modules of e3.at are not used, we do not describe them in detail here. For further information, see Großmann and Wolter (2010).

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

A.1 The economic model

The economic model shows a high degree of endogenization, although tax rates and labor supply are exogenous. As already stated, 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, and including also direct and indirect rebound effects.

In addition to the usual interdependencies between the circular flow of income, e3.at depicts the interdependencies between prices and volumes as well as between 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 (Großmann and Wolter, 2010).

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 by 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 IO model, which shows the interdependencies of all industries, and which is also important for linking the economic model with the material and the energy model. Figure A.1 shows the structure of the IO model.

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

However, 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, which is 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 that is carried out for each of the components of final consumption (intermediate consumption, gross fixed capital formation, final consumption expenditures by households and government, and exports) and for each of the 57 sectors. Thus, firms set their prices depending on their costs and on the prices of competing imports. Demand reacts to price signals and, in turn, determines production as indicated above. An important feature is that the e3.at model includes both demand and supply elements and is thus not only demand-driven.

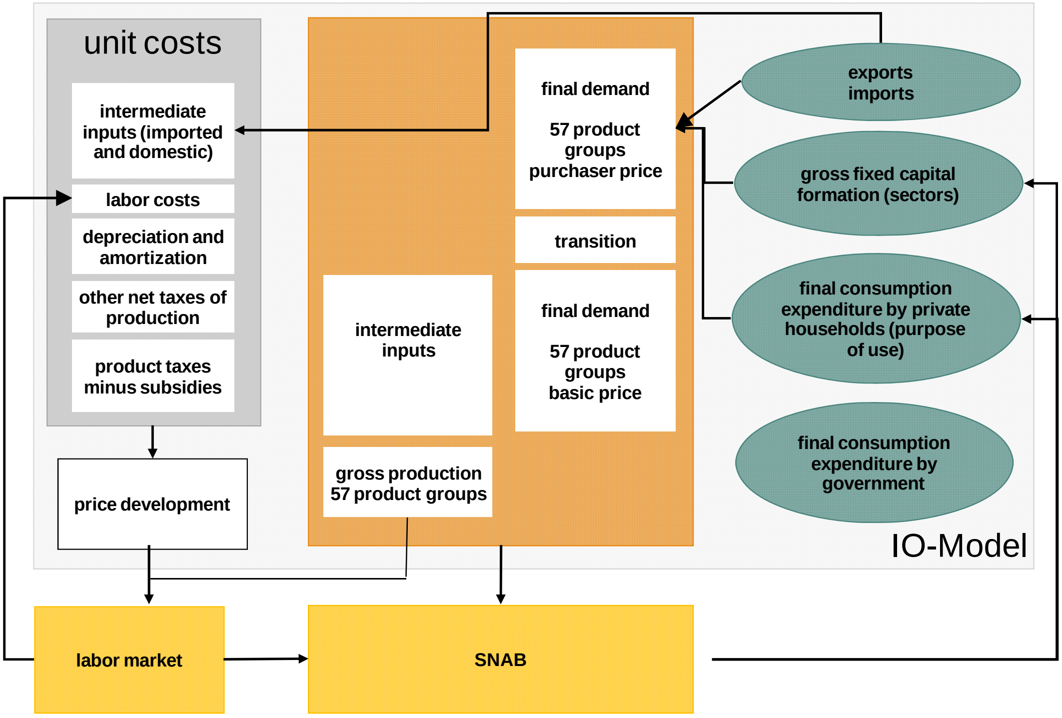

Figure A.1 Structure of the input-output model

Source: own illustration

The SNAB 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 and secondary distribution of income, use of income, acquisition of non-financial assets and accumulation accounts. The behavioral equations of this system explain the expenditures; the revenues are given by definition. Net lending, respectively, net borrowing is calculated by definition for each institutional sector. The government's budget, including the tax system and the social security system, is endogenously determined. The detail of this system allows the identification of the expenditures and revenues of the social security system, so that the system can be linked to the labor market and other parts of the model. The labor market consists of both an aggregated part and a part modeled in detail. Figure A.2 depicts the structure of the labor market.

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

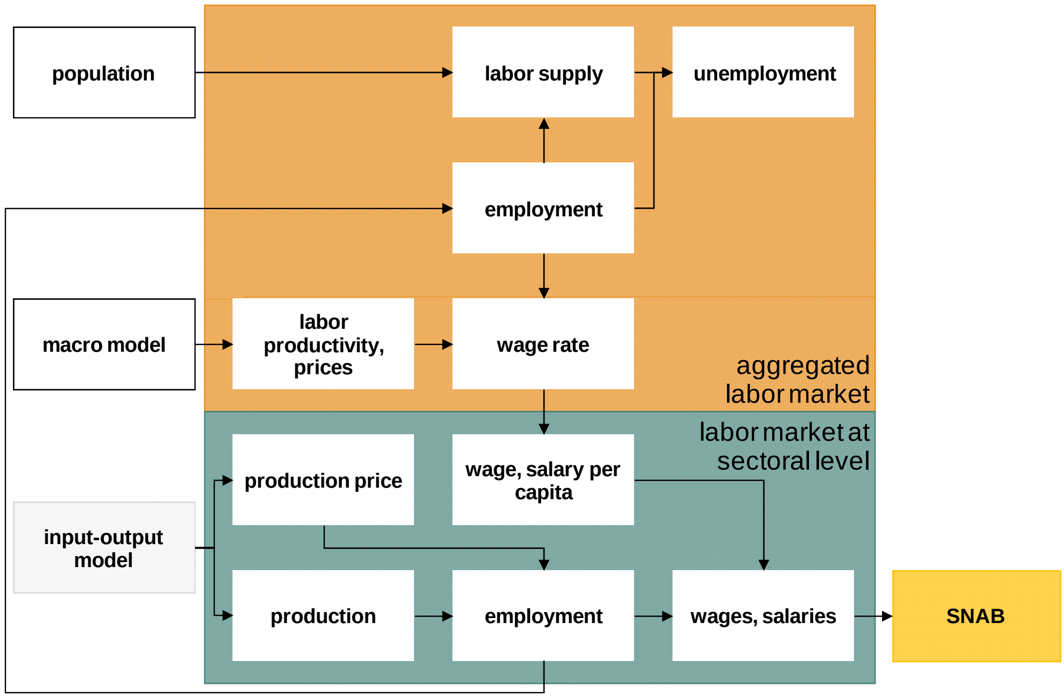

Figure A.2 Structure of the labor market

Source: own illustration

In the part modeled in detail, 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 overall 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 social security contributions yield the labor costs per capita.

The database of the labor model additionally consists of the average weekly working time, labor volume as well as of the employees' qualifications. It is assumed that the structure of employee qualification in each sector remains constant over the entire simulation period.

A.2 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 A.1, the material model differentiates 12 material categories that are part of three material groups (biomass, minerals and fossil fuels). The model covers materials extracted 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.

Domestic material extraction (in tons) is 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.

Table A.1 Overview of material inputs covered by the material model

	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 fossil fuels	coal crude oil natural gas other fossil fuels

Source: own illustration

Modeling the effects of material savings considers the following process levels (see Figure A.3): At the extraction level (1), no savings are possible. This means that the production value and extraction of materials 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 material extraction.

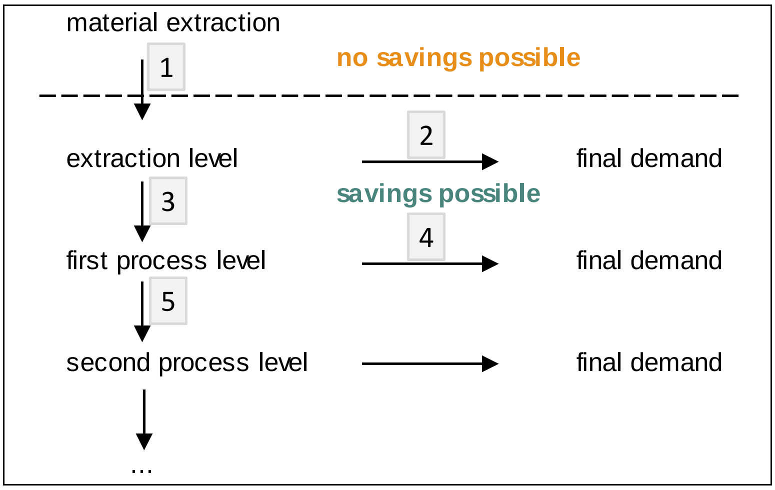

Figure A.3 Potential material savings along the process chain

Source: own illustration

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

The design of the material model allows to consider 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 IO coefficients, and the change of the structure of final demand, both of which are endogenous, are very important for the structure of physical inputs.

A.3 The energy model

The energy model describes the interrelations between economic development, energy consumption and CO_2 emissions. On the one hand, economic development influences primary energy use. On the other hand, expenditure for energy consumption has a direct impact on the economic variables.

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

The database of the energy model is the energy balance in physical units compiled by Statistik Austria, which has been available on an annual basis since 1970. The data on CO_2 emissions, which are connected with the primary energy use via fixed emission factors, are provided be the Austrian Environment Agency. Energy price data are taken from national statistical sources (e.g. Austrian Energy Agency, 2004) and the International Energy Agency (IEA, 2007). The IEA provides prices with and without taxes (excise and value added tax for selected energy sources). In order to ensure the comparability of the data, all prices refer to Terajoule (TJ).

i. Projection of energy balances

The energy balance of Statistics Austria differentiates between 37 energy sources and 21 industries. It 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 energies in much more detail than fossil fuels (see the gray shaded cells in Table A.2).

Table A.2 Energy sources considered

ENERGY SOURCES

coal	oil			gas	renewables			
	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

Source: own illustration

Regarding the structure (see Figure A.4), the energy balance comprises three main parts: energy supply, transformation and energy demand. This structure holds for all energy sources considered.

Starting with 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.

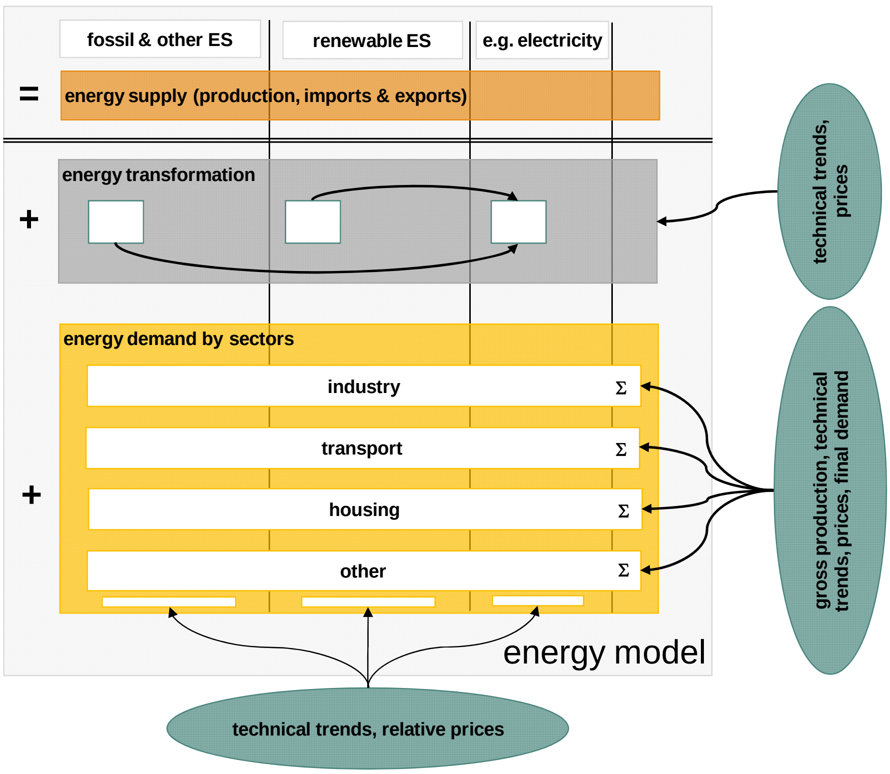

Figure A.4 Structure of the energy balance

Note: ES = energy sources

Source: own illustration

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 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 by-products) and biomass carbon to synthetic organic products. Thus, final consumption consists of non-energy and energy uses.

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

In a first step, for each of the 17 sources, final energy consumption for the 21 industries considered is projected with the growth rates of real production (see Figure A.5). For this purpose, the 57 economic sectors of the IO model were allocated to the 21 industries that are captured in the energy model. The final energy demand of the 21 economic sectors is explained – unless better information was available – for all energy sources together.

Logarithmic estimation only enters 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 each economic sector.

For the sectors “iron and steel” and “private households”, more detailed information is available, so that final energy consumption can be estimated separately for each energy source. The estimation is based on real production and average energy prices as well as on technological trends and learning curves. Assumptions for the learning curves are based on recognized literature (for detailed information, see Stocker et al., 2008).

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 (see Figure A.6). Demand for heat by private households is a function of the use of fossil fuels (e.g. oil, gas), district heating and renewable energy (e.g. heat pumps, wood pellets).

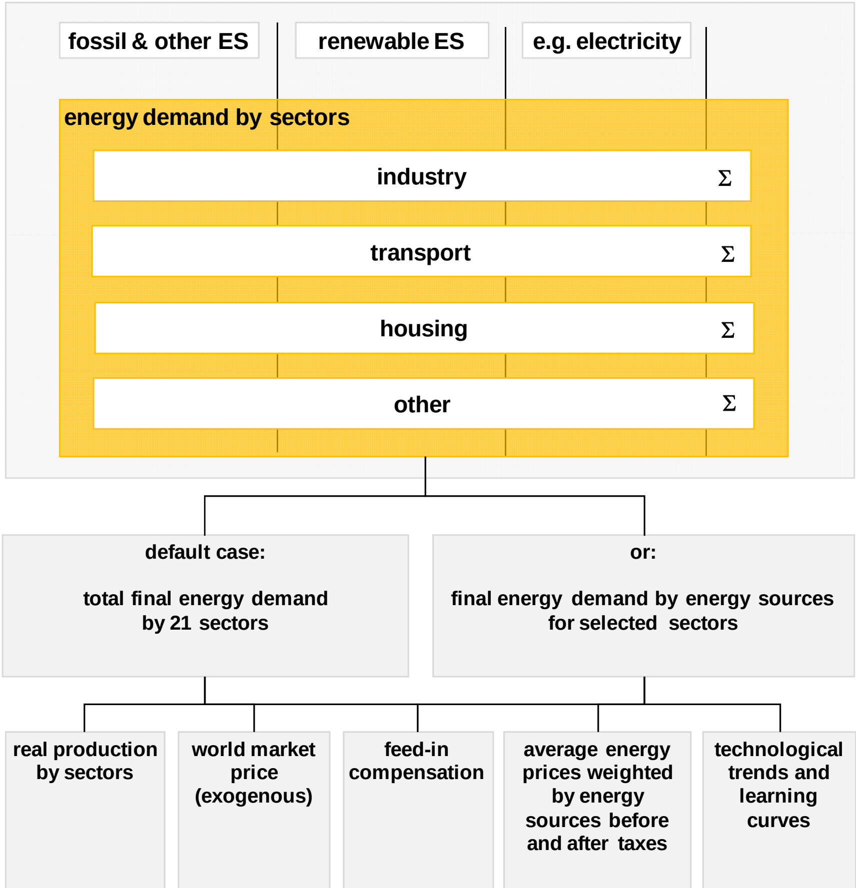

Figure A.5 Modeling final energy demand

Note: ES = energy sources

Source: own illustration

Apart from the oil products, the remaining sources of energy for the heat production of private households are estimated. 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, electricity demand as well as heat demand from the remaining sources of energy.

Final energy consumption for each energy source FEC_{ES} is the sum of the final energy demands over all 21 economic industrial sectors *IS*:

$$FEC_{IS,ES}[t] = FEC_{IS,ES}[t-1] \cdot \frac{ebtl_{IS}[t]}{ebtl_{IS}[t-1]}$$

$$FEC_{ES}[t] = \sum_{IS=1}^{21} FEC_{IS,ES}[t] \qquad \text{(A.1)}$$

with

$FEC_{IS,ES}$ … final energy consumption of the energy source $_{ES}$ and the industry *IS*
($\forall \in IS[1,21]; \forall \in ES[1,17]$, t = time)

$Ebtl_{IS}$ … total final energy demand of the respective industry ($\forall \in IS[1,21]$).

Total final energy consumption FEC_{ES} implies, in principle, the transformation output $ETO_{p,ES}$. For the subsequent years, the transformation output is determined by projecting the relationship between transformation output and final consumption from the year 2005 onwards. 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 energy transformation plants *p* (coking plant, blast furnace, refinery, power stations, cogeneration plants, heating stations, and gas production). The transformation output of oil and photovoltaics 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.

$$ETO_{p,ES}[t+1] = FEC_{ES}[t+1] \cdot \frac{ETO_{p,ES}[2005]}{FEC_{ES}[2005]} \cdot 100$$

$$ETO_{ES}[t+1] = \sum_{p=1}^{7} ETO_{p,ES}[t+1] \tag{A.2}$$

ETO … transformation output of plants ($\forall \in p[1,7]$)

FEC_{ES} … total final energy consumption over all industries ($\forall \in ES[1,17]$)

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

$$ETI_{p,ES}[t+1] = ETI_{p,ES}[t+1] \cdot \frac{ETI_{p,ES}[2005]}{ETO_{p,ES}[2005]} \cdot 100$$

$$ETI_{ES}[t+1] = \sum_{p=1}^{7} ETI_{p,ES}[t+1]. \tag{A.3}$$

In general, it is assumed that, under normal conditions, power and heat output develops proportionally (at a ratio of 1:1), i.e. if the entire final energy demand increases, the change in production of power and heat rises 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.

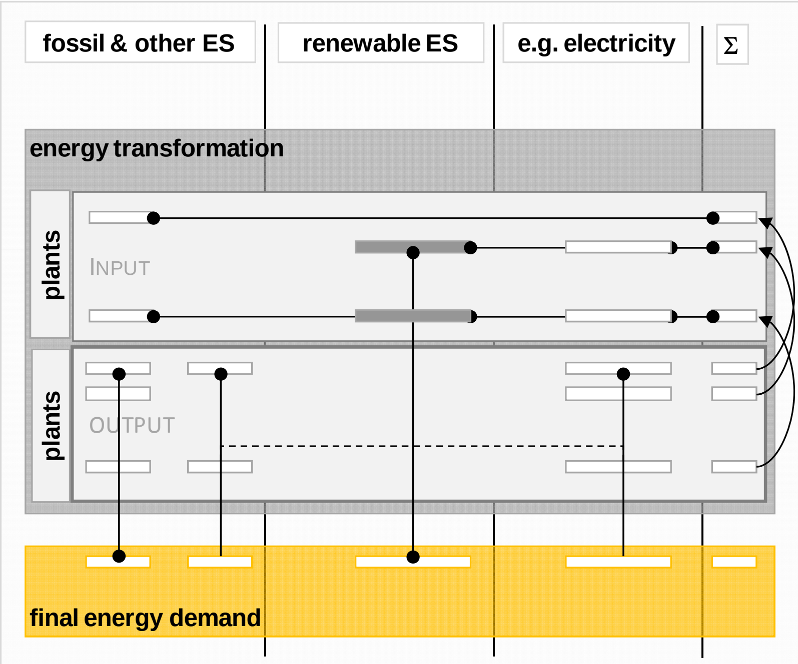

Figure A.6 Transformation of energy

Note: ES = energy sources

Source: own illustration

Domestic production, changes in stocks and 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 these grow proportionally. Energy exports vary according to the related exports in the economic model.

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 transformation input, minus transformation output, plus 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 A.7).

	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

Figure A.7 Balance equations

Source: Bittermann and Mayer (2011)

After determining gross domestic energy consumption, imports can be calculated as residuals (see Figure A.7). A change in energy imports influences economic imports in the IO model. An increased demand for oil, for instance, on the one hand augments the amount of imports and, on the other hand, affects the price, which again causes further reactions. Energy supply is determined by definition.

ii. Projection of energy prices

The determination of energy prices follows the duality of the selected modeling approach: On the one hand, energy prices have to be captured 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 IO 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 products and production.

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

2007 (IEA, 2007). The price history for industry and households follows the growth rates of the respective sources of energy.

The energy balance is the basis for calculating changes in the input coefficients of the energy industry. In the transformation sector, the input of the different energy sources ($EB_{PP\&CHP,ES,t}$) is shown explicitly for power plants (PP) and combined heat and power plants (CHP), and also the sum of the energy sources used ($EB_{PP\&CHP,t}$). From these components it is possible to determine the ratio of use:

$$ES - Ratio = \frac{EB_{PP\&CHP,ES,t}}{EB_{PP\&CHP,t}}. \tag{A.4}$$

The changed coal and gas inputs during power generation are connected to the IO table: The price-adjusted input coefficient (input of coal and gas into the energy sector), $AR_{GC,E,t}$, 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 $AR_{GC,E,t}$ decreases proportionally when the portion of fossil energy sources in power generation declines. The consequence of additional inputs of renewable energy – with unchanged electricity consumption – thereby leads to savings in inputs (coal and gas) and thus, *ceteris paribus,* to a reduction of the basic prices in the related sector.

So far, only one part of the changes to the cost structure of the energy industry has been captured. In addition, we have to analyze renewable energy by sources: (1) fuel-based renewable energy (firewood, wood pellets, combustible wastes, biogas, etc.) and (2) other renewable energy (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 hours). While renewable energy that is based on the regenerating of raw materials can be operated continuously, power stations using 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 energy 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 sector rise and thus accelerate 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 timber industry, the chemical industry or the agricultural sector increase their portion in the cost structure of the energy industry.

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

In both cases, renewable energy is fed into the electricity grid. The grid operator ("distributor") pays the feed-in compensation to the renewable power producers. The power distribution companies record the costs of the electricity fed into the grid in their cost calculations. Since the feed-in compensation per kWh for renewable energy is usually higher than for conventionally produced energy, within the energy sector the input coefficient 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 firewood) 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. For labor costs, due to lacking information, we assume a constant development.

Figure A.8 provides an overview of the connections between the economy and the energy model. Furthermore, the price effects of a higher use of renewable energy are summarized. At 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 energy prices in the scenarios.

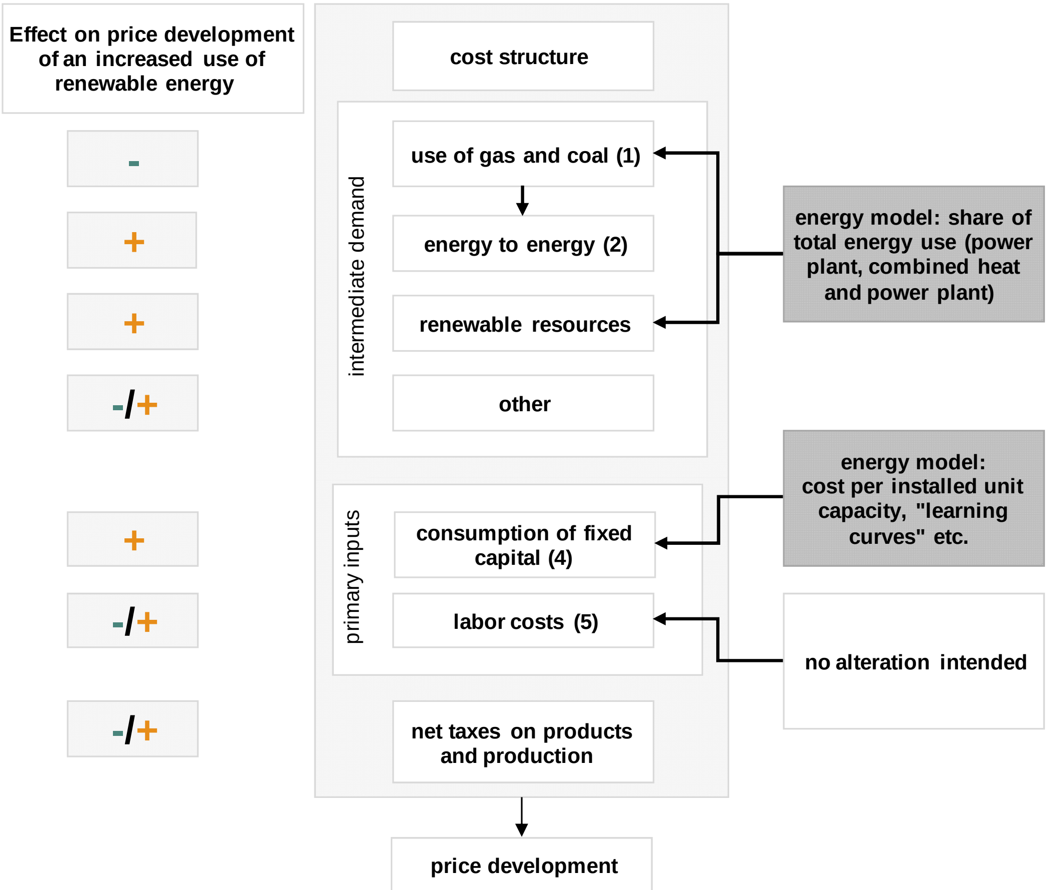

Figure A.8 Modeling of the development of energy prices

Source: own illustration

In addition, it has to be noted that prices for final consumption are based on the purchaser price principle, i.e. electricity tax etc. still positively affect the development of the purchaser prices. Furthermore, the energy sector can include additional criteria – e.g. the development of the price for electricity on the stock exchange – and, accordingly, further mark-ups in 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 emissions 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 SNAB – and allocates these costs equally in a way that all the production prices increase, but without additional profits for the energy industry.

iii. Feedbacks between the energy model and the economic model

The existing feedbacks between the economic model and the energy model are illustrated in Figure A.9. 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".

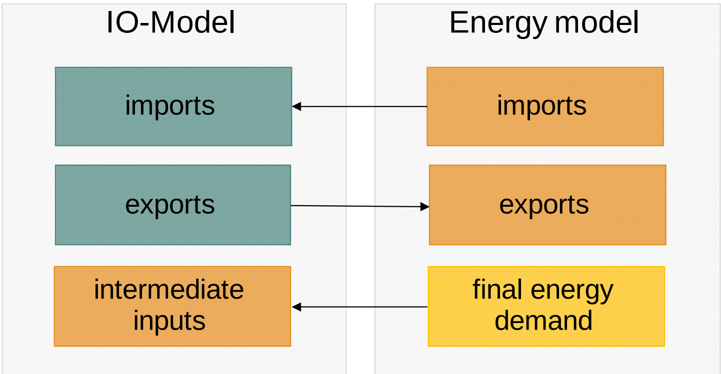

Figure A.9 Feedbacks between the energy model and the economic model

Source: own illustration

A similar logic applies to the exports. Here, however, the imported economic products 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 are dependent on the world import demand. This is given by the world trade model GINFORS. The level of the exports depends on the market shares, which change according to the competitiveness of the observed country.

Changes in industry-specific final energy demand also affect the intermediate flows of the "energy and services of the energy supply industry" 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 heat and power generation.

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Sorda G., Sunak Y., Madlener R. (2011). A Spatial MAS Simulation to Evaluate the Promotion of Electricity from Agricultural Biogas Plants in Germany, FCN Working Paper No. 1/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Madlener R., Hauertmann M. (2011). Rebound Effects in German Residential Heating: Do Ownership and Income Matter?, FCN Working Paper No. 2/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

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