Forecasting the *3E*'s (*E*nvironment-*E*nergy-*E*conomy): The Austrian model e3.at

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Abstract

A lot of energy models have been built to forecast energy demand and supply as well as CO_2 emissions. With most of these models, economy plays a minor role since they only focus on selected economic variables such as investment and prices.

E3 models provide an integrated view on environment, energy and economy. They differ in aspects such as model construction principles (bottom-up vs. top-down), regional coverage (national vs. global), economic foundation (e.g. CGE, econometric models) or time period (short vs. long run).

The Austrian (macro-)econometric, multi-sector model e3.at comprises the 3E's with all modules consistently linked to each other. In contrast to partial (energy) models, the integrated E3 modeling approach allows for quantifying direct and indirect effects in the economy, environment and energy system.

The model e3.at has been used in a number of projects e.g. funded by the Austrian Climate and Energy Fund for forecasting the 3E's as well as for calculating and evaluating scenarios with a focus on development of renewable energy and energy efficiency.

Keywords: macro-econometric multi-sector model, input-output-model, energy model, Gauss-Seidel technique for non-linear systems, causal regression analysis, scenario analysis

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1 Introduction

The increasing resource scarcity of fossil fuels amplify the necessity to lower consumption of these resources. Different strategies are possible: fossil fuels can be replaced by renewable sources or consumption can be reduced by improved energy efficiency. Different measures have different impacts on the 3E's. Therefore, emission reduction strategies should be evaluated before they come into operation to avoid unintended (distribution) effects or welfare losses.

E3 models are able to quantify effects on energy system, economy and environment simultaneously. Therefore, E3 models are usually no partial models and they provide an integrated view on sustainability. Possible impacts of political measures can be evaluated and rebound effects, winners and losers can be identified. Well-known examples of E3 models are GEM-E3 from the European Commission (e.g. Kouvaritakis et al. 2005) and E3ME from Cambridge Econometrics (e.g. Pöyry, CE 2014).

Other examples of E3 models are the German E3 model PANTA RHEI, the Russian model e3.ru and the Austrian model e3.at (all built by GWS). These models are classified as macro-econometric, multi-sector simulation models. They share the same modeling approach and use the same modeling software.

This paper reports on the key features and the use of the model e3.at. The Austrian model has been used in different projects e.g. funded by the Austrian Climate and Energy Fund for forecasting the 3E's as well as for calculating and evaluating scenarios with a focus on development of renewable energy and energy efficiency (Großmann et al. 2013, Stocker et al. 2011).

In the second section of this paper, a classification of E3 models is described. In the third section, the key features of the Austrian model e3.at are explained in a nutshell. In the fourth section, scenarios and results from an application of the model e3.at in the project "Feasible futures of the common good" are presented. The steps from scenario design to scenario calculation and evaluation are shown by using the graphical user interface IMAGINE©. Conclusions and further aspects are presented in section 5.

2 Classification of 3E models

E3 models and their applications are an integral part of empirical research and policy analysis. Such models are used to explain possible future impacts of structural changes on economy, energy and environment and to support ex-ante evaluation of policy measures.

In contrast to partial models, the 3Es are included in one model and all modules are consistently linked to each other. The integrated 3E modeling approach has the advantage that direct and indirect effects of a certain policy measure can be quantified for all 'E's.

Today, a broad range of E3 models exists (see e. g. Kemfert 2003). They differ in the underlying modeling approach, level of detail, data requirements, and modeling software. Due to these differences results from different models cannot be easily compared even if exogenous impulses are the same.

E3 models can be divided into bottom-up and top-down models. Bottom-up means that the model components (3Es) are designed in great detail. Top-down indicates a more aggregated modeling approach. The level of detail depends on data availability and the research topic posed.

E3 models that follow the *bottom-up* approach - such as POLES (Criqui 2009) - explicitly represent energy technologies, their operating costs as well as energy output and emissions. These models aim at identifying alternatives to limit GHG emissions but generally neglect feedback effects on the economy. Other models represent economic activities and products (from agriculture to services) in detail such as GEM-E3 (Capros 2013) and INFORUM type models[1] (Großmann et al. 2011, Bockermann et al. 2005).

In contrast, *top- down* models include less modeling details but a high degree of endogenization. The strength of top-down models lies in the complete representation of the economic circuit and economic agents involved. Top-down models are able to project the net impacts on employment and economic growth due to a full economic representation and the feedback effects within the modeling system.

Energy models that follow the top-down approach estimate coefficients to show the rate of substitution between inputs (e.g. fossil fuels and renewables) instead of modeling the cost structure of energy technologies in detail (e.g. WARM model, Carraro, Haleotti 1996).

Hybrid models are a combination of top-down and bottom-up models to retain the advantages of both types. An example for combining both approaches is documented in Schlesinger, Lindenberger, Lutz (2014).

E3 models can be further distinguished with regard to their economic foundation. For example, CGE models are based on the assumptions that all agents optimize their behavior. Firms maximize their

[1] http://www.inforum.umd.edu/, Almon 1991

profits and households maximize their utility. CGE models usually assume a price-driven market equilibrium regime. The economic behavior is usually given by elasticity taken from literature. Examples for this type of models are GEM-E3 and NEWAGE[1] (Capros et al. 2013).

Econometric models such as E3ME from Cambridge Econometrics or the model e3.at estimate model parameters for behavioral equations. Some of the CGE assumptions are refused such as the optimization behavior as well as perfect competition and perfect knowledge to be more realistic (Cambridge Econometrics 2014, Stocker et al. 2011).

Aside from CGE and econometric models, a number of other model types exist for assessing sustainable policy measures, i.e. system dynamic models such as ASTRA from Fraunhofer ISI, optimization models like MARKAL from IEA (Fraunhofer et al. 2013, Loulou, Goldstein, Noble 2004) and integrated assessment models like IMAGE from PBL Netherlands Environmental Assessment Agency (OECD 2012).

Models that comprise input-output tables reflect the industry / product structure as given in the IO tables. They often differ in their sectoral coverage: some models have a very detailed transportation sector while other set a focus on the energy sector (e.g. ASTRA, POLES).

Last but not least, E3 models can be distinguished by their geographical coverage (national, multi-regional, global). Examples for these model types are IMAGE, POLES (global models), MARKAL, e3.at (national models), GEM-E3, E3ME (multi-regional models).

[1] http://www.ier.uni-stuttgart.de/forschung/modelle/NEWAGE/index_en.html

3 Key features of the Austrian model e3.at

The Austrian model is classified as a national, macro-econometric, multi-sector simulation model (for a detailed description see Stocker et al. 2011). *Macroeconomic* indicates that it covers supply and demand side elements. Labor, energy and capital are inputs into the production process. Consumption, investment and foreign trade are demand factors. The model distinguishes different *sectors* or economic agents (households, government, firms and rest of world) as stated in the system of national accounts (SNA). The national accounts show the economic circle from production, distribution, redistribution to the use of income (top-down approach). Revenues and expenditures for different sectors can be identified. The incorporation of the complete economic circuit is important especially to reveal distributional effects of policy measures. For example, government's budget may be affected positively due to higher revenues from e.g. energy taxes whereas households and firms may be affected negatively. Another important variable calculated within the SNA is the disposable income of private households that influences amongst other factors (e.g. consumer prices) consumption.

Figure 1 gives an simplified overview of the e3.at model structure and main components.

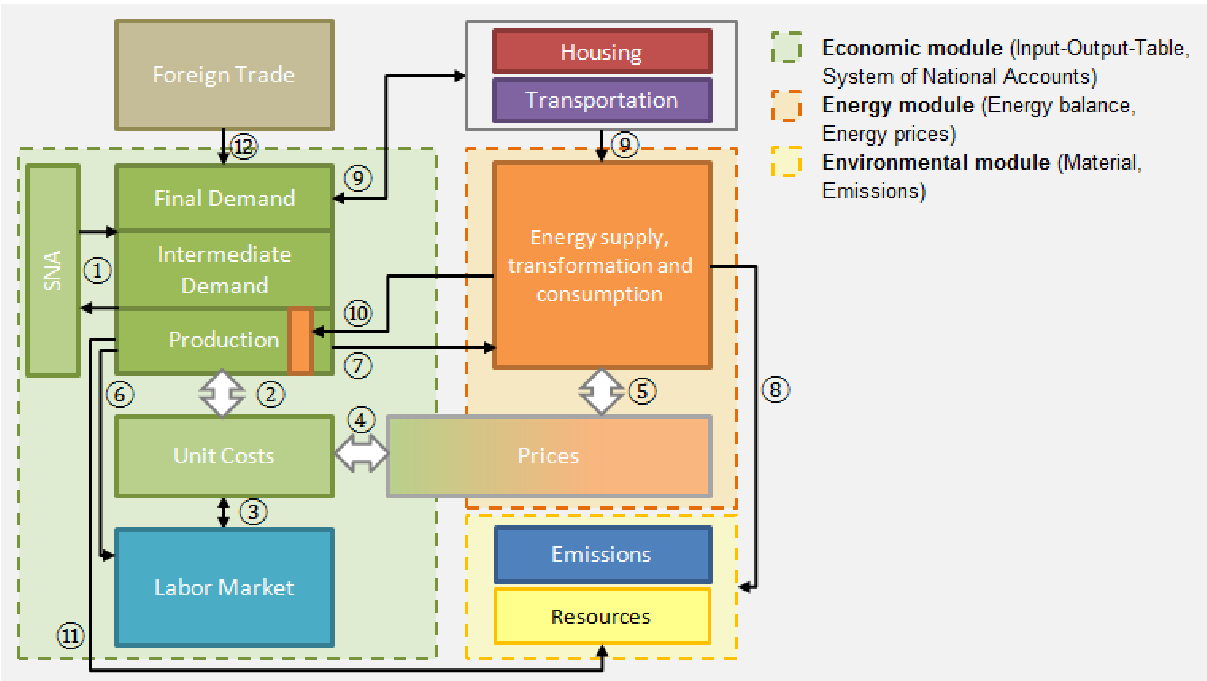

Figure 1: Simplified structure of the model e3.at

The arrow labeled with ① indicates the relations between the SNA and the input-output tables.

The input-output framework allows for detailed modeling of demand components and inter-industry relationships. Consumption of private households and government as well as investment and exports are modeled for 57 products respectively industries (bottom-up approach). The linkage between the demand and supply side in the economic model is defined as a Leontief production function.

The sum of all goods and services by final demand components are equal to the corresponding variable in the national accounts such as consumption or investment. Thus, detailed information can be consistently linked to macroeconomic, aggregated variables. The model structure combines bottom-up with top-down approaches.

The cost structure of each industry is fully captured. Material inputs, labor, energy and capital costs as well as taxes and subsidies on production are cost factors (② and ③ in Figure 1).

According to the modeling philosophy, prices are not set as an equilibrium price. It is assumed that firms set their price depending on their costs and on prices of competitors, e.g. energy and labor costs influence price setting behavior of the firms (④ and ⑤ in Figure 1). Thus, demand reacts on price signals. Consumer prices differ from producer prices due to subsidies and taxes on products such as value added tax or energy taxes.

The economic module is completed with a labor market module. Wages, employees and labor productivity are modeled on the industry level (⑥ in Figure 1). Labor supply is determined by demographic development and wage rates.

The economic part of the model is extended by an energy module and an environmental module.

The *energy module* shows the relations between economic development, energy prices and energy consumption as well as CO_2 emissions (⑤, ⑦ and ⑧ in Figure 1). Furthermore, the energy model represents energy supply, transformation and consumption by energy carriers (different fossil fuels and renewables) as stated in the energy balance.

The energy consumption by industries is linked to the economic model. Energy consumption, energy and output prices and the output by industries are closely connected. The strength of the relation between dependent and independent variables is hinged on the energy efficiency that is estimated for different industries.

In Austria, about 1/3 of total final energy consumption (TFEC) stems from energy in residential buildings and about 25 % of TFEC from fuel consumption. Therefore, the energy model has to be supplemented by a regional housing inventory model and a transportation model (⑨ in Figure 1). The housing inventory module shows the characteristics of the residential housing in nine Austrian federal states in detail. It differentiates age groups for buildings, size of buildings, energy demand per square meter and used energy carriers. Aside from existing housings, the demand for new buildings is linked to the regional household forecast up to 2050 from Statistik Austria. Different energy efficiency measures can be applied for new and existing buildings and results on energy demand can be simulated.

The detailed modeling of 17 energy sources enables the simulation of different renewable development strategies. Additionally, the connection between the energy and economic module is properly modeled to evaluate investment in renewable energy technologies. For example, an increased demand for wind turbines may push the production in the corresponding industry. Suppliers of intermediate goods and services may also increase their production (⑩ in Figure 1). Depending on capacity and competition, goods are either produced by Austrian companies or are imported.

The *environmental module* comprises the direct material inputs for twelve categories (main categories: biomass, minerals, fossil fuels) and differentiates between imported and domestic extracted materials. The domestically extracted respectively imported materials are linked to the extracting sector in the input-output tables respectively importing sector, and fossil fuels are connected to the energy module as well (⑧ and ⑪ in Figure 1). This modeling approach reveals the impacts, for example, of a reduced use of fossil fuels on the import dependency in monetary and physical terms.

The interrelations in e3.at are modeled by identities as well as behavioral equations. E3.at combines input-output analysis with regression analysis. The application of econometric methods facilitates an empirically validated parameterization of model variables that heavily rely on agent's behavior such as consumption, wages and productivity.

Causal regression is applied to forecast the dependent variable which is driven by independent variable(s). For example, energy consumption by industries is driven by the industry output and relative prices. Additionally, a time trend can be applied to capture an autonomous trend in energy efficiency.

The difference between regression analysis and time series analysis is that regression analysis focus on identifying variables that are related to other variables and assume that reactions that are seen in the past are also effective in future. In contrast to time series analysis, regression analysis is not used to predict changes between the dependent and independent variable over time. Future development in models that are based on regression analysis is given from exogenous variable(s).

The Austrian model e3.at is driven by population dynamics as given from Statistik Austria and trade results from global forecasting models. The world import demand for Austrian goods and services is equal to the exports of Austria (⑫ in Figure 1). This impulse activates responses in the highly interdependent and non-linear model equation system by using the Gauss-Seidel technique which is named after the German mathematicians Gauss and Seidel. They developed an iterative method which is used for solving nonlinear systems of equations. This method solves the left hand side of any equation using previous values for the variables on the right hand side. The computation of a left hand side variable uses the elements of variables that have already been computed. In the next iteration, all left hand side variables are calculated again. In every iteration, all model equations are computed. The non-linear equation system is solved if a certain convergence criteria is fulfilled. In e3.at, the convergence criteria is based on the endogenously calculated production. If the percentage deviation from the previous iteration is smaller than a given value (here 0.01 %) then the model has converged. The solution algorithm is applied year by year for a given time span.

The outcome of the model solution process is the so-called 'business-as-usual' (BAU) scenario. This scenario is based on exogenous assumptions and empirically observed responses from the past. For testing the impacts of possible, different developments, scenario analysis is carried out by changing variables exogenously. All other variables vary endogenously according to modeling context. The resulting differences (Figure 2) between scenarios can be interpreted as responses of the exogenous impulse(s) (‘what if’ - analysis).

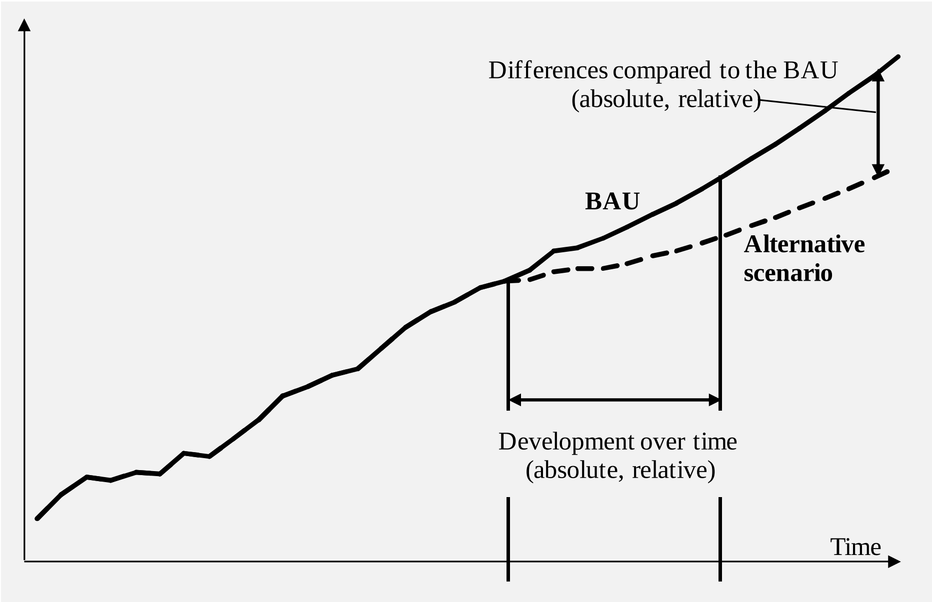

Figure 2: Comparing scenarios

4 Scenario design and results from the model e3.at

The current version of the model e3.at empowers the user to calculate direct and indirect impacts of different climate changes policies up to 2050. Examples are energy efficiency measures, development of renewable energy technologies and eco-social tax reforms.

In this section, the results of the recently finished project 'Feasible Futures for the Common Good. Energy Transition Paths in a Period of Increasing Resource Scarcities[1]' (FFG project number 825604, Großmann et al. 2013) are presented in a nutshell.

The aim of the project was to analyze the impacts of a worldwide development of renewable energy on the Austrian economy, environment and energy system. To accomplish this aim, physical requirements of a renewable energy systems were assessed and metal resources were analyzed globally. The model e3.at were used to quantify the impacts of possible resource scarcities on the 3E's in Austria.

Two scenarios with different assumptions with regard to renewable development in Austria and worldwide were created.

The reference scenario (REF) shows a consistent development of the Austrian economy, environment and energy system up to 2050. It describes future development based on observations in the past and does not assume additional efforts with respect to climate protection. In that sense, it is not a forecast because it does not include probable future policy measures.

The 'advanced scenario' (ADV) assumes an ambitious development of renewable energy in Austria and worldwide. In Austria, electricity will be generated mainly from wind and solar power. Compared to 2010, the use of photovoltaic will grow by a factor of 240 up to 2050 and reach about 72 PJ in 2050. Wind power will increase by a factor of 8 (2050: 52 PJ). Heat power will be generated mainly from biomass and to a lower amount from solar thermal, heat pumps and geothermal.

World market resource prices for fossil fuels and metals were set exogenously reflecting the increasing use for renewable energy technologies and decreasing demand for fossil fuels worldwide.

Further assumptions regarding energy efficiency and e-mobility were made for Austria. In the ADV additional efforts to increase the energy efficiency were made. Both existing and new residential buildings will be equipped with a higher efficiency standard (~40 kWh/m^2a energy consumption). As a result of these assumptions, energy demand per square meter will be lower than in the REF.

An increased share of renewable energy is assumed to be used in passenger transportation. Up to 2050 about 70 % of the passenger car fleet will be powered by an alternative engine (e.g. hybrid engine,

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[1] http://www.umweltbuero-klagenfurt.at/feasiblefutures

UBA 2010). Main important factors are decreasing differences in production costs for cars with a combustion engine and non-conventional cars (especially costs for batteries) as well as improved operating distance (UBA 2012, Hanappi et al. 2012).

In contrast to the REF, the ADV focuses on measures that assume a comprehensive reconstruction of the Austrian capital stock: an ambitious development of renewable energy, e-mobility and increasing energy efficiency in new and existing residential houses.

All input parameters were collected, verified and validated by project partners (Schriefl et al. 2013, Bruckner et al. 2013). Afterwards, all quantified information was implemented into the model e3.at.

The model e3.at is equipped with a graphical user interface (GUI) named IMAGINE© which has been used for designing, calculating and evaluating the REF and ADV scenarios.

IMAGINE© is equipped with an easy-to-use assistant that guides the user through the necessary steps of scenario building. Figure 3 shows the main dialog window with parameters on the left and values on the right.

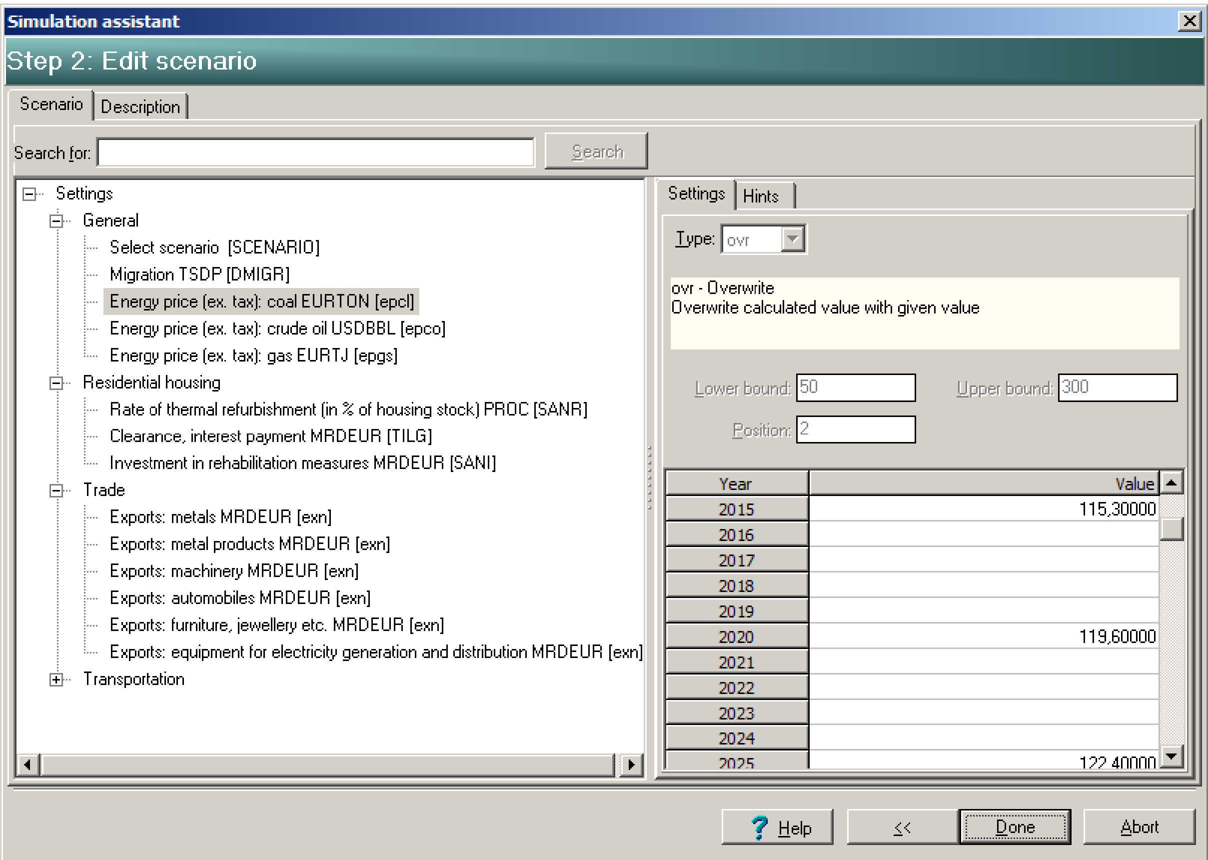

Figure 3: Scenario building

The most important parameters for the ADV scenario are:

- Additional investments in renewable energy, e-mobility, energy efficiency (in total 125 Bn. Euro)

- Higher metal prices due to ambitious development of renewable energy technologies (+145 %)
- Lower prices for fossil fuels reflecting decreasing demand for fossil fuels (-33 % oil, gas, 52 % coal)

All parameters are given as deviation in levels or percentage change from the REF scenario.

IMAGINE© collects the parameter changes, configures and runs the model in the background, stores the results and adds them to the list of available scenarios.

After running the model, users can analyze the scenario results. Various visualization options are offered. The user can compare one variable from different scenarios or a set of variables from one scenario (Figure 4).

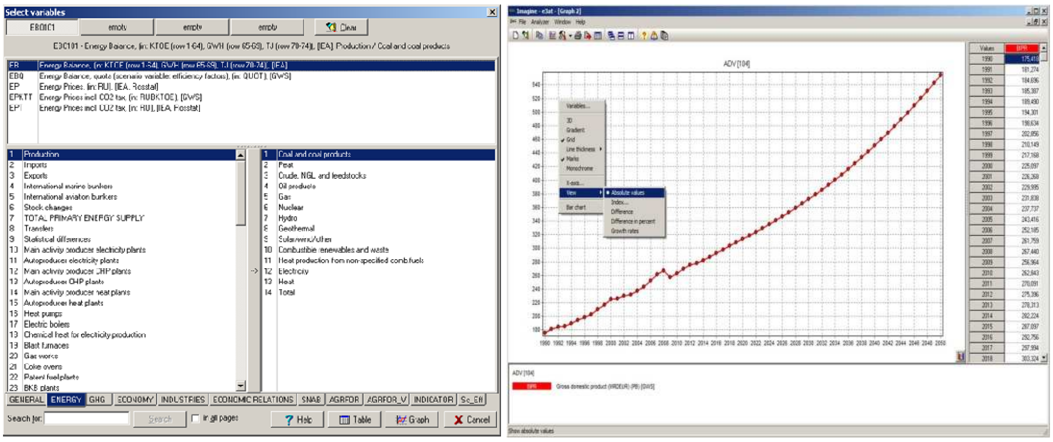

Figure 4: Looking at variables and visualization options

Sometimes, the aforementioned visualization options are not sufficient. In such cases, the model results can be linked to Microsoft Office© via Visual Basic Applications to create customized reports, spreadsheets etc. For an example see the following Figure 5.

ADV - REF	Absolute differences in respective values					Differences in %				
	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
General data										
Population [1.000]	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Number of households	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Components of real GDP										
GDP [Bn EUR]	0,0	5,8	9,2	13,9	16,3	0,0	1,9	2,5	3,2	3,0
Private consumption [Bn EUR]	0,0	1,6	3,1	5,7	8,5	0,0	1,0	1,6	2,6	3,2
Government consumption [Bn EUR]	0,0	0,3	0,3	0,3	0,3	0,0	0,5	0,6	0,4	0,3
Investments [Bn EUR]	0,0	2,5	2,3	2,2	2,1	0,0	4,1	3,4	2,9	2,5
Exports [Bn EUR]	0,0	-1,9	1,1	7,4	12,4	0,0	-1,0	0,5	2,5	3,1
Imports [Bn EUR]	0,0	-3,2	-2,2	2,0	7,4	0,0	-1,9	-1,2	0,9	2,5
Price indizes										
Consumer price index	0,0	0,7	0,2	-0,9	-0,6	0,0	0,5	0,1	-0,6	-0,3
Production price index	0,0	2,6	4,3	5,5	8,0	0,0	2,2	3,2	3,7	5,1
Import price index	0,0	6,1	9,5	12,1	17,8	0,0	4,8	6,4	7,4	10,0
Other economic data										
Disposable income of private households [Bn EUR]	0,0	6,2	11,7	19,4	31,5	0,0	2,8	4,1	5,1	6,2
Labor market										
Employees [1.000 full time equivalents]	0,0	26,1	42,1	65,5	95,5	0,0	0,8	1,2	1,7	2,3
Labor costs per employee [EUR per full time equivalent]	0,0	612,2	744,6	676,4	620,2	0,0	1,1	1,2	0,9	0,7
Environment										
CO_2-emissions [Mln tons]	0,0	-6,3	-12,7	-18,3	-23,7	0,0	-9,0	-18,0	-25,1	-30,4
Direct material input [1.000 tons]	0,0	2.772	1.304	1.881	2.618	0,0	1,1	0,5	0,6	0,7
Final energy consumption [TJ]	0,0	-31.429	-60.433	-82.912	-102.692	0,0	-2,7	-5,0	-6,5	-7,5

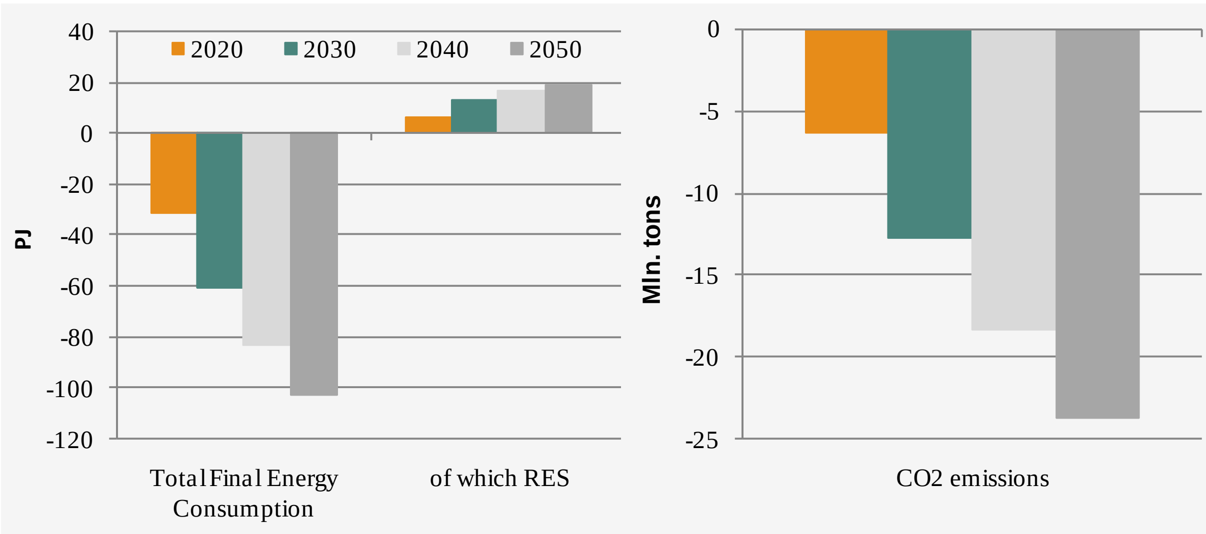

Figure 5: Differences in results comparing REF and ADV scenario. Own calculations with e3.at

The results show that the large investment in the residential sector, automobile industry and energy industry stimulates a higher growth path. The 'green' investment has a positive impact on the economy and environment.

The ambitious use of renewable energy sources (RES) in the energy sector raises their share in electricity and heat production close to 100 %. The share of RES in final energy consumption increased from 37 % in REF to about 50 % in ADV due to energy savings and the use of renewables for heat energy especially in the residential sector. A share of more than 50 % cannot be easily be achieved due to the characteristics of technology diffusion processes. Usually, heating systems are replaced every 20 years due to high costs. In the meantime, a switch between energy carriers is limited. For example, a gas heating system needs gas and cannot operated with coal or fuel oil.

Total final energy consumption will shrink to 103 PJ and the use of renewable energy will increase about 20 PJ in 2050 compared to REF (Figure 5). This development will reduce the import dependency of fossil fuels. Furthermore, CO_2 emissions will decrease and reach a level below 60 Mio. t CO_2 and the EU target can be fulfilled.

As a result of higher energy efficiency and ambitious use of renewables, the use of fossil fuels decreases. Simultaneously, the demand for metal (e. g. neodymium, steel) and non-metal resources (e. g. concrete, construction materials) for renewable energy technologies increases. This development compensates the drop in fossil fuels and total direct material inputs increases slightly compared to the REF (2.6 Mln. tons, Figure 5 and Figure 6).

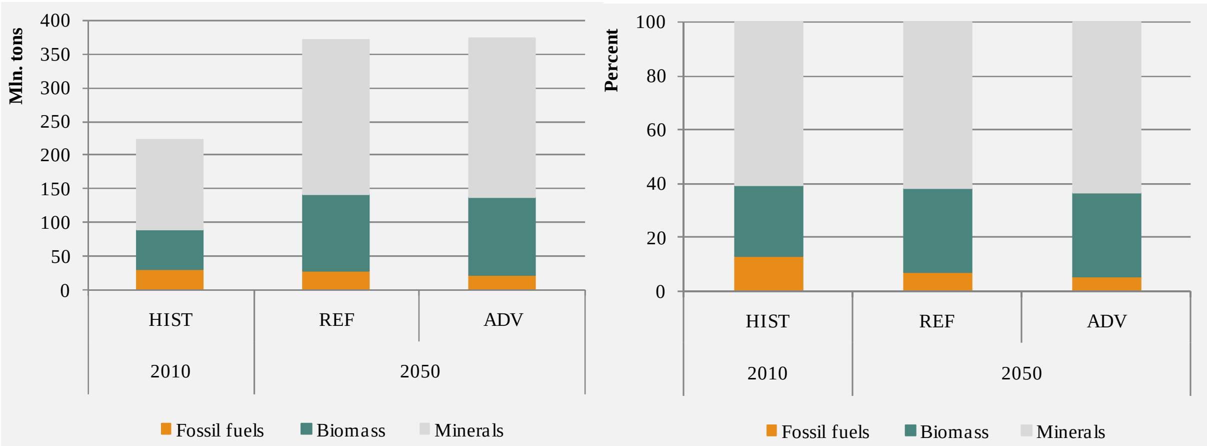

Figure 6: Direct material inputs in Mln. tons. Own calculations with e3.at

The assumption that the use of renewable energy technologies (RET) increases worldwide puts pressure on metal and non-metal resource prices due to their limited availability. Higher metal prices have impacts on many areas. Not only investment costs for renewable energy technologies increase but also prices for other goods like consumer products are affected. The effective burden on industry and consumers is highly dependent an possible adaptation strategies such as efficiency.

Innovation can minimize inputs of scarce and expensive resources or improve recycling technologies. A further step to avoid a strong demand for energy is to exploit the full energy saving potentials.

For a successful energy transition it is important that the energy security is guaranteed. The development of the electricity grid and enhancement of energy storage is an essential condition to synchronize energy supply and demand.

Figure 7 summarizes possible benefits, costs, opportunities and threats.

Benefits	Costs
▪ Stimulus for economic growth ▪ Higher employment ▪ Lower energy consumption ▪ Lower emissions ▪ Improved security of energy supply ▪ Savings of fossil fuels ▪ Reduction of import dependency	▪ Additional investment (RES, e-grid, energy-efficient buildings, machinery and equipment) ▪ Higher non-fossil resource prices ▪ Higher production costs ▪ Rising consumer prices (rent, goods)
Opportunities	**Threats**
▪ Innovation and new businesses (E-mobility, smart energy, recycling) ▪ Cost-efficient production ▪ New markets (competitive advantage)	▪ Shortage in non-fossil resources (political and military conflicts, environmental compliances) ▪ Limited substitution possibilities of materials ▪ Foreign competitors ▪ Social inequality

Figure 7: Results at a glance

5 Conclusions and further aspects

E3 models offer valuable insights into the interactions between the economy, environment and energy system. Strategies towards a sustainable economy can be evaluated in full. Direct and indirect effects of political measures become visible. Winners and losers of a policy measure can be identified effectively.

At the same time, E3 models tend to be inherently complex, mainly due to their huge databases and lots of interdependent model equations. Another issue with E3 models is that they are often considered as 'black boxes'. The acceptance of complex models and their results is strongly connected to their practicability and openness. With most models users can neither browse and verify the equation system nor perform simulations on their own. Thus, confidence in such models is limited.

To overcome these obstacles, all GWS models can be delivered with a GUI for data and scenario analysis. Model users can evaluate the comprehensive database and perform simulations. The simulation results are immediately available and can be compared to other scenarios and/ or other variables of the model system.

Additionally, the user interface comes with a model information system which contains a hyper-linked list of almost every model equation, variable and the regression coefficients. For each variable, the user can trace how this variable gets computed and where this variable is used.

All in all, GWS E3 models are powerful, transparent and easy to use tools for policy makers and key experts. For example, the German E3 model PANTA RHEI (Lutz 2011) is used by the German Federal Environment Agency, and the model e3.ru is applied by the Russian Ministry of Economy (Großmann et al. 2011).

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