Technical model documentation

Deliverable 5.1 of the project

BioTransform.at

Using domestic land and biomass resources to facilitate a transformation towards a low-carbon society in Austria

Gerald Kalt

AUSTRIAN ENERGY AGENCY

powered by klima+ energie fonds

Vienna, May 2016

Table of contents

1 Introduction

Biomass will be of crucial importance for reducing greenhouse gas (GHG) emissions and the dependence on fossil resources; not only in energy supply, as the EU's "Energy Roadmap 2050" and the National Renewable Energy Action Plans indicate, but also with regard to carbon-intensive products (i.e. products originating from fossil resources as well as such with high embedded fossil energy). Already today forestry and the wood processing industries are key elements of Austria's economy. Biomass is currently the most important renewable energy source and is usually considered to be of high importance for the establishment of a sustainable energy system.

The economic and societal challenges related to a significant reduction in GHG emissions and establishing a bioeconomy are considerable, and it is necessary to gain a clear view of how a transformation can be accomplished. While EU documents (and accompanying studies) provide some insight into pathways for the EU, there is currently little knowledge on the feasibility and implications of transformation on a smaller scale (i.e. on national level) and the possible contribution of locally available biomass resources. The project "BioTransform.at" aims at contributing to fill this research gap by answering the following core question:

To what extent can domestic biomass contribute to the establishment of a low-carbon society in Austria, taking into account all types of biomass use and the impacts of climate change on biomass supply as well as adaptation measures?

The subject of investigation includes all types of primary biomass (from forestry, agriculture and other sources), conversion processes (including industrial processes, food supply, animal husbandry, and energy generation) as well as all relevant kinds of demand for biogenic products and energy services provided with bioenergy. The geographical scope of the project is Austria; international trade is also taken into account.

The core element of the methodological approach is an optimization model implemented in the modelling environment TIMES-VEDA. This report presents a technical description of this model.

2   Modelling environment

The model is implemented in the programming environment of TIMES-VEDA. This section gives an overview of the structure and functionality of the environment. The following descriptions have been adopted from IEA-ETSAP (2011a) and IEA-ETSAP (2011b).

2.1   The TIMES model generator

The TIMES (The Integrated MARKAL-EFOM System) model generator was developed as part of the IEA-ETSAP (Energy Technology Systems Analysis Program) in order to derive long term energy scenarios and conduct in-depth energy and environmental analyses (Loulou et al., 2004). It combines two systematic approaches to modelling energy: a technical engineering approach and an economic approach and is used worldwide for the development of energy scenarios. It uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons. In a nutshell, TIMES is used for, "the exploration of possible energy futures based on contrasted scenarios" (Loulou et al., 2005).

TIMES models encompass all the steps from primary resources through the chain of processes that transform, transport, distribute and convert energy into the supply of energy services demanded by energy consumers (Loulou et al., 2005). On the energy supply-side, it comprises fuel mining, primary and secondary production, and exogenous import and export. Through various energy carriers, energy is delivered to the demand-side, which is usually structured sectorally into residential, commercial, agricultural, transport and industrial sectors. The "agents" of the energy demand-side are the "consumers". The mathematical, economic and engineering relationships between energy producers and consumers is the basis underpinning TIMES models.

All TIMES models are constructed from the following basic entities (Loulou et al., 2005):

- **Technologies** (also called **processes**) are representations of physical devices that transform commodities into other commodities. Processes may be primary sources of commodities (e.g. mining processes, import processes), or transformation activities such as conversion plants that produce electricity, energy-processing plants such as refineries, end-use demand devices such as cars and heating systems, etc.
- **Commodities** (including fuels) are energy carriers, energy services, materials, monetary flows, and emissions; a commodity is either produced or consumed by some technology.
- **Commodity flows** are the links between processes and commodities (for example electricity generation from wind). A flow is of the same nature as a commodity but is attached to a particular process, and represents one input or one output of that process.

These three entities are used to build an energy system that characterizes the country or region in question. All TIMES models have a "reference energy system", which is a representation of the energy system in the base year, before it is substantially changed either for a particular region or for a particular scenario.

- **Scenarios**: The principle insights generated from TIMES are achieved through scenario analysis. A reference energy scenario is usually first generated by running the model in the absence of any policy constraints. These results from the reference scenario are not normally totally aligned to national energy forecasts (generated by simulating future energy demand and supply), mainly because TIMES optimizes the energy systems providing a least cost solution.

  Further scenarios are then established by imposing additional policy constraint on the model (e.g. minimum share of renewable energy, maximum amount of GHG emissions or minimum level of energy security). Under these framework conditions the model usually generates a different least cost energy system with different technology and fuel choices. When the results are compared with those from the reference scenario, the different technology choices can be identified that deliver the policy constraint at least cost.

Once all the inputs, constraints and scenarios have been put in place, the model attempts to solve and determine the energy system that meets the energy service demands over the entire time horizon at least cost. It does this by simultaneously making equipment investment decisions and operating, primary energy supply, and energy trade decisions, by region. TIMES assumes perfect foresight, which means that all investment decisions are made in each period with full knowledge of future events (fuel price developments, technologies available in the future etc.). It optimizes horizontally (across all sectors) and vertically (across all time periods under consideration).

The results will be the optimal mix of technologies and fuels at each period, together with the associated emissions to meet the demand. The model configures the production and consumption of commodities (i.e. fuels, materials, and energy services); when the model matches supply with demand, it is said to be in equilibrium.

The main output TIMES are energy system configurations, which meet the end-use energy service demands at least cost while also adhering to the various constraints (e.g 80% emissions reduction, 40% renewable electricity penetration). In the first instance, TIMES models are suitable for answering the following questions: Is the target feasible? If yes, at what cost? The model outputs are energy flows, energy commodity prices, GHG emissions, capacities of technologies, energy costs and marginal emissions abatement costs. The following figure shows a schematic illustration of the TIMES model elements, inputs and outputs (white block arrows).

The following publications provide further information on the TIMES model: Loulou and Labriet (2008a), Loulou and Labriet (2008b), Loulou et al. (2005)
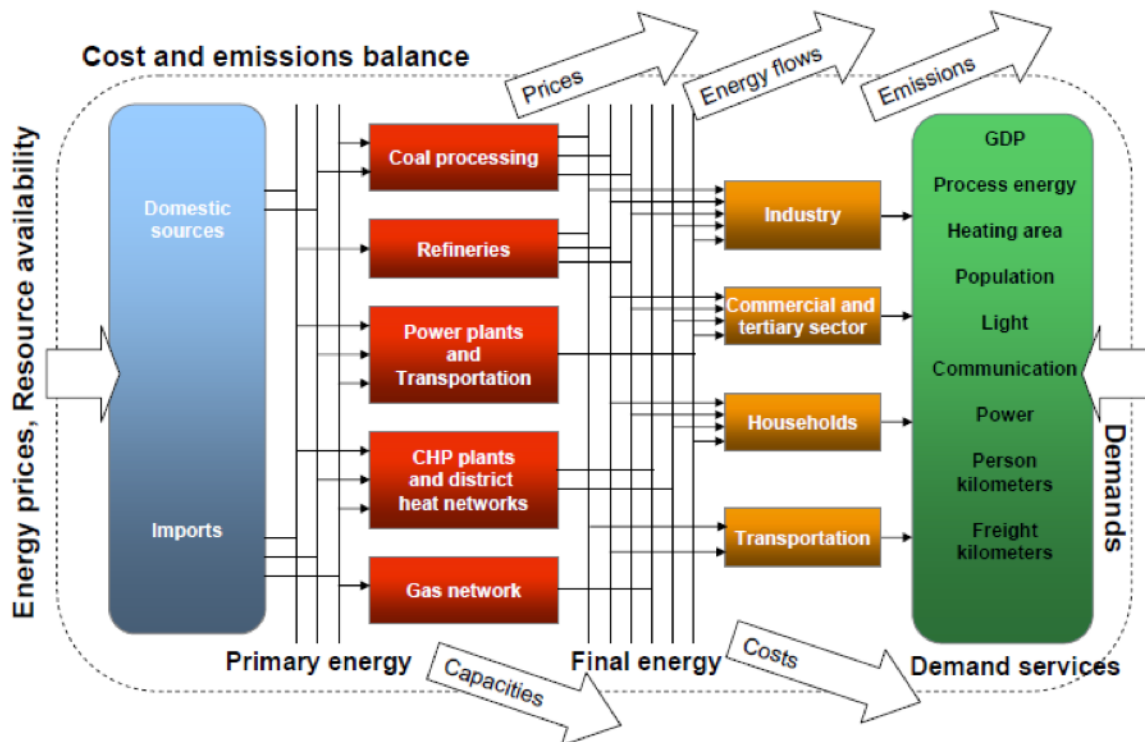
Figure 1: Schematic illustration of TIMES inputs and outputs (IEA-ETSAP, 2011a)

2.2 The VEDA system

VEDA is a set of tools geared to facilitate the creation, maintenance, browsing and modification of the large datasets required by complex TIMES models (IEA-ETSAP, 2011b). Furthermore, it facilitates the exploration of outputs created by such models. Accordingly, the VEDA system is composed of two subsystems: The VEDA Front-End (VEDA-FE) and the VEDA Back-End (VEDA-BE).

The following figure illustrates the functionality of VEDA: Data and assumptions, characterizing the model and energy system under consideration are fed into VEDA-FE as MS Excel files ("data handling"). VEDA-FE translates this information into TIMES code, which works in the GAMS[1] environment and produces text output that is read by VEDA-BE. VEDA-BE produces numerical and graphical output for the user ("results handling").

---

[1] The General Algebraic Modeling System (GAMS) is a high-level modelling system for mathematical programming problems.
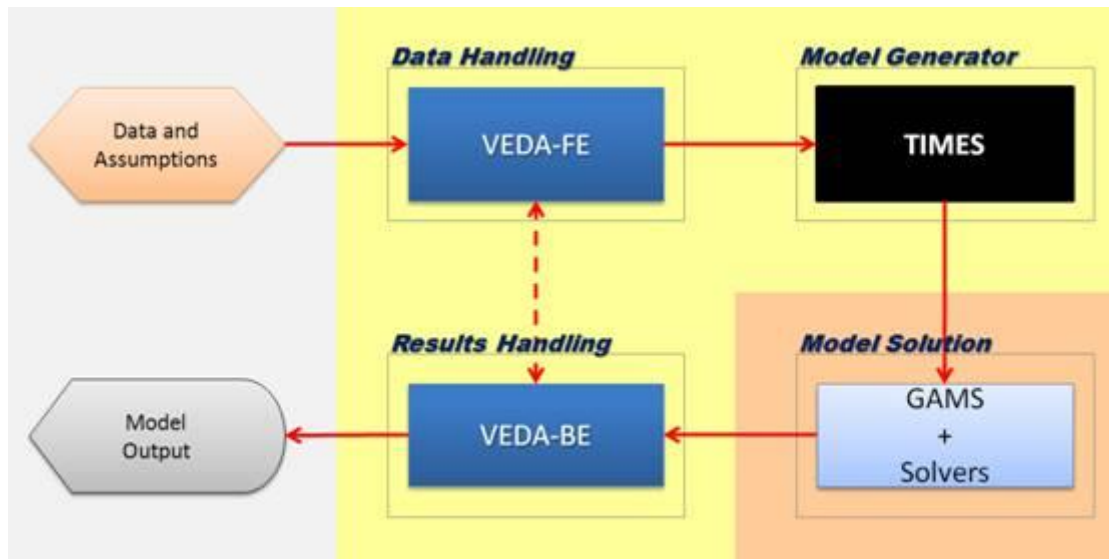
Figure 2: Overview of the VEDA system for TIMES modelling (IEA-ETSAP, 2011b)

3 Model structure

In the following sections, the structure of the "BioTransform.at model" ("BT-model") is described. This description includes the basic structure (3.1) technical information and specifics of the model (3.2), and the implementation in terms of VEDA input files (3.3).

3.1 Basics

The model comprises two main elements: An 'energy module', which is a representation of the Austrian energy system, and a 'biomass module', which includes all relevant aspects of biomass supply, processing and consumption. The two modules are interlinked in several ways: through biomass being used in the energy sector (i.e. being converted from mass to energy flows), through biofuel plants producing animal feedstuff as by-product or industrial energy demand depending on developments in wood processing industries.

The purpose of the model is to simulate transformations from the current, mainly fossil-based to biobased one economy. The drivers for all economic activities are the basic human needs: food, material and energy services (mobility, heated buildings etc.; see Figure 3). With the exception of food, these needs can be satisfied via conventional, "non-biobased" or bio-based value chains.

Conventional options are products and energy services based on fossil resources (or mineral, in the case of insulation material or construction, for example). Apart from fossil fuels, energy-intensive products like concrete, steel or bricks are also of major interest, as substitution of these products/materials with biomass can result in considerable GHG and energy savings.

In contrast to the conventional routes, which are primarily based on fossil resources, biobased industries and the bioenergy sector obtain their raw materials primarily from agriculture and forestry. Land, or land-use respectively, is therefore considered as the first element of the according supply chains (see Figure 3).

Hence, the scope of the biomass module goes beyond technical uses of biomass (i.e. for energy or materials) but also considers biomass flows induced by food consumption. For this purpose, specific per capita diets, such as vegetarian or reduced meat diet are defined (based on literature and statistical data) as well as their relative shares within the population (cf. supplementary material to Kalt et al., 2016). As for other categories this final demand is converted into an according demand for primary biomass, based on different conversion factors, in particular feed balance sheets. Primary biomass supply is linked to representations of agricultural land use, land use change and forest management.
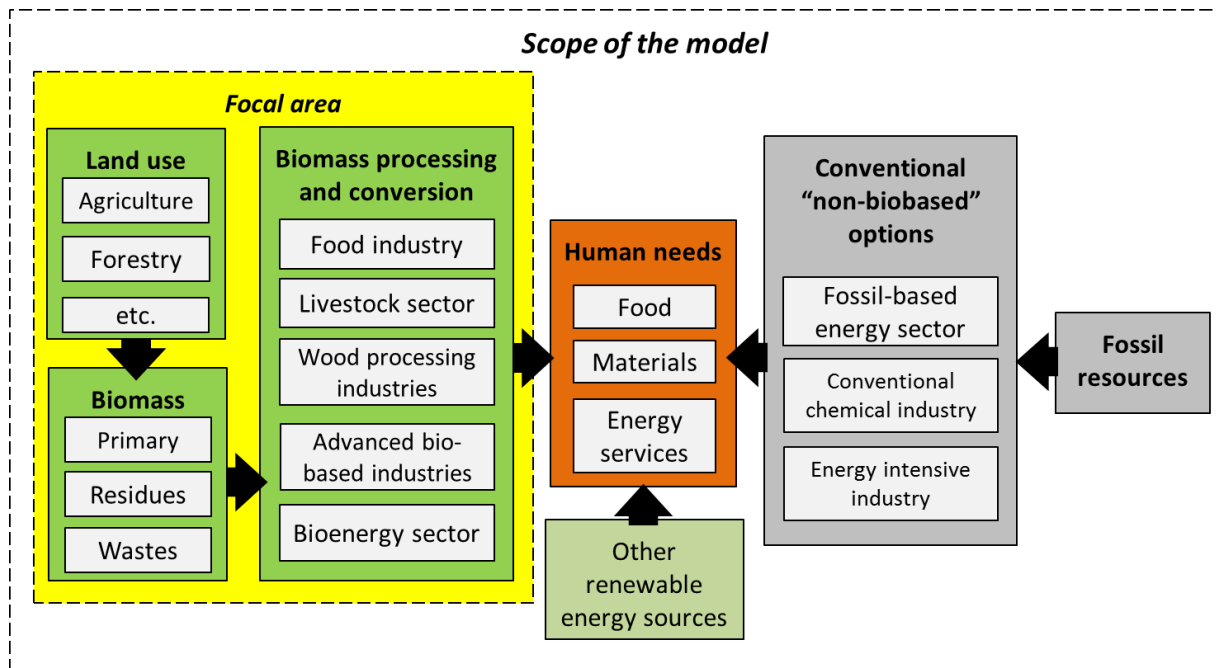
Figure 3: Schematic illustration of the basic idea and scope of the modelling approach

3.2 Technical information and specifics of the model

The general objective of the modelling endeavour is to develop scenarios to a low-carbon economy by minimizing net GHG emissions. Therefore, in contrast to the standard optimization objective of TIMES models, the BT-model is designed to minimize total aggregated GHG emissions in the considered timeframe from 2010 to 2050. Technically, this is achieved by defining a carbon price which exceeds all other costs by several orders of magnitude, so that low-carbon technologies/pathways are always preferred over such related to higher GHG emissions. This optimization is, however, severely restricted by numerous constrainst. These constraints can be classified as follows:

- **Exogenous (energy) demand settings**: Based on exogenous scenario developments (which have been developed with sector-specific models, e.g. for residential heat generation or transport fuel demand), the BT-model has limited degrees of freedom in the choice of fuels.
  As a rule, the model is free to replace fossil fuels with direct substitutes based on biomass. For example, natural gas can be replaced with biomethane (cleaned and conditioned biogas) for all applications (industry, residential heating etc.).
- **Dynamic constraints:** However, fuel switch (as well as most other endogenous parameters) is subject to dynamic constraints. Such constraints are generally required to avoid jumps in time series and achieve realistic model outputs.
  Other endogenous parameters which are subject to dynamic constraints include deployment of bioenergy capacities (heat plants, CHP plants etc.), arable land use (crop shares, land-use change etc.), material substitution (i.e. replacement of fossil-based/carbon-intensive products with biogenic counterparts) and several more.
- **Exogenous supply settings**: Since the focus of this project is on the potential role of biomass, deployment of other renewable is not determined by the model but predetermined exogenously (based on the WAM+-scenario described in Krutzler et al.,

7

2015). Hence, the model's degrees of freedom for minimizing GHG emissions in the energy sector are limited to fuel switch from fossil to biogenic fuels and decisions regarding biomass/fossil-based plant deployment in the electricity and district heat sector.

- **Restrictions to biomass supply:** In general, biomass supply is limited by land availability and land-use restrictions in the model, as well as natural conditions for growing crops in the considered geographic region, Austria (see section 5).

  Imports (and exports) of biogenic products are usually defined or restricted exogenously to achieve realistic results or investigate a certain research question. For example, what can be achieved with bioenergy without increasing net imports of biomass?

  The necessity to satisfy a certain demand for food (and feed, which is determined by demand for animal products like meat, milk etc.), largely defines agricultural land-use patterns (crop shares on arable land etc.). Food demand itself is determined by population development and dietary habits (see section 6.2). Hence, agricultural biomass supply for energy is limited to resources not required for food and feed supply. Arable land can only be used for energy crop production if it is not required for food or feed supply. This logic can be described as a "food and feed first approach".

TIMES-VEDA provides for a high degree of flexibility regarding time steps and resolution. The BT-model has been implemented with **a time resolution of 5 years**. This is sufficiently detailed for long-term scenarios until 2050, while providing significant advantages with regard to computing time and size of input data tables, compared to annual time steps.

Additionally, sub-annual time slices are implemented in the energy sector, to be able to take into account the structure of energy generation profiles (especially from fluctuating renewable energy sources) and energy consumption (load profiles) in the electricity and district heat sector. Three time slices for the seasonal level (summer, winter, transitional) and two for the day-night level are implemented.

3.3 Model implementation

3.3.1 Base year files

As mentioned above, the input data to VEDA-FE are organized in "Base year files" (B-Y files) and "Scenario files". Definitions of model elements (processes and commodities) and most data required for running the model are contained in the B-Y and the scenario files.

B-Y files contain process and commodity definitions, basic relationships between these elements (e.g. inputs and outputs of all processes, default conversion efficiencies, bounds on shares of certain inputs) etc. Each B-Y file represents a certain sector or aspect of the model. Figure 4 gives an overview of the B-Y files of the BT-model. The B-Y files can be classified as follows:[2]

- Supply sectors
- Transformation sectors
- Energy demand sectors
- Biomass demand sectors

---

[2] The term "sectors" is used even though not all B-Y files represent economic sectors (i.e. they represent sectors of the model, not sectors of the economy).

- GHG emissions and carbon accounting

The classification in Figure 4 in based on the *main* functionality of each sector. In fact, these distinctions are simplifications, as most sectors have more than one functionality (i.e. demand sectors in general also contain transformation processes). A particular case is the "Forestry & wood products" sector, as it contains the whole forestry supply chain, wood processing and also demand. This structure is due to technical reasons, which shall not be explained in detail here.

Another sector that needs to be mentioned due to its special function is the Emissions (EMI) sector. It contains processes required for greenhouse gas (GHG) and carbon accounting. The main functionality of the EMI processes is to aggregate the different types of GHG emissions and carbon flows related to activities in other sectors (e.g. energy consumption in the demand sectors, carbon stock changes in forests and on agricultural land etc.). More detailed information on GHG and carbon accounting is provided in Chapter 4.
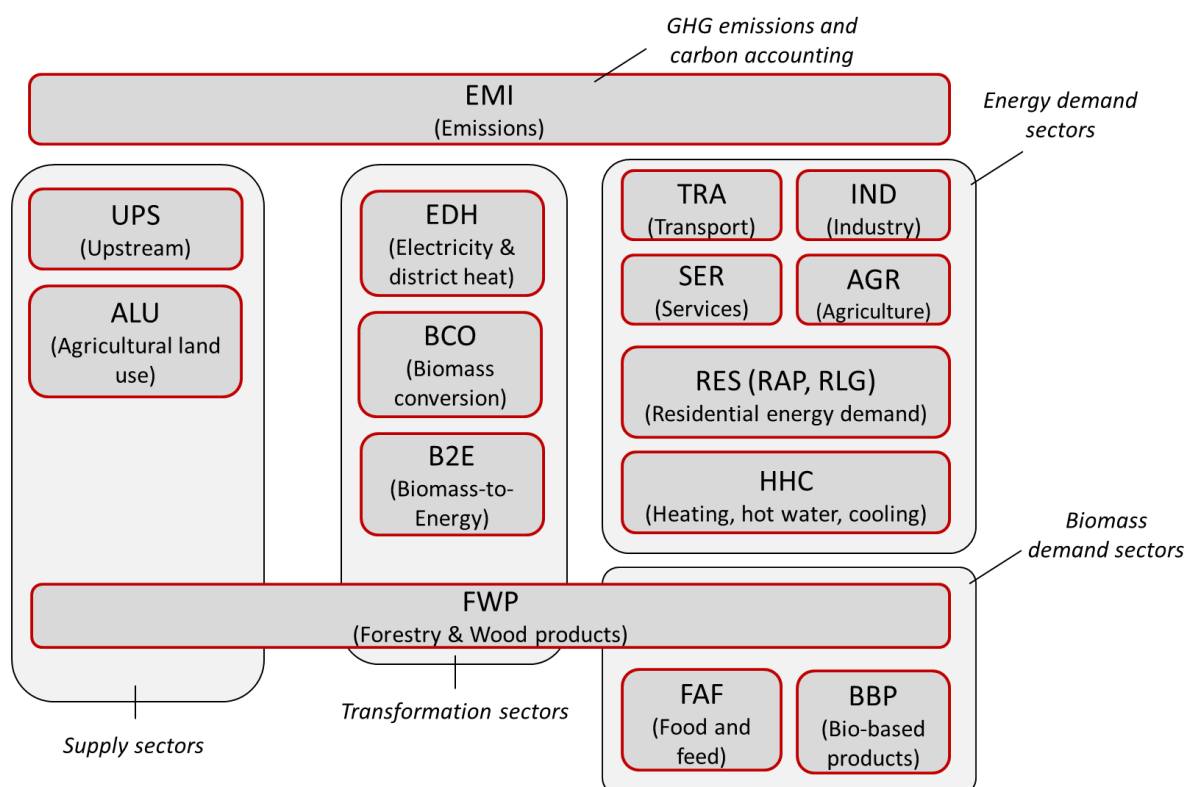

Figure 4. Base year files ("sectors") of the BT-model

3.3.2 Scenario files

Scenario files are generally required to exogenously define commodity flows and process activities in certain years/periods, refine the model structure with regard to relationships between certain flows and processes etc. Each scenario file usually refers to one specific B-Y file (in certain cases to several B-Y files). In the naming convention of the BT-model, the names of scenarios files always start with the abbreviation of the according sector.

More specifically, the following types of data and structures are organized in scenario files in the BT-model:

- Calibration data (e.g. imports and exports in the base year; input or output flows of certain processes like sawnwood production in the base year)
- Exogenous time series' and other scenario-specific settings (e.g. assumptions regarding developments of international trade flows; developments of dietary habits)
- Relationships between certain flows (e.g. quantities of by-products from certain conversion processes, material losses)[3]
- Relationships and interconnections between flows of different processes; for example biomass decay processes depending on activities/flows in previous years/periods
- GHG emission factors[3]
- Dynamic constraints (e.g. maximum growth rates, upper limits for capacities of certain processes like energy technologies)
- Demand developments[4]

The following table lists all scenario files.

Table 1. Scenario files of the BT-model

Sector (B-Y file)	Sector description (in brackets: main aspect[5])	Scenario files
AGR	Agriculture (energy demand)	• AGR_Agriculture: Scenario parameter settings like fuel shares or energy intensity development
ALU	Agriculture and land use (biomass supply)	• ALU_Crop_byproducts: crop-to-byproduct ratios, maximum recovery rates • ALU_Dyn: dynamic constraints for land allocation to crops • ALU_Emissions: Land-use change emission functions, soil emissions, byproduct decay functions • ALU_Fertilizer: Specific nitrogen demand of crops, nitrogen fixation by pulses etc., N supply from anaerobic fermentation • ALU_Land_use_Sc…: Different scenarios for land use (change); see section 5.1. • ALU_Yields_Sc…: Different scenarios for yield developments to 2050
B2E	Biomass-to-Energy (biomass conversion)	• B2E_Dyn: dynamic constraints for land allocation to crops • B2E_Supply_Trade: Calibration and exogenous developments in foreign trade of biogenic fuels, supply of biomass types with minor relevance (for which supply chains are not modelled endogenously; e.g. sewage sludge and sewage gas)
BCO	Biomass conversion	• BCO_Prod_Trade: Calibration and exogenous

---

[3] Implementation in scenario files instead of B-Y files is often preferable due to technical reasons, which shall not be explained in detail here.

[4] Implementation in scenario files instead of the standard demand files (see Gargiulo, 2009) is sometimes more convenient due to technical reasons, which shall not be explained in detail here.

[5] Examples: regulating demand/consumption of energy or material ("demand sector"), conversion of material to energy (conversion sector). This characterization only describes the main aspect; practically sectors have different functionalities (e.g. demand sectors producing by-products which are utilized in another sector)

Sector (B-Y file)	Sector description (in brackets: main aspect[5])	Scenario files
	(biomass conversion)	developments in certain biomass conversion processes
BBP	Biobased products (material demand)	• BBP_Dyn: dynamic constraints related to biobased products
EDH	Electricity and district heat (energy conversion)	• EDH_Capacities: Calibration, exogenous developments and constraints for electricity and district heat production capacities • EDH_Dyn: Dynamic constraints for electricity and district heat production capacities • EDH_Prices: Electricity import and export prices • EDH_Prod: Annual generation bounds for certain technologies • EDH_System_Losses: General settings required to mimic certain aspects of electricity and district heat supply (e.g. pumped storage plants, peak load constraints); distribution losses
EMI	Emission sector (GHG emissions and carbon balancing)	• EMI_Emission_factors: Fuel-specific emission factors; LCA-emissions of reference products etc.
FAF	Food and feed (food and feed demand)	• FAF_Diets_Sc…: Different scenarios for developments in dietary habits • FAF_Emissions: Implementation of livestock-related GHG emissions (manure, enteric fermentation) • FAF_Manure_4_energy: Settings for modelling manure potentials for energy • FAF_Nitrogen: N supply from manure • FAF_Prod_Trade_Losses_Sc…: Calibration and exogenous developments in foreign trade of food and feed, settings for wasted food and byproducts • FAF_Straw_animals: Straw demand for animal bedding
FWP	Forestry and wood processing (supply, coversion, demand)	• FWP_MGMT_...: Scenario for exogenously selecting a certain forest management method (linked to FWP_Forestry_Sc…, where parameters for each practice are defined) • FWP_Byprod_energy: Byproduct quantities linked to certain flows (e.g. bark, offcuts), endogenous energy demand of wood processing industries • FWP_Dyn_Sc…: Dynamic constraints for wood and forest product flows • FWP_Forestry_Sc…: Data related to different forest management practices (removals, carbon stock developments) • FWP_Recycling&Decay: Implementation of wood and paper recycling and according settings (recycling rates); decay functions for wood residues left in forest • FWP_Wood_flows: Calibration and exogenous developments in wood flows (consumption of wood processing industries, foreign trade etc.)

Sector (B-Y file)	Sector description (in brackets: main aspect[5])	Scenario files
HHC	Heating, hot water & cooling (energy demand)	• HHC_Heating&Cooling_Sc…: Different demand scenarios for heating and cooling energy demand in households and services sector
IND	Industry (energy demand)	• IND_Industry: Scenario parameter settings like fuel shares or energy intensity development
RES	Residential (energy demand)	• RES_Residual_demand: Exogenous development of residual energy demand for energy in residential sector (excluding heating & cooling); dynamic constraints for endogenous fuel shares
SER	Services (energy demand)	• SER_Residual_demand: Exogenous development of residual energy demand for energy in services sector (excluding heating & cooling); dynamic constraints for endogenous fuel shares
TRA	Transport sector (energy demand)	• TRA_Transport: Exogenous development of transport fuel demand; dynamic constraints for endogenous fuel shares
UPS	Upstream sector (fuel supply and conversion)	• UPS_Supply: Bounds on non-biogenous wastes for energy supply • UPS_ Upstream: Fuel price developments; parameter settings for consumption of sector energy (refineries etc.)

3.3.3 Data and model calibration

The standard base year of the BT-model is 2010. Biomass flows and foreign trade streams, energy supply and consumption, installed plant capacities, land use structure etc. are calibrated to statistical data. The main data sources for the energy module include the national energy balance (Statistik Austria, 2015a), the 'useful energy analysis' (Statistik Austria, 2015b) and statistical data provided by the Austrian energy regulator (E-Control, 2015). Data used for calibration of the biomass module are from foreign trade statistics (Eurostat, 2015), commodity balances (AWI, 2016) statistics on agricultural production (Eurostat, 2016), on wood supply and consumption (FAO, 2016a) and many more. Sources regarding biomass flows are to a large extent identical to the data used to map biomass flows in Austria in Del. 2.1 of the BioTransform.at project (Kalt, 2015). A complete list of data sources is provided in this publication.

Data for 2015 have not been available at the time the simulations were carried out. However, certain developments from 2010 to 2015 have been defined exogenously based on projections derived from developments until 2014. This approach ensures that relevant trends which took place after 2010 are represented in a realistic way. The following sectors and flow data are predetermined until 2015: the bioenergy sector (generation capacities and utilization), wood flows (production and consumption of the wood processing industries), bio-based product supply and consumption (biopolymers, bio-based insulation material etc.) as well as individual parameters in other sectors. Data on life-cycle emissions of conventional and bio-based products have been adopted from publicly available databases (IINAS, 2015; UBA, 2016), scientific publications (Adom et al., 2014; Patel et al., 2006) and environmental product declarations (IBU, 2016; Baubook, 2016).

4 Greenhouse gas accounting and carbon flows

4.1 Representation of "inventory-relevant" GHG emissions

GHG accounting is basically designed to emulate the IPCC's common reporting framework (CRF). "Inventory-relevant GHG emissions" (see Table 2) correspond to CRF categories included in the national GHG inventory. Apart from emissions from burning fossil fuels, this includes GHG emissions from agriculture as well as from land use, land use change and forestry (LULUCF). The according CRF categories represented in the model are: CRF1A (Energy; excluding fugitive emissions), CRF3 (Agriculture) and CRF4 (LULUCF).

GHG accounting is partly implemented in the biomass module and partly in the energy module. Following a 'full carbon accounting principle', the GHG balance of biomass utilization is calculated as the balance of GHG removals (due to carbon sequestration in forest wood, agricultural crops etc.) and emissions (from biomass combustion and natural decay). Carbon sequestration or emissions due to carbon stock changes in forests and artificial carbon pools are therefore fully incorporated, and accounting of harvested wood products (HWP) according to IPCC Guidelines (IPCC, 2014) is obsolete.

GHG emissions/removals due to land use changes are calculated based on functions that consider typical amounts of carbon stored in biomass and soil per unit area, following the approach of Houghton et al. (1983). These functions consider transition times required to reach the values for the new land use starting from the values of the previous land use and were calibrated with information from (Umweltbundesamt, 2014). Carbon sequestration on agricultural land converted to forest is modelled with a generic growth function (from Erb et al., 2013). Calculation of GHG emissions from agriculture (manure management, enteric fermentation, soils etc.) is based on emission factors derived from (Umweltbundesamt, 2014) and linked to livestock and crop production. Options for reducing specific GHG emissions (per livestock unit etc.) by changing agricultural practices are thereby neglected. Default emission factors according to IPCC Guidelines (IPCC, 2006) are applied in the energy module.

According to Decision 2/CMP.7 (UNFCCC, 2012), accounting of forest management in the second commitment period of the Kyoto Protocol shall be done on the basis of a Forest Management Reference Level (FMRL) (IPCC, 2014). The FMRL is a value of net emissions/removals against which the actual net emissions/removals are compared. Since no FMRL has been defined for the timeframe beyond 2020 (cf. UNFCCC, 2011), it is not possible to calculate emissions/removals from forest management for scenarios until 2050 in a way consistent with IPCC Guidelines.

Instead, the forest carbon stock in the base year 2010 is considered as reference value and net carbon stock changes between the base year and each model year translated into average annual CO_2 emissions/removals according to the following equation:

$$EMI_t^{FM} = 3.67 \cdot \frac{CS_t - CS_{2010}}{t - 2010} \quad \text{for t = 2015, 2020,\ldots 2050} \quad (1)$$

EMI_t^{FM} denotes the emissions from forest management (or forest carbon stock changes) and CS_t the carbon stock in year t. 3.67 is the mass conversion factor from C to CO_2 (IPCC, 2016). It is reasonable to determine average values, because carbon stock changes often vary considerably from one simulation period to the next. Net emissions/removals in the

target year 2050 would therefore not be representative if only the stock change from the previous to the respective period were considered.

4.2 Representation of biogenic carbon flows and further GHG emissions

Apart from the CRF categories mentioned above, further carbon flows (represented as CO_2-equivalents) are represented in the model on a technical level (Table 2). These categories represent biomass-related carbon sources and sinks in the inland, biogenic cross-border flows and life cycle emissions not covered by industrial energy consumption. The biogenic carbon cycle is modelled in such a way that carbon uptake during biomass production in forests, agriculture etc. and emissions to the atmosphere (from burning biomass and natural decay) are accounted for ('full carbon accounting principle').

In order to account for all flows within and beyond system boundaries, cross-border carbon flows related to biomass imports and exports are also traced (group 3 in Table 2: Biogenic cross-border carbon flows). The fourth and last group are life-cycle (LC) emissions of certain commodities. These emissions must be considered to account for the upstream processes of certain products. They are especially relevant in the case of biogenic products like construction wood or bio-plastics, because these products often have significantly lower LC emissions than their fossil-based counterparts. Also, LC emissions from synthetic fertilizers are taken into account, because of their great importance in connection with biofuels from crops and agricultural bioenergy in general.

Especially with regard to fossil-based reference products, LC emissions do not necessarily occur within the regional system boundaries (i.e. Austria). With regard to the optimization algorithm (to minimize total GHG emissions), they are treated like GHG emissions within the system boundary, although they are not included in the evaluation of "inventory-relevant GHG emissions".

Table 2. Structure of GHG emissions and carbon flows as represented in the BT-model

Groups	Sub-groups	Further differentiation
1. Inventory relevant GHG emissions	Energy	• Electricity and district heat • Agriculture • Industry • Services • Residential • Transport • Consumption of sector energy
	Agriculture	• Enteric fermentation • Agricultural soils • Manure management
	LULUCF	• Forest land remaining forest land (stock change) • Land converted to forest land

Groups	Sub-groups	Further differentiation
		• Land converted to crop land
		• Land converted to grassland
		• Land converted to settlements
2. Inland carbon sources and sinks related to biomass	Biomass production (in forestry/agriculture…)	Carbon uptake in forests, agricultural crops etc.
	Biomass combustion for energy	Wood log, wood chips, biodiesel etc.
	Natural decay of biomass	Wood residues left in forest, straw left on field etc.
	Biomass being consumed as food/feed	Different food/feed crops etc.
3. Biogenic cross-border carbon flows	Agricultural commodities	Different crops etc.
	Forest commodities	Different types of wood (roundwood, sawnwood etc.)
	Biogenic products	Plant oil, starch etc.
4. Life-cycle emission	Life-cycle emissions of biogenic products	LC emissions of different bioplastics etc.
	LCA emissions of reference (conventional, non-biogenic) products	LC emissions of different conventional polymers.
	Nitrogen fertilizers	LC emissions of nitrogen fertilizers
	Electricity imports	Average GHG emissions of electricity imports (based on EU-28 electricity mix, for example)

5   Modelling land use (change), agriculture and forestry

5.1   Land use and LUC

Land use and land use change (LUC) determine the (future) potential of domestic biomass supply. Furthermore, LUC results in changes in (soil and/or aboveground) carbon stocks, which are considered in the context of national GHG inventories (see section 4) and UBA (2015).

Regarding the implementation of future LUC in the BT-model, a dual approach is applied: On the one hand, certain developments are determined exogenously, in order to pay account to the main trends and demonstrate the potential effects of strict policy intervention in the field of conservation of agricultural land. On the other hand, it is possible to leave certain decisions regarding LUC to the optimization algorithm. For example, under certain circumstances the model may convert arable land to extensive grassland, in order to achieve GHG removals through increase of natural carbon stocks. (This option is, however, deactivated in the main scenarios presented in Deliverable 5.2 of the project (Kalt et al., 2016).

Data on land availability and use implemented in the BT-model are based on AWI (2016). Regarding LUC, developments in recent years and decades have been analysed, in order to derive projections for the future to be used as exogenous assumptions in simulation runs. The most notable developments in LUC (see Table 3) during the period 1990 to 2012 were:

- An increase in settlements, mainly at the expense of agricultural land
- A considerable decline in grassland, mainly due to expansion of forests
- A (net) decline in arable land

Table 3. Land use and land-use change matrix for 1990 to 2012 (Source: UBA, 2014)

in 1 000 ha	Forest land	Cropland	Grass-land	Wetlands	Settlements	Other land	Total 2012
Forest land	3 817	18	104	12	11	51	4 013
Cropland	5	1 368	52				1 425
Grassland	37	29	1.724				1 790
Wetlands	3		24	121			148
Settlements	14	116	42		366		538
Other land	16		47			410	473
Total 1.1.1990	3 892	1 531	1 993	133	377	461	8 387

To provide a better understanding on how exogenous LUC can be implemented in the BT-model, the developments assumed in the main scenarios of the project (Kalt et al. 2016) are presented in Figure 5. They are characterized as follows:

- **Business-as-usual LUC** (assumed for Scenario A and B in Kalt et al. 2016): The main developments from the period 1990 to 2012 are extrapolated to 2050.

16

- **Reduced LUC** (assumed in Scenario C): In Scenario C it is assumed that targeted measures to reduce LUC are successful, resulting in a 50 % reduction of annual LUC after 2020 and agricultural land remaining constant after 2030.
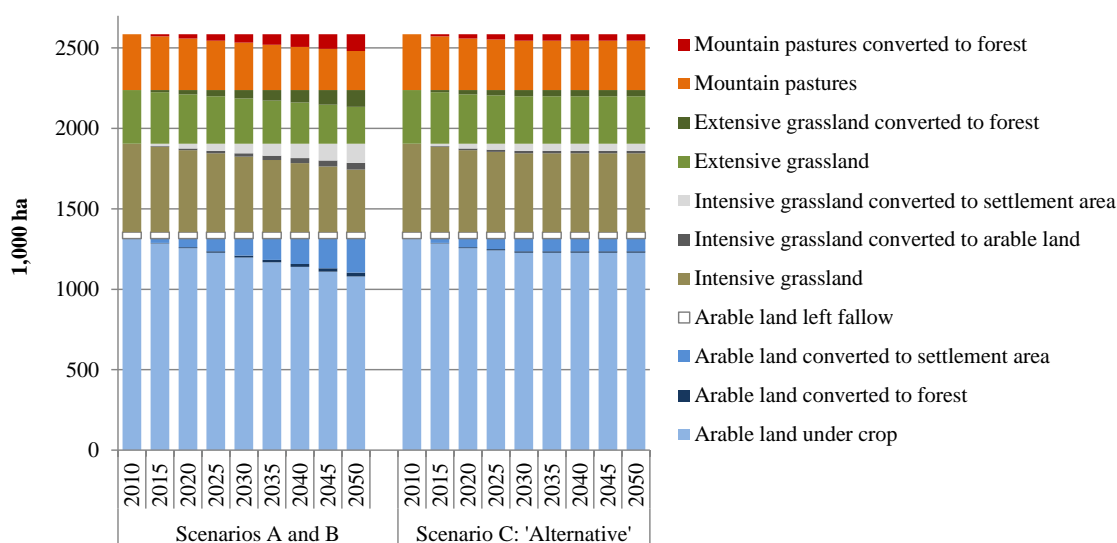

Figure 5. Agricultural land use and LUC scenarios until 2050

5.2 Arable land use and yield developments

The structure of arable land use (crop shares) is endogenous, but subject to constraints imposed by natural conditions and requirements of crops. The data on natural conditions are generated with a GIS-based approach (Schaumberger et al., 2011) and subsequent clustering of the present agricultural land into classes with specific suitability profiles. GIS data have been obtained from the Digital Soil Map of Austria (cf. Joint Research Centre of the European Commission, 2014; BFW, 2016) and climate data from the project 'Safe our Surface' (Beham et al., 2009). Crop requirements are based on the FAO's 'Ecocrop database' (FAO, 2016b).

Agricultural yields for the base year in 2010 are derived from agricultural statistics (AWI, 2016). In general, yields are dynamic and scenario-specific paramters. For the main scenarios presented in Kalt et al. (2016), assumptions for their future development based on the following considerations: In case of increased intensification of agriculture it is assumed that there are strong efforts to further increase crop yields along the path of the last decades. Crop yields in this scenario are based on a linear extrapolation of past trends of crop yields in conventional agriculture to 2050. In order to ensure that such an extrapolation doesn't result in unrealistically high yields, resulting crop yields in 2050 have been cross-checked against yields already achieved in controlled field trials today (AGES, 2015). This showed that such a continuation of linearly growing crop yields might be feasible in the case of Austria, albeit this is linked to certain ecological (and possibly social) costs.

In other scenarios it is assumed that average yields remain constant throughout the whole simulation period; as yield increases are quite likely (at least for some of the most relevant crops), this assumption may be interpreted as yield increases being compensated by a structural shift towards organic farming. Grassland yields and yields for forage crops, such as Alfalfa, are assumed to remain constant in all scenarios.

17

5.3 Forestry

Several forest management scenarios have been calculated with the dynamic forest succession simulator PICUS v1.4 (Lexer and Hönninger, 2001; Maroschek et al., 2014). The simulation model PICUS combines the abilities of a 3D gap model in simulating structurally diverse forest stands with process-based estimates of stand level primary production. PICUS builds on a 3-D structure of 10 x 10 m patches, extended by crown cells of 5 m height. Population dynamics emerge from growth, mortality and reproduction of individual trees. In addition, the simulation framework integrates a management module, a detailed regeneration module, and forest disturbance modules (e.g, for barkbeetle and wind damages). PICUS is driven by time series data of temperature, precipitation, radiation and VPD at monthly or daily resolution.

Several model runs have been carried out which differ with regard to forest management strategies. The simulation results are time series for wood removals (differentiated by wood qualities) and forest stock development (and according net carbon sequestration or emissions). Results are available and have been implemented in the BT-model on the level of "Bezirke".

Similar to the implementation of LUC, it is possible to either exogenously assume a certain forest management strategy (This approach was applied for developing the main scenarios), or leave the choice to the optimization algorithm.

Figure 6 shows a schematic illustration of the carbon flows related to forestry and wood use, which need to be considered in a full carbon accounting approach.
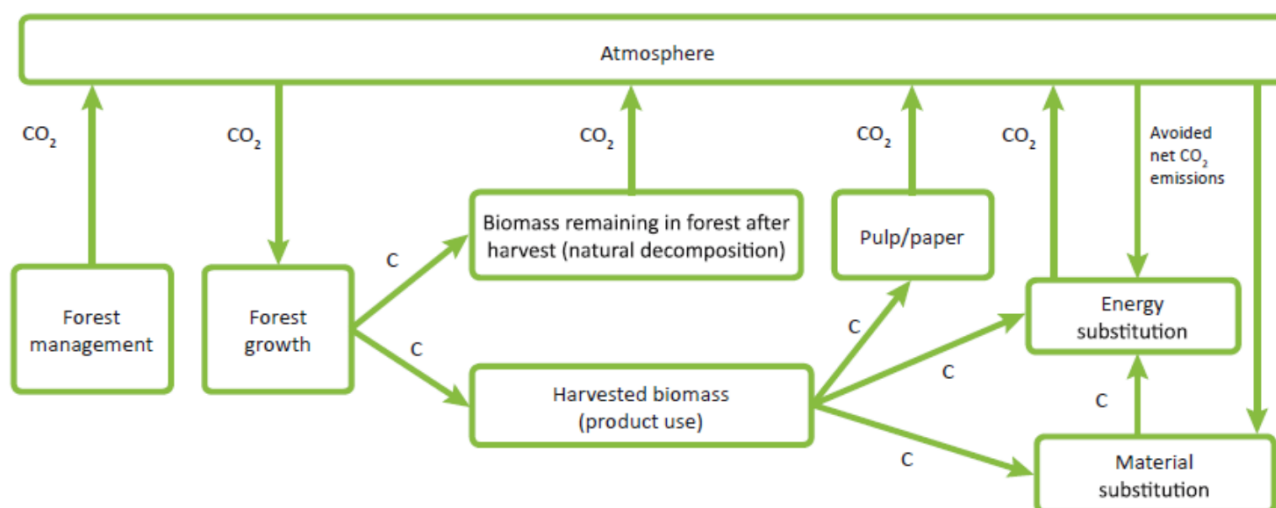

Figure 6. Schematic diagram of Carbon (C) and CO_2 flows related to forest management and utilization of wood products (adopted from Sathre and Gustavsson; in Kuittinen et al., 2013)

5.4 Straw and other crop residues

Straw and other crop residues like corn stover or sugar beet leaves are relevant for several aspects. First, they function as Nitrogen fertilizers if left on the field. Second, straw is

extensively used as bedding material for livestock. And third, residues can be used for energy recovery or raw material for bio-based products.

Figure 6 illustrates the implementation in the BT-model. The amount of residue production (per hectare) is determined by residue-to-crop ratios, which are specific for each crop type. Carbon stored in residues which are left on the field is assumed to be released according to a 1st-order (exponential) decay rate.

The maximum amount available for utilization is influenced by technical constraints to residues removal. Once removed and made available for utilization, carbon stored in residues is either released instantaneously (if, for example, residues are burned for energy recovery), or stored for a certain period of time. This is especially relevant in case on long-lived biobased products.
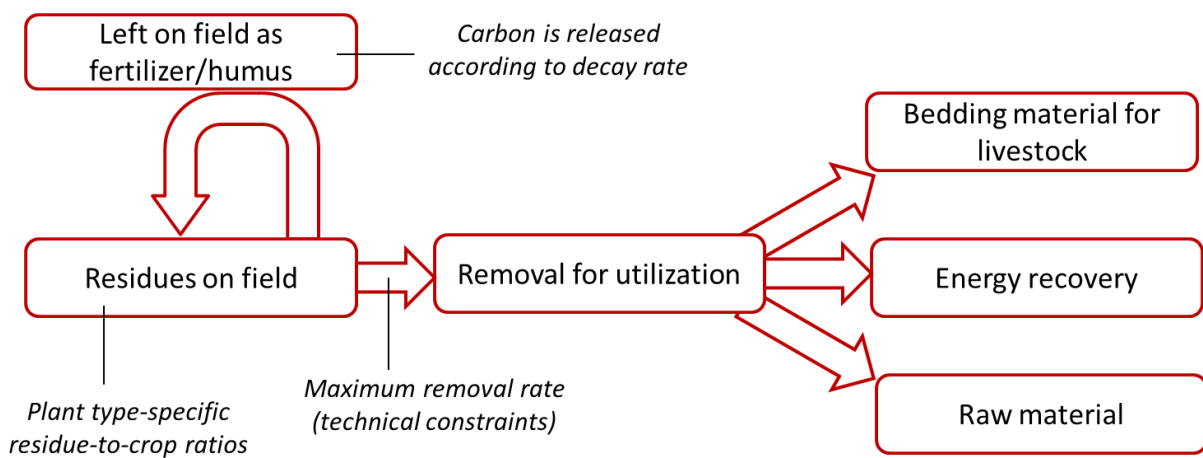
Figure 7. Schematic illustration of crop residues in the BT-model

6 Demands

6.1 Demand drivers

The main demand drivers are population and economic development. For the main scenarios presented in Kalt et al. (2016), both developments have been adopted from Krutzler et al. (2015) (Figure 8).
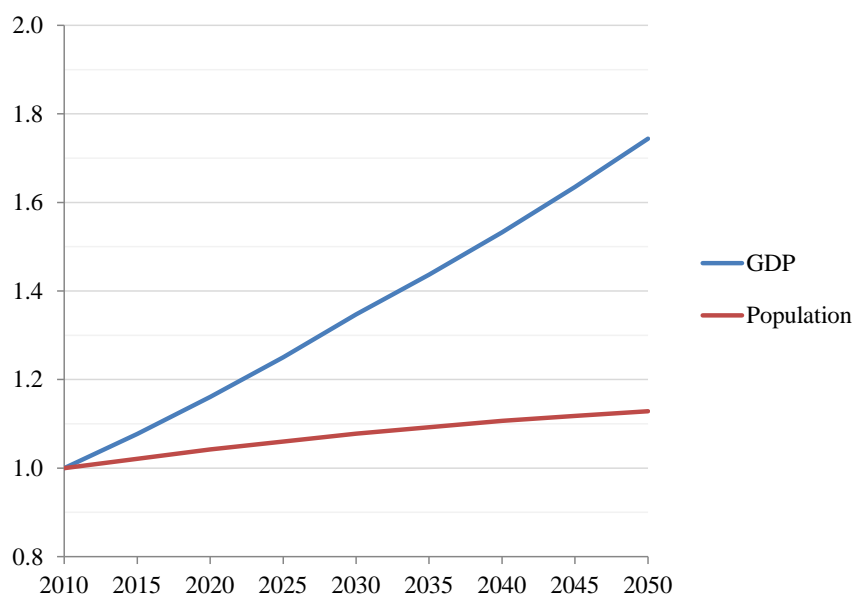

Figure 8. Relative growth of the main demand drivers GDP and population

Based on plausibility considerations, demand developments of certain commodities are directly linked to GDP or population growth. For example, demand for packaging material is directly linked to GDP development, whereas population development is assumed to determine the demand for hygienic paper, solvents, surfactants etc.; and of course of food demand.

For other demand commodities, specific trends are assumed to play a major role: Paper demand for newsprint and printing and writing paper are assumed to further decline due to increasing usage of portable electronic devices. Demand for virgin asphalt material (and asphalt binder; lignin is assumed to be a substitute for bitumen) is expected to decline as a consequence of enhanced recycling of reclaimed asphalt. Statistical data have been obtained from annual reports of the Austrian paper and pulp industry (Austropapier, 2013) and the European Asphalt Pavement Association (EAPA, 2015), respectively, and extrapolated to 2050.

The demand driver for construction material is floor space of newly constructed buildings and building conversions and extensions. According data are available from the national statistical authority (Statistik Austria, 2015c). Projections to 2050 have been derived on the assumption of a linear correlation between population growth and additional floor space. Further demands, which are practically negligible in the overall context, include feed demand for horses and other (pet) animals, and raw material consumption for miscellaneous material

uses not specified in supply balances (Statistik Austria, 2016). Material consumption for these applications is assumed to remain constant.

6.2 Food and feed demand

Domestic food and feed demand are based on population and dietary habits. Dietary habits refer to the average actual food intake per capita and year, differentiating 48 food products. Baseline per capita diets in 2010 are derived by combining data on domestic food supply according to Austrian commodity balances (AWI, 2016) with literature derived data on food losses in sectors outside the system boundary of commodity balances, in particular households (Beretta et al., 2013).

In the main scenarios, average per capita intake is allocated to four broad types of diets: Based on USDA dietary guidelines (USDA and HHS, 2010), three "healthy" diets – including meat, vegetarian and vegan – and one meat-rich diet to which all remaining food is allocated, are implemented (Figure 9). The distribution of the population in the base year are based on a study for the UK (Orlich et al., 2014) and a survey on purchases of animal products (European Commission, 2005).

Future developments of dietary habits (distribution among diet types) are exogenous scenario parameters. Based on trends in dietary habits during the last years and decades, a shift towards more healthy and low-meat diets is considered likely and implemented in the main scenarios (cf. supplementary material to Kalt et al., 2016).
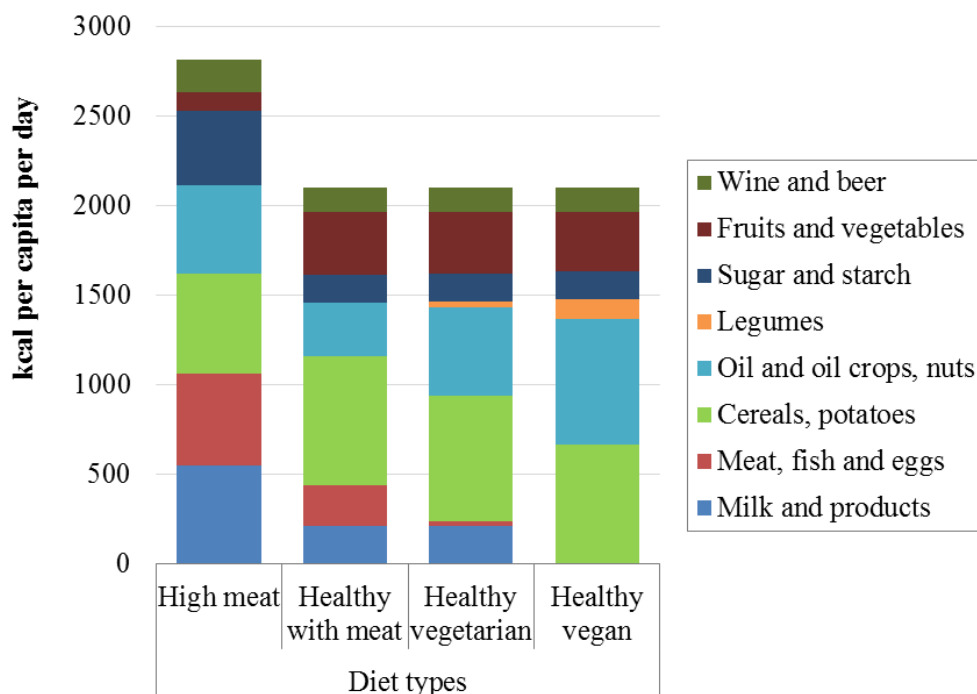

Figure 9. Diet types implemented in the BT-model

6.3 Energy demand

Developments of energy demand are (with some exceptions) exogenous scenario parameters in the BT-model. Most demands are defined on the level of final energy consumption. Exceptions are: Industrial energy demand in certain sectors, where it is linked to production of the wood-processing industries; and low-temperature heat consumption in the residential and the services sector, which is determined on the level of useful heat (since boiler efficiencies for different fuel types must be taken into account in case of endogenous fuel switch).

Energy demand developments in the main scenarios of the project are based on (Krutzler et al., 2015). Detailed information including time series' and options for fuel switch is provided in the supplementary material to Kalt et al. (2016).

6.3 Energy demand

7 References

Adom, F., Dunn, J.B., Han, J., Sather, N., 2014. Life-Cycle Fossil Energy Consumption and Greenhouse Gas Emissions of Bioderived Chemicals and Their Conventional Counterparts. Environmental Science & Technology 48, 14624–14631. doi:10.1021/es503766e

AGES (Hrsg.), 2015. Österreichische beschreibende Sortenliste 2015 Landwirtschaftliche Pflanzenarten (Schriftenreihe 21/2015). Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH.

Austropapier, 2013. Statistics of the Austrian paper and pulp industry.

AWI, 2016. Grüner Bericht 2015. Bundesanstalt für Agrarwirtschaft, BMLFUW.

Baubook, 2016. Baubook database – Insulation material [WWW Document]. URL https://www.baubook.info/zentrale/.

Beham, M., Mendlik, T., Gobiet, A., 2009. Studie „Save our Surface" im Auftrag des Österreichischen Klima- und Energiefonds Teilbericht 5a: Regionalisiertes Klimamodell. Wegener Center für Klima und Globalen Wandel, Universität Graz, Graz.

Beretta, C., Stoessel, F., Baier, U., Hellweg, S., 2013. Quantifying food losses and the potential for reduction in Switzerland. Waste Management 33, 764–773. doi:10.1016/j.wasman.2012.11.007

BFW, 2016. Digitale Bodenkarte eBOD [WWW Document]. URL http://bfw.ac.at/rz/bfwcms2.web?dok=7066.

EAPA, 2015. Asphalt In Figures [WWW Document]. URL http://www.eapa.org/promo.php?c=174.

E-Control, 2015. Website of Energie-Control Austria. Betriebsstatistik (Operating statistics) [WWW Document]. URL http://www.e-control.at/statistik/strom/betriebsstatistik.

Erb, K.-H., Kastner, T., Luyssaert, S., Houghton, R.A., Kuemmerle, T., Olofsson, P., Haberl, H., 2013. Bias in the attribution of forest carbon sinks. Nature Climate Change 3, 854–856. doi:10.1038/nclimate2004

European Commission, 2005. Attitudes of consumers towards the welfare of farmed animals. Special Eurobarometer 229/Wave 63.2-tns Opinion & Social.

Eurostat, 2015. Website of Eurostat - International trade.

Eurostat, 2016. Website von Eurostat. Pflanzliche Erzeugnisse - jährliche Daten.

FAO, 2016a. FAOSTAT - Forestry production and trade. Food and Agriculture Organisation of the United Nations. Statistics Division.

FAO, 2016b. Ecocrop database [WWW Document]. Food and Agriculture Organization of the UN. URL http://ecocrop.fao.org/ecocrop/srv/en/home.

Gargiulo, M., 2009. Getting Started With TIMES-Veda, Version 2.7. Energy Technology Systems Analysis Program (ETSAP).

Houghton, R.A., Hobbie, J.E., Melillo, J.M., Moore, B., Peterson, B.J., Shaver, G.R., Woodwell, G.M., 1983. Changes in the Carbon Content of Terrestrial Biota and Soils between 1860 and 1980: A Net Release of CO2 to the Atmosphere. Ecological Monographs 53, 235–262. doi:10.2307/1942531

IBU, 2016. Umwelt-Produktdeklarationen (Environmental product declarations). Institut Bauen und Umwelt e.V. (IBU), http://bau-umwelt.de/hp474/Umwelt-Produktdeklarationen-EPD.htm

IEA-ETSAP, 2011a. Energy Technology Systems Analysis Program. TIMES. http://www.iea-etsap.org/web/Times.asp

IEA-ETSAP, 2011b. Energy Technology Systems Analysis Program. VEDA. http://www.iea-etsap.org/web/Veda.asp

IINAS, 2015. GEMIS 4.9 - Globales Emissions-Modell integrierter Systeme.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 2: Energy.

IPCC, 2014. 2013 revised supplementary methods and good practice guidance arising from the Kyoto Protocol. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds) Published: IPCC, Switzerland.

IPCC, 2016. Website of the Intergovernmental Panel on Climate Change. Working Group III: Mitigation. Units, Conversion Factors, and GDP Deflators [WWW Document]. URL http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=477.

Joint Research Centre of the European Commission, 2014. Digital Soil Map of Austria [WWW Document]. European Soil Portal - Soil Data and Information Systems. URL http://eusoils.jrc.ec.europa.eu/library/data/250000/Austria.htm.

Kalt, G., 2015. Biomass streams in Austria: Drawing a complete picture of biogenic material flows within the national economy. Resources, Conservation and Recycling 95, 100–111. doi:10.1016/j.resconrec.2014.12.006

Kalt G., Baumann M., Lauk C., Kastner T. , Kranzl L., Schipfer F., Lexer M., Rammer W., Schaumberger A., Schriefl E., 2016. Transformation scenarios towards a low-carbon bioeconomy in Austria. Deliverable 5.2 of the project „BioTransform.at". (submitted to Energy Strategy Reviews)

Kranzl, L., Heiskanen, E., Rohde, C., Regodón, I., et. al., 2014. Laying Down The Pathways To Nearly Zero-Energy Buildings. A toolkit for policy makers. Final report of the IEE project "ENTRANZE: Policies to Enforce the Transition to nearly Zero-Energy Buildings in the EU-28".

Krutzler, T., Kellner, M., Heller, C., Gallauner, T., et al, 2015. Energiewirtschaftliche Szenarien im Hinblick auf die Klimaziele 2030 und 2050. Szenario WAM plus – Synthesebericht 2015. Umweltbundesamt, Vienna.

Kuittinen, M., Ludvig, A., Weiss, G., 2013. Wood in carbon efficient construction. Tools, methods and applications. €CO2.

Lexer, M.-J., Hönninger, K., 2001. A modified 3D-patch model for spatially explicit simulation of vegetation composition in heterogeneous landscapes. Forest Ecology and Management 144, 43–65.

Loulou, R., Goldstein, G., Noble, K., 2004. Documentation for the MARKAL Family of Models. ETSAP.

Loulou, R., Labriet, M., 2008a. ETSAP-TIAM: the TIMES integrated assessment model. Part I: Model structure, Computational Management Science 5(1-2): 7-40

Loulou, R., Labriet, M., 2008b. ETSAP-TIAM: the TIMES integrated assessment model. Part II: Mathematical formulation. Computational Management Science 5(1):41-66

Loulou, R., Remme, U., Kanudia, A., Lehtila, A., Goldstein, G., 2005. Documentation for the TIMES Model - PART I 1–78.

Loulou, R., Remme, U., Lehtila, A., Goldstein, G., Kanudia, A., 2005. Documentation for the TIMES Model Part II. Energy Technology Systems Analysis Programme.

Maroschek, M., Rammer, W., Lexer, M.-J., 2014. Using a novel assessment framework to evaluate protective functions and timber production in Austrian mountain forests under climate change - Springer. Regional Environmental Change 15, 1543–1555.

Müller, A., 2015. Energy Demand Assessment for Space Conditioning and Domestic Hot Water: A Case Study for the Austrian Building Stock. PhD Thesis, Vienna University of Technology.

Orlich, M.J., Jaceldo-Siegl, K., Sabaté, J., Fan, J., Singh, P.N., Fraser, G.E., 2014. Patterns of food consumption among vegetarians and non-vegetarians. British Journal of Nutrition 112, 1644–1653. doi:10.1017/S000711451400261X

Patel, M., Crank, M., Dornburg, V., Hünsing, B., et al, 2006. Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources - The Potential of White Biotechnology. The BREW Project. Final report. Utrecht University.

Sathre, R., Gustavsson, L., 2012. Time-dependent radiative forcing effects of forest fertilization and biomass substitution. Biogeochemistry 109(1-3), pp. 203-218.

Schaumberger, J., Buchgraber, K., Schaumberger, A., 2011. Studie „Save our Surface" im Auftrag des Österreichischen Klima- und Energiefonds. Teilbericht 5b: Landwirtschaftliche Flächennutzungspotenziale in Österreich und Simulation von Produktionsszenarien bis 2050. LFZ Raumberg-Gumpenstein, Irdning.

Statistik Austria, 2015a. Website of Statistik Austria - Energy balances [WWW Document]. URL http://www.statistik.at/web_en/statistics/energy_environment/energy/energy_balances/index.html

Statistik Austria, 2015b. Website of Statistik Austria - Useful Energy Analysis [WWW Document]. URL. http://www.statistik.at/web_en/statistics/energy_environment/energy/useful_energy_analysis/index.html

Statistik Austria, 2015c. Österreichische Konjunkturindikatoren-Meldung an EUROSTAT: Bewilligte Wohnungen in neuen Wohngebäuden und Bruttogeschoßflächen neuer Gebäude nach Quartalen von 2005 bis 2015. Statistik Austria, Vienna.

Statistik Austria, 2016. Supply Balance Sheets [WWW Document]. URL http://www.statistik.at/web_en/statistics/Economy/agriculture_and_forestry/prices_balances/supply_balance_sheets/index.html.

UBA, 2014. Austria's National Inventory Report 2014. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Umweltbundesamt.

UBA, 2015. Austria's National Inventory Report 2015. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Umweltbundesamt.

UBA, 2016. ProBas (Prozessorientierte Basisdaten für Umweltmanagementsysteme) database [WWW Document]. URL http://www.probas.umweltbundesamt.de/php/index.php.

Umweltbundesamt, 2014. Austria's National Inventory Report 2014. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol (No. REP-0475). Umweltbundesamt GmbH, Vienna.

UNFCCC, 2011. Report of the technical assessment of the forest management reference level submission of Austria submitted in 2011 (No. FCCC/TAR/2011/AUT).

UNFCCC, 2012. Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its seventh session, held in Durban from 28 November to 11 December 2011. Addendum. Part Two: Action taken by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol at its seventh session (No. FCCC/KP/CMP/2011/10/Add.1). United Nations Framework Convention on Climate Change.

USDA and HHS, 2010. Dietary Guidelines for Americans. U.S. Department of Agriculture, U.S. Department of Health and Human Services.

8 Annex

8.1 List of figures

8.2 List of tables