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MEDEAS

MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

Project Nr: 691287

Guiding European Policy toward a low-carbon economy. Modelling sustainable Energy system Development under Environmental And Socioeconomic constraints

Deliverable 4.4 (D16) – Transition rates & scenarios

Version 3.0.0

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Document info sheet

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Abstract

This deliverable provides the scenario implementation in all country-level models in a comparison with the expected WP3 pathway transition rates of change. The scenario implementation and the underlying and resulting transition rates of WP3 are summarized. Subsequently, the scenario implementation in the country-level MEDEAS models, i.e. the Austrian MEDEAS_at and the Bulgarian MEDEAS_bg are summarized and compared with the expected WP3 scenario implementation and pathway transition rates.

In the following sections, the country-level linear optimisation model results of TIMES-Austria and the model results of LEAP-Bulgaria concerning transition rates are depicted. First, the TIMES-Austria model results concerning scenario implementation and transition rates are summarized and compared with the expected values in WP3. Second, the LEAP-Bulgaria model results are compared. The focus is on the transition rates of renewable energies. Finally, the transition rates are derived and implemented in an input-output model for each country. Thereby, the transition rates of the implemented scenarios can be broken down into the detailed changes in input-output coefficients underlying the low-carbon transition of the Optimal-Level Transition (OLT) and Mid-Level Transition (MLT) scenarios.

The comparison reveals that MEDEAS_at and MEDEAS_bg provide a significantly lower growth trajectory in the real data from 2010 to 2015 for solar energy than what has been assumed in the scenarios for Austria and the actual growth has been considerably stronger in Bulgaria for solar energy. We conclude that the initial growth trajectories for wind and solar energy can be considered realistic, given that several annual growth rates exceed the average considerably and have therefore demonstrated the feasibility of a fast transition. Nevertheless, historical data only shows the beginning of the transition with exponential growth rates. While it is easy to keep up high growth rates in the first phase, maintaining this growth becomes more and more difficult the higher the saturation. Important to highlight is also that the growth trajectories are linear in TIMES-Austria, while WP3 assumes exponential growth with constant growth rates. The MEDEAS_at and MEDEAS_bg simulations also reveal such a non-linear dynamic. Concerning the comparison with LEAP-Bulgaria, a key difference is that hydroelectricity remains roughly constant in the MLT, but also in the OLT scenarios, while the scenario implementation in WP3 assumes a growth rate of 1.4% annually for both, Bulgaria and Austria.

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Finally, we transfer the scenario results into input-output structures to identify transition rates in the resulting input coefficients of the electricity sector. Notably, we find a strong moderation in the cost share of mining & quarrying in the OLT scenario in both countries. This share increased heavily in the aftermath of the price peak and after the financial crisis in Austria, and was already very high in Bulgaria. The serious drop of the overall intermediate inputs in the BGR case is likely to be caused by significantly lower need of mining and quarrying domestic products to proceed with construction of the renewable sources infrastructure. Whether this is true also for the nuclear electricity share (in the Bulgarian case) is not so unequivocal, because the share of nuclear power in the mix remains approximately stable over the analysed period (albeit with an abrupt rise after 2034, which is on the other hand reflected only as a gradual change in the model, given the methodology of linear interpolation).

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List of abbreviations and acronyms

AEA Austrian Energy Agency

ARU Anglia Ruskin University

BAU Business As Usual

BSERC Black Sea Energy Research Centre

CB carbon budget

COP Conference of the Parties

EU European Union

GHG Greenhouse Gas

Gt Gigatonnes

GtC Gigatonnes of Carbon

$GtCO_2eq$ Gigatons of carbon dioxide equivalent

IIASA International Institute for Applied Systems Analysis

INSTM National Interuniversity Consortium of Materials Science and Technology

IOA Input-Output Analysis

IPCC Intergovernmental Panel on Climate Change

LEAP Long-range energy alternatives planning system

LEAP-Bulgaria Bulgarian implementation of the LEAP system

MARKAL Market and allocation (predecessor to TIMES)

MEDEAS_w VENSIM implementation of the world model of MEDEAS

MEDEAS_eu VENSIM implementation of the EU model of MEDEAS

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MEDEAS_at VENSIM implementation of the Austrian model of MEDEAS

MEDEAS_bg VENSIM implementation of the Bulgarian model of MEDEAS

MLT Mid-level transition scenario

OLT Optimal transition scenario

SSP Shared socioeconomic pathway

TIMES The Integrated MARKAL-EFOM System

TIMES-Austria Austrian implementation of the TIMES system

UNFCCC United Nations Framework Convention on Climate Change

UVa University of Valladolid

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Executive summary

The focus of this deliverable is on the scenario implementation in all country-level models and a comparison with the expected WP3 pathway transition rates. First, the scenario implementation and the underlying and resulting transition rates of WP3 are summarized. Subsequently, the scenario implementation in the country-level MEDEAS models, i.e. MEDEAS model for Austria (MEDEAS_at) and MEDEAS for Bulgaria (MEDEAS_bg) are summarized and compared with the expected WP3 scenario implementation and pathway transition rates. The key objective was to fit the scenarios of the national level Vensim models MEDEAS_at and MEDEAS_bg to the Carbon Budget available for both countries within the Mid-level and the Optimal transition scenarios MLT and OLT.

In the second part of the deliverable, the country-level linear optimisation model results of TIMES and the model results of LEAP concerning transition rates are depicted. First, the TIMES-Austria model results concerning scenario implementation and transition rates are summarized and compared with the expected values in WP3. Second, the LEAP-Bulgaria model results are compared. The focus is on the transition rates of renewable energies. Finally, the transition rates are derived and implemented in an input-output model for each country. Thereby, the transition rates of the implemented scenarios can be broken down into the detailed changes in input-output coefficients underlying the low-carbon transition of the Optimal-Level Transition (OLT) and Mid-Level Transition (MLT) scenarios. The basis for the model calculations are transition rates that have been developed based on the MLT and OLT scenarios. These transition rates have been developed in the framework of WP3.

Comparing the transition rates of the Austrian MEDEAS_at and the Bulgarian MEDEAS_bg with the scenarios in WP3, we find:

- a significantly lower growth trajectory in the real data from 2010 to 2015 for solar energy than what has been assumed in the scenarios for Austria.
- the actual growth has been considerably stronger in Bulgaria for solar energy.

We conclude that the initial growth trajectories can be considered realistic, given that several annual growth rates exceed the average considerably and have therefore demonstrated the feasibility of a fast transition. Nevertheless, historical data only shows the beginning of the transition with exponential growth rates. While it is relatively easy to keep up high growth rates in

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the first phase, maintaining this growth trajectory becomes more and more difficult the higher the saturation. As the technology implementation reaches maturity, it will become harder to keep up the high growth rates. There are several physical (infrastructures) and political feedbacks that reduce adoption rates, including political resistance by multiple actors in the energy sector.

Comparing the transition rates of TIMES-Austria, the following observations can be made:

- the growth trajectories are linear in TIMES-Austria, while WP3 assumes exponential growth with constant growth rates.
- a considerably slower adoption of wind and solar PV in comparison with the WP3 scenario implementation.

Comparing the transition rates of LEAP-Bulgaria with the scenario implementation in WP3, the observed changes are ambiguous. We find:

- hydroelectricity remains roughly constant in the MLT, but also in the OLT scenarios in Bulgaria, while the scenario implementation in WP3 assumes a growth rate of 1.4% annually for Bulgaria and Austria
- The growth trajectory for wind comes closest to a very strong growth rate used in WP3, which leads to a doubling of wind electricity from 2030 to 2050 in the MLT and a stronger growth in the OLT scenario.
- The comparably similar growth of solar PV, albeit with a higher share in the beginning, results in the roughly same level as the share of wind.
- Notably, nuclear electricity generation remains fairly constant throughout the modelled time period until 2050 in the MLT scenario, but a strong investment leap into nuclear fuels in 2035 in the OLT scenario is modelled.

The fourth part of the deliverable concerns the transfer of the scenario results into input-output structures to identify transition rates in the resulting input coefficients of the electricity sector. The methodology implemeted is applied the modelling of monetary fluxes with input-output models. Specifically, we focus on the technical input coefficient structural changes, as understanding to this concept is crucial for analysing structural changes in the economy (i.e. transition to the low-carbon economy in this case).

The following key findings can be derived from this analysis:

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- We find a strong reduction in the cost share of mining & quarrying in the OLT scenario in both countries. This share increased heavily in the aftermath of the financial crisis in Austria, and was already very high in Bulgaria.
- The serious drop of the overall intermediate inputs in the Bulgarian case is likely to be caused by significantly lower need of mining and quarrying domestic products to proceed with construction of the renewable sources infrastructure.
- Regarding the differences between MLT and OLT scenarios in Bulgaria, we can observe that in the case of MLT (with slightly higher deployment of wind, instead of nuclear power, which has a lower share than in OLT) the inputs from other sectors such as Land transport and transport via pipelines or the sector electricity itself are slightly lower.

An uncertainty concerns the nuclear electricity share (in the Bulgarian case), because the share of nuclear power in the mix remains approximately stable over the analysed period of the scenarios.

The analyses concerning cost share trajectories are necessary ingredients to derive labour demand effects of the energy transition in WP6.2.

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Introduction

The development of a consistent scenario framework requires the comparison of initial scenarios and implemented scenarios and related transition rates of changes. This is crucial when multiple modelling frameworks are used at different scales. This deliverable focuses on the scenario implementation in all country-level models and a comparison with the expected WP3 pathway transition rates of change. The key objective of the scenario development process was to fit the scenario input data of the national level Vensim models MEDEAS_at and MEDEAS_bg to the Carbon Budget available for both countries within the Mid-level and the Optimal transition scenarios MLT and OLT. Given that a scenario comparison between the different models requires implementation at the national scale, no comparison with other levels (MEDEAS_eu and MEDEAS_w) is possible. The analysis therefore focuses on the national level models.

In Section 1, the scenario implementation and the underlying and resulting transition rates of WP3 are summarized. In the first sub-section, the fitting of GHG emission pathways for Austrian OLT-2020 and MLT- 2030 scenarios and the resulting energy share transition rates are reported. In the second sub-section, the fitting of GHG emission curves for Bulgarian OLT-2020 and MLT-2030 scenarios and the resulting energy share transition rates are reported.

In Section 2, the scenario implementation in the country-level MEDEAS models, i.e. MEDEAS_at and MEDEAS_bg are summarized and compared with the expected WP3 scenario implementation and pathway transition rates.

In Section 3, the country-level linear optimisation model results of TIMES and the model results of LEAP concerning transition rates are depicted. First, the TIMES-Austria model results concerning scenario implementation and transition rates are summarized and compared with the expected values in WP3. Second, the LEAP-Bulgaria model results are compared. The focus is on the transition rates of renewable energies. Finally, the transition rates are derived and implemented in an input-output model for each country. Thereby, the transition rates of the implemented scenarios can be broken down into the detailed changes in input-output coefficients underlying the low-carbon transition of the Optimal-Level Transition (OLT) and Mid-Level Transition (MLT) scenarios. The basis for the model calculations are transition rates that have been developed based on the MLT and OLT scenarios. These transition rates have been developed in the framework of WP3.

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Section 4 provides an implementation of the scenario results within an input-output framework. The first part describes the methodology implemented in this part of the deliverable, namely an input-output method applied to the modelling of monetary fluxes. First, we provide a brief overview of input-output coefficients and then focus on the technical inout coefficients, because this is crucial for analysing structural changes in the economy concerning the transition to the low-carbon economy in this case. We report OLT and MLT scenario implementations and related input coefficient changes for Austria and Bulgaria, describing the key observations concerning transition changes in both countries.

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1. Scenario development and transition rates (WP3)

The basis for the model calculations are transition rates that have been developed based on the MLT and OLT scenarios. These transition rates have been developed in the framework of WP3.

First, we parameterized the scenarios on the basis of the past evolution of transition rates of renewable energies with a focus on the global scale. Although the focus of this Deliverable is on the national scale of Austria and Bulgaria, we report here also the past transition rates on a global scale that have informed WP3 and the MEDEAS world model MEDEAS_w and also have implications for the transition rates in Austria and Bulgaria.

Below we show trends regarding the global use of different types of energy from 1995 to 2010, based on our own calculations with the WIOD data. Figure 1 shows the evolution of the energy mix by different sources on the global level on a log-normal scale, based on the WIOD database.

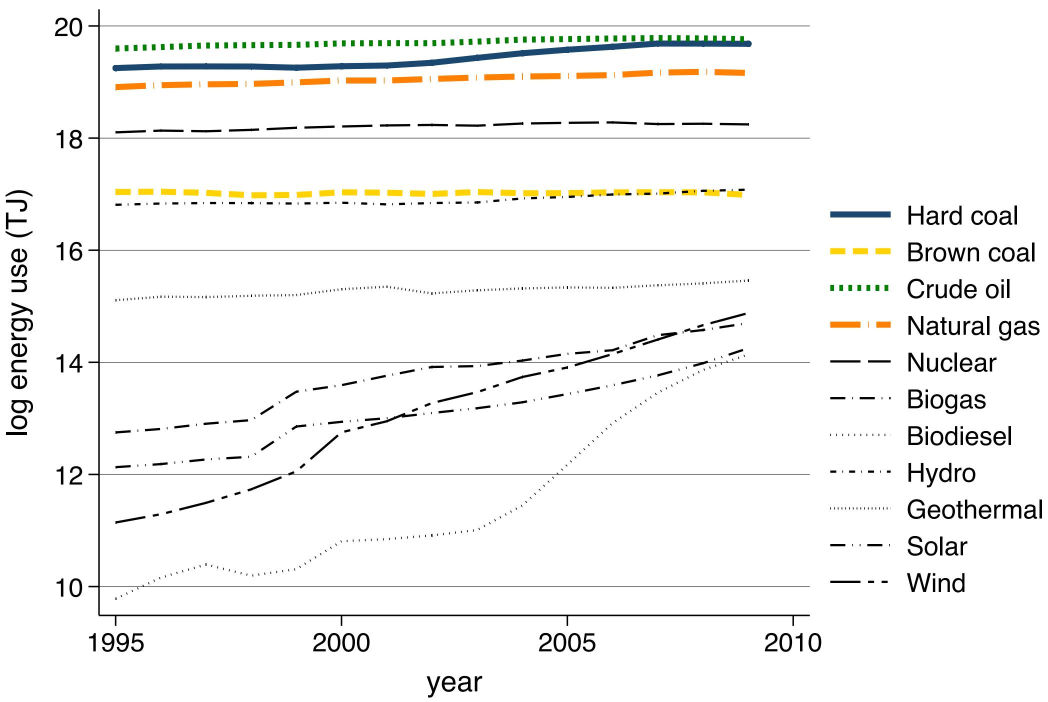

Figure 1: Log global energy use by source (TJ) (*Source: own calculations based on WIOD)*

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Note that the rates of change are changing through time. The rates have increased drastically for biodiesel (dashed line) from 2003 onwards. On the fossil side, also the use of hard coal has increased from 2003 onwards, but then remained on a plateau from 2007 onwards.

Most importantly, wind energy has overtaken all other new renewable energies and also outpaced biogas. Given our focus on the relation of solar PV and wind energy in relation to fossil energy sources, this is a crucial phenomenon. It is also important to highlight that wind outpaced solar PV and this gap is not closing in 2009. Although country characteristics concerning solar radiation and wind exposure will matter for the detailed trajectories below, also the global trajectories have effects on economies-of-scale, learning curves, costs and ultimately technology adoption.

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1.1. Methodology to develop scenarios and transition rates in WP3

The key objective to develop the transition rates was the aim to fit the scenarios of the national level Vensim models MEDEAS_at and MEDEAS_bg to the Carbon Budget available for both countries within the Mid-Level and the Optimal Transition scenarios MLT and OT.

For this procedure INSTM used an updated version of the theoretical scenarios elaborated in the D5.1 in WP5, considering the requirements of the Austrian Energy Agency (AEA)- called OLT2020_aea and MLT2030_aea, and reported in task 3.5b, and adjusting the values of the list of variables agreed by all the partners during the Florence General Assembly (February 2018) including further parameters such as a selection RCPs emissions scenarios, modification in the efficiency policies section and the % of recycling minerals.

The INSTM methodology consists of trying to fit the Greenhouse Gas (GHG) pathways described for OLT2020_eu_aea and MLT2030_eu_aea scenarios in Europe (see table 1) with the emissions curve elaborated by the MEDEAS EU model in Vensim version (MEDEAS_eu), in order to obtain information about the possible input variables involved in reaching the desired Carbon Budget (108 GtCO2 cumulated from 2012 to 2050).

First of all, INSTM started assuming the Green Growth_eu and the countries Green Growth_at and Green Growth_bg set of variables as the baseline scenarios for the development of the simulations of scenarios as tentative to achieve the desirable Carbon Budgets trajectories developed in task 3.5b : theoretical scenarios for EU (OT2020_eu_aea and MLT2030_eu_aea) and countries (OT2020_at_aea, OT2020_bg; MLT2030_at_aea, MLT2030_bg_aea), realised modifiing the INSTM in D5.1 according AEA requirements. In fact, the set of Green Growth scenarios (developed by UVa, D4.2) represent the first step to decarbonisation, because the emissions pathways in the Green Growth scenarios are lower than in BAU scenarios at all geographical levels, but anyway not sufficient to fit the desirable theoretical carbon budgets; thus INSTM considered that a series of variables have to be revisited.

For this reason, INSTM adjusted the set of exogenous variables in MEDEAS_eu, in particular, those referred to socio-economic aspects and renewable energy development, trying to individuate the best set of parameters that allow matching as close as possible the emission curves elaborated in task 3.5b (WP3) and task 5.1 (WP5). These curves were calculated as a simple exponential or

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power decay function to lead the design of decarbonisation scenarios. These were grouped in the OLT scenario family, that lists mitigation actions implemented from 2020, and the MLT scenario family, where actions come into effect from 2030. Before those years, the emissions trends are assumed to evolve as BAU.

The summary of theoretical carbon budgets [1] scenarios elaborated by INSTM are reported in the following table.

Table 1: Carbon Budgets goals from 2012 to 2100 elaborated in D5.1

Carbon Budgets 2012- 2100 D5.1(WP5)	OLT (GtCO2 eq)	MLT (GtCO2 eq)
World	1949	1949
Europe	122	122
Austria	1,85	1,85
Bulgaria	1,45	1,7(*)

(*) waiting in BAU trend until 2030 almost all the 1,45 has been burnt by the next 10 years (2039), no improvement for any higher decay power

MEDEAS models consider a time span up to the year 2050, thus the carbon budgets for the simulations are the only portion of 2012-2050. Moreover, a special set of theoretical scenarios has been developed for TIMES MARKAL model comparison (for AEA).

All the carbon budgets targets from 20102 to 2050 are reported in the following table.

[1] Carbon budgets (see : https://www.wri.org/ipcc-infographics) have been evaluated according to their definition: they represent the amount of CO2 can be released in the atmosphere from 2012 to 2100 to obtain a global warming no higher than 2°C in agreement with the COP 21 goal.

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Table 2: Carbon Budgets goals from 2012 to 2050 evaluated in task 3.5 a and 3.5b of WP3

Carbon Budgets 2012-2050 (task 3.5a and 3.5b in D3.5)	OLT Theoretical curves nomenclature	OLT Carbon Budgets (GtCO2 eq)	MLT Theoretical curves nomenclature	MLT Carbon Budgets (GtCO2 eq)
World	OLT2020_w	1605	MLT2030_w	1882
Europe	OLT2020_eu	109	MLT2030_eu	121
Austria	OLT2020_at	1,66	OLT2030_eu	1,79
Bulgaria	OLT2020_bg	1,28	MLT2020_bg	1,60
Europe modified for AEA	OLT2020_eu_aea	108	MLT2030_eu_aea	108
Austria modified for AEA	OLT2020_at_aea	1,66	MLT2030_eu_aea	1,66
Bulgaria modified for AEA	OLT2020_bg_aea	1,28	MLT2030_bg_aea	1,28

The simulated scenarios reported in the present analysis refer to the achievement of AEA theoretical scenarios (the same carbons budget by 2050, for OLT nad MLT, for EU , Au, Bg) for EU (OT2020_eu_aea and MLT2030_eu_aea) and countries (OT2020_at_aea, OT2020_bg; MLT2030_at_aea, MLT2030_bg_aea).

The scenario framework including the main characteristics of each scenario is described in the table below. In order to fit the carbon budget, INSTM has developed a set of Green Degrowth scenarios for the MLT and the OLT scenario families. Nomenclature of simulated scenarios are reported in table 3.

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Table 3: MEDEAS models simulated scenarios reported in task 3.5 b. They aims to reach decarbonisation targets represented by the Carbon Budgets goals from 2012 to 2050 elaborated for AEA and reported in the previous table 2.

Europe	BAU_eu	UVa
	Green Growth_eu	UVa
	Green Degrowth 2020_eu_aea	INSTM
	Green Degrowth 2030_eu_aea	INSTM
Austria	BAU_at	UVa
	Green Growth_at	UVa
	Green Degrowth 2020_at_aea	INSTM
	Green Degrowth 2030_at_aea	INSTM
Bulagaria	BAU_bg	UVa
	Green Growth_bg	UVa
	Green Degrowth 2020_bg_aea	INSTM
	Green Degrowth 2030_bg_aea	INSTM

The scenarios include modifications of a set of variables concerning socio-economic aspects and renewable energy development in particular, which are described in the related sub-sections below. Due to the different model structures and model objectives, the models also differ concerning exogenous and endogenous parameters. Therefore, a harmonization procedure was necessary as the scenario input data had to be made exogenous for some parameters in MEDEAS which are exogenous by default in TIMES and LEAP. Nevertheless, given the optimisation procedure in TIMES and the simulation experiments in MEDEAS, the scenario rate of change comparisons between the different model scenario implementations remains necessarily qualitative.

The Input-Output Analysis was confronted with the different scenario assumptions concerning GDP growth. For harmonization purposes, and to provide an analysis that isolates the energy mix effects on coefficient changes from the effects of GDP growth (ceteris paribus), we first conducted analyses that only changed the energy mix according to the proportions derived in TIMES-Austria and LEAP-Bulgaria. Subsequently, we selected the endogenous growth paths that were reported in

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D4.2, given that MEDEAS endogenously derives GDP growth trajectories when any resource constraints become effective.

Table 2: Scenarios and underlying characteristics used for comparison

Dimension	BAU	MLT			OLT		
Sub-family		Green Growth	Green Degrowth	Endo-genous growth	Green Growth	Green Degrowth	Endo-genous growth
Main characteristics of the scenario	This is the baseline extrapolating 2012 parameters	The mid-level transition considers the start of transition policies in 2030			The optimal-level transition considers direct policy implementation to identify the optimal mitigation path		
Year of policy implementation	-	2030			2020		
GDP		SSP2	modified	end.	SSP2	modified	end.
Best approximation to carbon budget reached			X			X	
Model coverage:							
MEDEAS_at	X	X	X	X	X	X	X
MEDEAS_bg	X	X	X	X	X	X	X
TIMES-Austria	X				X		
LEAP-Bulgaria	X	X			X		
IOA-Austria				X			X
IOA-Bulgaria				X			X

In the first sub-section, we report the simulations of GHG theoretical emission pathways for Austrian OT2020_at_aea and MLT2030_at_aea scenarios and the resulting energy share transition rates.

In the second sub-section, we report simulations of GHG theoretical emission pathways for Bulgarian OT2020_bg_aea and MLT2030_bg_aea scenarios and the resulting energy share transition rates.

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1.2. Scenarios and transition rates for Austria (WP3)

The energy source transition rate changes will be derived after fitting the GHG emission scenarios.

We report here the simulation of the GHG emission scenarios for Austria considering two cases: when the emission reductions policies are applied starting from 2020 and 2030. In the case of OLT2020_at_aea and MLT-2030_at_aea scenarios for Austria, the cumulated CB that can be burnt from 2012 until 2050 is 1,6 $GtCO_{2eq}$(or 0,43 GtC). As mentioned before, the tajectories to simulate have to be the same Carbon Budget by 2050 for OLT and MLT trajectories, and same rate of emissions for both in 2050.

Since the emission pathways of the Green Growth_at do not match the desirable carbon budget, INSTM considered that a series of variables had to be revisited. The results of simulation experiments are reported in the following figure 2.

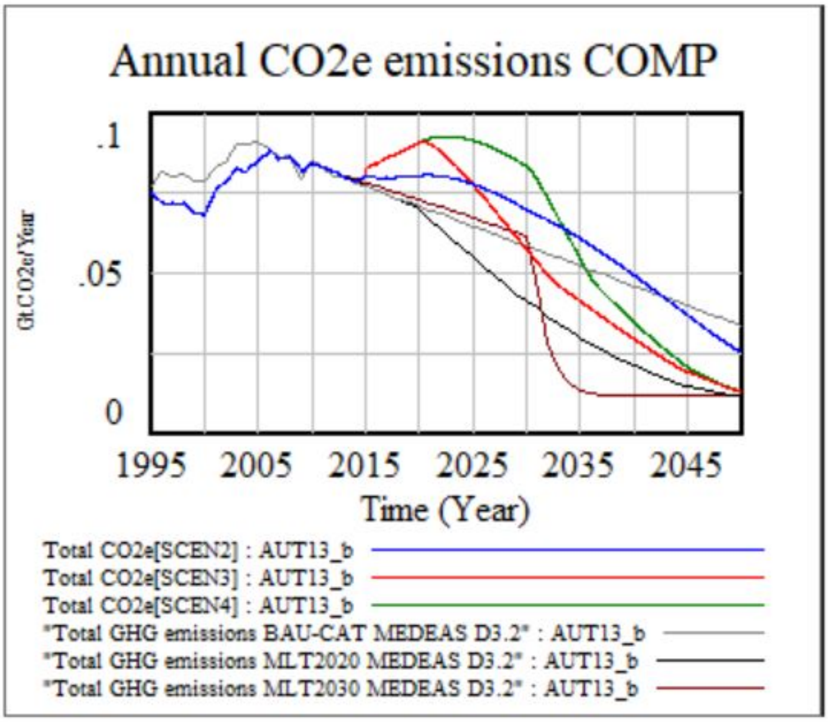

Figure 2 : Total GHG emissions pathways for Austria. The black line is the OT2020_at_aea emission scenario, the dark red is the MLT2030_at_aea emission scenario, the grey one is the BAU_at emission scenario, the blue line is the Green Growth_at scenario, and the red one the Green Degrowth_at_aea 2020 and the green one the Green Degrowth 2030_at_aea, both for Austria.

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In the figure 2, the black line is the OLT2020_at_aea emission scenario taking into account AEA requirements, the dark red is the MLT2030_at_aea emission scenario taking into account AEA requirements, the grey one is the BAU_at emission scenario, the blue line is the *Green Growth_at* scenario, and the red one the *Green Degrowth_at_aea 2020* and the green one the *Green Degrowth 2030_at_aea* for Austria.

The *Green Degrowth 2020_at_aea* and the *Green Degrowth 2030_at_aea* differentiate themselves only by the year in which the policies start except for the GDP. The historical GDP values 2015-2017 and the projection 2018- 2019 are taken from the OECD database (https://data.oecd.org/gdp/real-gdp-forecast.htm#indicator-chart) and the projections from 2020 to 2100, the GDP follow the trend of Green Growth_at.

The "Techno-ecological potential electric RES" parameters are not revisited and they are maintained similar to those used in Green Growth_at. P nuclear scen3-4 (%annual variation) is fixed at 1,5% in Green Degrowth 2020_at_aea and Green Degrowth 2030_at_aea as in Green Growth_at, while in BAU_at is set to zero. The variables in section Projection electric RES are maintained equal to Green Growth_at excepted for P PHS and P CSP annual growth percentages that assumed respectively the values 10% and 36%.

The following table depicts the annual growth rates for the renewable energy sources.

Table 3: Variables within the section Projection electric RES for Austria (Source : WP3.5b).

Projection electric RES					
P hydro growth	annual growth%	1,4%	Start year P growth RES elec	Year	2020
P got-elec growth	annual growth%	6,8%	Target year P growth RES elec	Year	2025
P solid bioE-elec growth	annual growth%	7,0%			
P oceanic	annual growth%		share installed PV urban vs tot PV	Dmnl	75%
P onshore wind	annual growth%	17,4%			

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The most important information for the comparison with the country-level scenario implementation and transition rates modeled with TIMES-Austria and LEAP-Bulgaria and the country-level input-output model implementation is the annual growth rate for wind and solar PV.

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1.3. Scenarios and transition rates for Bulgaria (WP3)

As in the case of Austria, the energy source transition rate changes will be derived after fitting the GHG emission scenarios. We report here the fitting of the GHG emission scenarios for Bulgaria considering two cases: in one case policies are applied starting from 2020 and the other one they start from 2030. In the case of OLT2020_bg_aea and MLT2030_bg_aea scenarios for Bulgaria, the CB that can be burnt until 2050 is 1,4 $GtCO_{2eq}$(or 0,38 GtC). As for the previous case of Austria, also for Bulgaria the theoretical OLT2020_bg_aea and MLT2030_bg_aea trajectories reported here have the same Carbon Budget by 2050 for OLT and MLT trajectories, and same rate of emissions for both in 2050 (see provisional version of task 3.5b being a part of the last WP3 deliverable - D3.5- will be realesed by the end of 2018).

Since the emission pathways of the *Green Growth_bg* do not match the desirable carbon budget, INSTM considered that a series of variables had to be revisited. The results of simulation experiments are reported in the following figure.

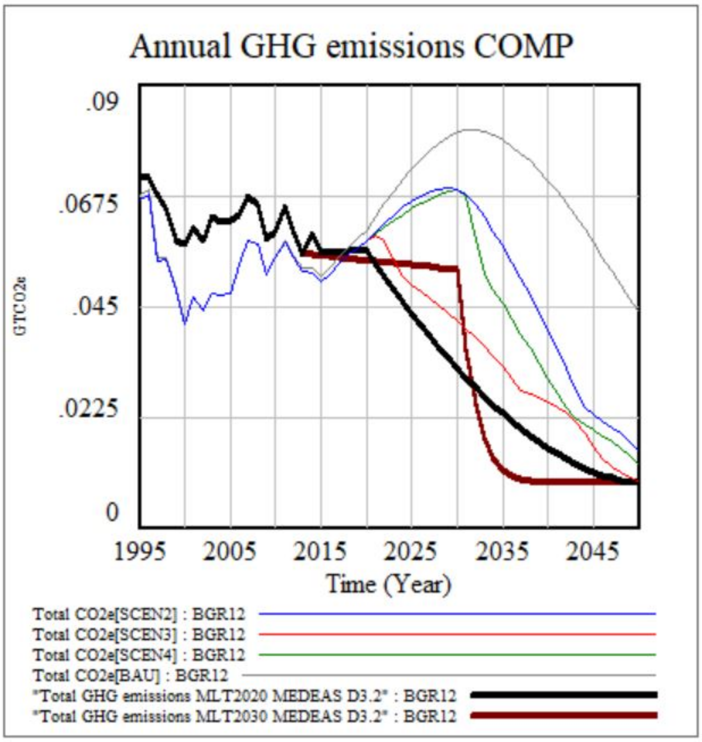

Figure 3 : BULGARIA. Total GHG emissions pathways for Bulgaria.

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In the figure, the black line is the OT2020_bg_aea emission scenario, the dark red is the MLT2030_bg_aea emission scenario, the grey one is the BAU_bg emission scenario, the blue line is the Green Growth_bg scenario, and the red one the Green Degrowth 2020_bg_aea and the green one the Green Degrowth 2030_bg_aea for Bulgaria.

The Green Degrowth 2020_bg_aea and the Green Degrowth 2030_bg_aea differentiate itself only by the year in which the policies start. The GDP and population trends are the same used for Green Growth_bg and BAU_bg.

The "Techno-ecological potential electric RES" parameters are not revisited and they are maintained similar to those used in Green Growth_bg. P nuclear scen3-4 (%annual variation) is fixed at 1,5% in Green Degrowth 2020_bg_aea and Green Degrowth 2030_bg_aea as in Green Growth_bg, while in BAU_bg is set to zero.

The variables in section Projection electric RES are maintained equal to Green Growth_bg excepted for P PHS and P CSP annual growth percentages that assumed respectively the values 10% and 36%. The share installed PV urban vs total PV is set at 75% as Green Growth_bg (in BAU 50%).

The following table depicts the annual growth rates for the renewable energy sources.

Table 4 : Variables within the section Projection electric RES for Bulgaria (Source : WP task 3.5b – provisional version).

Projection electric RES					
P hydro growth	annual growth%	1,4%	Start year P growth RES elec	Year	2020
P geot-elec growth	annual growth%	6,8%	Target year P growth RES elec	Year	2025
P solid bioE-elec growth	annual growth%	7,0%			
P oceanic	annual growth%		share installed PV urban vs tot PV	Dmnl	75%
P onshore wind	annual growth%	17,4%			

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Most importantly, wind and solar PV are set at roughly the same level as for Austria. This will be the most important information for the comparison with the country-level scenario implementation and transition rates modeled with TIMES-Austria and LEAP-Bulgaria and the country-level input-output model implementation.

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2. MEDEAS country-level scenario implementation and transition rates

A comparison of the scenario transition rates with the MEDEAS national model implementation of MEDEAS for Austria and MEDEAS for Bulgaria is conducted in this chapter.

The country-level MEDEAS model structure is embedded in a nested structure into the MEDEAS model at world level (MEDEAS_w) and the Euoprean model (MEDEAS_eu). The following flow chart figure describes the embedded structure.

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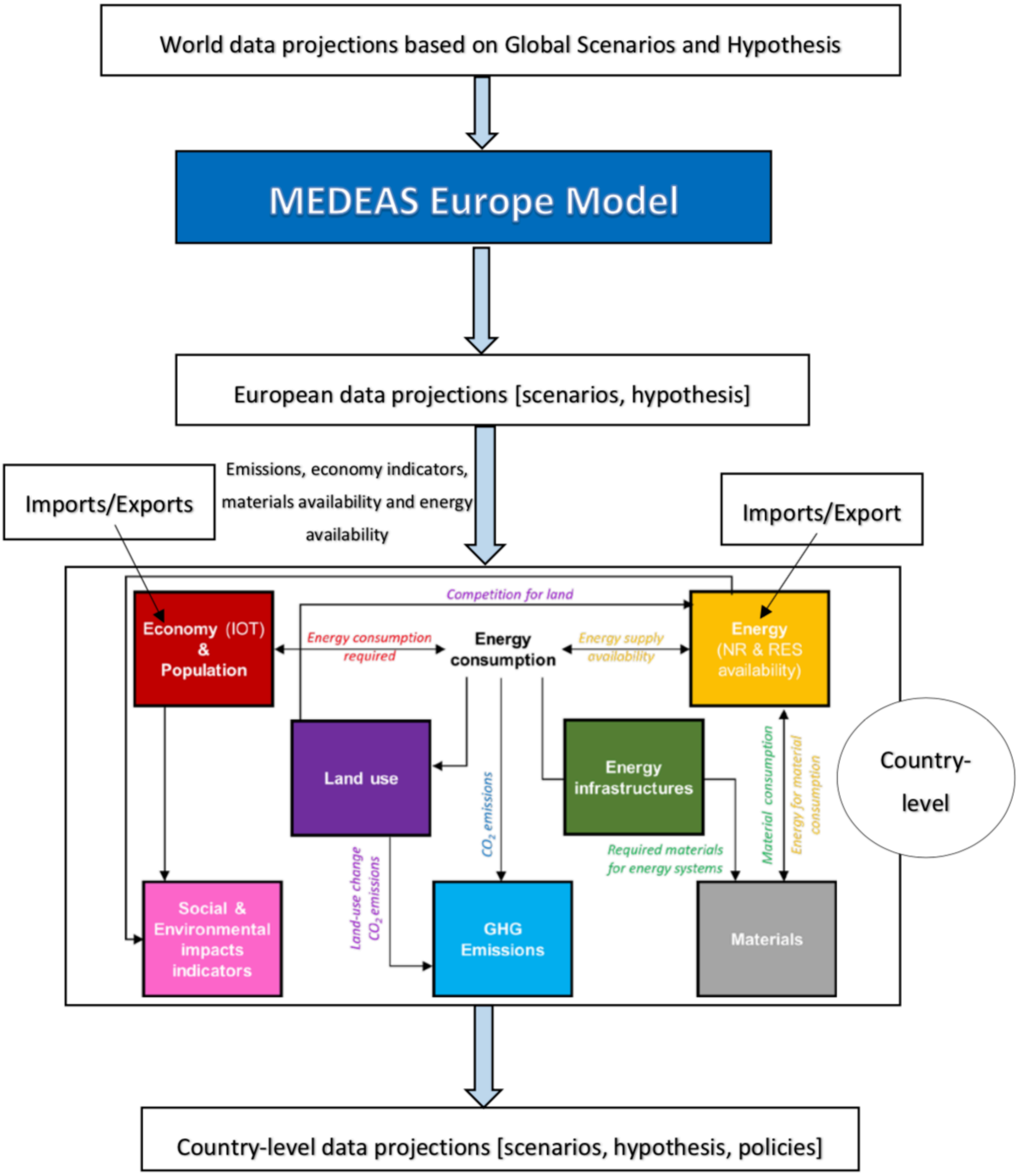

Figure 4: Country-level MEDEAS model embedded in the European MEDEAS model

First, both national models have been calibrated with the most recent past trajectories of renewable energy production in both countries. The following figures depict the underlying energy production per capita (ktoe/cap) for wind and solar energy.

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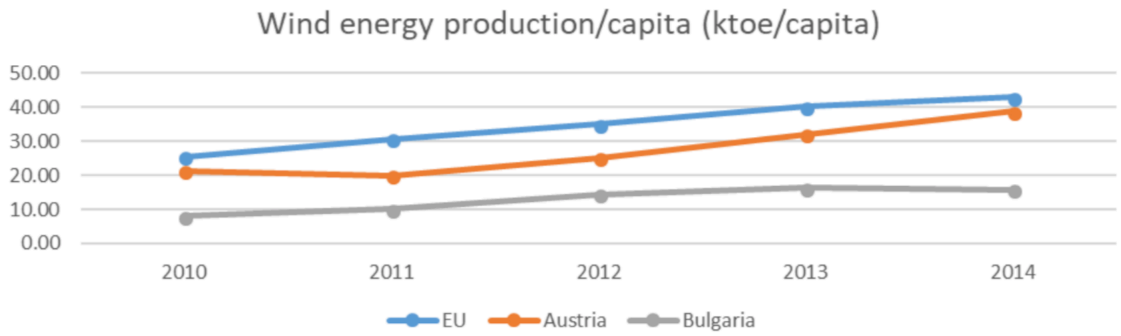

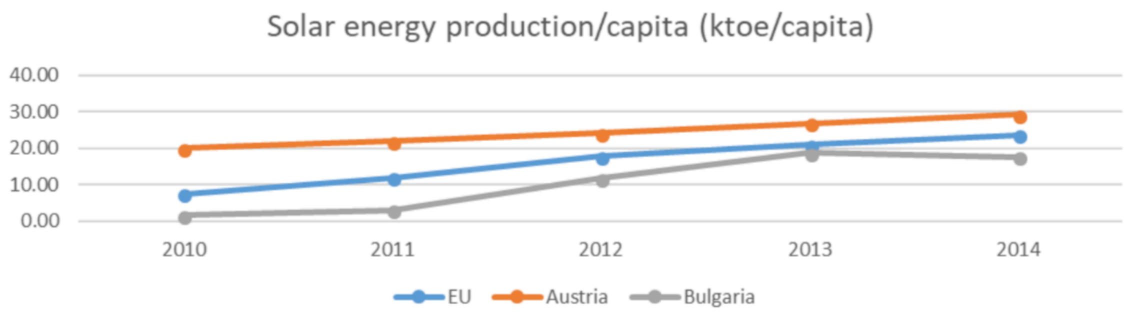

Figure 5: Wind and solar energy production per capita in the EU, Austria and Bulgaria

Concerning wind, the following observations can be made: Notably, neither Austria nor Bulgaria were reaching the EU average until 2014 in the case of wind. Nevertheless, Austria had a rapid growth in wind energy production, while the rapid growth in Bulgaria in the 2000s did not continue.

Concerning solar energy, the following observations are noteworthy with regard to the model implementation: Bulgaria had a late but rapid growth of solar energy production from 2011 to 2013, but from a negligible level, and without a persistent change of the growth trajectory after 2013.

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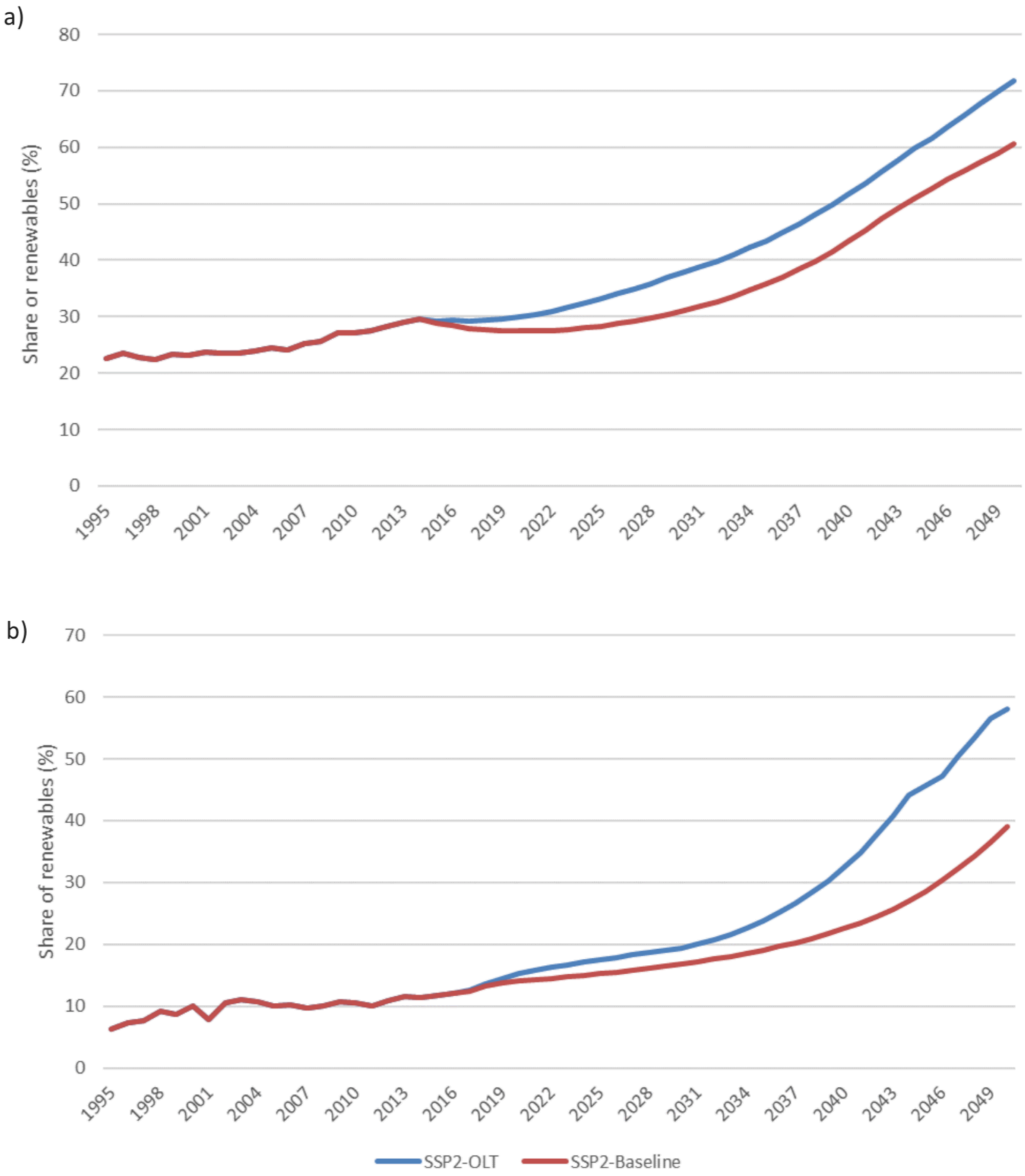

Figure 6: Share of renewables in the energy mix of (a) Austria and (b) Bulgaria for the OLT and the BAU scenario.

For comparative purposes, we provide here the annual percentage changes for the country-level solar and wind energy production. This helps to compare with the parameterization used in WP3. Table 3 provides the rates of change for solar energy production, and table 4 provides the same data for wind.

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Table 5 : EU-28 and country-level solar energy production and annual change

Variable	2010	2011	2012	2013	2014	Scenario
EU-28 (ktoe)	3716.94	6037.63	9009.01	10643.07	12008.67	
Austria (ktoe)	167.51	183.25	203.35	227.86	249.69	
Bulgaria (ktoe)	11.51	22.51	85.41	136.1	127.35	
EU-28 (%)		62%	49%	18%	13%	
AUT (%)		9%	11%	12%	10%	19%
BGR(%)		96%	279%	59%	-6%	19%
EU-28 (ktoe)	3716.94	6037.63	9009.01	10643.07	12008.67	

Table 6 : EU-28 and country-level wind energy production and annual change

Variable	2010	2011	2012	2013	2014	Scenario
EU-28 (ktoe)	12844.7	15451.88	17717.63	20364.46	21771.5	
Austria (ktoe)	177.5	166.5	211.73	271.07	330.76	
Bulgaria (ktoe)	58.57	74.05	105.01	118.16	114.47	
EU-28 (%)		20%	15%	15%	7%	
AUT (%)		-6%	27%	28%	22%	17,4%
BGR(%)		26%	42%	13%	-3%	17,4%
EU-28 (ktoe)	12844.7	15451.88	17717.63	20364.46	21771.5	

Comparing the transition rates with the scenarios in WP3, we find a significantly lower growth trajectory in the real data from 2010 to 2015 for solar energy than what has been assumed in the scenarios for Austria (see Tables 3 and 4). Conversely, the actual growth has been considerably stronger in Bulgaria for solar energy. Nevertheless, the longer growth trajectories can be considered realistic, given that several annual growth rates exceed the average considerably.

Important for our concerns is the relation to the WP3 scenarios (see Tables 1 and 2), but also the relation to a complete transition with a fully renewable energy provision in Austria and Bulgaria. This relationship has implications for the input-output structure of the economy and the resulting

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input-output analyses. The following sections will look at the scenario implementation and the resulting transition rates for Austria and Bulgaria with the country-level models TIMES-Austria and LEAP-Bulgaria.

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3. Country-level model scenario implementation and results

3.1. TIMES-Austria scenario implementation and transition rates

TIMES-Austria is the linear optimisation model used in MEDEAS. The optimisation is linear because the relations between variables are assumed to be linear. TIMES is a frequently used energy system model generator using optimisation to minimize the costs of the energy system. TIMES optimises across all sectors and across all time periods, and therefore provides for an optimal inter-temporal allocation of costs. This has important implications for the scenario results in comparison with the scenario implementation in WP3, as will be discussed below. TIMES-Austria was developed to create medium to long-term scenarios for the Austrian energy system. The optimisation is conducted according to a number of constraints that are built into the model and can be parameterized. The main output from TIMES are energy system structures, which meet the end-use energy service demands at the least cost.

Crucially, in the TIMES model, energy demand development is to a large extent the result of exogenous scenario parameters including, most importantly, GDP growth and population growth. These parameters need to be assumed or modelled within a different framework. In MEDEAS, growth is exogenous only until energy limits are reached (if reached). Notably, there is no feedback from the energy system to GDP within TIMES, which has implications for WP3 scenario transition rate comparisons.

The system boundaries of the TIMES model include the Austrian energy system and it is structured into several sectors (industry, households, agriculture, electricity and district heat supply etc.). To allow for direct and easy comparison with historical data the structure of the model and model results is largely consistent with Austrian energy statistics.

TIMES includes several assumptions that have implications for the results. First, 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.). Second, TIMES-Austria assumes perfect equilibrium between supply and demand. This equilibrium is created by the price-elasticity of demand. This elasticity is currently assumed constant in TIMES-

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Austria due to the lack of data and knowledge for how this influences energy demand. In fact, in TIMES-Austria prices only influence the competitiveness of different fuel technologies, power plants and buildings.

A more detailed description of the model structure, including other assumptions and implications and also a number of limitations can be found in Deliverable 5.1 on the model cross-comparison and qualitative evaluation (MEDEAS 2018b).

The following figure depicts the structure of TIMES-Austria.

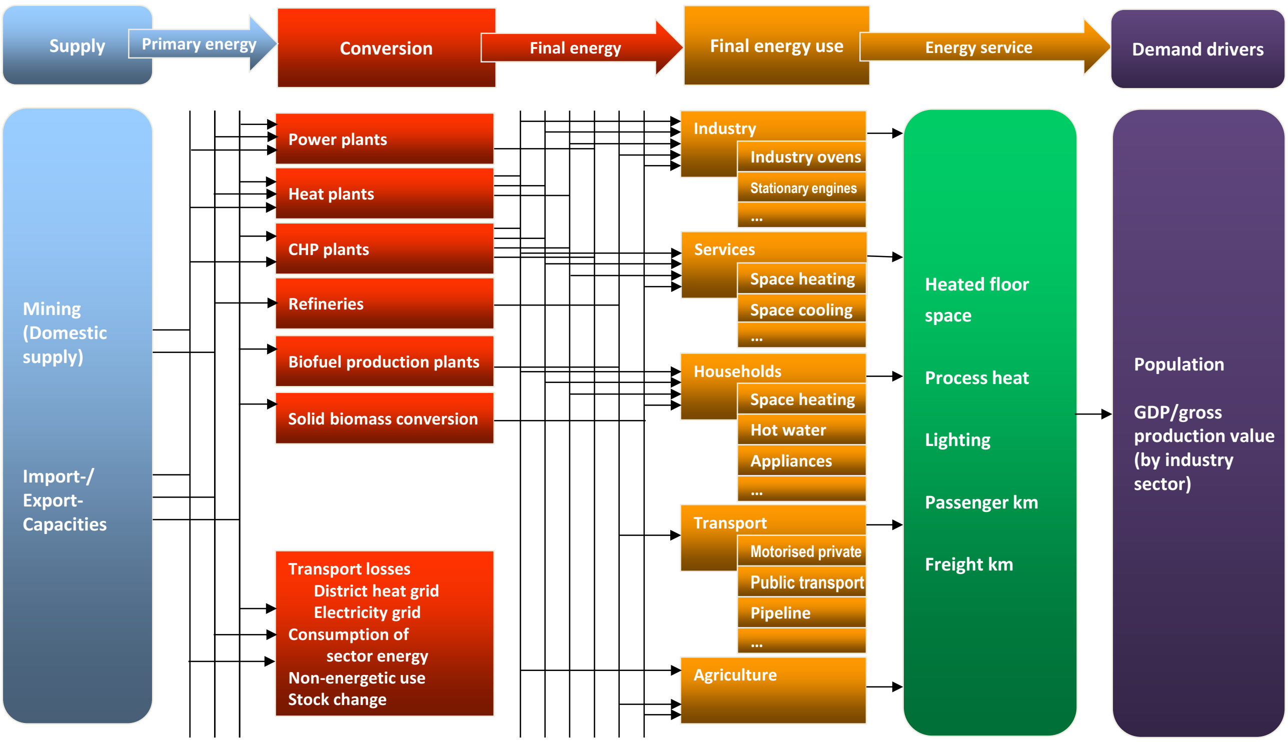

Figure 7: The structure of TIMES-Austria (Source: AEA, 2017).

Resulting from the scenario implementation in TIMES-Austria, the following rates of change for renewable energies in each scenario have been reported:

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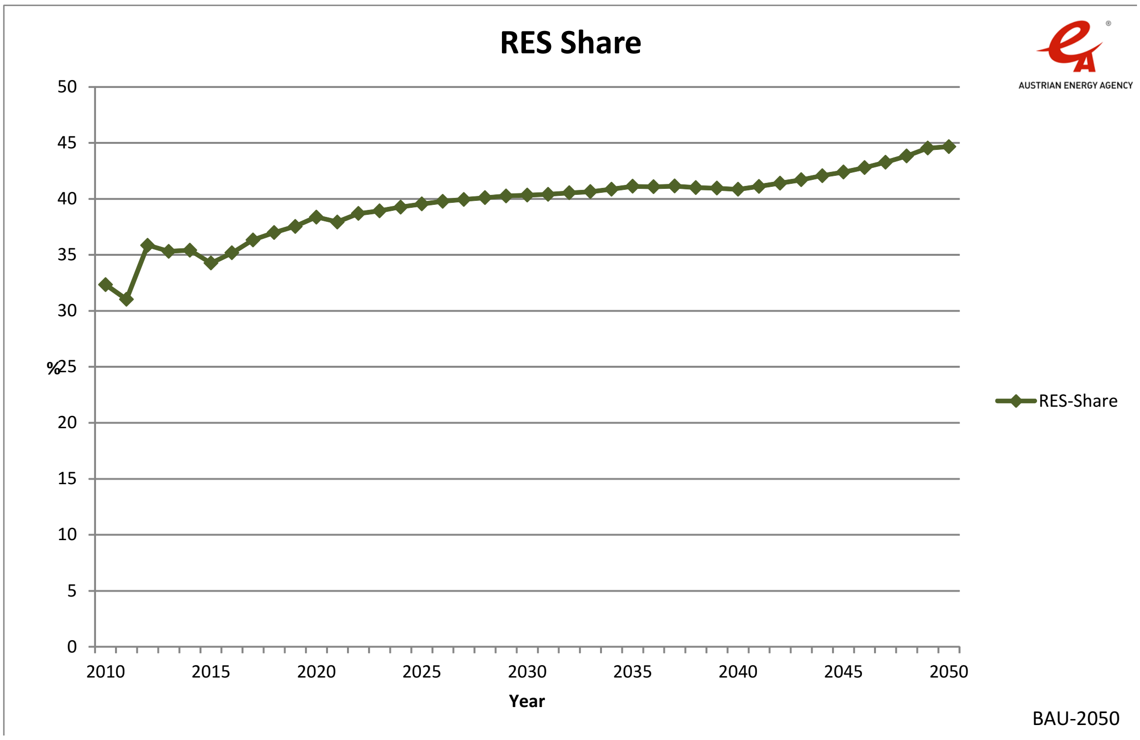

Figure 8: RES Share – Scenario BAU.

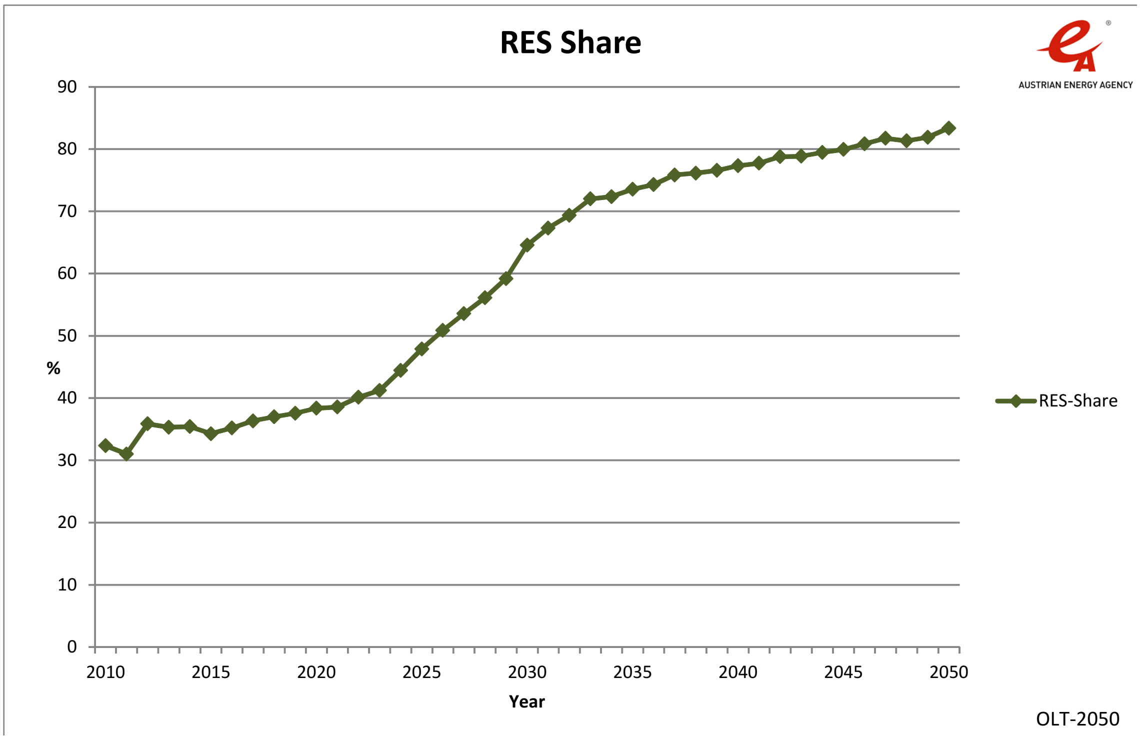

Figure 9: RES Share – Scenario OLT.

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The following figures compare the results from BAU and OLT scenarios for final energy consumption, GDP, and the renewable energy shares in Austria.

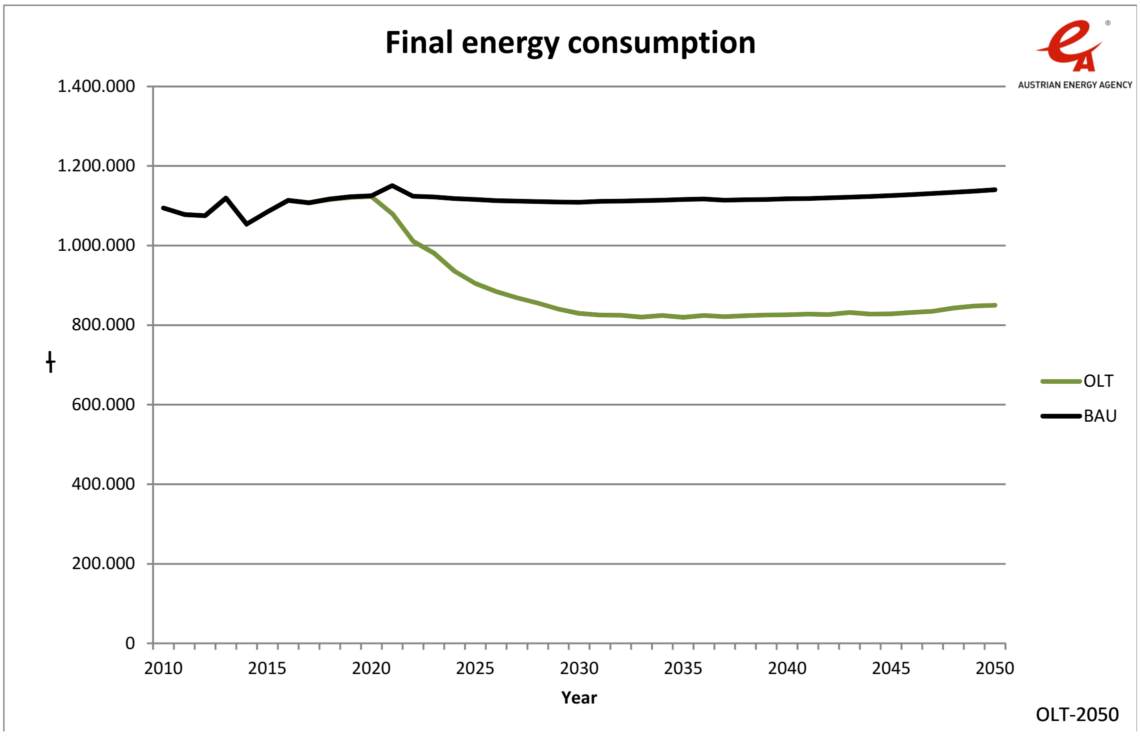

Figure 10: Final energy consumption.

The final energy consumption (FEC) by energy carrier in the OLT scenario is depicted in the following figure.

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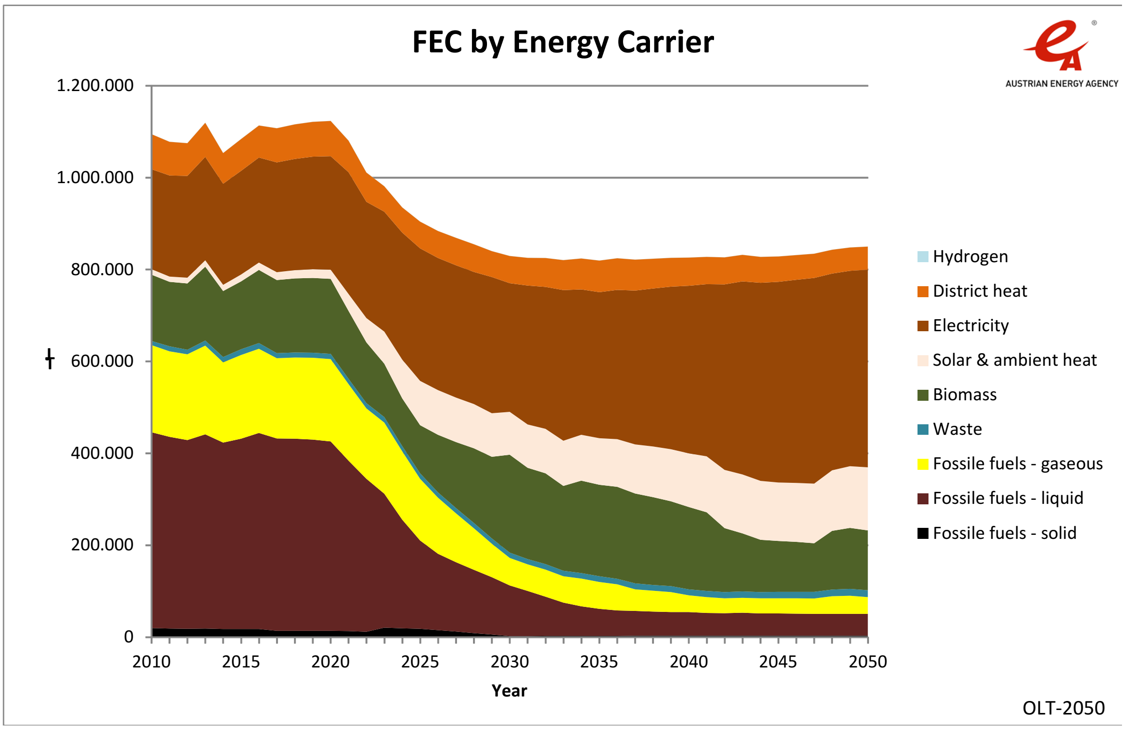

Figure 11: FEC by Energy Carrier – Scenario OLT.

The underlying gross domestic consumption is depicted below.

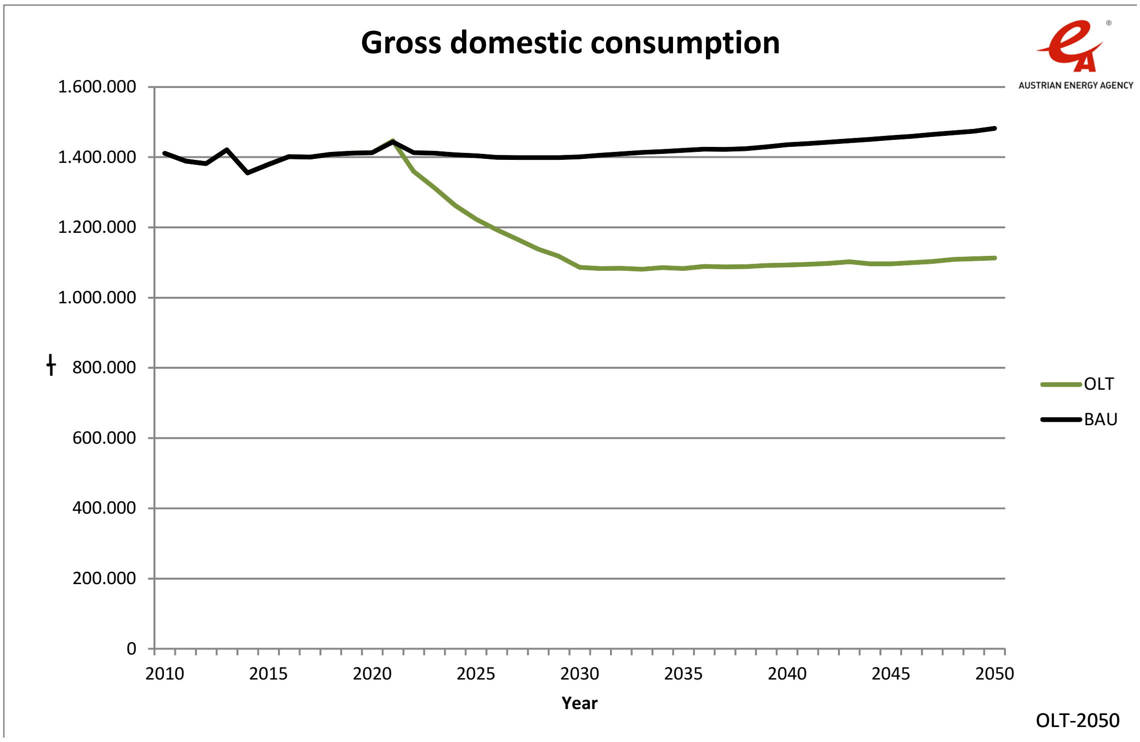

Figure 12: Gross domestic consumption.

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The most important result for our purposes is the renewable energy share transition rate for each scenario, which can be seen in the following figure.

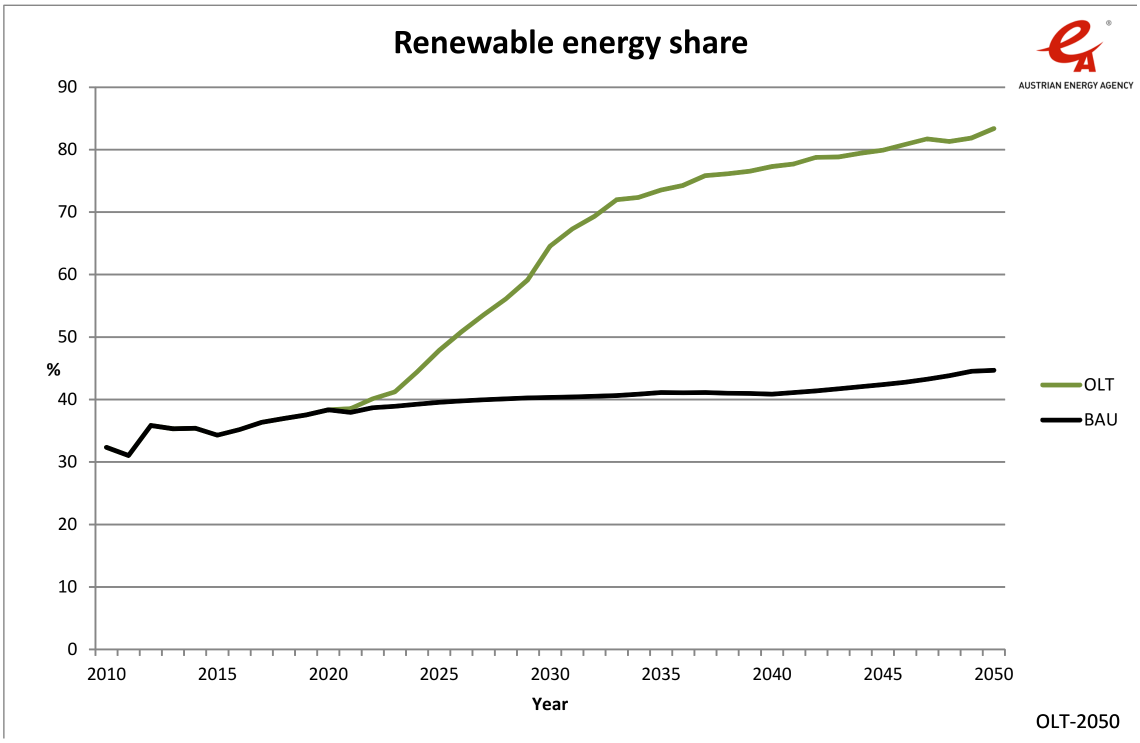

Figure 13: Renewable energy share.

Finally, the subsequent figure depicts the results for all energy shares in electricity generation for the BAU and OLT scenario.

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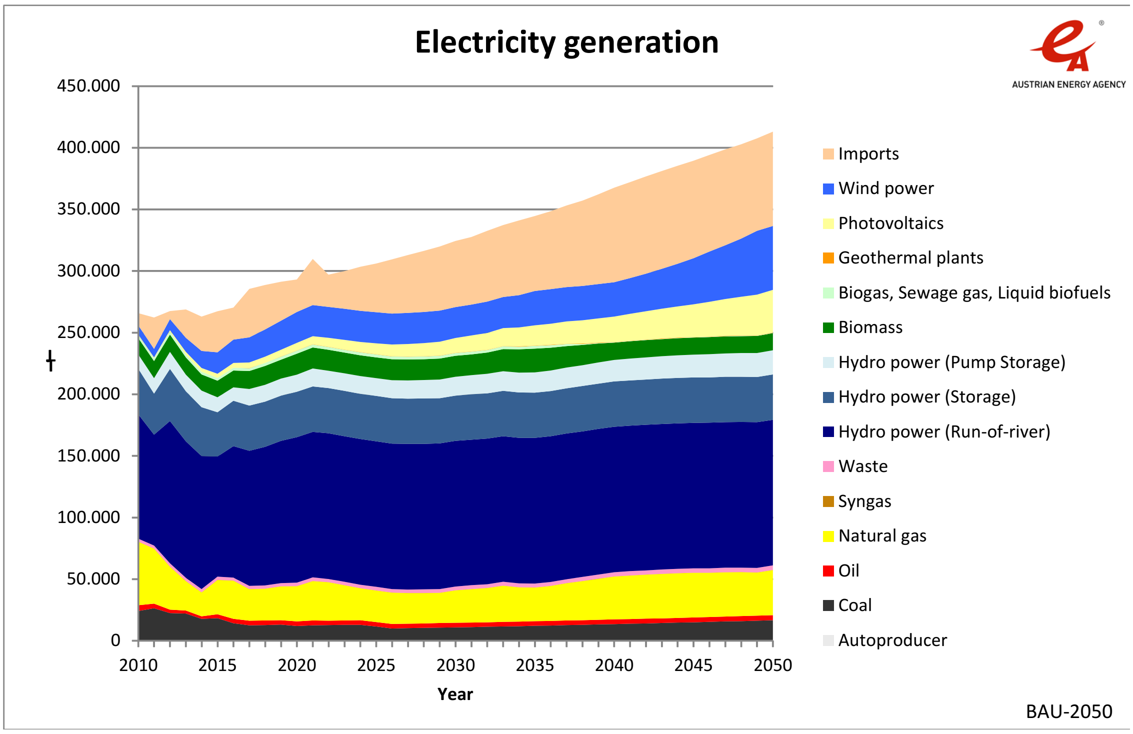

Figure 14 Electricity generation – Scenario BAU.

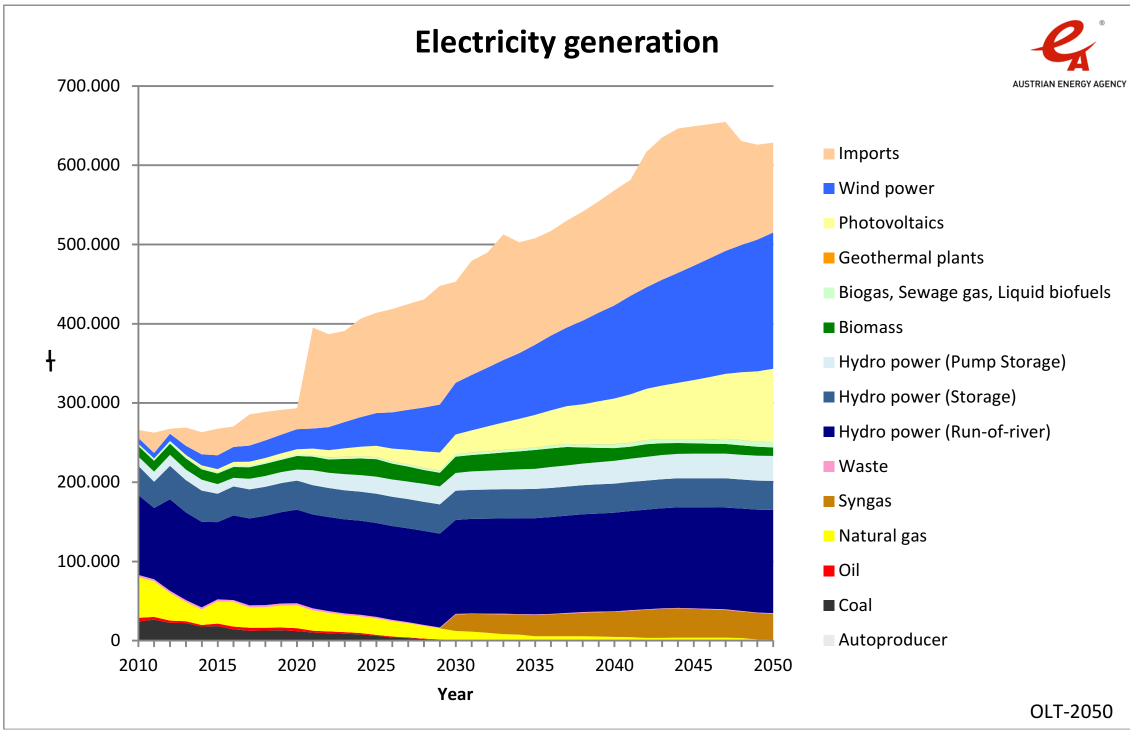

Figure 15: Electricity generation – Scenario OLT.

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Please note that no MLT scenarios are reported because it was impossible to meet the targeted CO2 budget within the given degrees of freedom when policy measures only start in 2030.

In comparison with the WP3 scenario implementation, the following observations can be made. First, and most importantly, the growth trajectories are linear in TIMES-Austria, while WP3 assumes exponential growth pathways with constant growth rates.

Second, the total electricity demand is much higher in OLT (600 PJ compared to 400 PJ) due to electrification efficiency measured and increased use of hydrogen.

Third, a considerably slower adoption of wind and solar PV in comparison with the WP3 scenario implementation can be noted. The OLT in TIMES-Austria results in a doubling of wind and trippling of solar PV electricity generation, while hydro-electricity remains fairly constant. Note that in TIMES-Austria the maximum capacities for PV and wind are based on studies of technological potential of the respective technologies.

Finally, TIMES-Austria reports a fluctuating demand of electricity via imports. A sudden rise can be observed at the start of OLT. This is due to the fact that, if the model can not satisfy demand with domestic production, electricity is imported in order to keep the system balanced. Furthermore, Syngas provides a potential that leads to an abrupt increase in electricity generation, remaining constant afterwards, while natural gas is phased out. This will be different in the case of LEAP-Bulgaria, as discussed in the subsequent chapter. Finally, also coal is phased out, but not as rapid as in the Bulgarian case.

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3.2. LEAP-Bulgaria scenario implementation and transition rates

LEAP-Bulgaria is the energy planning system that has been implemented in MEDEAS. LEAP-Bulgaria is an adaptation of the LEAP model generator. The structure and data have been adapted to the Bulgarian energy system. Similar to TIMES, Long-range Energy Alternatives Planning System (LEAP) is a model generator. Notably, it supports the development of models with a number of different techniques, including simple accounting, simulation, and also least-cost optimisation. LEAP models account for GHG emission sources and sinks coming from both energy and non-energy sectors.

The LEAP model generator can also be used with a number of different methodologies for modelling the low-carbon transition. The demand side can be modelled bottom-up, via top-down macroeconomic modelling and via accounting. The supply side can be modelled via accounting, simulation and optimisation techniques. LEAP does not only cover energy consumption, production and resource extraction in all sectors of an economy, but also the social costs and benefits and their environmental impacts.

Similar to the description of the modelling framework of TIMES, a more detailed description of the model structure, including other assumptions and implications and also a number of limitations can be found in Deliverable 5.1 on the model cross-comparison and qualitative evaluation (MEDEAS 2018b).

The following figure represents the flow chart structure in LEAP.

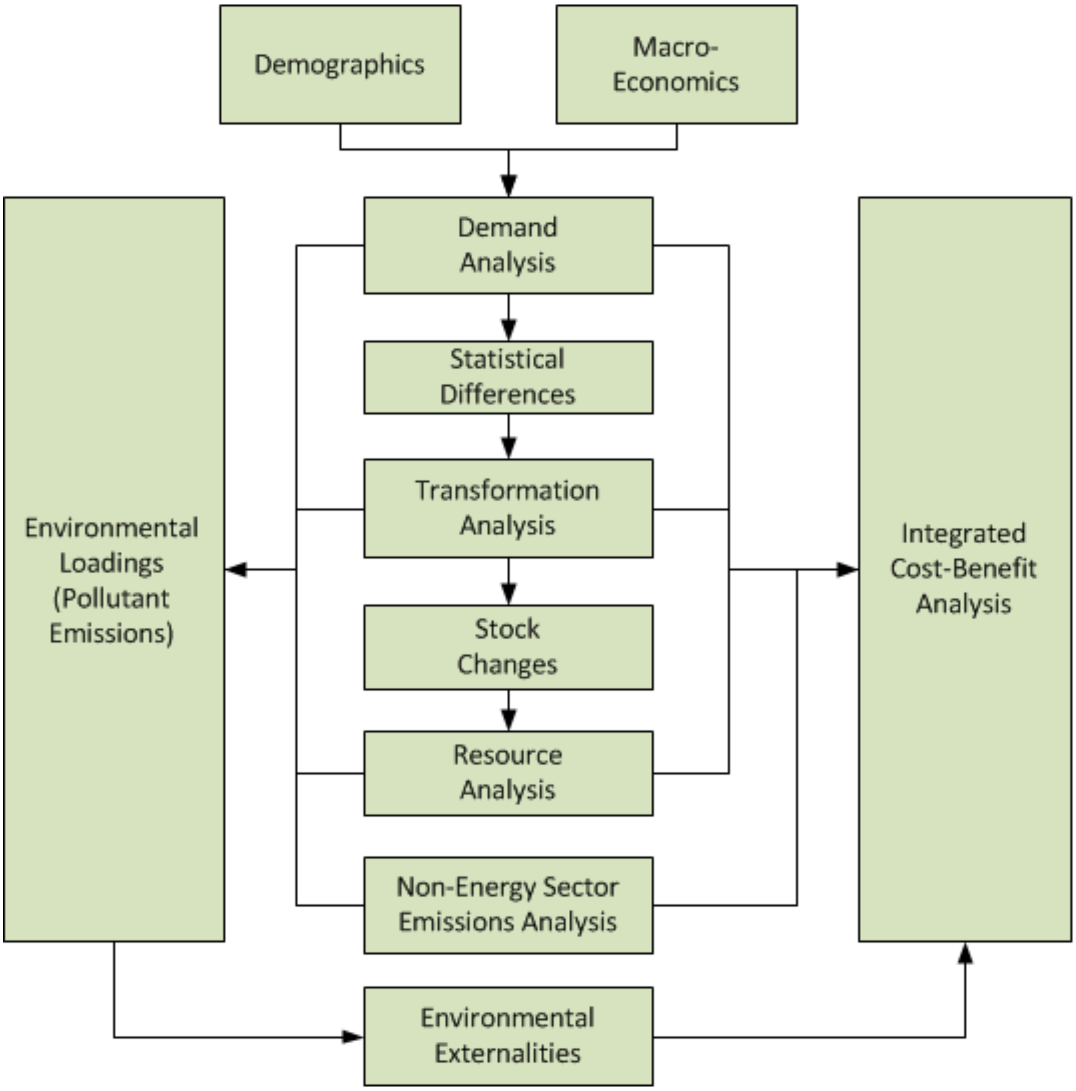

Figure 16: Simplified representation of LEAP's structure (MEDEAS, 2018).

Based on the scenario implementation of LEAP-Bulgaria, the following transition rates can be derived. The electricity generation by feedstock fuel (by primary energy resource) in SSP2, OLT, and MLT is shown in the figures below.

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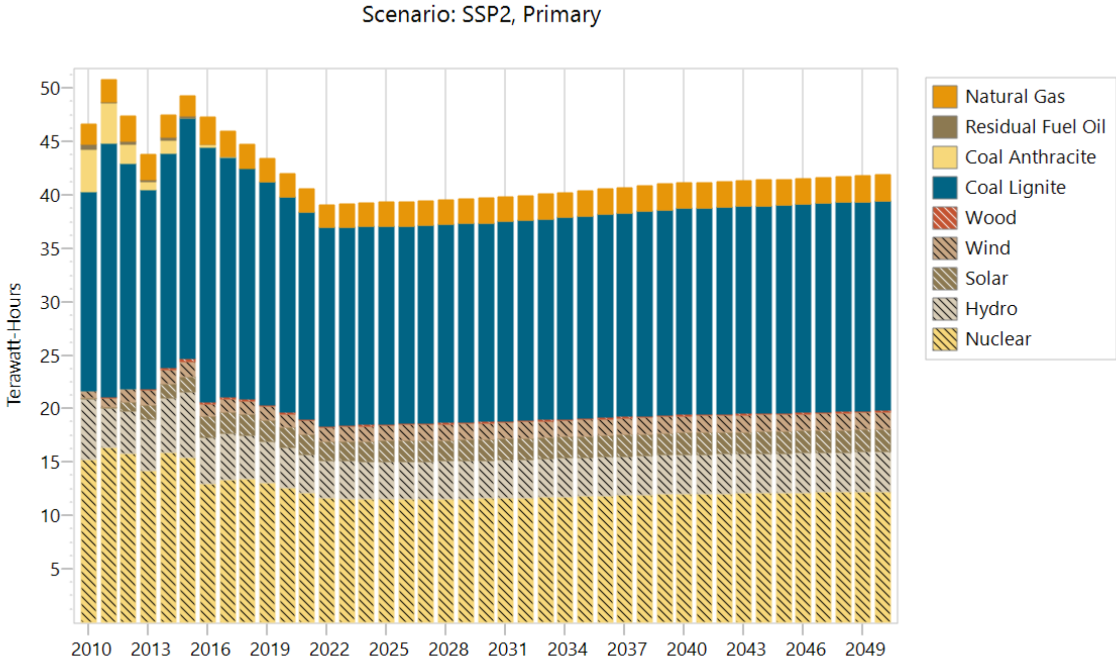

Figure 17: Electricity generation by feedstock fuel in SSP2

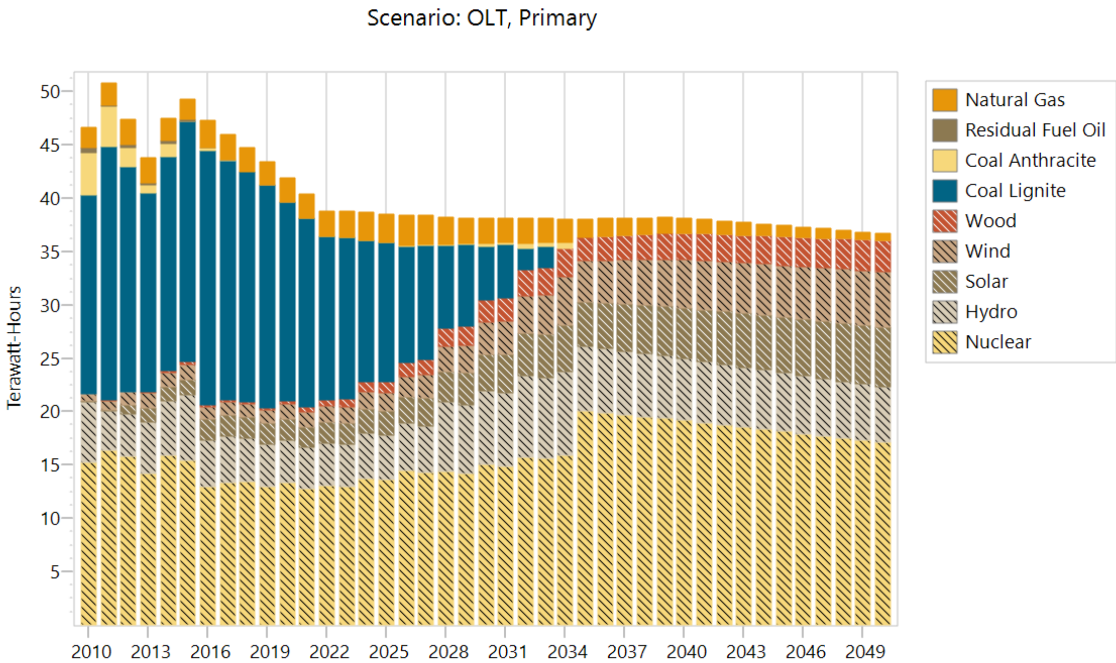

Figure 18: Electricity generation by feedstock fuel in OLT

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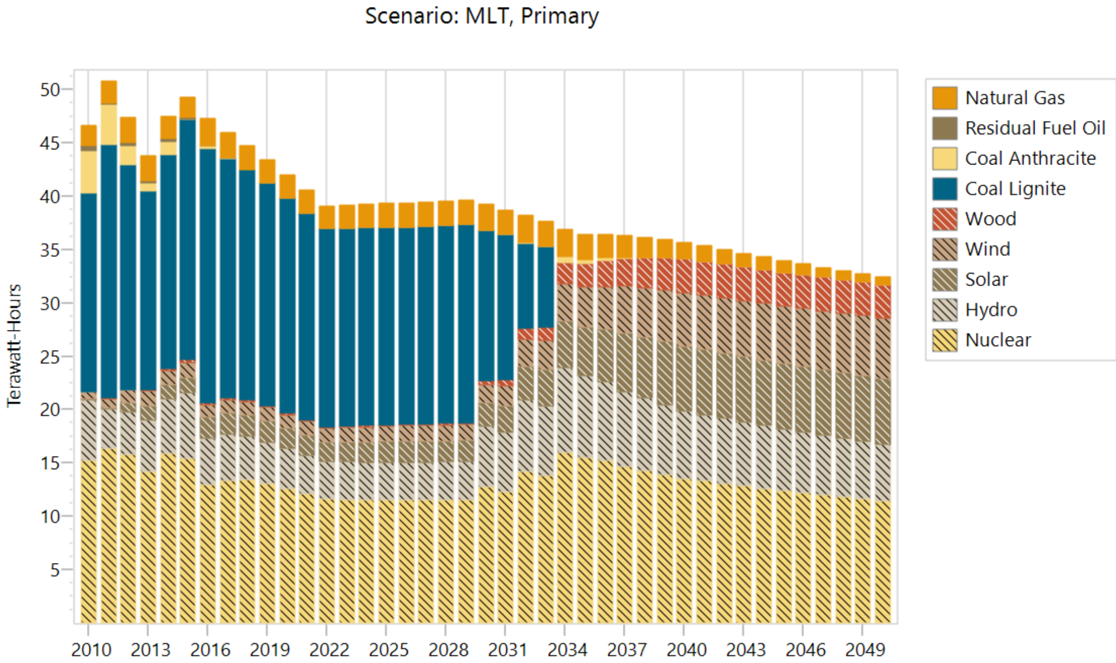

Figure 19: Electricity generation by feedstock fuel in MLT

The following figures show the electricity generation capacities (exogenous + endogenous) in the three scenarios SSP2, OLT and MLT.

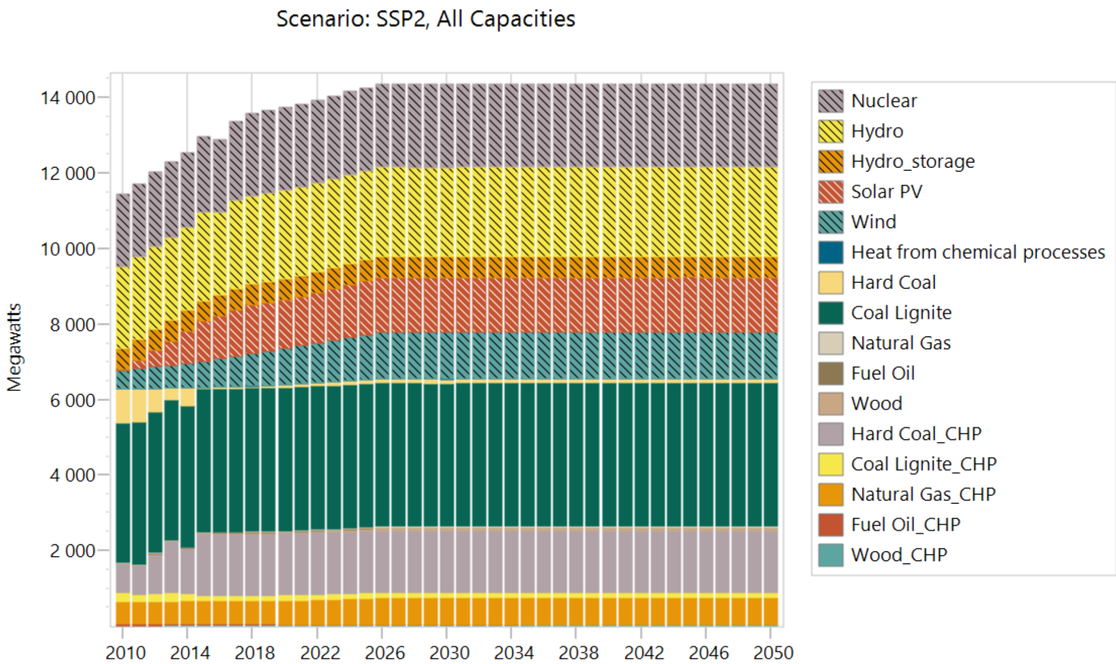

Figure 20: Electricity generation capacities in SSP2

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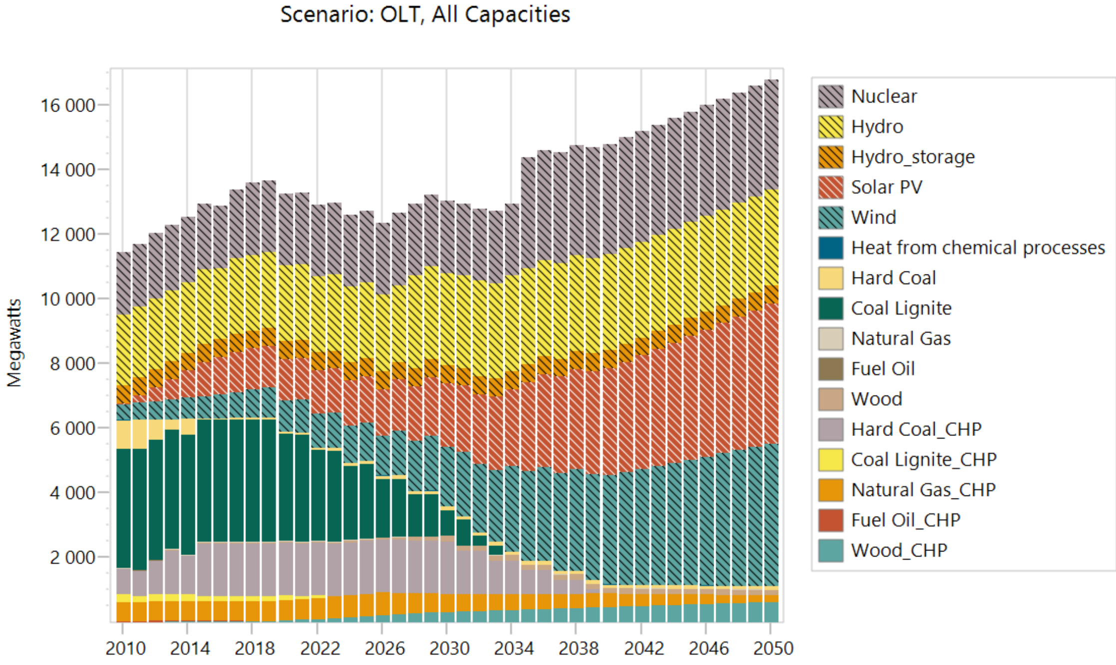

Figure 21: Electricity generation capacities in OLT

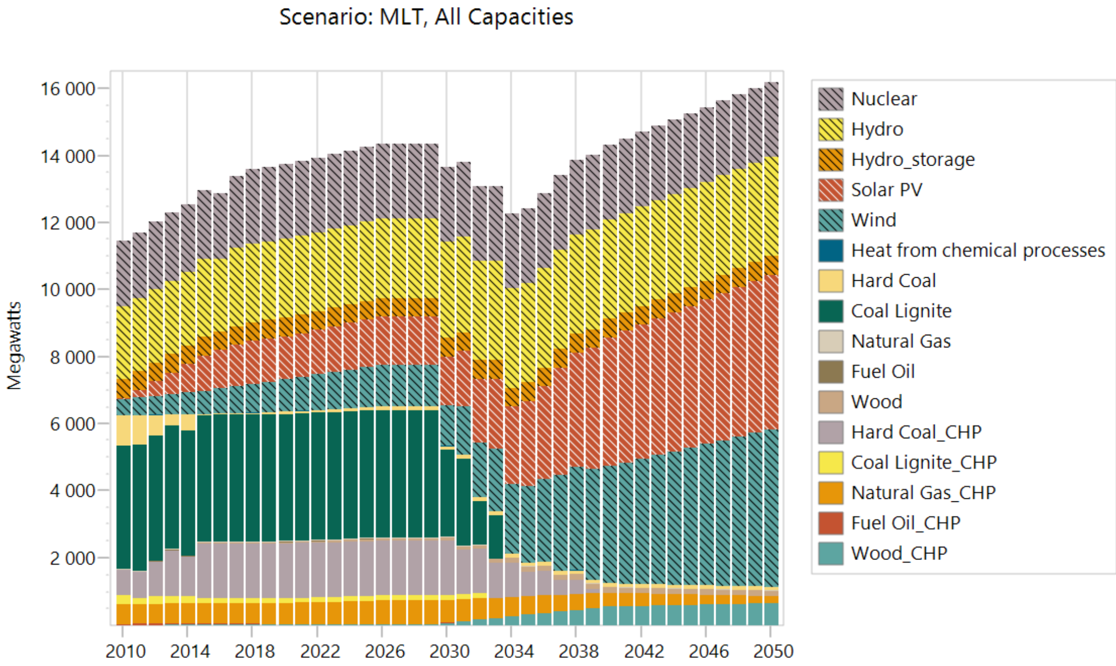

Figure 22: Electricity generation capacities in MLT

In comparison with the scenario implementation in WP3, the observed changes are ambiguous. Hydroelectricity remains roughly constant in the MLT, but also in the OLT scenarios in Bulgaria.

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The scenario implementation in WP3 assumes a growth rate of 1.4% annually for Bulgaria and Austria. A similar difference and observation was also made for Austria.

As expected and also observed in MEDEAS, the shares for hard and lignite coal are phased out by the 2030s, although relatively abruptly. This may be due to the cost optimization of the current capacity utilized. Only a fraction of natural gas is being used until 2050.

The growth trajectory for wind comes closest to a very strong growth rate used in WP3, which leads to a doubling of wind electricity from 2030 to 2050 in the MLT and a stronger growth in the OLT scenario. The comparably similar growth of solar PV, albeit with a higher share in the beginning, will result in the roughly same level as for wind. Notably, nuclear electricity generation will remain fairly constant throughout the modelled time period in the MLT scenario, but a strong leap can be observed in 2035 in the OLT scenario.

Finally, an important distinction can be made with regards to the state in 2050. While the SSP2 scenario seems to describe 2050 as a steady state in equilibrium, both the MLT and the OLT scenarios depict a relatively strong growth trajectory for renewable energies in 2050. This growth trajectory is fundamentally different from the overall growth trajectory observed in the MEDEAS scenario implementations.

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4. Input-Output Analysis implementation of the scenarios and transition rates

This part of the deliverable was developed with input-output analysis, a method applied to the modelling of monetary fluxes. First, we provide a brief overview of input-output basics. Then, an explanation of the so-called "technical coeffients" is provided, as understanding of this concept is crucial for analysing structural changes in the economy (i.e. transition to the low-carbon economy in this case). The result part of this section will focus on the transition rates of change concerning input coefficients of the electricity sector. These coefficient changes can be understood as changes resulting from the scenarios implemented at the country level in TIMES and LEAP, as discussed above.

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4.1. Methodology to calculate IO coefficient transition rates

The basic input-output transaction table consists of rows showing “Who gives to whom?” and columns showing “Who receives from whom?” in an economy. To identify key features of the post-carbon input-output economic structure it is necessary to focus on the technical coefficients for intermediate inputs. Technical coefficient is a ratio of input to a given sector to its output, measured in monetary terms (Miller and Blair, 2009). The determinants of the technical coefficients cover technological progress (Leontief, 1983), but also infrastructure policies, substitution due to relative price changes, as well as industrial structure (Peneder, 2003).

The following descriptions of input-output basics are based on Miller and Blair (2009). If the economy is divided into ***n*** sectors, and if we denote by $\boldsymbol{X_i}$ the total output (production) of sector ***i*** and by $\boldsymbol{Y_i}$ the total final demand for sector ***i***’s product, we may write sector ***i***’s output:

$$X_i = z_{i1} + z_{i2} + \dots + z_{ii} + \dots + z_{in} + Y_i$$

X_i … TOTAL OUTPUT (PRODUCTION) OF SECTOR i

z_{i1} … PRODUCTS GOING FROM SECTOR i TO SECTOR 1

Y_i … TOTAL FINAL DEMAND FOR SECTOR i’s PRODUCT

The z terms on the right-hand side represent the interindustry sales by sector i, thus the entire right-hand side is the sum of all sector i’s interindustry sales and its sales to final demand. The above equation represents the distribution of sector i’s output. The following equation reflects the outputs of each of the n sectors:

$$\boldsymbol{X_1 = z_{11} + z_{12} + \dots + z_{1i} + \dots + z_{1n} + Y_1}$$

$$\boldsymbol{X_2 = z_{21} + z_{22} + \dots + z_{2i} + \dots + z_{2n} + Y_2}$$

$$\dots\dots\dots\dots$$

$$\boldsymbol{X_i = z_{i1} + z_{i2} + \dots + z_{ii} + \dots + z_{in} + Y_i}$$

$$\dots\dots\dots\dots$$

$$\boldsymbol{X_n = z_{n1} + z_{n2} + \dots + z_{ni} + \dots + z_{nn} + Y_n}$$

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Consider the information in the ***i***th column of ***z***'s on the right-hand side – that are sales to sector ***i*** (***i***'s purchases of the products of various producing sectors in the economy):

$$\begin{matrix} z_{1i} \\ z_{2i} \\ \dots \\ z_{ii} \\ \dots \\ z_{ni} \end{matrix}$$

These elements are the sales to sector ***i***, that is, ***i***'s purchases of the products of the various producing sectors in the country; the column thus represents the sources and magnitudes of sector ***i***'s inputs.

Clearly, in engaging in production, the sector also pays for other items – for example, labour and capital – and uses other inputs as well, such as inventoried items. All of these together are termed the **value added** in sector **i**. In addition, **imported goods** may be purchased as inputs by sector **i**.

All of these inputs (value added and imports) are often lumped together as purchases from what is called the **payments sector**, whereas the **z**'s on the right-hand side of the equation serve to record the purchases from the **processing sector**, the so-called **interindustry inputs**. Since each sector can also use its output as its own input, interindustry inputs include **intraindustry inputs** as well.

The magnitudes of these interindustry flows can be recorded in a table, with **sectors of origin (i.e. sellers) listed on the left**, and **the same sectors, now "destinations" (i.e. purchasers), listed across the top**. From the column point of view, these show each sector's **inputs**; from the row point of view, the figures are each sector's **outputs**.

In the traditional Leontief input-output model, the sectoral outputs are derived from exogenously specified final demands. The model is also being referred to as "demand-driven" because it is the final demand vector **y** (or final demand matrix **Y**) that drives the model entirely. It determines total outputs (**x**), intermediate inputs (**Z**) and primary inputs (**W**) via a set of fixed coefficients. This approach examines how much is needed of the output from preceding, vertical stages or of the primary inputs, either for final use or for a unit of output of some industry (Augustinovics, 1970).

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The first step in using the information given in IO tables is to calculate the individual technical input coefficients, also called **technical coefficients**, i.e. the direct backward linkages[2].

The interindustry flows from sector ***i*** to ***j*** (for a given period – mostly 1 year) depend entirely and exclusively on the total output required from sector ***j*** for the same period. For example, the more cars produced in a year, the more steel will the automobile producers need during that year. The **technical coefficient – ratio of input to a given sector to its output** – defines the exact nature of this relationship. Technical coefficient is the ratio of input to sector's total output, which is the euro's worth of inputs from sector *i* per euro's worth of output of sector *j*.

Input-output analysis works here with an assumption of **constant returns to scale**, which means that the coefficient does not depend on (and does not change with) the amount of items produced. The assumption of these coefficients to be constant means that the inputs acquired by sector ***j*** from sector ***i*** depend only and entirely on the total output of sector ***j***. Technical coefficients a_{ij} are calculated as shown in equation (1).

(1) $$a_{ij} = \frac{z_{ij}}{x_j}$$ or in matrix form

(2) $$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$$ [$\hat{\mathbf{x}}$ … diagonalised vector **x**] or

(3) $$\mathbf{A} = \begin{bmatrix} \frac{z_{11}}{x_1} & \frac{z_{12}}{x_2} & \frac{z_{13}}{x_3} \\ \frac{z_{21}}{x_1} & \frac{z_{22}}{x_2} & \frac{z_{23}}{x_3} \\ \frac{z_{31}}{x_1} & \frac{z_{32}}{x_2} & \frac{z_{33}}{x_3} \end{bmatrix}$$ if applied to table form

This assumed fixed relationship between a sector's output and its inputs implies also the assumption of a **fixed proportion of inputs, i.e. a fixed production function**. This means, input-output analysis requires that a sector use **inputs in fixed proportions** – not only a_{ij} is assumed fixed, but also the ratio between total output of a sector and its primary inputs (e.g. labour,

[2] The term backward linkages is used to describe the level of interconnection between a particular sector and the sectors from which it purchases inputs. The elements of the A matrix only capture the direct backward linkages, while the elements of the Leontief inverse take account of both, direct and indirect backward linkages (Miller and Blair, 2009).

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capital, …). Suppose that sector 4 from the example above also buys inputs from sector 2, and that, for period of observation, z_{24}=\$750. Therefore, $a_{24}=z_{24}/X_4$=\$750/\$15,000=0.05. For X_4=\$15,000, inputs from sector 1 and sector 2 were used in the proportion $P_{12}=z_{14}/z_{24}$=\$300/\$750=0.4. This is simply the reflection of the fact that $P_{12}=z_{14}/z_{24}=a_{14}\times X_4/a_{24}\times X_4=a_{14}/a_{24}=0.02/0.05=0.4$. P – the proportion – is the ratio of the technical coefficients, and since the coefficients are fixed (=the production have constant returns to scale), then the input proportion is fixed.

Technical coefficients development can be used to estimate changes in the product mix within each sector, as will be described below in the part on strucutral decomposition.

This ratio between total output of a sector and its primary inputs for an economy with ***s*** primary inputs is given by the coefficient $\boldsymbol{c_{si}}$, which is formalized in Eq. (4). Note that the **sum of technical input coefficients** (***A matrix***) and primary input coefficients (***C***) have to amount to unity (***i'***), because of Eq. (9) [compare Eq. (6)]. This fixed ratio only refers to monetary inputs included in value added and not any physical ones which are not accounted for in value added (natural resources). The assumption of fixed input coefficients can be in theory justified on the basis of the Walras-Leontief production function, where firms are assumed to operate a cost-minimizing strategy.

(4) $$c_{sj} = \frac{w_{sj}}{x_j}$$ or in matrix annotation

(5) $$\mathbf{C} = \mathbf{W}\hat{\mathbf{x}}^{-1}$$

(6) $$\mathbf{i'A + i'C = i'}$$

(7) $$x_j = \mathrm{Min}\left(\frac{z_{ij}}{a_{ij}} \text{for all } i,\ \frac{w_{sj}}{c_{sj}} \text{ for all } s\right)$$

Usually the question to be answered in demand-side IO modelling, is the following: If final demand from one or more of the exogenous sectors (e.g.: households, government, etc.) is expected to increase or decrease in the future, how would this affect the total output ***x*** necessary to satisfy this new demand and its effects throughout the economy? In order to get ***x***, Eq. (2) is firstly transformed into Eq. (8). Replacing ***Z*** in (9) then gives Eq. (10). Bringing all the ***x*** onto one side equals (11), which can then be transformed into (12) and finally ***X*** can be found when pre-

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multiplying ***y*** with the so called **Leontief Inverse** in Eq. (13). This inverse, $(\mathbf{I}-\mathbf{A})^{-1}$, provides a new matrix which shall be denoted as **Ω** and its elements as α_{ij}. A value of say 0.5 for α_{23}, would indicate that in order to satisfy 1 dolar worth of increase in the service sector's (*j*=3) final demand (Δy_3=1), requires 0.5 dollar worth of increased output in the manufacturing sector (*i*=2), i.e. Δx_2 = 0.5.

(8) $$\mathbf{A}\hat{\mathbf{x}} = \mathbf{Z}$$

(9) $$\mathbf{y} = \mathbf{Yi}$$

(10) $$\mathbf{x} = \mathbf{A}\hat{\mathbf{x}}\mathbf{i} + \mathbf{y}$$

(11) $$\mathbf{x} - \mathbf{A}\mathbf{x} = \mathbf{y}$$ [Note that $\hat{\mathbf{x}}\mathbf{i} = \mathbf{x}$]

(12) $$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$$

(13) $$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$ Leontief inverse … denoting the elements of $(\mathbf{I}-\mathbf{A})^{-1}$ as α_{ij} this can be resolved as:

$$\begin{aligned} x_1 &= \alpha_{11}y_1 + \alpha_{12}y_2 + \ldots + \alpha_{1j}y_j + \ldots + \alpha_{1n}y_n \\ &\vdots \\ x_i &= \alpha_{i1}y_1 + \alpha_{i2}y_2 + \ldots + \alpha_{ij}y_j + \ldots + \alpha_{in}y_n \\ &\vdots \\ x_n &= \alpha_{n1}y_1 + \alpha_{n2}y_2 + \ldots + \alpha_{nj}y_j + \ldots + \alpha_{nn}y_n \end{aligned} \quad (14)$$

The results presented below are based on projections of the technical coefficients for Austria and Bulgaria. Assumed energy mixes from TIMES Austria and LEAP Bulgaria are taken as the source of data for the modelled scenarios.

WIOD 2016 release combined with EXIOBASE v3 (with detailed sectors of electricity production) are used as the source of data for the analysis. The research approach consists of disaggregating the WIOD sector Electricity, gas, steam and air conditioning supply into EXIOBASE v3 sectors with more detailed composition of the electricity production sector by different energy sources. The WIOD sector Electricity, gas, steam and air conditioning supply contains the following EXIOBASE v3

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sectors: Electricity by coal; Electricity by gas; Electricity by nuclear; Electricity by hydro; Electricity by wind; Electricity by petroleum and other oil derivatives; Electricity by biomass and waste; Electricity by solar photovoltaic; Electricity by solar thermal; Electricity by tide, wave, ocean; Electricity by Geothermal; Electricity nec; Transmission services of electricity; Distribution and trade services of electricity; Coke oven gas; Blast Furnace Gas; Oxygen Steel Furnace Gas; Gas Works Gas; Biogas; Distribution services of gaseous fuels through mains; Steam and hot water supply services.

We model a substitution of the fossil energy sources (namely Electricity by coal; Electricity by gas; Electricity by nuclear; and Electricity by petroleum and other oil derivatives) with suitable renewable energy sources (Electricity by wind; Electricity by biomass and waste; Electricity by solar photovoltaic), and, in case of Bulgaria, for nuclear power as well. The share of the other energy sources on the overall output of the aggregated WIOD sector Electricity, gas, steam and air conditioning supply adapt according to the energy mix from TIMEAS and LEAP.

For the modelling needs, we have clustered the EXIOBASE v3 sectors into 7 parts:

- **Electricity by hydro**
- **Electricity by wind**
- **Electricity by biomass and waste**
- **Electricity by solar PV**
- **Electricity by nuclear**
- **Share of other RES and transmission + gas + steam**
- **Electricity by fossil fuels**

For each of these 7 parts, the shares (percentage of the total output of the aggregated WIOD sector) are calculated in case of each technical coefficient of the „Electrcity, gas, steam and air conditioning supply“ sector in the WIOD structure. The gradual developments in changing the energy mix are then tracked by the technical coefficients developments.

However, this approach only works when the WIOD 2016 release and EXIOBASE v3 tables are made compatible. Therefore, we have developed a „WIOD-EXIOBASE converter“, matching the

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EXIOBASE v3 (usually more detailed) sectors into the WIOD 2016 release (usually more aggregated) sectors, which is shown in Table 5 below. EXIOBASE sectors are summarized into a WIOD sector below (or the other way round where WIOD provides more detailed sectors). The structure of the table follows the WIOD 2016 release classification. EXIOBASE sectors with a different order in EXIOBASE v3 classification are marked by yellow; the WIOD 2016 release sectors that are distributed among more EXIOBASE sectors with a different order are marked by green. Omitted EXIOBASE sectors (due to their incompatibility with WIOD while being of very low importance) are marked by red colour; the same applies for WIOD sectors that do not have their respective counterparts in EXIOABSE v3 sectors.

Table 7 : EXIOBASE v3 – WIOD 2016 release conversion table

WIOD sector	EXIOBASE sector
Crop and animal production, hunting and related service activities	Paddy rice
	Wheat
	Cereal grains nec
	Vegetables, fruit, nuts
	Oil seeds
	Sugar cane, sugar beet
	Plant-based fibers
	Crops nec
	Cattle
	Pigs
	Poultry
	Meat animals nec
	Animal products nec
	Raw milk
	Wool, silk-worm cocoons
	Manure (conventional treatment)
	Manure (biogas treatment)
Forestry and logging	Products of forestry, logging and related services (02)
Fishing and aquaculture	Fish and other fishing products; services incidental of fishing (05)
Mining and quarrying	Anthracite
	Coking Coal
	Other Bituminous Coal
	Sub-Bituminous Coal
	Patent Fuel

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WIOD sector	EXIOBASE sector
	Lignite/Brown Coal
	BKB/Peat Briquettes
	Peat
	Crude petroleum and services related to crude oil extraction, excluding surveying
	Natural gas and services related to natural gas extraction, excluding surveying
	Natural Gas Liquids
	Other Hydrocarbons
	Uranium and thorium ores (12)
	Iron ores
	Copper ores and concentrates
	Nickel ores and concentrates
	Aluminium ores and concentrates
	Precious metal ores and concentrates
	Lead, zinc and tin ores and concentrates
	Other non-ferrous metal ores and concentrates
	Stone
	Sand and clay
	Chemical and fertilizer minerals, salt and other mining and quarrying products n,e,c,
Manufacture of food products, beverages and tobacco products	Products of meat cattle
	Products of meat pigs
	Products of meat poultry
	Meat products nec
	products of Vegetable oils and fats
	Dairy products
	Processed rice
	Sugar
	Food products nec
	Beverages
	Fish products
	Tobacco products (16)
Manufacture of textiles, wearing apparel and leather products	Textiles (17)
	Wearing apparel; furs (18)
	Leather and leather products (19)
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)
	Wood material for treatment, Re-processing of secondary wood material into new wood material
	Pulp
Manufacture of paper and paper products	Secondary paper for treatment, Re-processing of secondary

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WIOD sector	EXIOBASE sector
	paper into new pulp
	Paper and paper products
Printing and reproduction of recorded media	Printed matter and recorded media (22)
Manufacture of coke and refined petroleum products	Coke Oven Coke
	Gas Coke
	Coal Tar
	Motor Gasoline
	Aviation Gasoline
	Gasoline Type Jet Fuel
	Kerosene Type Jet Fuel
	Kerosene
	Gas/Diesel Oil
	Heavy Fuel Oil
	Refinery Gas
	Liquefied Petroleum Gases (LPG)
	Refinery Feedstocks
	Ethane
	Naphtha
	White Spirit & SBP
	Lubricants
	Bitumen
	Paraffin Waxes
	Petroleum Coke
	Non-specified Petroleum Products
	Nuclear fuel
	Plastics, basic
	Secondary plastic for treatment, Re-processing of secondary plastic into new plastic
Manufacture of chemicals and chemical products	N-fertiliser
	P- and other fertiliser
	Chemicals nec
	Charcoal
	Additives/Blending Components
	Biogasoline
	Biodiesels
	Other Liquid Biofuels
Manufacture of basic pharmaceutical products and pharmaceutical preparations	
Manufacture of rubber and plastic products	Rubber and plastic products (25)
Manufacture of other non-metallic mineral products	Glass and glass products

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WIOD sector	EXIOBASE sector
	Secondary glass for treatment, Re-processing of secondary glass into new glass
	Ceramic goods
	Bricks, tiles and construction products, in baked clay
	Cement, lime and plaster
	Ash for treatment, Re-processing of ash into clinker
	Other non-metallic mineral products
Manufacture of basic metals	Basic iron and steel and of ferro-alloys and first products thereof
	Secondary steel for treatment, Re-processing of secondary steel into new steel
	Precious metals
	Secondary preciuos metals for treatment, Re-processing of secondary preciuos metals into new preciuos metals
	Aluminium and aluminium products
	Secondary aluminium for treatment, Re-processing of secondary aluminium into new aluminium
	Lead, zinc and tin and products thereof
	Secondary lead for treatment, Re-processing of secondary lead into new lead
	Copper products
	Secondary copper for treatment, Re-processing of secondary copper into new copper
	Other non-ferrous metal products
	Secondary other non-ferrous metals for treatment, Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
Manufacture of fabricated metal products, except machinery and equipment	Foundry work services
	Fabricated metal products, except machinery and equipment (28)
Manufacture of computer, electronic and optical products	Office machinery and computers (30)
	Medical, precision and optical instruments, watches and clocks (33)
Manufacture of electrical equipment	Electrical machinery and apparatus n,e,c, (31)
	Radio, television and communication equipment and apparatus (32)
Manufacture of machinery and equipment n.e.c.	Machinery and equipment n,e,c, (29)
Manufacture of motor vehicles, trailers and semi-trailers	Motor vehicles, trailers and semi-trailers (34)
Manufacture of other transport equipment	Other transport equipment (35)
Manufacture of furniture; other manufacturing	Furniture; other manufactured goods n,e,c, (36)
Repair and installation of machinery and equipment	
Electricity, gas, steam and air conditioning supply	Electricity by coal
	Electricity by gas
	Electricity by nuclear
	Electricity by hydro

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WIOD sector	EXIOBASE sector
	Electricity by wind
	Electricity by petroleum and other oil derivatives
	Electricity by biomass and waste
	Electricity by solar photovoltaic
	Electricity by solar thermal
	Electricity by tide, wave, ocean
	Electricity by Geothermal
	Electricity nec
	Transmission services of electricity
	Distribution and trade services of electricity
	Coke oven gas
	Blast Furnace Gas
	Oxygen Steel Furnace Gas
	Gas Works Gas
	Biogas
	Distribution services of gaseous fuels through mains
	Steam and hot water supply services
Water collection, treatment and supply	Collected and purified water, distribution services of water (41)
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Secondary raw materials
	Bottles for treatment, Recycling of bottles by direct reuse
	Food waste for treatment: incineration
	Paper waste for treatment: incineration
	Plastic waste for treatment: incineration
	Intert/metal waste for treatment: incineration
	Textiles waste for treatment: incineration
	Wood waste for treatment: incineration
	Oil/hazardous waste for treatment: incineration
	Food waste for treatment: biogasification and land application
	Paper waste for treatment: biogasification and land application
	Sewage sludge for treatment: biogasification and land application
	Food waste for treatment: composting and land application
	Paper and wood waste for treatment: composting and land application
	Food waste for treatment: waste water treatment
	Other waste for treatment: waste water treatment
	Food waste for treatment: landfill
	Paper for treatment: landfill
	Plastic waste for treatment: landfill

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WIOD sector	EXIOBASE sector
	Inert/metal/hazardous waste for treatment: landfill
	Textiles waste for treatment: landfill
	Wood waste for treatment: landfill
Construction	Construction work (45)
	Secondary construction material for treatment, Re-processing of secondary construction material into aggregates
Wholesale and retail trade and repair of motor vehicles and motorcycles	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoires
	Retail trade services of motor fuel
Wholesale trade, except of motor vehicles and motorcycles	Wholesale trade and commission trade services, except of motor vehicles and motorcycles (51)
Retail trade, except of motor vehicles and motorcycles	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52)
Land transport and transport via pipelines	Railway transportation services
	Other land transportation services
	Transportation services via pipelines
Water transport	Sea and coastal water transportation services
	Inland water transportation services
Air transport	Air transport services (62)
Warehousing and support activities for transportation	Supporting and auxiliary transport services; travel agency services (63)
Postal and courier activities	Post and telecommunication services (64)
Publishing activities	
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	
Telecommunications	
Accommodation and food service activities	Hotel and restaurant services (55)
Computer programming, consultancy and related activities; information service activities	Computer and related services (72)
Financial service activities, except insurance and pension funding	Financial intermediation services, except insurance and pension funding services (65)
Insurance, reinsurance and pension funding, except compulsory social security	Insurance and pension funding services, except compulsory social security services (66)
Activities auxiliary to financial services and insurance activities	Services auxiliary to financial intermediation (67)
Real estate activities	Real estate services (70)
	Renting services of machinery and equipment without operator and of personal and household goods (71)
Scientific research and development	Research and development services (73)
Legal and accounting activities; activities of head offices; management consultancy activities (Other business services)	Other business services (74)
Architectural and engineering activities; technical testing and analysis (Other business services)	
Advertising and market research (Other business services)	
Other professional, scientific and technical activities; veterinary activities (Other business services)	

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WIOD sector	EXIOBASE sector
Administrative and support service activities (Other business services)	
Public administration and defence; compulsory social security	Public administration and defence services; compulsory social security services (75)
Education	Education services (80)
Human health and social work activities	Health and social work services (85)
	Membership organisation services n,e,c, (91)
Other service activities	Recreational, cultural and sporting services (92)
	Other services (93)
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	Private households with employed persons (95)
Activities of extraterritorial organizations and bodies	Extra-territorial organizations and bodies

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4.2. Results – IO technical coefficients transition rates

Based on the current coefficients and the projected coefficient change based on the composition of energy sources in case of Austria and Bulgaria, we can derive the transition rates of change for each input coefficient. Data about the energy mix projections are outputs from TIMES (for Austria) and LEAP (for Bulgaria), provided by AEA and BSERC. There are two scenarios considered in the model – Optimal level transition and Mid-level transition. For Austria, only OLT is considered due to the optimization procedure which did not find a solution to remain in the carbon budget for Austria.

The technical coefficients for the WIOD 2016 release sector Electricity, gas, steam and air conditioning supply are modified according to the disaggregation described above (with the help of technical coefficients from EXIOBASE v3). The current composition of the aggregated electricity sector (consisting of the 21 more detailed sectors from EXIOBASE as described in the previous section) – in terms of input cost shares (intermediate inputs to the sector) – is gradually replaced by the projected electricity sector based on the energy mixes provided by TIMES and LEAP for Austria and Bulagria for OLT and MLT for 2030 and 2050.

If one wants to change the composition of the intermediate inputs in the aggregate sector due to “internal” changes in the sector’s composition (here because of the replacement of the fossil fuels based electricity production), it is necessary to bear in mind that the same amount of the aggregated sectoral output (which is kept fixed in this case) in monetary terms does not necessarily imply the same amount of electricity produced due to different requirements of wind and solar PV energy compared to the fossil fuels. Thus, if the electricity from wind and solar PV is to be cheaper, the same level of output will mean more electricity produced, whereas if the renewable energy would be more expensive, then the fixed level of output (in terms of the monetary flows) would mean actually less electricity produced.

Yet another factor that has to be taken into account is the energy return on energy investment (EROI) of these various energy sources. Our approach assumes a comparable EROI for coal, solar PV and wind energy, which according to some sources (Hall et al., 2014) is roughly comparable. Therefore, the gradual replacement of coal etc. with wind and solar PV (which together make the majority of the newly deployed sources of electricity generation) is possible 1:1. Otherwise, it

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would have to be necessary to define a ratio of replacement according to the relation of EROIs for the different energy sources that are being mutually replaced by each other.

The two scenarios, OLT and MLT, are different in their levels of GDP per capita evolution. Data about the GDP per capita expected evolution are taken from Deliverable 4.2 (MEDEAS EU), from the “outputs” data document. The OLT scenario is assumed to cover GDP developments for BAU+SCEN2, and MLT scenario covers data for SCEN3+SCEN4 from MEDEAS EU outputs data.

It should be noted that since GDP is an endogenous variable in MEDEAS, the GDP trend can be achieved only if there are no environmental/physical constraints, limiting the GDP evolution. The scenarios used to calculate the monetary fluxes (inputs to the electricity sector) are however not adjusted by the environmental constraints. This is mostly the case of the OLT scenario, which assumes a 1.9% GDP growth over the whole period until 2050. MLT scenario fits better to the environmental limits, described in task 3.5 (by INSTM). MLT scenario used here assumes 0.7% annual GDP growth until 2030, and then 2.5% GDP decline until 2050. For a more detailed scenario comparison, please see the section 1.1 above.

The two scenarios are presented to illustrate two possible trends that might occur. The comparison between the OLT and MLT gives not only an idea of the outcomes of policies with a different starting year, but also a general idea about the demand effects in case of two contradicting GDP trends, growth and decline (also called “degrowth” in some places[3]). Therefore it gives an information on what can be expected at the country level if such transition takes place and if a certain GDP level comes about.

To summarize, the IOA coefficient changes are a result of the energy mix rate changes. The IO model introduced below is therefore not really comparable with MEDEAS, TIMES and LEAP, but rather an additional analytical step using the scenario results from MEDEAS (GDP evolution), TIMES and LEAP (energy mixes).

The following three figures (23, 24 and 25) show the expected (projected) developments of the technical coefficients – inputs to the sector Electricity, gas, steam and air conditioning supply, with modelled inputs on the basis of the projected energy mixes for OLT in Austria and both OLT and MLT in the case of Bulgaria (see figures 15, 21 and 22 above in the preceding chapter). Linear

[3] Please note that with this word, we do not refer to the policy proposals described by the degrowth movement, but we rather mean a GDP decline. „Degrowth“, as a set of policies, does not necessarily mean a GDP decline, but rather orientation towards different measures that GDP growth.

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interpolation was used to obtain the monetary flows into the sector for the projections in the periods 2014-2030 and 2030-2050. Linear interpolation is a good approximation, as the composition of electricity sources also changes linearly in both TIMES and LEAP. Any non-linear interpolation would depend considerably on the scenario evolution after 2050, because we cannot assume that 2050 is approaching a steady state concerning the energy mix.

The results show a non-exhaustive analysis of the transition to the renewable energy, as we are modelling only the changes in the electricity sector. Even though this sector belongs to the ones with the highest shares of GHG emissions production (https://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-by-sector-in#tab-chart_1), it is by no means the only one and if one would want to have a complete analysis of the monetary flows in the low-carbon economy, similar approach would have to be applied to transportation, other industrial sectors as well as the residential and commercial sectors. Nevertheless, we believe that even for transportation and possibly also other industries, switching from fossil fuels produced electricity to renewable energy based one means a necessary prerequisite for example for electromobility.

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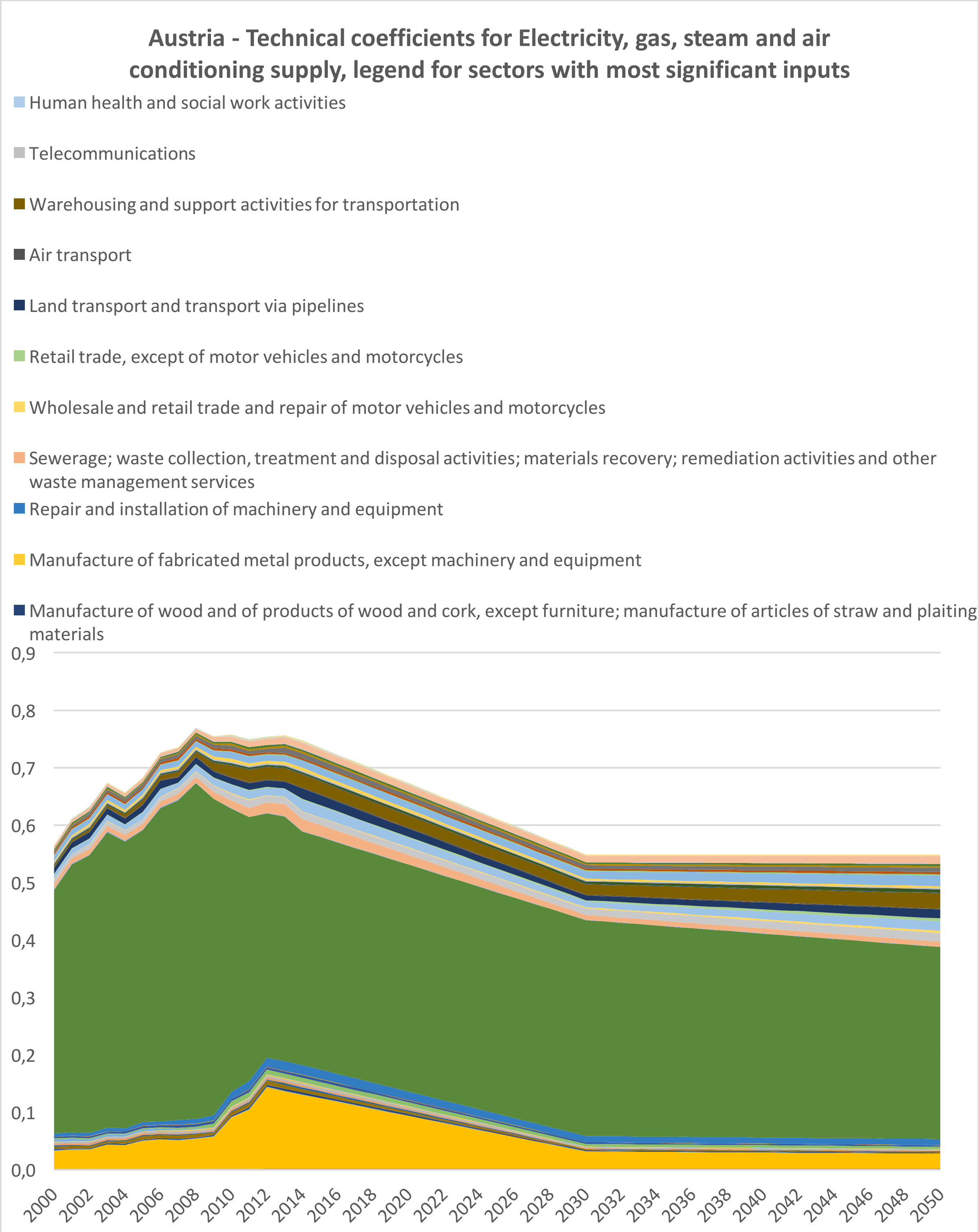

Figure 23: Inputs from other sectors to the sector Electricity, gas, steam and air conditioning supply (WIOD D35) for OLT for Austria – all in monetary terms.

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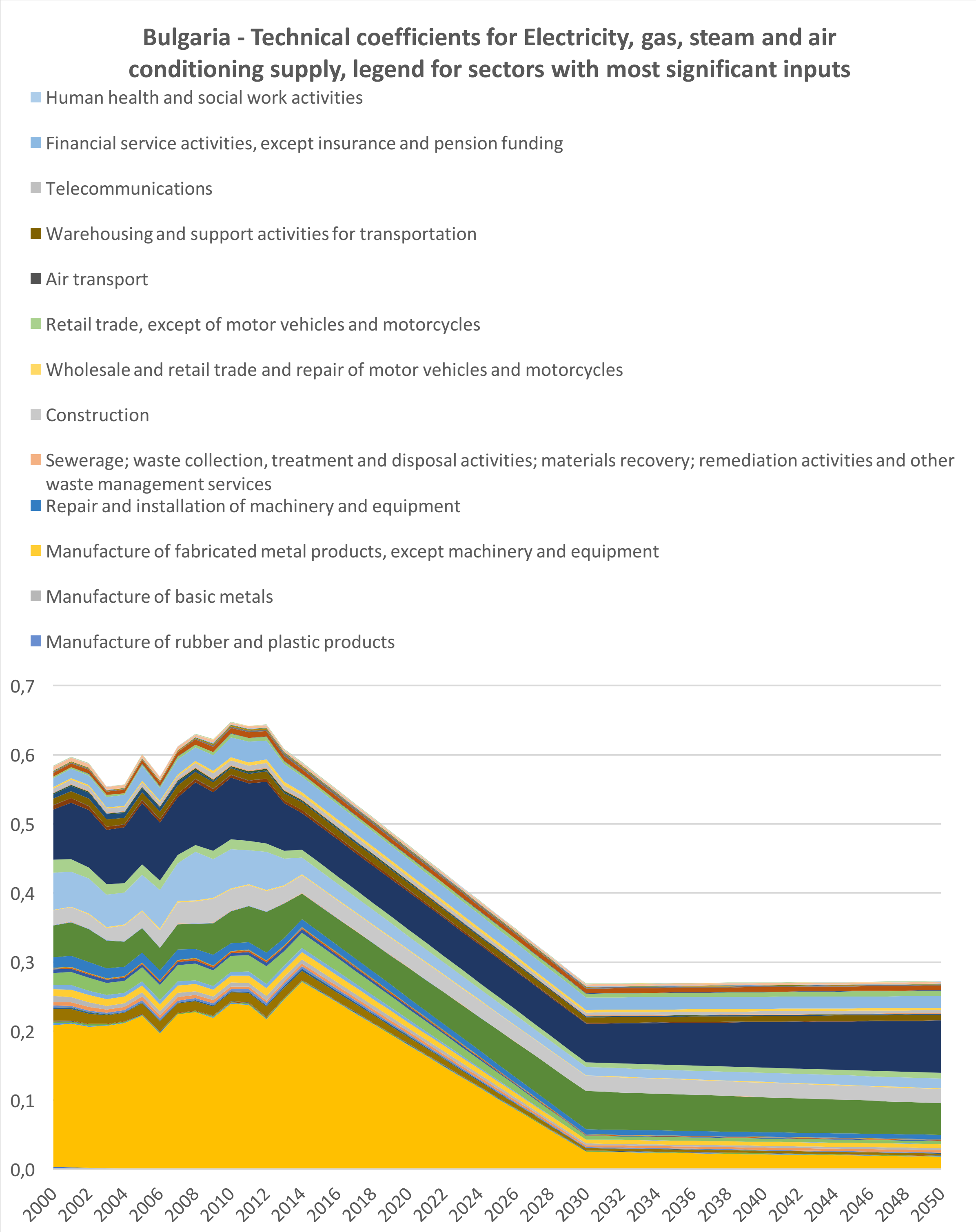

Figure 24: Inputs from other sectors to the sector Electricity, gas, steam and air conditioning supply (WIOD D35) for OLT for Bulgaria – all in monetary terms.

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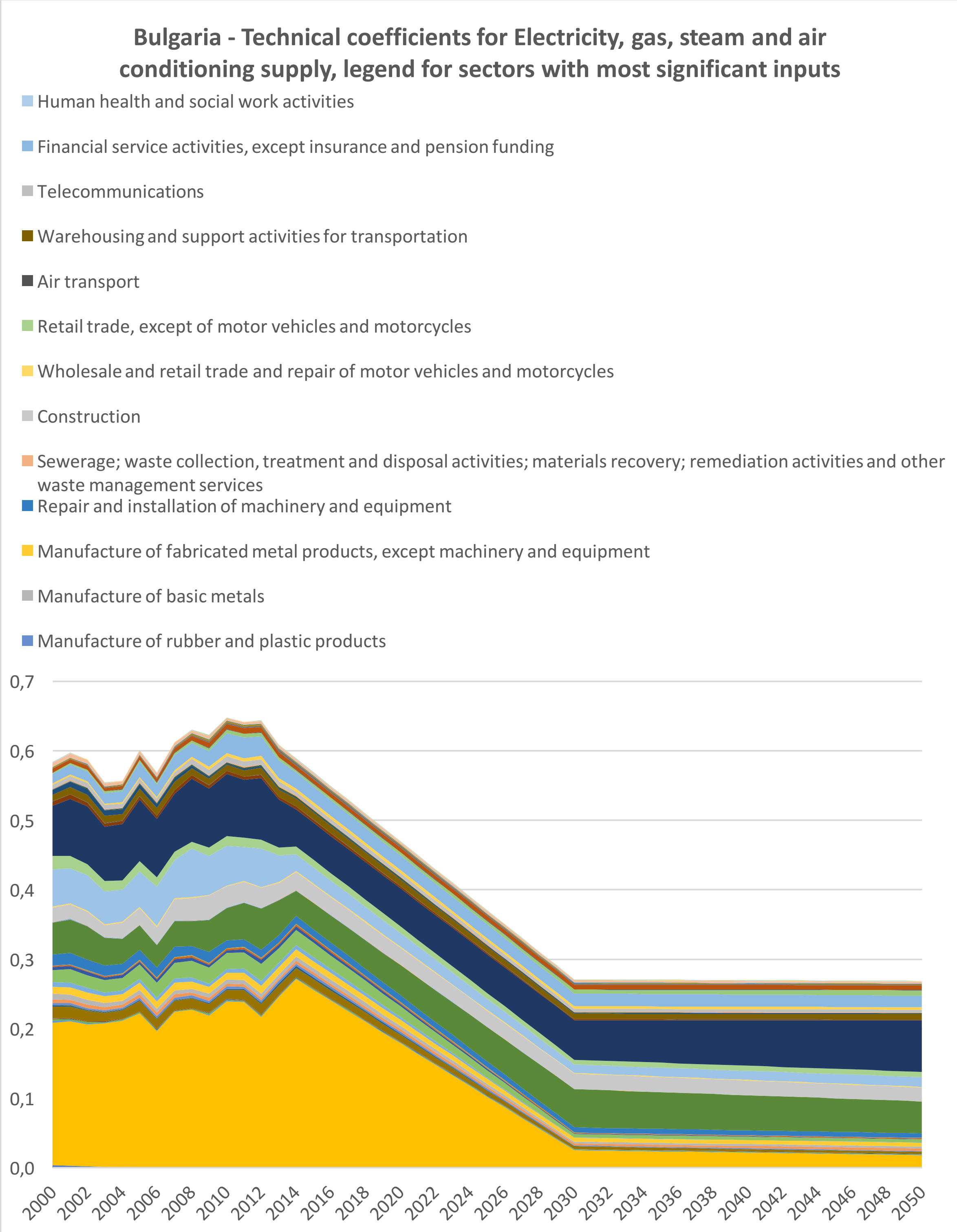

Figure 25: Inputs from other sectors to the sector Electricity, gas, steam and air conditioning supply (WIOD D35) for MLT for Bulgaria – all in monetary terms

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We can observe a straightforward trend, visible in both countries and scenarios: decreasing inputs from the sector Mining and Quarrying, which is even more significant in the case of Bulgaria. The serious drop of the overall intermediate inputs in the BGR case is likely to be caused by the significantly lower need for mining and quarrying domestic products, especially coal, for renwable energies. Nevertheless, a small share remains to proceed with construction of the renewable sources infrastructure. Whether this is true also for the nuclear infrastructure (in the Bulgarian case) is not so unequivocal, because the share of nuclear power in the mix remains approximately stable over the analysed period (with an abrupt rise after 2034, which is on the other hand reflected only as a gradual change in the model, given the methodology of linear interpolation).

Apart from the Mining and quarrying sector, an increasing share of sector Architectural and engineering activities can be observed in Austria, very likely for infrastructures' installation. The same applies to Repair and installation of machinery and equipment, for the same reasons, which is first diminshed and then increases again in case of both countries for both scenarios. The exact share of this sector defines the domestic demand for these two sectors' inputs, and, contrarily to the demand for inputs generated abroad such as various components of the renewable energy producing devices or nuclear fuel, means a strengthening factor for the domestic economy.

Concerning the nuclear energy in Bulgaria, there is also another observation that needs further explanation. The data on the electricity production by different sources were taken from EXIOBASE (using an approach that combines more detailed EXIOBASE data to model more aggregate WIOD sectors). However, EXIOBASE seems to have lack of available data on inputs for the electricity production from nuclear power. The problem is, therefore, that if the EXIOBASE data are inserted into the model, for the 2014 energy mix (as the starting point for the modelled period) the model says that the share of nuclear energy on electricity production is negligible – which is contradicting the data from BSERC on the current energy mix in Bulgaria. This was corrected with increasing the input shares according to the BSERC data. Dispite these difficulties and necessary corrections EXOIBASE and WIOD are the best datasets available.

Regarding the differences between MLT and OLT scenarios (which is only available for Bulgaria), we can observe that in the case of MLT (with slightly higher deployment of wind instead of nuclear power, which has a lower share than in OLT) the inputs from other sectors such as Land transport and transport via pipelines or the sector electricity itself are slightly lower.

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5. Conclusions

In this deliverable, we explored the 1) Scenario developments and transition rates, 2) MEDEAS country-level scenario implementation and transition rates 2030 and 2050, 3) Country-level models (TIMES and LEAP) scenario implementation and results, and 4) an Input-Output Analysis implementation and results.

First, the scenarios of the national level Vensim models MEDEAS_at and MEDEAS_bg were compared to the Carbon Budget available for both countries within the transition scenarios MLT and OLT. Since the emission pathways obtained with the *Green Growth* scenario (reported in D4.2) does not fit the desirable carbon budgets, INSTM adjusted the set of exogenous variables for the EU (not reported in this analysis), and the national level of Austria and Bulgaria – in particular those related to socioeconomic aspects and renewable energy development, trying to come up with the best set of parameters approximating as close as possible the emission curves elaborated in task 3.5b of WP3.

For Austria, the *Green Degrowth 2020_at_aea* and the *Green Degrowth 2030_at_aea* as defined in task 3.5b, differ from Green Growth both for increases in RES growth and for the historical GDP values 2015-2017 and the GDP projection 2018-2019, that were taken from the OECD database (https://data.oecd.org/gdp/real-gdp-forecast.htm#indicator-chart). Population is instead kept as in the Green Growth_at scenario. *Green Degrowth 2020* is also referred to as part of the OLT family, whereas *Green Degrowth 2030* as part of the MLT family (due to the later starting point of the transition). For Bulgaria, the Green Degrowth 2030_bg_aea and the Green Degrowth 2030_bg_aea scenarios, both Population and GDP were not modified in comparison to Green Growth_bg, because both variables already were decreasing, so in those scenarios we increased only RES growth rates in comparison to Green Growth.

The most important information for the comparison with the country-level scenario implementation and transition rates modelled with TIMES-Austria and LEAP-Bulgaria and the country-level input-output model implementation is the annual growth rate for wind and solar PV. Wind and solar PV are set at roughly the same level for both Bulgaria and Austria.

In the second part of the deliverable, a comparison of the scenario transition rates with the MEDEAS national model implementation of MEDEAS_at and MEDEAS_bg is conducted. Concerning wind energy, Austria went through a period of rapid growth in wind energy production, with growth rates of 22-28% between 2012-14, while in Bulgaria the 2000s boom in wind energy was followed by a stagnation afterwards, with a negative growth rate of -3% in 2014. In the area of

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solar energy, Bulgaria had a late but rapid growth of its production from 2011 to 2013, with growth rates peaking 279% in 2012, but from a negligible level, and without a persistent change of the growth trajectory after 2013.

In part 3 of the deliverable, the country-level linear optimisation model results of TIMES and the model results of LEAP concerning transition rates are reported. The TIMES-Austria model results and the LEAP-Bulgaria model results concerning scenario implementation and transition rates are compared with the expected values in WP3. The focus is on the transition rates of the energy mix, leading to the economy based on renewable energies (with a share of nuclear power in Bulgaria).

In comparison with the WP3 scenarios implementation, we found a significantly lower growth trajectory in the real data from 2010 to 2015 for solar energy than what has been assumed in the scenarios for Austria (between 9-12%, compared to 19% in the scenarios), and the actual growth considerably stronger in Bulgaria for solar energy (between 59% and 279%, compared to 19%). Furthermore, in Austria, while WP3 assumes exponential growth with constant growth rates, the growth trajectories are linear in TIMES-Austria. A slower adoption of wind and solar PV in comparison with the WP3 scenario implementation is also observed. Comparing the transition rates of LEAP-Bulgaria with the scenario implementation in WP3, the observed changes are ambiguous (e.g. hydroelectricity remaining roughly constant in the MLT, but also in the OLT scenarios in Bulgaria, while WP3 assuming a growth rate of 1.4% annually; nuclear electricity generation remaining constant throughout the modelled period in MLT, but a strong investment leap into nuclear fuels in 2035 in OLT).

The fourth part brings in the Input-Output Analysis. The scenario results are transferred (and modified, as described in the section 4.2) and used as data inputs into input-output structures to identify transition rates and the resulting input coefficients of the electricity sector. The methodology implemented is the modelling of monetary fluxes in the economic structure of the two compared countries, Austria and Bulgaria. Specifically, we focus on the technical input coefficient structural changes.

The basis for the model calculations are transition rates that have been developed based on the MLT and OLT scenarios. The changes in technical coefficients, presented in section 4.2, follow the energy mix rate changes taken from TIMES and LEAP for Austria and Bulgaria. Monetary fluxes to the electricity sector and their expected developments in the light of the proposed energy mixes are shown. The IO model is not fully comparable with MEDEAS, TIMES and LEAP, but rather an additional analytical step using the scenario results from those models.

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A clear trend is visible in both Austria and Bulgaria, for both scenarios considered. Inputs from the sector Mining and Quarrying decrease, which is very likely due to the global trade supply chains of renewable energy (note that the model only tracks down the domestic demand), compared to the inputs to energy from fossil fuels (such as coal in Bulgaria, for example). The next step of the analysis would be to conduct a multi-regional input-output analysis, in order to see the changes in demand globally, as well as to observe where exactly the demand for materials necessary for the construction, operation and maintenance will be generated. This also connects with the analyses concerning materials needed for the energy transition, as analysed in WP6.2.

Concerning the comparison between OLT and MLT (available only for Bulgaria), within the MLT scenario (with higher deployment of wind instead of nuclear power compared to OLT) the inputs from other sectors such as Land transport and transport via pipelines or the sector electricity itself are lower, although not significantly. This might be in line with the above-stated argument: Wind energy as well as nuclear power requires imports, but apparently nuclear power requires more of them. Higher deployment of wind energy would thus have bigger effects on the domestic economy, if wind would be to compete with nuclear power. The calculated cost shares are necessary ingredients to calculate labour demand effects of the energy transition in WP6.2.

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