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Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
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B) Project overview

1 Kurzfassung

Hintergrund und Zielsetzungen

Zur Eindämmung der Klimakrise ist eine Dekarbonisierung bzw. rasche und weitreichende Transformationen in allen Bereichen erforderlich. Im breiten Portfolio der Mitigationsoptionen werden erneuerbare Energiequellen zusammen mit Effizienzverbesserungen und Änderungen des Lebensstils eine Schlüsselrolle bei der Erreichung der angestrebten Emissionsreduktionen spielen.

Die österreichische Regierung hat sich zum Ziel gesetzt, bis 2030 die Elektrizitätsnachfrage in Österreich zu 100% (national bilanziell) mit Erneuerbaren Energieträgern (EE) abzudecken. Im Jahr 2020 hielt EE-Strom einen Anteil von 78% an der gesamten Stromerzeugung in Österreich. Die Erreichung des 100%-Ziels bis 2030 erfordert jedoch grundlegende Veränderungen im österreichischen Elektrizitätssystem, die mit erheblichen Investitionen verbunden sind.

Ziel von START2030 war es, die ökonomischen Auswirkungen und die sozialen Folgen einer Transformation zu einem 100%-EE-Elektrizitätssystem in Österreich bis 2030 zu analysieren. Vier Politikszenarien, in denen das 100%-Ziel erreicht wird, wurden analysiert, um das breite Spektrum der mit der Transformation verbundenen potenziellen Auswirkungen abzubilden. Diese Szenarien für Österreich wurden in ein konsistentes Szenario der Entwicklung des europäischen Elektrizitätssystems integriert und in enger Zusammenarbeit mit den relevanten Stakeholdern spezifiziert. Die Modellanalyse, für die die Modelle DYNK und ATLANTIS weiterentwickelt und miteinander gekoppelt wurden, liefert Erkenntnisse über die Emissionswirkungen sowie über die makroökonomischen Implikationen und Verteilungseffekte der Transformation. Auf der Grundlage der Modellanalyse und einer umfassenden Literaturrecherche wurden Politikempfehlungen entwickelt.

Arbeitspakete

Vor dem Hintergrund der oben beschriebenen Forschungsziele umfasste die Forschungsarbeit in *START2030* die folgenden sieben Arbeitspakete (WPs):

WP1 bildete die Grundlage für die nachfolgenden WPs und bestand aus drei Tasks: (1) die Analyse der strategischen energiepolitischen Dokumente in der EU und Österreich, (2) eine Untersuchung der Fördermaßnahmen und Kapazitätsentwicklungen in den EU-Mitgliedstaaten und (3) die Erstellung einer Datenbank zur zukünftigen Entwicklung exogener Modellparameter.

In **WP2** wurde ein Basisszenario für das europäische Stromsystem definiert, um die österreichischen Szenarien (WP3) in einem europäischen Kontext zu simulieren. Basierend auf einer Literaturrecherche und Diskussionen bei einem Stakeholder-Workshop wurde das Szenario "Sustainable Transition" (TYNDP2018) als europäisches Referenzszenario ausgewählt.

WP3 befasste sich mit der Entwicklung von Energieszenarien für Österreich bis 2030. Vier Szenarien wurden als Ausgangspunkt für die Modellsimulationen entwickelt. Die Szenarien wurden in einem Gruppen-Delphi-Ansatz mit Experten verschiedener Disziplinen und Stakeholdern ausgearbeitet.

In **WP4** wurden das makroökonomische Modell DYNK und das Stromsystemmodell ATLANTIS für die Kopplung vorbereitet. Die Anpassungen umfassten die Erweiterung der Nachfrage- und Angebotsseite in DYNK sowie die Erweiterung des Stromnetzes für Österreich und die Integration eines Speichersimulationsmoduls in ATLANTIS.

Die Schnittstelle zwischen den Modellen wurde in **WP5** definiert. Die Daten zu Stromerzeugung und -verteilung sowie Investition in Erzeugungsanlagen aus ATLANTIS wurden mit den entsprechenden Variablen im Makromodell verknüpft, die die Technologie des Stromsektors in Bezug auf die Inputs definieren.

In **WP6** wurden Modellsimulationen durchgeführt, um die Auswirkungen der Transformationsszenarien zu bewerten. Die Analyse gibt Aufschluss über die verteilungspolitischen, makroökonomischen und ökologischen Auswirkungen der Transformation sowie über Veränderungen im Elektrizitätssystem. Darüber hinaus wurden Sensitivitätsanalysen (Gas- und CO_2-Preise) durchgeführt.

In **WP7** wurden auf Basis der Modellanalyse und einer Literaturrecherche Politikempfehlungen für die Gestaltung der Transformation hin zu dem Ziel von 100% erneuerbaren Energien für das österreichische Stromsystem entwickelt.

Ergebnisse und Schlussfolgerungen

Die Simulationen zeigen, dass, obwohl alle Szenarien 100 % EE-Strom (national bilanziell) erreichen, im Jahr 2030 immer noch Strom aus Gaskraftwerken benötigt wird, um die variable Erzeugung aus EE auszugleichen, Netzengpässe zu vermeiden und in den Wintermonaten Wärme aus Kraft-Wärme-Kopplungsanlagen zu erzeugen. Aus sozioökonomischer Sicht ist der Übergang zu einem erneuerbaren Stromsektor im Vergleich zu einer Referenzentwicklung nahezu neutral. Er weist weder schädliche Auswirkungen auf noch führt er zu hohen Multiplikatoreffekten durch zusätzliche Investitionen. Bei hohen Gaspreisen ist ein Rückgang des BIP und des Haushaltseinkommens zu beobachten, wodurch sozialpolitische Maßnahmen erforderlich werden könnten.

Um das österreichische Elektrizitätssystem vollständig zu dekarbonisieren, wären mehr EE als im EAG festgelegt und mehr Speicher erforderlich. So könnte überschüssiger Strom gespeichert werden, um ihn in Zeiten geringer EE-Stromproduktion zu nutzen. Dadurch könnte der Bedarf an Gaskraftwerken minimiert oder sogar ganz vermieden werden.

2 Executive Summary

Background and objectives of the project

To mitigate the climate crisis ambitious emission reductions and respectively rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings) as well as industrial systems are required that are unprecedented in terms of scale. In the wide portfolio of mitigation options renewable energy sources will play a key role in delivering the aspired emission reductions, together with efficiency improvements and changes in lifestyles.

The Austrian government has stipulated a goal of 100% RES-E supply in Austria (national balance) by 2030. As of 2020, RES-E held a share of 78% in total electricity generation in Austria. Bridging the gap to the 100% target over the following years will require fundamental changes in the Austrian electricity system entailing considerable investment. The economic and social impacts of these investments might vary substantially depending on the technology mix ultimately implemented.

The objective of *START2030* was to provide comprehensive analyses of the economic incidence and social impacts of a transition to a 100% RES-E system in Austria by 2030. Four scenarios in which the 100% target is achieved were analysed to depict the broad range of potential effects associated with the transformation. In addition, the scenarios for Austria were integrated in a consistent scenario for the European electricity system. The policy scenarios have been specified in close co-operation with relevant stakeholders. The model-analysis delivers insights in terms of the emission impact as well as regarding the macroeconomic and distributional effects of the RES-E scenarios. Based on the model analysis and a comprehensive literature review, policy recommendations have been derived.

Work packages

Given the research objectives described above, *START2030* comprised the following seven content-related work packages (WPs):

WP1 provided the basis for the subsequent WPs and consisted of three tasks: (1) the review of strategic energy policy documents at EU level and in Austria, (2) a survey of past and present RES-E policy and market developments in EU Member States, and (3) the compilation of a database on the projected development of exogenous model parameters (e.g. population development, fuel prices).

In **WP2**, a baseline scenario for the European electricity system was defined so that the Austrian scenarios (WP3) could be simulated in a European context. Based on a literature review and discussions at a stakeholder workshop, the Sustainable Transition scenario (TYNDP2018) was chosen as a "most likely" European benchmark scenario.

WP3 covered the definition of energy scenarios for Austria. Four exploratory scenarios up to 2030 were developed as starting point for the model simulations. The scenarios were crafted in a Group Delphi approach with experts of different disciplines and stakeholders.

In **WP4**, the macro-economic model DYNK and the electricity system model ATLANTIS were prepared for linking. Adjustments included the expansion of the demand and supply side in DYNK as well as the expansion of the electricity grid for Austria and the integration of a storage simulation module in ATLANTIS.

The interface between the models was defined in **WP5**. The electricity generation, distribution and investment data derived in the ATLANTIS model were linked to corresponding variables in the economic model that define the technology of the electricity sector in terms of inputs.

In **WP6**, model simulations were conducted to assess the effects of the transition scenarios. The model analysis informs about the distributional, macro-economic and environmental impacts of the transformation, as well as about changes in the electricity system (e.g. investment requirements, changes in electricity mix and price). Furthermore, a sensitivity analysis was performed, especially with respect to gas and CO_2 price developments.

In **WP7**, policy recommendations for designing the transformation towards a 100% renewables target for the Austrian electricity system were developed based on the model analysis and a literature review. Emphasis was put on the social dimension of the transition.

Results and conclusions

The simulations show that although all scenarios achieve 100% RES-E on a national balance, electricity from gas-fired power plants will still be needed in 2030 to balance variable renewable generation, to avoid grid congestion, and for heat generation from combined heat and power plants in winter months. From a socio-economic perspective, the transition towards a renewable electricity sector is almost neutral when compared to a reference development. It does neither reveal harmful impacts nor lead to high multiplier effects from additional investment. With high natural gas prices, a decrease in GDP and household income, which might motivate redistributive policies, can be observed.

In order to completely decarbonize the Austrian electricity system even more renewables and more storage would be needed as stated in the EAG. With more renewables in electricity and district heating and storage, surplus electricity could be stored to be used in times of low RES-E production. This could minimize or even completely prevent the need for gas-fired power plants.

3 Background and objectives

Climate change is one of the most pressing issues society faces. The greenhouse gas (GHG) emission reductions required to limit climate change to well below 2°C or even 1.5°C above pre-industrial levels as stated in the Paris Climate Agreement call for a fundamental decarbonisation. The EU has taken up the challenge of decarbonisation and committed itself to the following mid- and long-term emission reduction goals: By 2030 EU GHG emissions should be reduced by 55% compared to 1990 levels (EC 2020) and for 2050 carbon neutrality is strived for (EC 2021a).

To achieve the ambitious reduction targets, a rapid and far-reaching transformation of the energy system as well as of our economies and societies are required. In the wide portfolio of mitigation options renewable energy sources will play a key role in delivering the aspired emission reductions (together with efficiency improvements and changes in lifestyles).

The EU aims at increasing the share of renewable energy sources in gross final energy consumption to at least 27% by 2030 (Directive (EU) 2018/2001)[1]. Electricity from renewable electricity sources (RES-E) is expected to play a key role in the transition to a renewable energy system. This is also reflected in Austria's target of achieving 100% RES-E supply[2] by 2030.

As of 2020, RES-E held a share of 78% in total electricity generation in Austria. Bridging the gap to the 100% target over the next 8 years will nevertheless require fundamental changes in the Austrian electricity system, which entails considerable investment. The economic and social impacts of these investments vary depending on which technology mix will ultimately be implemented. In the context of the energy crisis due to the war in Ukraine, higher gas prices increase the challenges of the energy transition and entail a substantial burden for consumers.

The objective of *START2030* was to provide comprehensive analyses of the economic incidence and social impacts of a transition to a 100% renewable electricity system by 2030. This entailed the following sub-targets:

- development of a set of RES-E scenarios in which the 100% target in Austria is achieved;
- integration of the national scenarios into a consistent scenario in line with the development of the European electricity system to generate plausible results on electricity trade;
- expansion and linking of the macroeconomic model (DYNK) and the electricity system model (ATLANTIS) to be able to deliver insights in terms

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[1] In the "Fit-for-55"-Package, the EC proposed to raise this target to 40%.

[2] Control and balancing energy to stabilise grid operation are not included in the calculation of 100% renewable electricity supply.

of the emission impact, as well as regarding the macroeconomic and distributional effects of different RES-E scenarios on households;

- development of policy recommendations based on the model analysis and a comprehensive literature review (with a focus on vulnerable groups); and
- close communication with relevant stakeholders (i.e. policymakers, interest groups, NGOs, researchers) for the development of scenarios and discussion of results and policy recommendations.

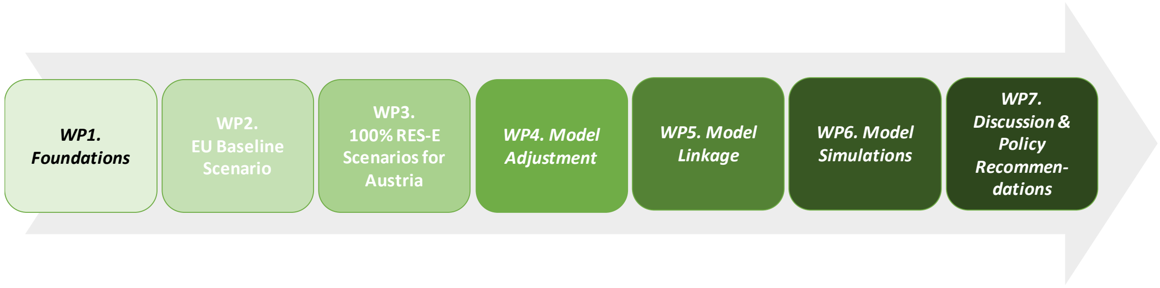
The value added of the project compared to the existing literature consists of a synthetic view of energy, environmental, economic and social aspects of a transition in the electricity system. The synthetic view, on the one hand, refers to the simultaneous analysis of the different areas by considering all relevant feedback mechanisms via an inter-linked model system. On the other hand, the project expands the analysis in the areas of energy and socio-economics. That applies to including the different grid levels (and not only electricity generation) and decentralised generation (e.g. prosumers) and including distributional aspects as well as the economic impact of intra-industrial change in the electricity sector in the analysis.

In a liberalised power market, some users of electricity will be leaders in using green electricity. The results of the *START2030* project will enable researchers to define methods for disaggregating the users according to the relevant criteria and in future modelling development integrating this disaggregation into a new model type.

4 Project content and results

The *START2030* project was organised in seven content-related work packages (Figure 1). In the following the content and the methodology applied in each work package is briefly described.

Figure 1. Work Package Structure of START2030



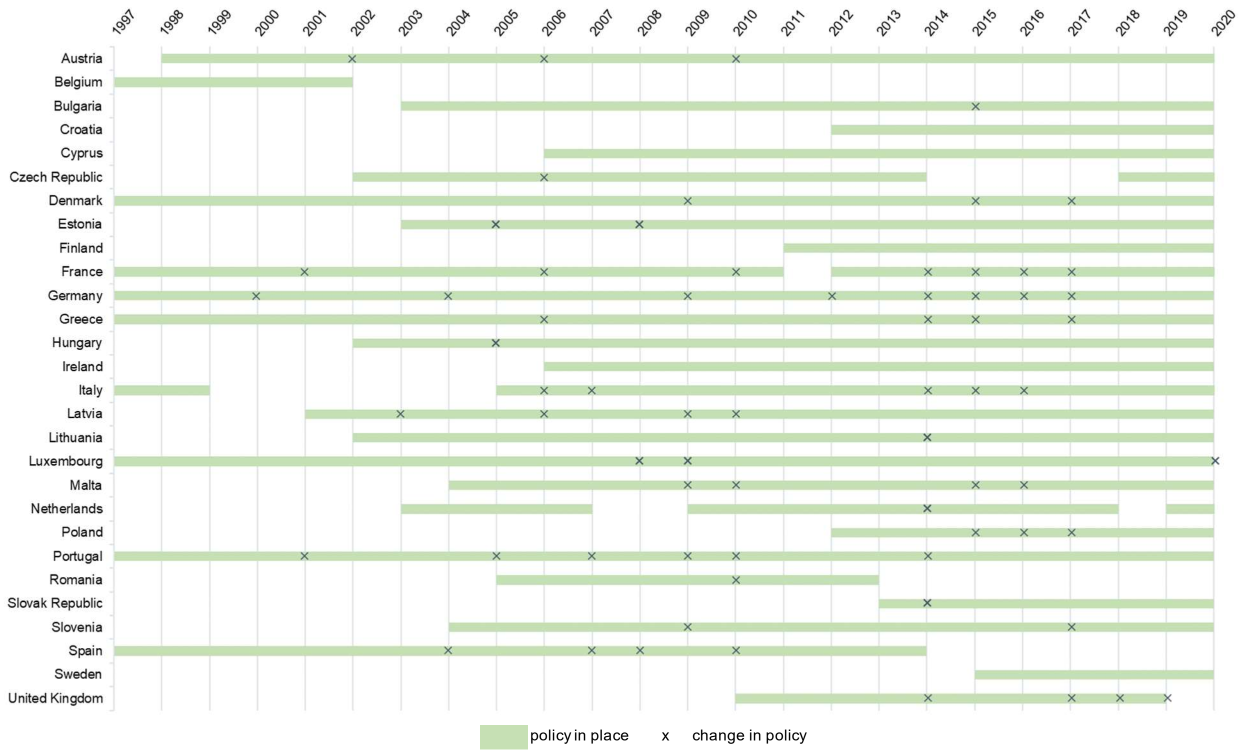
WP1. Foundations

WP1 was dedicated to the analysis of the strategic energy policy framework in Austria and the EU as well as to the analysis of the RES-E policy framework to provide both a review of the relevant policy documents and a database with exogenous parameters for the development of the scenarios (WP2, WP3) and model simulations (WP6).

The 2020 targets for energy and climate (EC 2008) and the 2030 framework for climate and energy policies (EC 2014) underline the political commitment on the general EU level and the increased consideration of climate change issues in energy policy. In the Roadmaps for 2050, the long-term reduction path is laid out for the EU confirming the objective of limiting global warming at a temperature increase of 2°C. These EU targets are challenging for the EU Member States, which is reflected in national energy policy strategies, such as the Austrian #mission2030 (BMNT and BMVIT 2018) and the Austrian National Energy and Climate Plan (NEKP; BMNT 2019), but also in the recent program of the federal government of Austria and the EU's New Climate and Energy Package "Fit for 55" (Kettner and Feichtinger 2021). The strategic energy policy documents and directives most relevant for the electricity system were summarised in a research brief (Kettner and Böheim 2022), including a discussion of options for adapting the EU's energy policy framework in the context of recent developments, in particular the war in Ukraine.

RES-E support schemes differ between the European countries (e.g. Kettner et al. 2009, Ragwitz et al. 2011). Feed-in tariffs and feed-in premiums as well as quota systems with tradable green certificates are the most relevant support schemes in the EU as of today. According to the recast of the renewable energy directive (Directive 2018/2001/EU) and its proposed changes in the context of the "Fit for 55" Package (EC 2021b), after 2020 RES-E support schemes should be designed to avoid unnecessary distortions of electricity markets and in a way that generators consider electricity supply and demand as well as potential grid constraints, i.e. generators should respond to price signals and maximise their market revenues. Based on a comprehensive literature review as well as the processing of statistical data, a survey of past and present RES-E policy and market developments in EU Member States has been conducted. To enable policymakers to get a quick overview of the development of specific instruments over time illustrations like the following example for feed-in-tariffs (Figure 2) have been developed for all policy instruments (see also Annex 1).

Figure 2. Feed-in-tariffs in EU-27 member states and the UK (1997 – 2020)



Source: Own illustration based on Ragwitz and Steinhilber (2013) and Renewables Global Status Reports 2012-2020.

Furthermore, for each key RES-E technology (wind power, solar PV, hydropower and biomass), a detailed quantitative data set, that describes the historic trends for the period from 1990 to 2020 at Member State level, has been derived. The data includes information on implemented policy schemes on an annual basis (i.e. by type of policy instrument, distinguishing between main and accompanying instruments) mainly based on the IRENA Renewables Global Status Reports complemented by a review of the relevant literature as well as RES-E market developments (i.e. installed capacities).

As an input for model simulations a database on the projected development of exogenous model parameters has been compiled based on an extensive survey of the relevant literature. The database includes population and labour force projections as well as projections of urbanisation degrees, car ownership (by fuel type), export dynamics, domestic fuel production, energy efficiency, and fuel and carbon prices.

WP2. A Baseline Scenario for the European Electricity System

WP2 analysed various European development scenarios in order to select a suitable European baseline scenario to implement.

Six scenarios from a total of twenty were examined in greater detail (see D2.1) to identify suitable European benchmark scenarios. The parameters for consumption, power park development, fuel and CO_2 price, and grid extension projects were the basic requirements for a closer examination. As a result, the following scenarios were investigated in greater depth: Sustainable Transition (TYNDP2018, ENTSO-E 2018), Distributed Generation (TYNDP2018), EUCO2030 (TYNDP2018), National Trends (TYNDP2020, ENTSO-E 2020), Global Ambition (TYNDP2020), and Distributed Generation (TYNDP2020). Bottom-up scenarios were prioritised here because top-down scenarios are the fulfilment of predefined storylines.

As a result, the scenarios Sustainable Transition (TYNDP2018) and National Trends (TYNDP2020) have been identified as appropriate bottom-up baseline scenarios. The data in the Sustainable Transition (TYNPD2018) and National Trends (TYNDP2020) scenarios are primarily based on individual TSO assumptions, as well as national legislation and target agreements. It is important to note that the TYNDP2020 was still in draft form and was being reviewed by the European Agency for Cooperation of Energy Regulators (ACER). Since the final version of the TYNDP2020 was not expected to be released until the middle 2021, and implementation of such a large European scenario takes some time, the Sustainable Transition scenario (TYNDP2018) was chosen as a "most likely" European benchmark scenario in a stakeholder workshop.

In the Sustainable Transition scenario (TYNDP2018), decarbonisation in the energy sector is primarily driven by the closure of coal-fired power plants. To achieve a rapid and economically sustainable CO_2 reduction, decommissioned coal power plants will be replaced by gas-fired power plants. The benefits of this scenario are as follows: It is a bottom-up approach with all necessary data included. It had been developed with strong stakeholder engagement and already received ACER approval. The only disadvantage is that it does not depict the EU Member States' National Energy and Climate Plans (NECP). The Sustainable Transition scenario has the lowest predicted power consumption compared to the other analysed scenarios due to the preferred use of gas in the heating, transportation, and energy production sectors. The installed power is expected to rise significantly in the coming years, particularly in the fields of solar and wind energy. Coal and nuclear power plants are starting to be phased out. Until 2030, the shares of energy sources such as gas, biomass, and hydropower remain largely constant. Between 2020 and 2030, there already is a significant increase in renewable energy. The Sustainable Transition 2030 scenario's fuel prices were derived from the WEO 2016 New Policies Scenario. Furthermore, CO_2 prices were raised in order to prioritise gas over coal in the Merit-Order. The TYNDP 2018 includes over 166 transmission projects and 15 storage projects in total. 12 of the 15 storage projects are (pumped) storage power plants, and three are compressed air storage power plants (CAES).

The Sustainable Transition scenario recommendation from the TYNDP2018 was discussed in the stakeholder workshop and its use as European baseline scenario was largely supported by the participants. As a result, the scenario was implemented into the ATLANTIS model for the continental European countries in which the Austrian scenarios (defined in WP3) are inserted. For the implementation of these scenarios, known power plant and power line projects were considered. Otherwise, scenario power plants were implemented to reach the targets for the installed power plant capacity per country.

WP3. Scenarios for 100% Renewable Electricity in Austria

WP3 covered the definition of four energy scenarios for Austria. Visions of alternative futures (exploratory scenarios) up to 2030 have been developed as starting point for the model simulations. A community of experts from different disciplines (most notably engineering, economics, energy planning) and stakeholders (from public administration, interest groups and social partners as well as NGOs), covering both academics and practitioners, has participated in a Delphi approach to define the scenarios. The participants were selected to cover a broad range of expertise as well as different views.

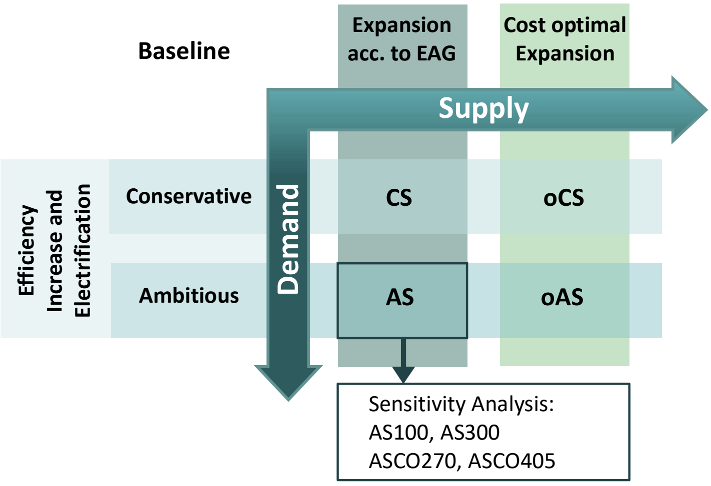
The Delphi technique was developed as a forecasting tool under uncertainty by the RAND Corporation in the early 1960s (Häder 2009). It is a systematic, multi-stage survey method with feedback and is often used as a tool to assess future events, trends or technological developments. Each Delphi is based on an expert panel and aims at integrating the judgments of experts from different disciplines or with different viewpoints. In *START2030* a classical Delphi approach has been combined with a Group Delphi (Schulz and Renn 2009): During an online workshop with live voting in April 2021, the experts and stakeholders involved in the Delphi first discussed the issues covered to ensure that the experts have a common understanding of the survey for the second Delphi round conducted via an online questionnaire.

In preparation for the Delphi, the current situation of renewable energy sources for electricity generation in Austria has been analysed in detail, which also serves as starting point for the model simulations. The findings have been summarised in a fact sheet that can be downloaded from the *START2030* website (https://start2030.wifo.ac.at/publications.htm). Moreover, to identify which renewable energy sources could contribute to which extent to the target of 100% RES-E in Austria, the potentials of the individual RES were analysed.

Hydropower, wind energy, solar energy and PV, biomass, biogas, sewage and landfill gas as well as geothermal energy were considered.

The basic assumption reflects Austria's target postulating 100% coverage of electricity supply by renewable energies until 2030. The scenarios hence depict a range of different futures but share one key assumption, i.e. that the share of 100% RES-E on a national balance in Austria is achieved in 2030. To reach this target different pathways are possible, depending on several parameters. First, this refers to which RES contribute to the overall target. The second key parameter is the development of electricity demand that will be influenced e.g. by the development of e-mobility, the use of heat pumps, energy efficiency improvements, and the future role of prosumers. Further general drivers include population development, economic growth or fuel price developments as reviewed in WP1. Against this background, four basic scenarios have been defined as illustrated in Figure 3. In addition to these main scenarios, sensitivity analysis is performed with respect to sharply increasing gas and CO_2 prices.

Figure 3. START2030 Scenarios



Source: Own illustration.

As noted before, in all scenarios a share of 100% RES-E in Austria by 2030 is achieved. With respect to the demand side, one pathway assumes a conservative development of energy efficiency and moderate electrification while the other assumes ambitious energy efficiency improvements and accelerated electrification. With respect to the supply side, one pathway depicts the additional RES-E capacity as envisaged by the Austrian Renewable Expansion Act (Erneuerbaren Ausbau Gesetz; EAG), while the other aims at illustrating a cost optimal RES-E mix. Combining the demand and supply side yields a matrix of four scenarios to be simulated.

While with respect to the supply side, RES-E potentials ultimately determine the framework conditions, there is a broad range of potential developments in energy demand. Therefore, the Delphi approach focused on these demand-side parameters. Key demand-side parameters for the RES-E scenarios for Austria were identified as well as potential pathways for their development based on a survey of existing scenarios (Austrian Energy Scenarios – MonMech, IEA scenarios, etc.; cf. UBA 2017a, UBA 2017b, UBA 2019, IEA 2020).

In the first round of the Delphi, the online workshop, the status quo of the different parameters as well as scenarios for their future development as derived from the literature survey (Austrian Energy Scenarios – MonMech, IEA scenarios, etc.; cf. UBA 2017a, UBA 2017b, UBA 2019, IEA 2020) were presented. For each parameter, the workshop participants were then asked to give a judgement about its future development in a conservative scenario via live voting. Afterwards, the results of the voting were discussed. For the second round of the Delphi, the participants participated in an online survey to give their judgement about the development of the parameters for both the conservative and the ambitious scenario. Based on the results of the Delphi, the development pathways for the different parameters in the two-demand side scenarios finally were defined (see Annex 2).

In the final task of WP3, the parameters have been linked to policies in a two step-methodology. First, cost structures and the price of electricity have been assessed. This analysis will allow to quantify potential deviations of certain parametrisations from the equilibrium of cost optimisation in WP5. In a second step, we will identify the support level necessary to achieve the targeted scenario results. For this purpose, we assume that electricity generators' revenues and any financial support have to cover the long-term marginal cost of RES-E generation.

WP4. Model Adjustment

Both models have been adjusted for the *START2030* project. With respect to the DYNK model, the following main expansions have been implemented:

(i) Expansion and adaptation of the supply side of DYNK

This task included the disaggregation of the energy sector (35) in NACE classification into electricity generation & supply (NACE 35A), gas supply (NACE 35B) and heat & steam generation and supply (NACE 35C) in the actual input-output (IO) table incorporated in DYNK. This undertaking could be carried out on the basis of a special dataset delivered by Statistics Austria, where these sectors are disaggregated in the supply as well as the use table. Integrating these disaggregated sectors in DYNK not only consists of disaggregation, but also requires the disaggregated modelling of these commodities in demand (private consumption, external trade) and supply (wage formation, input demand, output prices).

The separate modelling of electricity generation is a crucial prerequisite for linking to the electricity sector model ATLANTIS. The technology of the electricity sector in the IO model part of DYNK is defined as the weighted sum of different generation technologies, where the weights are the shares of the different technologies in total monetary[3] electricity output from ATLANTIS. The switch between technologies that takes place in ATLANTIS can thereby be fully carried over to DYNK. Specific technology and cost data for the different generation technologies (investment, costs of operation, fuel, emissions, labour and investment related) as well as the electricity output price all stem from the ATLANTIS model results, although part of these variables would also be a result of the DYNK solution. The data set from ATLANTIS has been applied for calibrating the base year and has as well be taken from ATLANTIS in the different scenarios.

(ii) Adaptation in household modelling

This task comprised the split up of the household sector into groups according to household income. That included the full derivation of disposable income for different household groups, which has as a prerequisite the availability of all income components at this level. Further, the consumption per commodity bundle of the different household groups by category was assigned to the household groups. Both data sets needed to be consistent with the totals from National Accounts.

For households, prosumer activity was also modelled. For this purpose, the impact of electricity price increases on production capacity for electricity by prosumers was calibrated, based on assumptions about feed-in activity of prosumers and on the price elasticity of electricity demand.

For the simulation model of the electricity sector, ATLANTIS, the following model expansions have been implemented:

(i) Expansion of the data input mechanism of ATLANTIS

For the linkage of the two models, the data input mechanism of the ATLANTIS model had to be adjusted, so that the output from the DYNK model (electricity demand) can be imported into ATLANTIS. For this, the import tables and import mechanism were adjusted accordingly.

(ii) Expansion of the electricity grid for Austria in ATLANTIS

The database of the ATLANTIS simulation model already contained information about the transmission network at the voltage levels of 380kV and 220kV. For *START2030*, the existing power grid database was updated with the newest available information (including known projects until 2030). Furthermore, the electricity grid was expanded to include the 110kV network of Austria. Information about the 110kV network of Austria is not publicly available from the various distribution system operators, open-source data was used instead. With a tool developed at the Institute of Electricity Economics and Energy Innovation, the 110kV network information was downloaded from the Open Street Map

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[3] Physical generation (MWh) multiplied by wholesale price (€/MWh).

project (https://www.openstreetmap.org/) and converted into an ATLANTIS readable format. The Open Street Map project has very detailed information about the power lines and power stations even at the 110kV level. This information was then combined with the already existing database of the 380kV and 220kV lines.

(iii) Adaption of the storage simulation module

Battery storages (complementing pumped-storage power plants) are expected to play a bigger role in the future electricity system in Austria to store excess-energy from renewable energies and use the stored energy in times with less renewable energies and high demands. The ATLANTIS model already includes a module for simulating pumped-storage power plants; this module has been extended to battery storages. Battery storages usually are connected to the lower voltages of the distribution grid. However, our simulation only includes the 380kV, 220kV and 110kV grid information. Therefore, battery storages are aggregated and implemented on a per node basis.

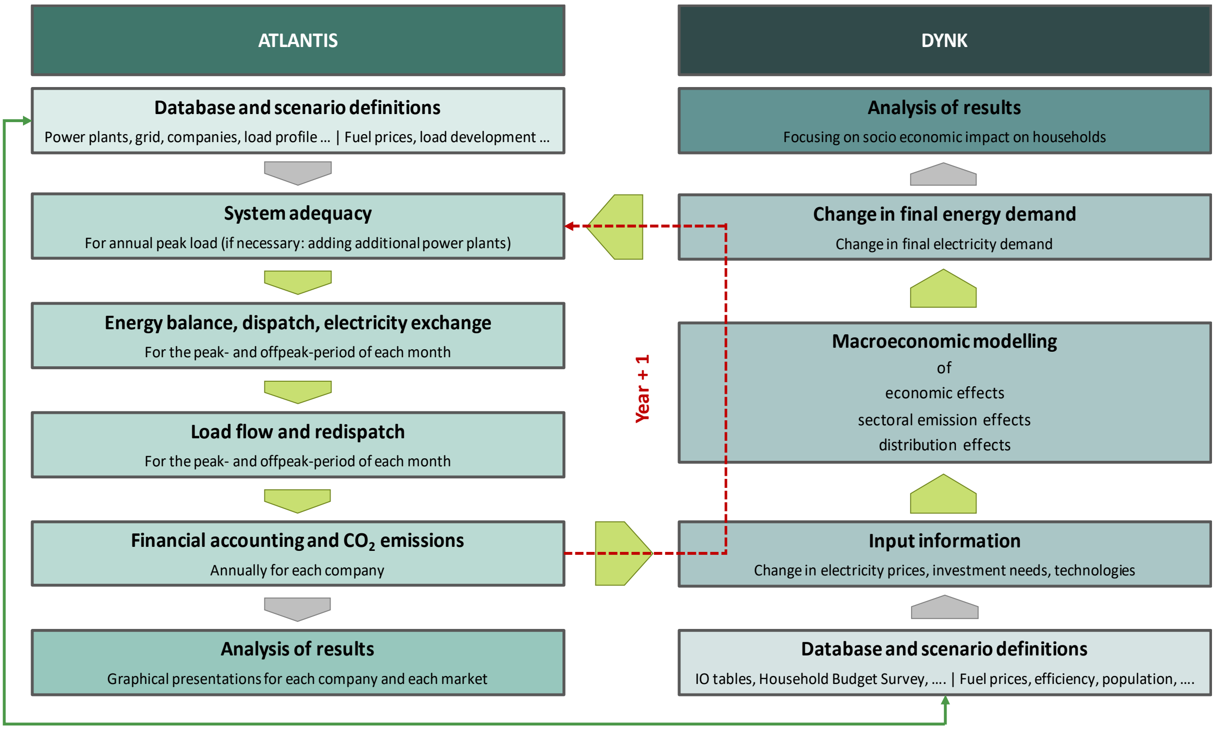
(iv) Calculation of investments in the electricity grid

Transmission investment costs are based on aggregated annual expansion plans according to TYNDP 2018 and APG. Since project costs are highly case dependent empirical specific investment costs per km were applied. These are 2.5 M€/km for 220/380kV overhead lines and 15.0 M€/km for 220/380 kV cables respectively.

WP5. Model Linkage

Figure 4 sketches the exchange of data between the two models. DYNK provided changes in final electricity demand to ATLANTIS. ATLANTIS modelled which technology mix is used to meet the demand, and calculated investment needs and changes in the electricity price as well as changes in electricity exports and imports. Together with the changes in the technology mix, these parameters were fed back into the macroeconomic model. This process was repeated until convergence was achieved.

Figure 4. Flow chart of the simulations with the combined model system



Source: Own illustration.

This task also included researching exogenous data (such as development of inflation, demographics, etc.) required for the models.

WP6. Model Simulations

The simulations for the scenarios developed in WP3 have been conducted with the linked models detailed in WP5.

(i) Implementation of baseline values and exogenous drivers

Before simulations started, both models were updated to ensure consistency for all exogenous drivers (like GDP growths, fuel prices, etc.). These parameters come either from the data research from WP5 or from the expert feedback from the workshops. To start the simulations, a baseline value for the Austrian electricity demand from DYNK is set in ATLANTIS.

(ii) Model simulations of the effects of the policy scenarios

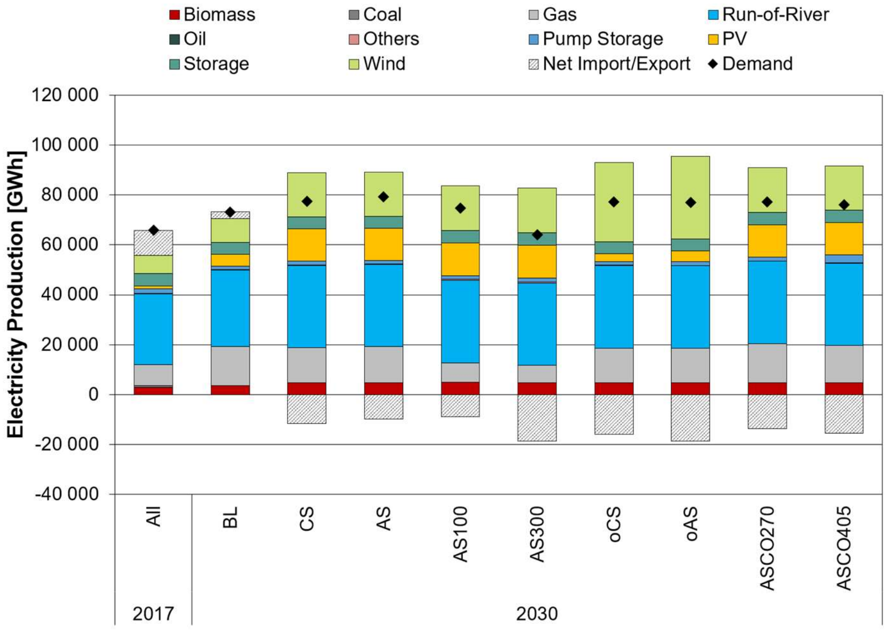
After simulating the required years of 2017 to 2030 in ATLANTIS, the results (installed capacity per power plant type and year, produced electricity per power plant type and year, electricity price and fixed and operational costs per power plant type and year) were shared with DYNK leveraging a cloud server infrastructure. Due to technical and practical reasons the data exchanged between ATLANTIS and DYNK comprised full scenario results for the simulations period of 2017 to 2030. DYNK used the results from ATLANTIS as inputs for its simulation runs and the resulting change in the Austrian electricity demand from

DYNK was shared with ATLANTIS again. This process was repeated until sufficient convergence is achieved, and the results of the ATLANTIS model do not impact the results of the DYNK model anymore. Practice has shown that after 2-3 rounds convergence was achieved and the simulations could be terminated. This iteration process was done for each of the scenarios described in WP3.

The results of the simulations are described in detail in Kettner et al. (2023) and Gaugl et al. (2023). Here, we present only the main results for electricity demand, GDP and CO_2 emissions, as well as additional technical sensitivity analysis.

Figure 5 compares demand, produced electricity per power plant type, and net import/export for the base year 2017 and the different scenarios for 2030. Final electricity consumption in Austria increases in all scenarios compared to 2017, except for the sensitivity scenario with a gas price of EUR 300/MWh (AS300): In the Baseline Scenario (BL) electricity consumption increases by 11% (9 TWh) compared to 2017. The Conservative Scenario (CS) and the Ambitious Scenario (AS) show higher increases in electricity demand by 17% (12 TWh) and 21% (14 TWh) respectively. In AS300, by contrast, electricity demand falls by 2% (1 TWh). In 2030, in every scenario Austria is changing from a net-importing country to a net-exporting country. In 2017, hydro power plants (sum of run-of-river, storage and pump storage) make up for the biggest part of the electricity production with 35.2 TWh, followed by gas (8.3 TWh) and wind (7.2 TWh). Even with big investments in PV and wind, hydro power will remain the main source of renewable electricity in 2030.

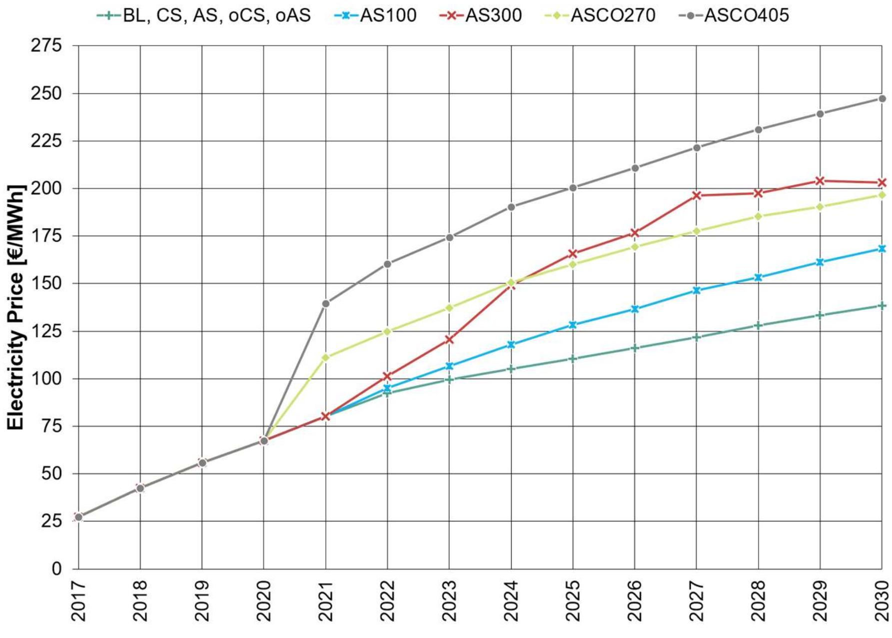
Figure 5. Electricity generation in the base year 2017 and 2030



Source: Own illustration.

Figure 6 shows the development of wholesale electricity prices (without grid costs and taxes). Even if 100% RES-E on a national balance is achieved, there are times when electricity production from RES is not sufficient and therefore gas power plants have to be dispatched to cover the excess demand. All four scenarios show a higher electricity production from gas power plants in 2030 compared to 2020. As PV and wind are highly volatile, their fluctuations have to be compensated by gas power plants. Austria's gas power plants are also used to compensate this variability in renewable generation in neighbouring countries. Furthermore, in times with simultaneous high wind and PV production, grid congestions lead to a redispatch of power plants. BL as well as (o)CS and (o)AS show (almost) identical price increases from EUR 30/MWh in 2017 to EUR 138/MWh in 2030. The sensitivity analysis (scenarios AS100 and AS300) shows that higher gas prices have a substantial impact on production costs of gas power plants and therefore on the electricity price. The main driver for higher production costs from gas generators remains, however, the assumed increasing price of CO_2 certificates. The sensitivity analysis with a CO_2 price of EUR 270 yields an electricity price similar to AS100, for a CO_2 price of EUR 405 the increase in the wholesale electricity price is even higher.

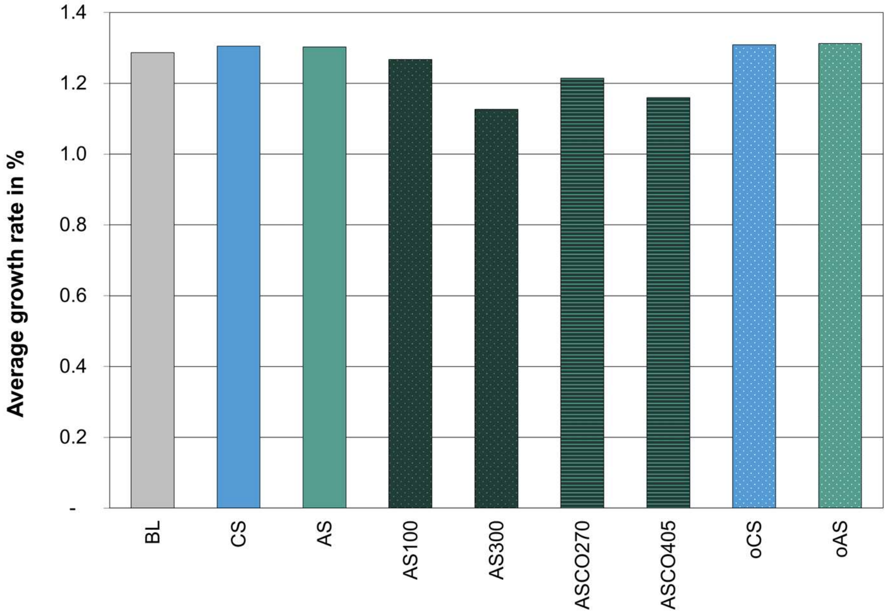
Figure 6. Development of the electricity prices for each scenario



Source: Own illustration.

Gross domestic product (GDP) increases by 1.3% per annum in the baseline. In CS and AS, GDP is 0.2% higher than in the BL in 2030. This slight increase mainly reflects higher electricity exports, higher investment in renewable electricity generation in Austria as well as the indirectly triggered higher private consumption and investments. However, imports linked to the investment in RES-E plants contribute negatively to the "trade balance" due to their high import share and thereby dampen the primary positive effect of investment. Changes in employment in the CS compared to the baseline are negligible. In oCS and oAS, the effects on GDP and employment are almost identical as in CS and AS. Even though higher exports of RES-E in oCS and oAS contribute positively to the GDP, the lower investment activities in RES-E cancel out the former effect. In the scenarios with higher gas or CO_2 prices (AS100 AS300; ASCO270, ASCO405), these higher prices result in a reduction of real GDP, when compared to AS but also compared to BL. For all sensitivity scenarios, this development is driven by a deterioration of trade balance and consumption in real terms.

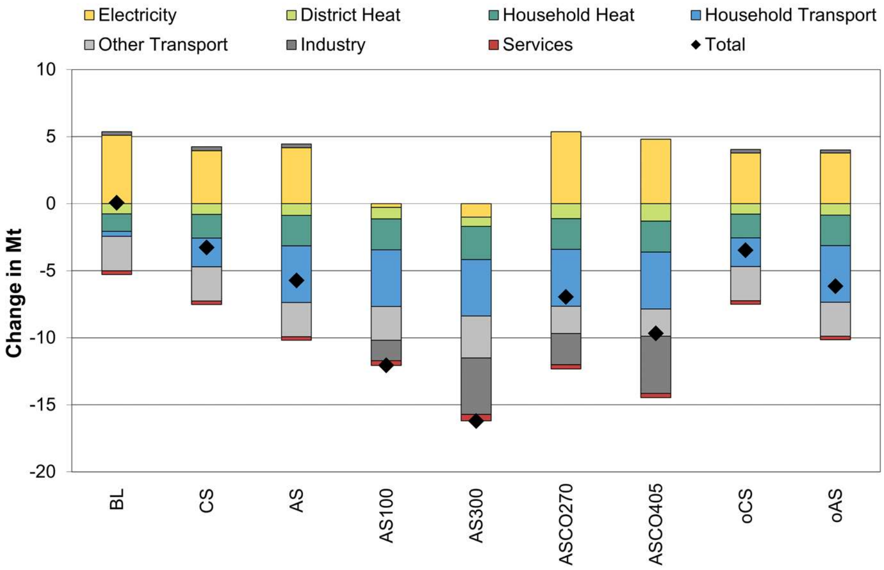
Figure 7. Real GDP growth



Source: Own illustration.

In BL, CO_2 emissions in 2030 are roughly at the same level as in the base year 2017. Emissions from the industry sector grow moderately; emissions from electricity generation show a pronounced increase of 5 Mt and respectively 89%, due to the expansion of gas-based electricity generation (see above). Increasing emissions from industry and electricity generation are compensated by CO_2 emission reductions in the other sectors: The strongest reductions are found for district heating as well as heating in the household sector (see Figure 8). In CS, CO_2 emissions decrease by 4.7% compared to the base year 2017; the reductions in AS amount to 8%. The strongest reductions are found for emissions from household heating systems and passenger transport. Since no additional measures for the sectors industry, services and non-household transport are assumed, the development of CO_2 emissions in these sectors is almost identical to the baseline. In the sensitivity scenarios with higher gas prices (AS100 and AS300), the decline in CO_2 emissions in Austria compared to BL is considerably more pronounced than in AS, especially for electricity generation (approximately -49% in AS100 and -56% in AS300 in 2030). With respect to the other sectors, industry and services show the highest reductions. In the sensitivity scenarios with higher carbon prices (ASCO270, ASCO405), the reductions are somewhat lower since electricity generation from gas power plants in Austria is further expanded to substitute coal-based electricity generation in other EU Member States.

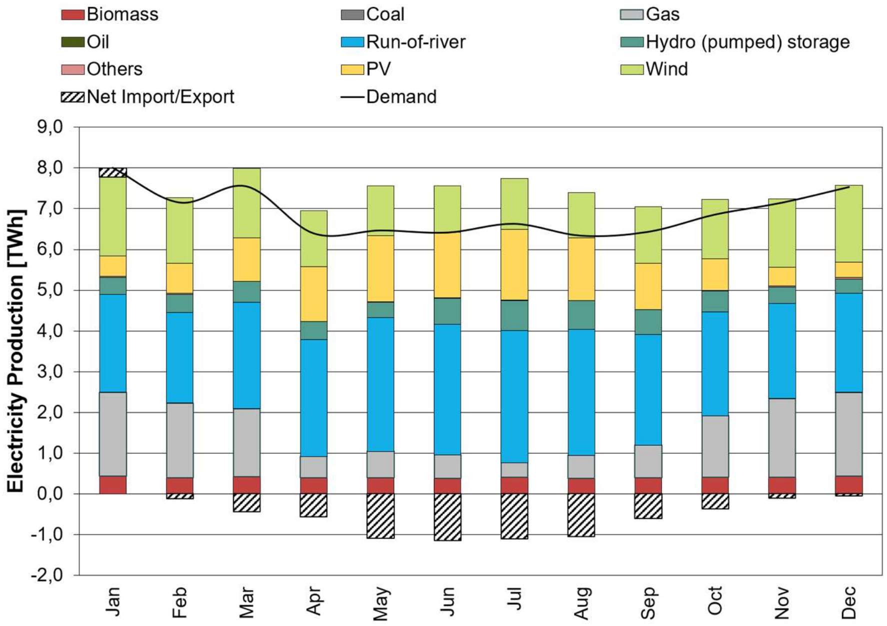
Figure 8. Change in CO2 emissions in 2030 compared to 2017.



Source: Own illustration.

In addition to sensitivity analyses with respect to the gas and carbon price, the effects of changes in the model specifications (Zonal Pricing Model with and without redispatch as well as 'must run constraints' for CHPs in ATLANTIS; crowding out of energy investment in DYNK) were tested and compared to AS. AS takes CHP and industrial must-run power plants into account to accommodate the need for heat production. Monthly electricity generation in AS in 2030 is presented in Figure 9.

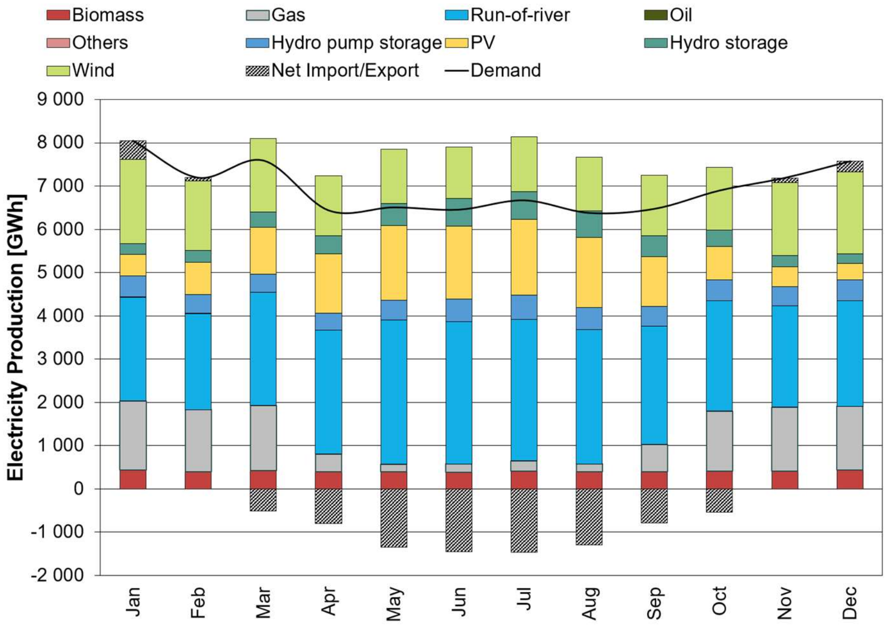
Figure 9. Monthly electricity generation in AS in 2030



Source: Own illustration.

Without grid restrictions within the countries and electricity exchange limited based on NTCs between countries, no renewable production has to be curtailed especially from wind (18 TWh) and PV (13.2 TWh). Therefore, gas-fired power plants (10.7 TWh) are not needed as often, and net-export is about 7.3 TWh. The monthly generation per power plant type for 2030 in Figure 10 shows the typical Austrian seasonal behaviour: Summer is characterized by higher generation from PV and hydro power, while wind generation is higher in the winter months. Higher demand in combination with less production from hydro power plants and PV increases the need for gas-fired power plants in winter months. During summer Austria is able to net-export electricity. In contrast, in winter Austria is still a net-importing country.

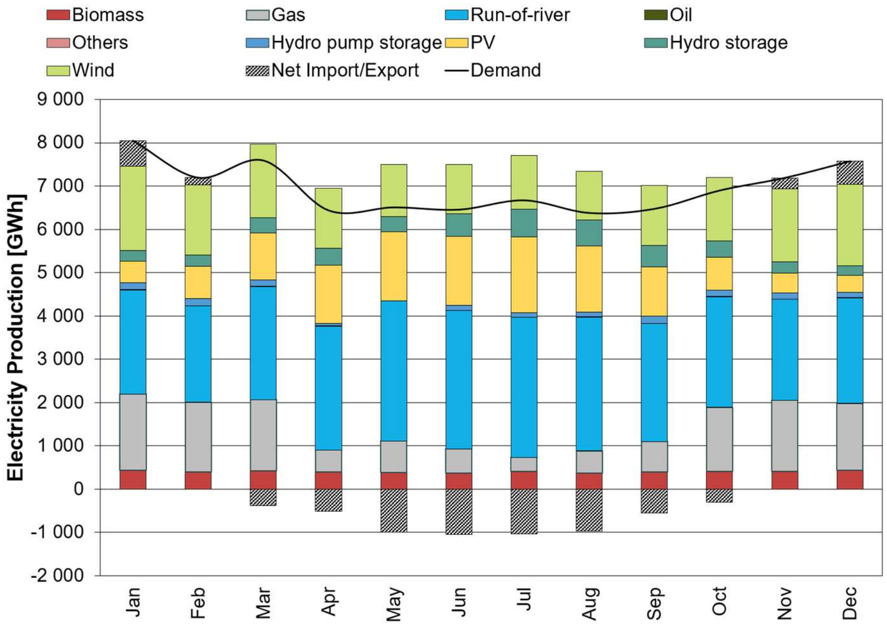
Figure 10. Monthly electricity generation without grid restrictions (Zonal Pricing Model) in 2030



Source: Own illustration.

By implementing grid restrictions based in the model, electricity production from renewable energies has to be cut-off (wind -0.15 TWh and PV -0.33 TWh compared to the ZP model) and a redispatch to gas-fired power plants is needed (see Figure 11). Furthermore, pump-storage power plants, which are mostly located in the western part of Austria, cannot be used as efficiently to cover consumption in the demand centers in the eastern part of Austria, as indicated by the reduction of electricity from pump-storage power plants (-4.1 TWh compared to the ZP model). With constant demand and less electricity production in Austria, net-export decreases as well (-3.1 TWh compared to the ZP model). Monthly production per power plant type shows the same seasonal behaviour, but production from gas-fired power plants is higher compared to the ZP model in every month due to necessary redispatch measures. The grid restrictions also lead to higher imports in December, January and February and smaller exports in the rest of the year.

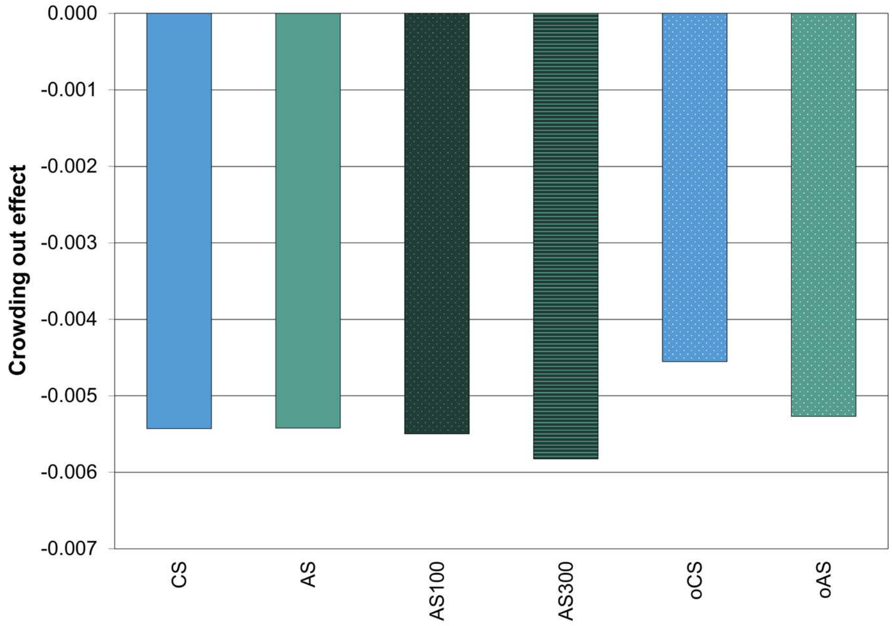
Figure 11. Monthly electricity generation in the Redispatch Zonal Pricing Model in 2030



Source: Own illustration.

The simulation results of DNYK presented before assume that no crowding out of energy investment occurs. Nevertheless, we tested this assumption that might be challenged. Here we assumed that general investments of the very same sector namely Electricity, Gas and Heat (NACE35) are crowded out by the investments in RES-E plants. As shown in Figure 12, differences in the simulation results between the two variants are negligible. The reason for the small difference is twofold. On one hand RES-E investments (mainly PV and Wind power) have a small impact on GDP due to the high import share of these technologies. On the other hand, the import share of the crowded-out investment-structure (i.e. the structure of sector NACE D35) is also relatively high. Hence, if the (import-intense) investment is additional the impact is small, and if other (also import-intense) investments are crowded out the impact stays small.

Figure 12. Changes in average real GDP growth 2017-2030 due to crowding out of energy investment



Source: Own illustration.

WP7. Policy Recommendations

The innovative approach of coupling the macroeconomic model DYNK with the model of the continental European electricity system ATLANTIS leads to new insights for energy policy on the impacts of the transition to 100% RES-E in Austria. The linked model system shows that the changes in electricity consumption due to rising electricity prices are quite small. Only given very high gas prices electricity demand decreases considerably. This reflects the fact that electricity demand is inelastic and hence only high changes in prices will lead to a notable decrease in demand.

The analysis furthermore shows that electricity from gas-fired power plants will still be needed in 2030 despite all scenarios achieve 100% RES-E on a national balance (i) to level out the variable renewable generation, (ii) to avoid grid congestions (redispatch-measurements), and (iii) to deliver heat for district heating from combined heat and power plants in winter months.

In the cost optimised scenarios the installation of wind power plants is more cost-efficient than PV installations given current high battery prices which make storage expensive, since the full load hours for wind are much higher (as wind power is also produced during night hours) and it helps levelling out the lower generation from hydro power plants during winter months. Moreover, the addition of around 10,000 TWh of wind capacity until 2030 is not realistic given current institutional constraints in Austria. Approval and installation of PV is much easier (especially on rooftops) compared to wind and therefore also an interesting option for homeowners, especially in the context of the current energy crisis with strongly rising energy/electricity prices and potentially reduced energy security.

In all scenarios Austria becomes a net-exporting country of electricity under a conservative European scenario regarding the renewable electricity expansion in other countries. If, however, more and more countries increase their investment in RES-E this could change.

The small investment and price impacts lead to negligible macroeconomic effects. The impacts on GDP and employment are positive but very small in all main scenarios. With high natural gas prices in the sensitivity scenarios a decrease in GDP can be observed. The same holds true for distributional impacts which are also small but positive. All households are better off in the main scenarios in terms of disposable income. In scenarios with high gas prices, household income is negatively affected and this might motivate redistributive policies accompanying the transition in the electricity sector.

The main policy conclusions from the project can be summarized as follows:

1. The expansion of renewable electricity generation plays an important role both in terms of achieving the climate targets and in terms of increasing the security of supply by fostering the resilience of the energy system.
2. The transition towards renewables in the electricity sector is almost neutral (slightly positive) from a socio-economic perspective. It does neither reveal harmful impacts nor lead to high multiplier effects from additional investment.
3. Households owning a PV installation generally benefit more strongly from the transformation of the electricity system than others. However, there is a stronger uptake of PV systems in higher income quintiles which is not only due to income constraints of lower quintiles but also to the fact that a higher share of these households live in multi-family houses facing constraints for the implementation of a PV system.
4. The switch to 100% RES-E is accompanied by substantial adjustment costs. People with low incomes are particularly affected. In order to avoid energy poverty, the social dimension of the transformation of the energy system requires therefore special attention.
5. In order to mitigate the transition process and relieving the adjustment cost burden policies to support the transition towards 100% RES-E should therefore be focused on
    a. replacing old, energy-inefficient large household appliances (washing machine, tumble dryer, refrigerator, etc.). The subsidy for appliance replacement should be staggered according to social need and amount to up to 100% of the purchase costs
    b. obliging the energy suppliers to implement savings in the household sector exclusively through energy efficiency measures among

particularly vulnerable groups (as part of their obligations under the European Energy Efficiency Directive)

c. generating incentives for the installation of PV systems in low-income households which would contribute to further improving their participation in the electricity transformation and fostering resilience towards increases in electricity prices.

5 Conclusions and recommendations

Findings derived from the project

The innovative approach of coupling the macroeconomic model DYNK with the model of the continental European electricity system model ATLANTIS leads to new insights on the impacts of the transition to 100% RES-E in Austria. The linked model system shows that the changes in electricity consumption due to rising electricity prices are quite small. Only given very high gas prices (as in the scenario with a gas price of 300 €/MWh) electricity demand decreases considerably. This reflects the fact that electricity demand is inelastic and hence only high changes in prices will lead to a notable decrease in demand. As can be seen from the results of the electricity system model ATLANTIS, changes in electricity demand as illustrated by the scenarios mostly affect imports and exports. This is mainly due to the fact that run-of-river, PV and wind are (mostly) variable and cheap generation technologies which are not cut-off if not necessary (from a grid perspective).

In the cost optimised scenarios, the installation of wind power plants is more cost-efficient than PV installations, since the full load hours for wind are much higher (as wind power is also produced during night hours) and it helps levelling out the lower generation from hydro power plants during winter months. If prices for batteries will decline in the future, this could change as excess PV production could be stored in batteries for utilisation during night hours. Moreover, the addition of around 10,000 TWh of wind capacity until 2030 is not realistic given current institutional constraints in Austria, in particular private and political opposition in some provinces. Approval and installation of PV is much easier (especially on rooftops) compared to wind and therefore also an interesting option for homeowners, especially in the context of the current energy crisis with strongly rising energy/electricity prices and potentially reduced energy security.

The analysis shows that electricity from gas-fired power plants will still be needed in 2030 despite all scenarios achieve 100% RES-E on a national balance (i) to level out the variable renewable generation, (ii) to avoid grid congestions (redispatch-measurements), and (iii) to deliver heat for district heating from combined heat and power plants in winter months.

In all scenarios Austria becomes a net-exporting country of electricity. However, it should be noted that the implemented European scenario is conservative regarding the renewable electricity expansion in other countries. Many countries have already updated their plans to increase renewable electricity production. If neighbouring countries also install more renewables, they might have high renewable generation at the same time as in Austria and vice versa. This could potentially be challenging regarding the export of electricity in times of high RES-E and a lack of importing possibilities in times of low production from hydro, PV, and wind.

The small investment and price impacts lead to negligible macroeconomic effects. The impacts on GDP and employment are positive but very small in all main scenarios. With high natural gas prices in the sensitivity scenarios a decrease in GDP can be observed. The same holds true for distributional impacts which are also small but positive. All households are better off in the main scenarios in terms of disposable income. In scenarios with high gas prices, household income is negatively affected, and this might motivate redistributive policies accompanying the transition in the electricity sector. The main conclusion from the simulations is that the transition towards renewables in the electricity sector is almost neutral (slightly positive) from a socio-economic perspective. It does neither reveal harmful impacts nor lead to high multiplier effects from additional investment.

Households owning a PV installation generally benefit more strongly from the transformation of the electricity system than others. However, there is a stronger uptake of PV systems in higher income quintiles which is not only due to income constraints of lower quintiles but also to the fact that a higher share of these households lives in multi-family houses facing constraints for the implementation of a PV system. Policies supporting the installation of PV systems in low-income households would therefore contribute to further improving their participation in the electricity transformation and fostering resilience towards increases in electricity prices.

Further steps that will be taken by the project team

In future projects, the analysis of the impacts of the energy transition could be enhanced by analysing the characteristics of prosumer households and identifying factors supporting or constraining the adoption of PV systems, which would give more detailed insights into the distributive effects of the energy transition.

Relevance for other target groups

The project results are in general applicable for various stakeholder groups like the scientific community (national and international), Austrian policy makers, and private companies. The results provide an indication of the effects of reaching the 100% RES-E target stipulated by the Austrian government. Furthermore, the findings can be an indicator for the future value and the optimal system integration of RES-E which concerns the electricity industry, energy regulators as well as the Austrian/European energy policy. Moreover, the modelling approach can be extended towards other research questions, which can be interesting for the international research community. Finally, the discussion of options to mitigate negative impacts of rising energy prices on households (*START2030 Research Brief #1*) already fed into Austrian policy development. Furthermore, as follow-up activities several WIFO research briefs on the design of policy instruments mitigating the effects of the energy crisis have been published and were well received by the Austrian policy maker community (Böheim et al. 2022a; Böheim et al. 2022b; Felbermayr et al. 2022a, Felbermayr et al. 2022b).

Summarising, three major target groups can draw from the project results:

Academia: Researchers and academics, in different institutions and research settings, can build on the results and spur further investigation into the topic and to enforce an academic debate on the socio-economic impacts of decarbonising the electricity system. In order to guarantee easy access to the results for other researchers, the simulation results will be fed into the NetZero2040 explorer (https://www.netzero2040.at/scenario-explrer).

Administration: The stakeholder and dissemination workshops (see Annex 3) have provided a platform for intensive discussions with stakeholders from administration. The discussion of options to mitigate negative impacts of rising energy prices on households (*START2030 Research Brief #1*) already fed into Austrian policy development.

Other Stakeholders: The project has been carried out in close contact with stakeholders (most notably social partners, interest groups and NGOs) and used the specific expertise they can bring to our project from their respective perspective. These groups can particularly draw from the policy recommendations developed to protect low-income households in the context of the current energy crisis.

To make our results accessible and employable for policymakers and other relevant stakeholders, we have summarised the most important and policy relevant research results in a policy brief. Moreover, we have regularly reached out to a broader set of stakeholders via WIFO's e-newsletter, the project website, and the social media accounts of the project members (LinkedIn, Twitter, Mastodon).

C) Project details

6 Method

The value added of the *START2030* project compared to the existing literature consists of an integrated view of energy, environmental, economic and social aspects of a transition in the electricity system. The integrated view, on the one hand, refers to the simultaneous analysis of the different areas by considering all relevant feedback mechanisms via an inter-linked model system. On the other hand, the project expands the analysis in the areas of energy and socio-economics. That applies to including the different grid levels (and not only electricity generation) and including distributional aspects as well as the economic impact of intra-industrial change in the electricity sector in the analysis. In the following, the two models used in the analysis – DYNK and ATLANTIS – as well as the approach for linking is briefly described.

The Dynamic New Keynesian Model DYNK

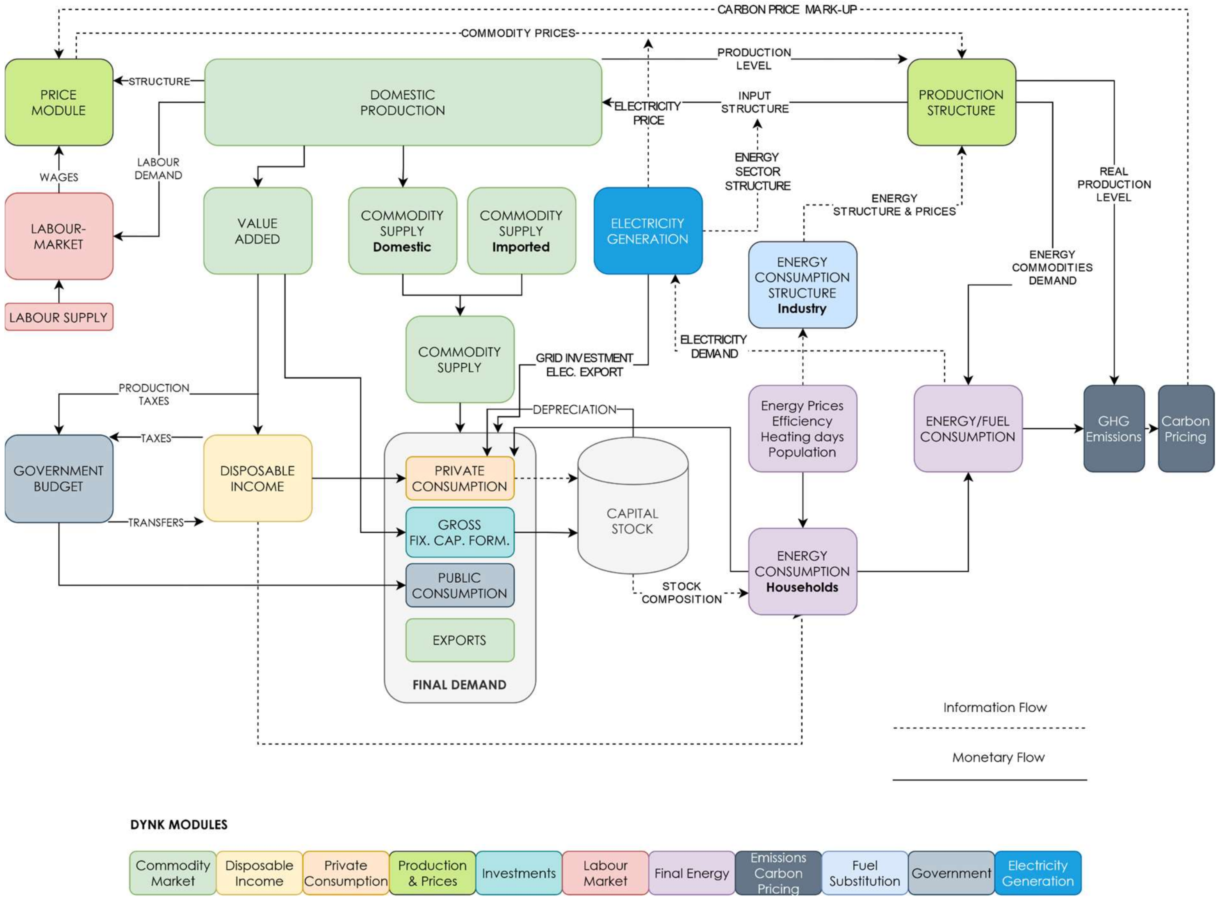
The DYNK model resembles an Input-Output-Model in its core and expands this approach by specific production and consumption functions, a commodity price system, wage bargaining on the labour market, and a commodity and production taxation system. Due to these expansions DYNK bears some similarities with DSGE (Dynamic Stochastic General Equilibrium) models, since it explicitly describes an adjustment path towards a long-term equilibrium. The DYNK model treats Austria as a single integrated economy and traces the inter-linkages between 76 industries as well as the consumption of ten household income groups using 59 consumption categories.

Four different sources of technical change are modelled in DYNK at a disaggregate level: total factor productivity (TFP), factor-bias and material efficiency in production and energy efficiency in private consumption. These components of technological change – together with changes in relative prices – drive economic growth and resource use and therefore decoupling. The term 'New Keynesian' refers to the existence of a long-run full employment equilibrium which will not be reached in the short-run due to institutional rigidities. These rigidities include liquidity constraints for consumers (deviation from the permanent income hypothesis), wage bargaining (deviation from the competitive labour market) and an imperfect capital market. Depending on the distance to the long-run equilibrium, the reaction of macroeconomic aggregates to policy shocks can differ substantially.

DYNK links physical energy and material flow data to real sectoral activities, intermediate inputs in production and consumption activities. This covers the final energy demand in detail of up to 22 energy types[4].Due to its detailed modelling structure of consumption and production activities the DYNK model is well suited for the analysis of the driving forces of resource use (energy and materials) in the Austrian economy.

The current model comprises eleven modules (see Figure 13). The solution process is an iteration over all modules until convergence is achieved. Each of these modules is presented shortly in the following sub-sections. Except for the newly developed module "TechSwitch", a more detailed description of modules and data sets used in DYNK can be found in Kirchner et al. (2019).

Figure 13. Structure of DYNK



Module 1: Commodity market

This module represents the input-output core of the model. The commodities demanded by public and private consumers, investment and exports are supplied by a set of sectors. The production necessary to satisfy the demand is calculated

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[4] Based on the physical energy flow accounts of Statistics Austria https://www.statistik.at/statistiken/energie-und-umwelt/energie/physische-energieflussrechnungen

using a Leontief-equation. Thereby it is guaranteed that the demand of commodities equals supply. The results of this module are employment, value added and production value per sector. The data set used are Input-Output Tables of the Austrian Economy for the year 2017 (Statistics Austria 2021b).

Module 2: Disposable income

Disposable income for private households is derived from value added that is generated in the sectoral production activities. Pre-defined transfers and unearned income are added, and taxes and social contributions are subtracted using tax rates of the respective year. This yields 'disposable income' for private households which is the basis for consumption in the next modules.

Data sources are the national non-financial accounts of private households for the year 2017 (Statistics Austria 2021d).

Module 3: Private Consumption

The consumption decisions of private households (part of final demand) are simulated in this module using several behavioural equations that apply coefficients estimated by time series analysis using Austria-specific data. These equations comprise consumption of energy products (space heating, electricity for appliances and vehicle utilisation), durable commodities (housing and vehicles) and a bundle of residual non-durable and non-energy commodities. The commodity composition of this residual bundle is defined by the application of an AIDS (Almost Ideal Demand System). In all equations estimated coefficients and prices define the commodity structure in the respective simulation. The resulting consumption vector is part of final demand and therefore input in module 1.

The applied data comprises a wide range of consumption related data taken from data bases of EUROSTAT and Statistics Austria (for details see Kirchner et al. 2019).

Module 4: Production and Prices

In this module a Translog production function specification is applied. The function determines, based on input commodity prices and technology, factor and investment demand as well as output prices. Own- and cross-price elasticities are applied to determine the composition of 5 input-bundles (factors), i.e. Capital (K), Labour (L), Energy (E), Imported commodities (M) and domestically produced commodities (D), or KLEMD in total. This means that the five factor shares react to relative price constellations whereas the sub-commodity-structure of the factors is constant (Leontief technologies). The principle of the Translog estimations and equations can be found in Sommer and Kratena (2017) or in the documentation of FIDELIO2 (Streicher et al. 2017).

The module applies production functions with a Translog specification for each sector. To estimate the coefficients of the Translog equations, system estimations and the seemingly unrelated regression (SUR) estimation method are applied for each specific sector. The coefficients are seen as exogenous in this model. The primary source for the estimations were derived from the WIOD (World Input Output Database, Release 2013 and 2016) data set that contains World Input Output Tables (WIOT) in current and previous year's prices, Environmental Accounts (EA), and Socioeconomic Accounts (SEA).

Module 5: Investments

In DYNK, each sector has a specific commodity structure of its investment based on the Input-Output-Tables of Statistics Austria. The change in each investment level is linked to the moving average of the economic surplus[5] (factor K) of the sector of the previous 5 years. By this approach investment needs to satisfy changes in demand (rising production leads to rising value added) as well as investments due to shifts to the factor capital via the production function (Module 4).

Module 6: Labour market

The labour market determines the price index for the factor labour which is one of the five factors in production function (Module 4) and thereby influences the sectoral production prices throughout the economy. The labour market simulates wage bargaining, formalised in wage curves by industry. These wage curves are specified as the employees' gross wage rate per hour by industry. The labour price (index) of the Translog model is then defined by adding the employers' social security contributions.

Module 7: Energy & Emissions

This module derives the final energy demand of the economy from the economic development. Here the real[6] inputs of energy are linked to the physical energy consumption of each sector via energy intensity coefficients (Terajoule per EUR). The coefficients are derived from the monetary values in the Input-Output-Table and the physical units provided by the Physical Flow Accounts of Statistics Austria (2021e).

Module 8: Emissions and Carbon pricing

The energy related carbon emissions are linked via carbon intensity coefficients to the energy consumption derived in Module 7. I.e. these emissions are linked to the respective fuel use based on sectoral emissions provided by Statistics Austria (2021c). Process emissions that occur due to processes other than

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[5] Gross surplus is a part of value-added.

[6] I.e. nominal values deflated by the respective gross commodity price.

combustion are linked to real production values of the respective sectors, again via emission coefficients.

An exogenous carbon price is used to derive additional costs for the emissions, i.e. the combustion of fuels or process emissions. The derived costs are used as a mark-up on the commodity taxes system of the Input-Output-Tables. Thereby the (gross) prices for specific carbon-containing commodities increase and lead to substitution and saving reactions throughout the system.

Module 9: Fuel Substitution

The sub-structure of commodities of each of the five factors in Module 4 (KLEMD) are constant, i.e. "Leontief technologies". The sole exception is factor energy (E).

This factor energy comprises six commodities[7]. They represent the input of energy in form of coal, oil, gas, electricity, district heat and renewables in the production process. Five of the six shares of these energy factors are defined by another Translog specification as in Module 4[8]. Hence these factors are also endogenous depending on relative (gross) prices and trends.

The main sources for the estimation of the Translog coefficients were EUROSTAT energy balances and WIOD (revision 2016) environmental accounts as well as fossil energy carrier prices from the IEA database. The method here is again a system estimation using the SUR (Seemingly Unrelated Regression) estimation method to estimate the parameters of equations of the shares and the unit costs for each specific sector.

Module 10: Government

In module 10 the revenues and expenditures of the regional government are simulated. If expenditures exceed revenues the difference (net lending) is added to the public debt. Only a few elements of revenue and expenditure can be derived from the SUT structure (taxes in Module 1) and the household’s income composition (taxes in Module 2). Hence the public household is simulated in a relatively simple fashion. Nevertheless, a mechanism is applied that allows choosing whether or not public debt is endogenous or exogenous. This enables the model to run specific scenarios that focus on the impact of and on public net lending.

Module 11: Electricity Generation

This new module represents the interface to the ATLANTIS model and allows to simulate changes of the annual physical electricity generation (and their cost) in

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[7] CPA05_07 Mining of fossil fuels, CPA16 wood products, CPA19 mineral oil products, CPA35.1 Electricity, CPA35.2 Natural Gas, CPA35.3 District heat

[8] The share of district heating is unchanged because our Translog specification can only handle 5 factors and the share of district heating in ETS industries ins negligible.

DYNK. A necessity to simulate changes in electricity generation in DYNK was to extract the NACE[9] sector "Electricity generation" from the sector "Electricity, Gas and Heat generation and supply (NACE D35) in all Input-Output-Tables of DYNK. This disaggregation has been based on a custom analysis of relevant primary statistics by Statistics Austria. The input structure of the electricity generation sector was then further differentiated into eleven technology-specific costs structures according to the technologies in ATLANTIS plus a residual that represents grid and distribution services. The production value of the eleven technologies is based on the production costs provided by ATLANTIS; their commodity structure is based on the structures of respective electricity generation technologies for Austria in the multi-regional Input-Output-Table EXIOBASE (www.exiobase.eu).

The inputs from ATLANTIS are investments in electricity generation technologies, the generation costs of the respective electricity generation mix as well as electricity generation costs and wholesale price.

The investments in electricity generation technologies are translated into a commodity structure based on literature reviews focusing on the three most relevant[10] technologies wind (Kaltschmitt et al. 2020, Wallasch 2019, Resch et al. 2017), hydro (Aufleger et al. 2020, Resch et al. 2017 and BMK 2021), and PV (Bruendlinger et al. 2017, Fechner 2021, Resch et al. 2017). The resulting investment vector is then transferred to the electricity sector's investment in Module 5. The wholesale price of electricity is translated to end-user prices by adding grid costs, fees and taxes. The resulting price determines the output price index of the electricity sector in Module 4. The generation mix defines the commodity input structure of the electricity sector by using weighted input structures for each technology. The weight is determined by the results of ATLANTIS. Furthermore, variations in cost components (costs of operation, fuel, emission permits, labour compensation and depreciation) are considered as well. The adapted input-structure is transferred to a change in intermediate inputs of the sector in the Input-Output-Tables in Module 1.

The Electricity System Model ATLANTIS

ATLANTIS is a techno-economic model of the continental European power system that incorporates both the technical and economic aspects of the power system for long-term scenario simulations. The technical aspects of the model include, inter alia, the continental European electricity system based on 4,022 nodes (power stations) with regionalised demand distribution, the transmission grid (including 6,864 lines and 1,471 transformers), and 79,146 generators (including thermal power plants, renewables, and storage units). The power flow is

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[9] Statistical Classification of Economic Activities in the European Community.

[10] Most relevant in the sense, that changes in electricity generation capacity occur almost exclusively in these technologies compared to the reference scenario.

modelled as direct current (DC) optimal power flow (DC-OPF), which is a good approximation of reality in the transmission grid. Due to the scale of the continental European power system, the temporal framework is based on discretised time duration curves. Since the model is intended for long-term system planning and given the uncertainty of input data over such lengthy time frames this is reasonable. The economic aspects of the model include information about electricity companies, fuel prices, inflation rates, etc. to calculate electricity trading between companies, market prices as well as balance sheets and profit and loss accounts for the included companies.

The ATLANTIS model is structured into six different modules, as can be seen on the left side of Figure 4. In the first step, the database and scenarios are implemented. The database includes ATLANTIS-specific information, e.g. the power plants, the transmission network, load profiles, etc. as well as other exogenous parameters that are aligned with the DYNK model such as fuel prices, CO_2 prices, inflation rates, etc.

In the following step, system adequacy is evaluated. This entails assessing whether the winter and summer peak load can be covered with the existing generation capacities given the restrictions of the existing transmission grid (based on a DC-OPF). As a result, a lack of generation and/or transmission capacity is identified.

For this study, each month was divided into two peak and two off-peak periods in order to strike a reasonable balance between accuracy and computational time. ATLANTIS runs two different models per period, where the results of the first model (Zonal Pricing Model) set the initial values for the second one (Redispatch Zonal Pricing Model) for faster model run times. The models are explained in detail in the following sections.

Single node per country - Zonal Pricing Model

In the Zonal Pricing (ZP) model, the Merit-Order is calculated per country/zone with the Net Transfer Capacities (NTCs)[11] allowing a coupling between the markets. Within a zone, the cost-optimal dispatch of power plants is calculated by defining a linear optimisation problem with the objective of maximising social welfare as defined in Equation 1a. With this the respective zonal price (market clearing price for each zone) is determined. Trading between "cheaper" and "more expensive" zones can thus arise while complying with the commercial restrictions of the NTCs. The ZP-Model provides the zonal price per country/market, the trade flows between the countries/markets as well as the ideal dispatch per power plant (no grid restrictions). The following constraints have to be considered: maximum supply in a market (Eq. 1b); maximum

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[11] NTCs cause restrictions in electricity imports and exports between the countries.

demand in a market (Eq. 1c); limit of trading between two markets based on the defined NTCs (Eq. 1d); and balance constraint (Eq. 1e).

$$\max_{qD,qS} \left\{ \sum_i \left[\sum_n (qD_{n,i} \cdot pD_{n,i}) - \sum_a (qS_{a,i} \cdot c_{var}S_{a,i}) \right] \right\} \tag{1a}$$

subject to:

$$qS_{a,i} \leq qS_{max_{a,i}} \tag{1b}$$

$$qD_{n,i} \leq qD_{max_{n,i}} \tag{1c}$$

$$export_{i \to j} - import_{i \to j} \leq NTC_{i \to j} \qquad \forall (i,j | i \neq j) \tag{1d}$$

$$\sum_a qS_{a,i} - \sum_n qD_{n,i} + \sum_{i \neq j} import_{i \to j} - \sum_{i \neq j} export_{i \to j} = 0 \qquad \forall i \tag{1e}$$

with:

i, j	countries, market areas
k	defined technical profiles between market areas
n	block bid of demand
a	block bid of supply
$qD_{n,i}$	cleared part of demand block n in market i [MW]
$qS_{a,i}$	cleared part of supply block a in market i [MW]
$pD_{n,i}$	demand price [€ /MWh]
$c_{var}S_{a,i}$	marginal costs of supply block a in zone i [€ /MWh]
$import_{i \to j}$	import in market i from market j [MW]
$export_{i \to j}$	export from market i to market j [MW]
$NTC_{i \to j}$	net transfer capacity between market i and j [MW]

Grid restrictions with DC-OPF - Redispatch Zonal Pricing Model

The Redispatch Zonal Pricing (RDZP) model takes the results of the power plant dispatch from the ZP model as starting values for the solver but incorporates the grid restrictions by implementing a DC-OPF. The DC-OPF is defined as a mixed-integer linear optimisation problem with the objective of minimising overall system costs (Eq. 2a). The first sum defines the cost of power plant dispatching, the second sum describes the cost of using phase shifting transformers and the third sum defines the costs for cross-market redispatch. Constraint 2b defines the equilibrium of generation, demand and the power flows to and from a node; equation 2c represents the unit commitment[12] for thermal power; load flow limits of lines are set with 2d for AC-lines and 2e for DC-lines; 2f ensures the power balance between generation demand and export/import per market; 2g sets the limits for the control angle of phase shifting transformers and 2h sets the limits angle of power lines (since the DC load flow is a simplification of the AC load flow, which requires a very small phase angle along a line).

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[12] If the power plant is dispatched or not.

$$\min \left\{ \sum_{G} c_{var,G} \cdot p_G \cdot P_{Base} + \sum_{l} (\alpha \cdot \Lambda_{l,DC} + \lambda \cdot \sigma_{l,PST}) + \sum_{Cl} \delta \cdot H_C^+ \right\} \quad H_C^+ \in \{0,1\}_Z \tag{2a}$$

subject to:

$$\sum_G p_{G,n} - \sum_D p_{D,n} = \sum_m flow_{n\rightarrow m} - \sum_m flow_{m\rightarrow n} \qquad \forall \text{ m} \tag{2b}$$

$$p_{min,G} \leq \beta \cdot p_G \leq p_{max,G} \qquad \beta \in \{0,1\}_Z \tag{2c}$$

$$-p_{ACmax,l} \leq flow_{n\rightarrow m} \leq p_{ACmax,l} \qquad \forall \text{ AC lines} \tag{2d}$$

$$-p_{DCmax,l} \leq flow_{n\rightarrow m} \leq p_{DCmax,l} \qquad \forall \text{ DC links} \tag{2e}$$

$$\sum_G p_{G,C} - \sum_D p_{D,C} - saldo_C^{LF} = 0 \tag{2f}$$

$$-\sigma_{max,PST} \leq \sigma_{l,PST} \leq \sigma_{max,PST} \qquad \forall \text{ l} \tag{2g}$$

$$-\Lambda_{max,DC} \leq \Lambda_{l,DC} \leq \Lambda_{max,DC} \qquad \forall \text{ l} \tag{2h}$$

with:	G	generation units
	D	demand
	C	market areas, bidding zones (countries)
	n, m	nodes
	$c_{var,G}$	marginal generation costs [€ /MWh]
	$p_{G,n}$	(optimised) power injection of unit G at node n [p.u.]
	$p_{D,n}$	demand at node n [p.u.]
	P_{Base}	power base for per unit calculation [MW]
	α, δ, λ	penalty weights
	β	binary switching variable for unit commitment [-]
	$\sigma_{l,PST}$	(optimised) angle of phase shifter [rad]
	$\sigma_{,ax,PST}$	maximum angle of phase shifters [rad]
	$flow_{n\rightarrow m}$	active power flow on line l between node n and m [p.u.]
	$p_{min,G}$	minimum power of unit G [p.u.]
	$p_{max,G}$	maximum power of unit G [p.u.]
	$p_{ACmax,l}$	maximum allowed transmission capacity of AC line l [p.u.]
	$p_{DCmax,l}$	maximum power of DC line l [p.u.]
	$\Lambda_{l,DC}$	(optimised) commitment of DC links [rad]
	$\Lambda_{max,DC}$	maximum controlling range of a DC link [rad]

In many countries the heat produced by combined heat and power (CHP) plants is needed in winter months for district heating purposes, making them must-run power plants that have to produce even if they would not be dispatched based on the Merit-Order system. For this model run, power plants with heating output have a must-run flag set in the winter months (November, December, January, and February) and are therefore forced to produce. According to Austria's energy balance from Statistics Austria, in 2021 heating demand for district heating was 26 TWh. CHP plants contributed 14.7 TWh, showing the importance of the heat production of CHP plants (Statistics Austria 2021a). Some industrial power plants are also needed throughout the year and, for that reason, have a must-run flag set for the whole year.

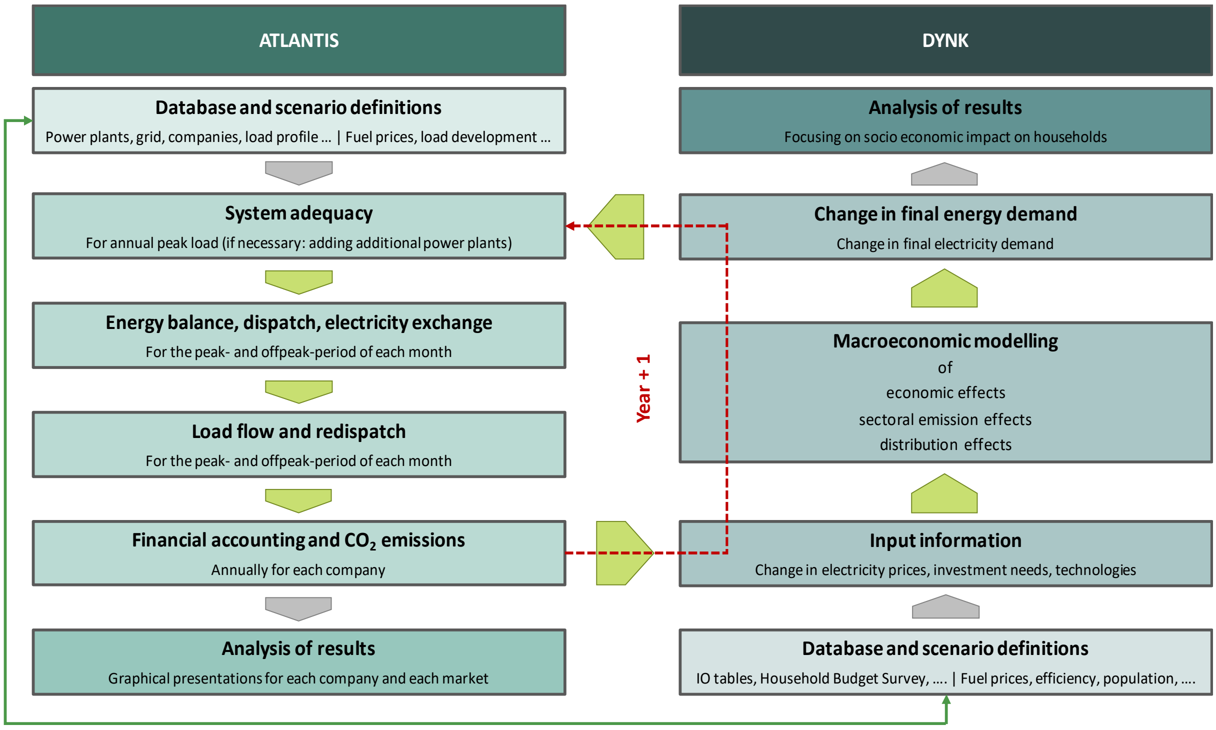
In case of line congestions, an intra-zonal redispatch is carried out and, if this is not sufficient, a redispatch across zones is done. In addition to the results of the ZP-Model, the RDZP-Model also provides the line utilisation and the "positive" and "negative" redispatch for each power plant.

The approach for linking the models

The basis for linking ATLANTIS and DYNK is handling the ATLANTIS model's output as a disaggregate technological representation of the different electricity sub-sectors. The ATLANTIS solution's data on electricity generation and distribution of the RDZP model is linked to the corresponding variables in the DYNK model. For example, in ATLANTIS the simulation yields results for fixed (capital) and operational (energy, labour, materials) costs as well as produced electricity per power plant type which is fed into DYNK. The resulting electricity price of the ATLANTIS model is linked to the output price index in DYNK. In the other direction, the resulting electricity demand of DYNK is fed into the ATLANTIS model. This is done until convergence is reached. Due to technical and practical reasons, the data exchanged between ATLANTIS and DYNK comprises full scenario results (up to 2030). Both models were calibrated to the year 2017 and the simulations cover the period from 2017 to 2030.

The different modules of the ATLANTIS model as well as the links between ATLANTIS and DYNK are depicted in Figure 14.

Figure 14. Flow chart of the simulations with the combined model system



Source: Own illustration.

As the models are operated by two different organisations, cloud servers are utilised to exchange the results. An ad-hoc data structure based on Excel files was developed for exchanging data between the two models. For this, the data input mechanisms of the two models have been adapted. Likewise, the output of the ATLANTIS model was updated to specifically write the results needed for DYNK (installed capacity per power plant type and year, produced electricity per power plant type and year, electricity price, and fixed and operational costs per power plant type and year) into a single file.

7 Work and time table

Work Package		REPORTING PERIOD 1												REPORTING PERIOD 2											
		2020		2021												2022									
		11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
1	**Foundations**																								
	Analysis of the strategic energy policy framework in Austria and the EU	▨	▨																		M1.1	D1.1			
	Analysis of the RES-E policy framework	▨	▨	▨																	M1.2				
	Compilation of database for model simulations	▨	▨	▨	D1.2																				
2	**A Baseline Scenario for the European Electricity**																								
	Research of various European development scenarios	▨	▨	M2.1																					
	Analysis of the different European scenarios		▨	▨	▨	▨	D2.1																		
	Consolidation of the European baseline scenario				▨	▨	▨	M2.2																	
	Implementation of the scenario into ATLANTIS						▨	▨	M2.3																
3	**Scenarios for 100% Renewable Electricity in**																								
	Analysis of the status quo			▨	▨	M3.1																			
	Identification of the potential for RES-E				▨	▨	M3.2																		
	Definition of key parameters for RES scenarios for Austria					▨	M3.3																		
	Group Delphi on proposed scenarios with experts and other stakeholders					M3.4	M3.5 D3.1	▨	M3.6																
	Finalisation of the scenarios								▨	D3.2															
4	**Model Adjustment**																								
	Expansion of the supply side of DYNK							▨	▨	▨	▨	▨	▨	▨	M4.1										
	Expansion of the demand side of DYNK								▨	▨	▨	▨	▨	▨											
	Adjustment of the data input mechanism of ATLANTIS							▨	▨	▨	▨	▨	▨	▨	M4.2										
	Expansion of the electricity grid for Austria in ATLANTIS								▨	▨	▨	▨	▨	▨											
	Adaption of storage simulation module								▨	▨	▨	▨	▨	▨											
	Calculation of investments in the electricity grid									▨	▨	▨	▨	▨											
5	**Model Linkage**																								
	Data collection for linked model system												▨	▨	▨	▨	M5.1								
	Model linkage													▨	▨	▨	▨	▨	M5.2						
6	**Model Simulations**																								
	Implementation of baseline values and exogenous drivers into the models																▨	▨	M6.1						D6.1
	Model simulations of the effects of policy scenarios																	▨	▨	▨	▨	M6.2			
	Sensitivity analysis																			▨	▨	▨	▨	M6.3	
7	**Conclusions and Policy Recommendations**																								
	Review of policy measures to mitigate energy / electricity poverty in EU MS																	▨	▨	M7.1	▨	▨	▨	▨	D7.1
	European perspective on 100%-RES-E in Austria																			▨	▨	▨	▨	▨	D7.2
	Development of policy measures for Austria																				▨	D1.1	▨	▨	
8	**Project Management, Stakeholder Involvement and Dissemination**																								
	Project management and coordination	M8.1	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Project website	D8.1	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Expert, stakeholder and dissemination workshop													M8.2							M8.3				M8.4
	Reporting												D8.2												D8.3

Milestones:

M1.1 Analysis of the strategic energy policy framework completed
M1.2 Analysis of the RES-E policy framework completed
M2.1 Completion of the scenario research
M2.2 One European baseline scenario chosen
M2.3 Implementation of the scenario into ATLANTIS completed
M3.1 Analysis of status quo completed
M3.2 Identified potentials for RES in Austria
M3.3 Three basic scenarios for RES in Austria
M3.4 Design of Delphi Completed
M3.5 Delphi Workshop
M3.6 Group Delphi Completed
M4.1 DYNK expansion accomplished
M4.2 ATLANTIS expansion accomplished
M5.1 Data collection for linked-model system accomplished
M5.2 Linked model-system tested for simulation
M6.1 Executable common Baseline scenario
M6.2 Completed Scenario Results
M6.3 Implementation of Sensitivity Analysis
M7.1 Review of policy measures to mitigate energy / electricity poverty completed
M7.2 Analysis of the Austrian RES-Scenarios from a European perspective completed
M8.1 Kick-off meeting
M8.2 Expert workshop
M8.3 Expert and Stakeholder workshop
M8.4 Dissemination workshop

Deliverables:

D1.1 START2030 Policy Brief #1
D1.2 Database with exogenous parameters for model simulations
D2.1 List of pros and cons and likeliness of the different scenarios
D3.1 Online Questionnaire
D3.2 Finalised 100% RES scenarios for Austria
D6.1 START2030 Working Paper #1
D7.1 Review paper on measures mitigating price increases
D7.2 START2030 Working Paper #2
D8.1 Project webpage
D8.2 Interim report
D8.3 Final report

8 Publications and dissemination activities

Publications	
Peer-reviewed publications	
	Kettner, C., Kratena, K., Sommer, M., 2022, The socio-economic impact of renewable electricity generation with prosumer activity, *e & i Elektrotechnik und Informationstechnik 139, 624–631*. https://doi.org/10.1007/s00502-022-01072-7
	Kettner, C., Böheim, M., Schratzenstaller, M., Time for a Windfall Profit Tax? Electricity Market Design in Times of Crises, submitted to Comelli, A., et al. (eds.) Critical Issues in Environmental Taxation Vol. XXV, Edward Elgar, forthcoming.
Working papers	
	Gaugl, R., Sommer, M., Kettner, C., Bachhiesl, U., Klatzer, T. F., Gruber, L., Kratena, K., Wogrin, S., 2023, Integrated Power and Socio-Economic Analysis of Austria's Renewable Electricity Transformation, *START2030 Working Paper #1.* https://start2030.wifo.ac.at/outputs/START2030_Working_Paper_1.pdf
	Kettner, C., Böheim, M., Sommer, M., Gaugl, R., Bachhiesl, U., Gruber, L., Klatzer, T. F., Wogrin, S., Kratena, K., 2023, Transformation to a Renewable Electricity System in Austria: Conclusions from an Integrated Model Analysis, *START2030 Working Paper #2.* https://start2030.wifo.ac.at/outputs/START2030_Working_Paper_2.pdf
	Kettner, C., Wretschitsch, E., Taxes and subsidies in EU energy policy - Fit for 55?, *WIFO Working Papers* 2023 (665). https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=de&reserve-mode=active&content-id=1528640199418&publikation_id=70570&detail-view=yes [13]
Other publications	
	Gaugl, R., 2021, Renewable Electricity in Austria – Status Quo, START2030 Fact Sheet.
	Kettner, C., Böheim, M., 2022, Strom aus erneuerbaren Energieträgern im Spannungsfeld zwischen Klimazielen und Ukraine Krieg. State of Play und Perspektiven der Regulierung, *Start2030 Policy Brief #1*, July 2022. https://start2030.wifo.ac.at/outputs/START2030_PolicyBrief_1.pdf
Contributions to Publications	
	Wogrin, S., Tejada-Arango, D. A., Gaugl, R., Klatzer, T. F., & Bachhiesl, U. (2022). LEGO: The open-source Low-carbon Expansion Generation Optimization model. *SoftwareX*, 19, [101141]. https://doi.org/10.1016/j.softx.2022.101141.
	R. Gaugl, S. Wogrin, U. Bachhiesl, L. Frauenlob, (2022). GridTool: An Open-Source Tool to Convert Grid Data, submitted to *SoftwareX*.
	Lenhardt, L., Gaugl, R., & Wogrin, S. (2022). Achieving 100% Renewable Electricity in Austria – Analysing the EAG-GOALS. *EnInnov2022-Kurzfassungsband*.
	Klatzer, T. F., Bachhiesl, U., & Wogrin, S. (2022). Power System Analyses with the Low-carbon Expansion Generation Optimization (LEGO) model. Paper presented at 1st International Workshop on "Open Source Modelling and Simulation of Energy Systems", Aachen, Germany.
Project workshops	

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[13] Research for this publication was partly also conducted in the project *SoMBI* funded by the Jubiläumsfonds of the Austrian National Bank.

	Stakeholder Workshop (April 27th, 2021)
	Expert Workshop (November 17th, 2021)
	Workshop at EnInnov2022 (February 18th, 2022)
	Workshop on Policy Recommendations (June 23rd, 2022)
	Dissemination Workshop at WIFO (October 18th, 2022)
Presentations at external conferences	
Conference "Korea-EU carbon neutrality policies and economic diplomacy", Groningen, October 2022	
	Kettner, C., Taxes and subsidies in EU energy policy - Fit for 55?.
32nd EURO Conference, Espoo, Finland, July 2022	
	Wogrin, S., The Austrian path to climate neutrality using the open-source LEGO model.
23rd Global Conference on Environmental Taxation, Parma, September 2022	
	Kettner, C., Renewable Electricity in the EU - State of Play and Prospects for Regulation.
43rd IAEE International Conference, Tokyo, August 2022	
	Kettner, C., A Comprehensive Analysis of Austria's Transformation towards 100% RES-E by 2030. *Virtual presentation*.
Other dissemination activities	
Project webpage	
	https://start2030.wifo.ac.at/
WIFO-Newsletter	
	START2030: Key Results Presented in a Dissemination Workshop (October 20th, 2022) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189725&j-cc-node=news&j-cc-id=1665687943801
	Stakeholder Workshop on Simulation Results and Conference Participations (August 26th, 2022) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189725&j-cc-node=news&j-cc-id=1661313795837
	100 Percent Renewable Energy Sources in the Electricity Sector (February 23rd, 2022) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189725&j-cc-node=news&j-cc-id=1643137457042
	START2030 Online Workshop on Model Linking (November 26th, 2021) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189725&j-cc-node=news&j-cc-id=1635461238653
	100 Percent Renewable Energy Sources in the Electricity Sector (October 21st, 2021) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189725&j-cc-node=news&j-cc-id=1621537954462
	Virtual Project Presentation: 100 Percent Renewable Energy Sources in the Electricity Sector (April 28th, 2021)

	https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189573&j-cc-node=news&j-cc-id=1618515789706
	WIFO and TU Graz Analyse the Effects of a Transformation of the Electricity System (January 31st, 2021) https://www.wifo.ac.at/jart/prj3/wifo/main.jart?rel=en&content-id=1487278189573&j-cc-node=news&j-cc-id=1608582593748
ACRP Poster Session, Klimatag 2021 online	
	Kettner, C., A Social, Technological and economic evaluation of Austria's Renewable electricity Transformation 2030 (*START2030*), ACRP21_02

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Böheim, M., Huemer, U., Kettner, C., Kletzan, D., Schratzenstaller, M. (2022a). Unterstützungsmaßnahmen für Unternehmen zur Abfederung hoher Energiekosten. WIFO Research Brief 2022(24).

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Bründlinger, R., D. Christ, H. Fechner, M. Kaltschmitt, J. Müller, G. Peharz, D. Schulz and L. Sens (2020). Photovoltaische Stromerzeugung. In M. Kaltschmitt, W. Streicher, & A. Wiese (Eds.), Erneuerbare Energien: Systemtechnik · Wirtschaftlichkeit · Umweltaspekte, Berlin: Springer, pp. 339–460. https://doi.org/10.1007/978-3-662-61190-6_5

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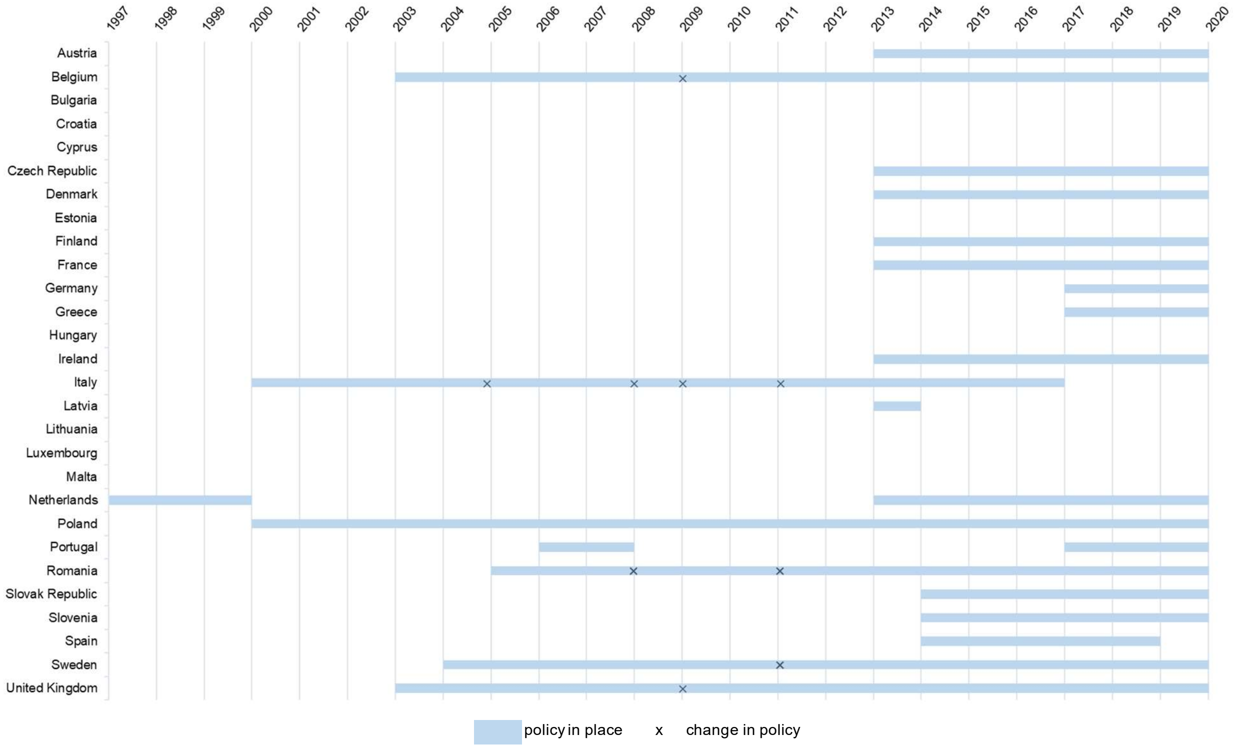
Annex

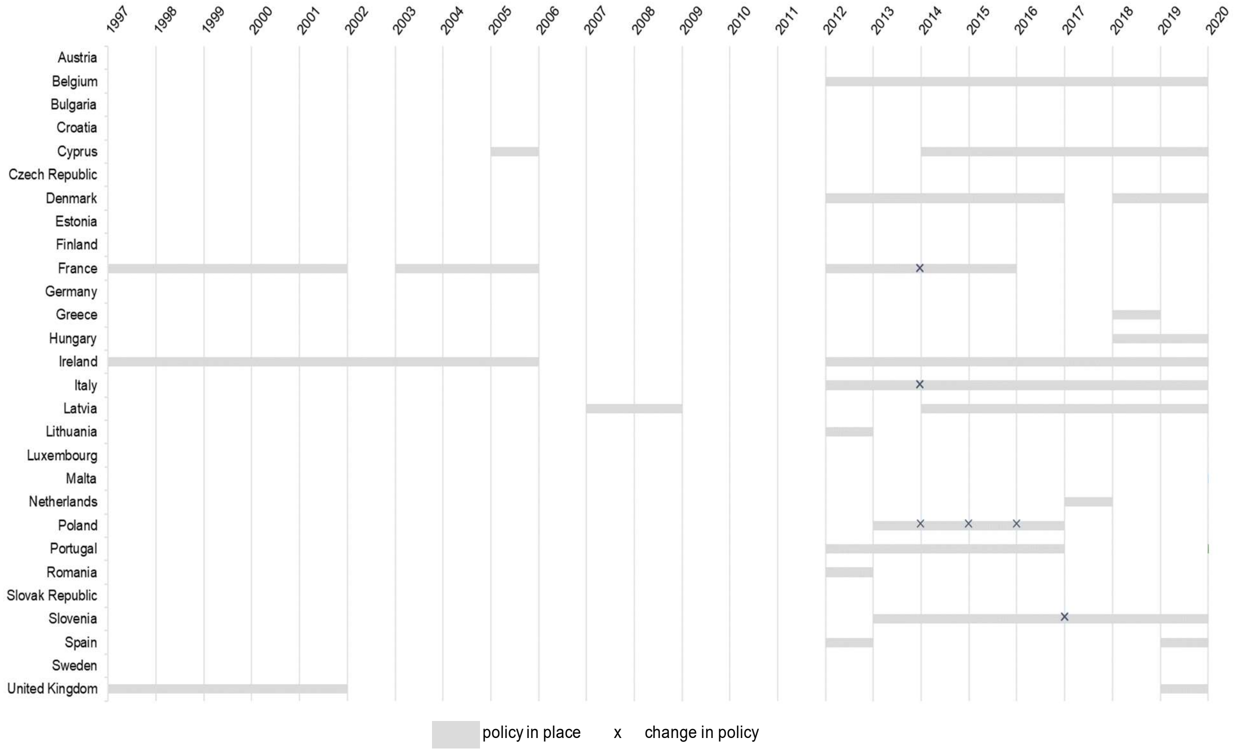
Annex 1. Overview of RES-E Support Schemes in EU Member States

Figure A1.1. Tradable Renewable Energy Certificates in EU-27 member states and the UK



Source: Own illustration based on Ragwitz and Steinhilber (2013) and Renewables Global Status Reports 2012-2020.

Figure A1.2. Tendering in EU-27 member states and the UK



Source: Own illustration based on Ragwitz and Steinhilber (2013) and Renewables Global Status Reports 2012-2020.

Annex 2. Input parameters for Scenarios

Parameter	2017	2030		
		Baseline	**Conservative Scenario**	**Ambitious Scenario**
CO_2 Price EU in €/CO_2	9	135	135	135
International Oil Price €/GJ	10.8	22.8	22.8	22.8
International Gas Price €/GJ	7.7	13.9	13.9	13.9
International Coal Price €/GJ	4	5	5	5
Energy demand of households in kWh/m^2	127	102	93	86
Shares in final household energy consumption in %				
Oil	18	10	9	7
Gas	26	27	24	21
Renewables	25	48	49	57
Other	19	18	18	15
Percentage of renewables covered by heat pumps	7	17	14	19
Percentage of available roof area equipped with a photovoltaic system in %				
Single family- and two-family houses		23	25	40
Multi-family house		27	30	50
Percentage of residential photovoltaic systems with battery storage in %		10	15	25
Share of the individual drive modes in the passenger car fleet in %				
Petrol	42.5	43.5	30.3	25.4
Diesel	56.6	43.5	45.9	33.5
Electric	0.9	13.0	23.8	41.1
Fuel consumption of passenger cars				
Petrol-driven in l/100km	8	8	8	7
Diesel-driven in l/100km	7	7	7	6
Electrically powered in kWh/100km	15	15	15	12

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