Abstract In order to meet the targets of the Paris Agreement, a rapid and far-reaching phase-out of fossil fuels is required. Against this background, Austria aims to cover 100% of its electricity generation from renewable energy sources by 2030. To meet this target in a standard scenario of final electricity demand, renewable electricity generation needs to be expanded by 27 TWh compared to 2019 (11 TWh PV, 10 TWh wind power, 5 TWh hydropower, and 1 TWh biomass). With respect to the ambitious expansion target for PV, the contribution of households, i.e., prosumers, will be of crucial importance. Depending on their background (most notably, type of building, income), the ability of different household groups to participate in the electricity market as prosumers—and hence, the possible distributive impacts of the electricity transformation—will vary substantially. Prosumers reduce the consumption of electricity from the grid and can thereby realize cost savings, increasing their consumption opportunities for other (non-energy) goods.

This paper investigates the economic and distributive impact of increasing household PV electricity generation in Austria until 2030. For this purpose, the household module of the macroeconomic model DYNK is expanded, differentiating the degree to which households engage in “prosumer” activities. A set of PV support policy scenarios is then defined to simulate the increase in the number of prosumers as well as the distributive impacts on the different household types and the macroeconomic impacts with the expanded model. The simulation results show a small but positive effect of increased investment in residential photovoltaic systems on the GDP. With respect to the distributive effects, the design of the support scheme is essential. Targeting support for low-income households also has positive impacts on GDP growth.

Keywords Photovoltaics · Investment · Prosumer · Macroeconomic modelling · Household types

Zusammenfassung Um die Ziele des Pariser Klimaabkommens zu erreichen, ist ein rascher und weitreichender Ausstieg aus fossilen Energieträgern erforderlich. Vor diesem Hintergrund strebt Österreich an, seine Stromerzeugung bis 2030 zu 100% aus erneuerbaren Energiequellen zu decken. Um dieses Ziel zu erreichen, soll in einem Standardszenario der Elektrizitätsnachfrage die erneuerbare Stromerzeugung gegenüber 2019 um 27 TWh ausgebaut werden (11 TWh PV, 10 TWh Windkraft, 5 TWh Wasserkraft und 1 TWh Biomasse). In Hinblick auf dieses ehrgeizige Ausbauprogramm für PV wird der Beitrag der Haushalte, also der Prosumers, von entscheidender Bedeutung sein. Abhängig von ihrer Ausstattung (insbesondere Gebäudetyp, Einkommen) wird die Fähigkeit verschiedener Haushaltsgruppen, als Prosumers am Strommarkt teilzunehmen, stark variieren, was sich auch in den möglichen Verteilungswirkungen der Elektrizitätsversorgung niederschlagen wird. Prosumers reduzieren den Verbrauch von Strom aus dem Netz und können dadurch Kosteneinsparungen erzielen, wodurch ihre sonstigen Konsummöglichkeiten erhöht werden.
Dieser Beitrag untersucht die volkswirtschaftlichen und verteilungspolitischen Auswirkungen einer stärkeren Durchdringung mit PV-Anlagen im Haushaltsbereich in Österreich bis 2030. Dazu wird das Haushaltsmodul des makroökonomischen Modells DYNK in Hinblick auf Prosumer-Aktivitäten erweitert. Anschließend wird eine Reihe von Szenarien zur PV-Förderung definiert, um die Zunahme der Prosumers sowie die Verteilungswirkungen auf die verschiedenen Haushaltstypen und die makroökonomischen Effekte mit dem erweiterten Modell zu simulieren. Die Simulationsergebnisse zeigen einen kleinen, aber positiven Effekt erhöhter Investitionen in Haushaltsphotovoltaikanlagen auf das BIP. In Hinblick auf die Verteilungswirkungen ist die Ausgestaltung des Fördersystems wesentlich. Die Fokussierung der Unterstützung auf Haushalte mit niedrigem Einkommen wirkt sich auch positiv auf das BIP-Wachstum aus.

Schlüsselwörter Photovoltaik · Investitionen · Prosumer · Makroökonomische Modellierung · Haushaltstypen

1 Introduction

For meeting the targets of the Paris Agreement, a rapid and far-reaching phase-out of fossil fuels is required. Against this background, Austria aims at covering 100% of its electricity generation from renewable energy sources by 2030. To meet this target in a standard scenario of final electricity demand, the Austrian Renewable Energy Expansion Act (Erneuerbare-Energien-Ausbau-Gesetz, EAG, [1]) stipulates that renewable electricity generation shall be expanded by 27TWh compared to 2019 levels (11TWh PV, 10TWh wind power, 5TWh hydro power and 1TWh biomass). With respect to the ambitious expansion target for PV, the contribution of households, i.e., prosumers, will be of crucial importance.

Depending on their background, the ability of different household groups to participate in the electricity market as prosumers—and hence the possible distributive impacts of the electricity transformation—will vary substantially. Prosumers reduce consumption of electricity from the grid and can spend potential savings in non-energy consumption, being then better off in terms of non-energy consumption than other households.

For Austria, to the best of our knowledge, only one study on the drivers of residential PV adoption is available. Braito et al. [2] focus on differences in household PV investment between Austria and Italy, using survey data. For Austria, they find that environmental protection was the most dominant motive for adopting residential PV systems followed by a reduction of the dependence on fossil fuels. By contrast, the most important motive for refraining from investing in a PV system was that it was regarded a bad investment. For Germany, Jacksohn et al. [3], using data from the German Socio-Economic Panel, show that economic factors—i.e., costs and revenues—are most relevant in households’ investments in PV (and solar thermal) systems. Particularly investment costs can explain investment since they are more certain than potential future revenues. Sociodemographic and housing characteristics also have a significant impact on the investment in household PV installations: For instance, households living in detached houses or rural areas are found to more likely invest, as are households with higher income. By contrast, investment probability decreases with the age of the household head and is lower if the household head is female. Finally, the analysis finds only little relevance of environmental preference and personality traits. Based on an online survey, Korcay et al. [4] find that German homeowners have a high basic willingness to adopt a PV system, but have a low willingness to pay, confirming the decisive role of costs in PV investments. Moreover, their analysis shows that purchase intentions strongly depend on subjective norms as well as on the attitude towards PV.

This paper investigates the economic and distributive impact of increasing household PV electricity generation in Austria until 2030. For this purpose, the household module of the macroeconomic model DYNK is expanded, differentiating the degree to which households engage in prosumer activities. A set of PV support policy scenarios to increase prosumer activities is then defined to simulate the distributive impacts on the different household types and macroeconomy with the expanded model.

The paper is structured as follows: Sect. 2 provides a short description of the macroeconomic model DYNK, focussing on the expansion of the household module with respect to prosumer activities. Sect. 3 presents the policy scenarios, followed by the description of simulation results in Sect. 4. The final section concludes.

2 Modelling framework

The simulations are conducted with DYNK (Dynamic New Keynesian), a macroeconomic model with input-output linkages covering the economic interdependencies between multiple sectors in a single region and integrates a variety of module blocks (see Fig. 1).

2.1 General model features

The DYNK model describes the interlinkages between 74 NACE industries as well as the consumption of five household income groups (quintiles) by 47 consumption categories (COICOP) in the Austrian economy.

1 Nomenclature Statistique des Activités Économiques dans la Communauté Européenne (Statistical Classification of Economic Activities in the European Community).
2 Classification of Individual Consumption by Purpose.
The modelling approach bears some similarities with DSGE (Dynamic Stochastic General Equilibrium) models, as it explicitly describes an adjustment path towards a long-run equilibrium. This feature of dynamic adjustment towards equilibrium is most developed in the consumption block and in the macroeconomic closure via a fixed short- and long-term path for the public deficit. 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 magnitude of the distance to the long-run equilibrium, the reaction of macroeconomic aggregates to policy shocks can differ substantially.

DYNK is an input-output model in the sense that it is demand-driven, as all what is demanded is produced. The price block in DYNK is similarly elaborated as in a CGE (Computable General Equilibrium) model, with user-specific prices and a proper account of margins, taxes less subsidies, and import shares that are different for each user. Besides the price block, also other parts of the DYNK model, in particular the labour market block, have similar specifications as a dual CGE model (see for example Conrad and Schmidt [5] or Löfgren et al. [6]). The dual model is based on price and cost functions instead of production functions and therefore these models in a certain sense are also "demand-driven", especially if constant returns to scale do not allow for price setting on the supply side.

For more comprehensive descriptions of the DYNK model, see for instance Kratena and Sommer [7], Sommer and Kratena [8] or Kirchner et al. [9].

2.2 Integrating prosumer activities in the household module

For the analysis of prosumer activities, both the demand and supply side of DYNK are expanded. On the supply side, the cost structure of the input-output sector "energy" (NACE sector D35), which comprises the generation and distribution of electricity, natural gas and district heat, has been disaggregated into natural gas supply/distribution (D35B), district heat supply/distribution (D35C) and the sector that generates and provides public electricity (D35A) in a special evaluation by Statistics Austria. The electricity sector has then been further disaggregated into subsectors comprising 10 electricity generation technologies (such as gas power plants, PV, wind and hydro) as well as electricity trade and distribution (i.e. grid operation).

On the demand side, the module of the private households has been expanded. The module on households in DYNK comprises investment behaviour.
in durable commodities, such as own houses, vehicles and electric appliances. We expand this approach by a new type of durables—“energy supply and storage appliances”—allowing to simulate the economic impacts and the increasing role of prosumers in the electricity system and assessing impacts of these developments on different household groups.

A special evaluation of the microcensus “Energy Consumption of Private Households” by Statistics Austria [10] shows that whether or not a household commands over a PV system depends mainly on two factors: (1) the type of building (single-family house, SFH, vs. multi-family house, MFH) and (2) the income level. Households with higher incomes are more likely to have a PV system installed than low-income households. The building type is even more decisive: Irrespective of the household income level, in multi-family houses the proportion of households with a PV system is significantly lower than in single-family or two-family houses. This reflects i.a. existing legal provisions (especially the requirement of majority voting for the installation of a PV system on the roof or façade of a multi-family building). For modelling prosumer activity, the household sector in DYNK was therefore split up into ten types, differentiating between single-/double and multi-family houses on the one hand and five household income groups (quintiles) on the other hand. The corresponding consumption and income data for the ten household types was derived from Statistics Austria’s Household Budget Survey.

The investment decisions of the different household groups were added to the consumption block and are modelled as follows. The highest household income group (quintile 5) behaves according to the Permanent Income Hypothesis (PIH) and does not attempt to adjust, given their liquidity constraints. Its stock of photovoltaic appliances—allowing to simulate the economic impacts of rational behaviour where any increase in electricity prices is fully compensated by additional consumer capacity leaving the costs of energy services unchanged. The parameters $\mu$ and $\gamma$ were calibrated to reproduce the allocation of PV investments across household groups in the base year.

The new household structure has then been integrated into the adapted DYNK model and the household variables (income, consumption structures) have been linked to relevant variables of the new disaggregated electricity sector in the adapted DYNK.

### 3 Policy scenarios

With respect to prosumer activities, we focus on three different scenarios:

1. **Baseline Prosumer Scenario (BS):**
   In this scenario, the absence of subsidies for incentivising household PV investments is assumed. The prosumers are only compensated via a reduction in consumption of electricity from the grid and—given strong separability between energy and non-energy consumption—spend this saving in non-energy consumption and are better off in terms of non-energy consumption than other households.

2. **Prosumer Support Scenario 1 (PS1):**
   In this scenario, a common investment subsidy (30%) is granted to all households for prosumer investment. Prosumer households are better off than in the baseline, also relative to other households.

3. **Prosumer Support Scenario 2 (PS2):**
   In this scenario, an income-dependent investment subsidy is granted to households for prosumer investment. The overall support level is fixed at the level of PS1. Households from the two highest income quintiles will not receive any investment support; households from the third income quintile will receive a subsidy of 30%; and the remaining support budget will be distributed to the two lowest income quintiles.

The three scenarios are integrated into a common baseline scenario regarding the development of the Austrian electricity system—integrated in the Sustainable Transition Scenario of the TYNDP 2018 [12]—simulated with the model ATLANTIS [13, 14]. In this scenario, the target of 100% renewable electricity generation in Austria by 2030—excluding control and balancing energy—is met. The different energy...
sources contribute to the achievement of the overall target according to the sub-targets defined by the Austrian government (11 TWh PV, 10 TWh wind power, 5 TWh hydro power and 1 TWh biomass). Accordingly, we assume that higher investment in household PV systems will result in lower investment in (larger scale) business PV plants. Given the development of electricity demand and supply in the scenario, the electricity price for households in all scenarios will rise from 17 ct/kWh in the base year 2017 to 38 ct/kWh in 2030. This reflects price formation according to the merit order with a rising gas price and the increasing role of gas for providing control and balancing energy in an electricity system predominantly based on renewable energy sources.

For the residential PV systems, constant average investment costs of 1300€ per kWp [15] are assumed for the whole simulation period (2017 to 2030). With respect to the specific electricity output, 1000 kWh per kWp are assumed.

4 Simulation results

The following sections summarise the results of the model simulations in terms of the effects on the adoption of residential PV systems as well as the macroeconomic and distributive effects. Even though the expansion of residential PV systems requires investments of several hundred million Euros the effects are relatively small since (i) the investments occur over a period of 14 years, (ii) the effects and investments are compared to a baseline where PV investments also take place due to rising electricity prices. Moreover, the economic effects are small as they are presented on the household level, and as net effects.

4.1 Adoption of residential PV systems

As a result of rising electricity prices, household PV investments of the highest income quintile will accelerate compared to past investment trends. In the baseline scenario (BS), the total additional capacity installed between 2017 and 2030 amounts to 1.7 GWp (see Table 1). In the prosumer scenarios PS1 and PS2, subsidies lead to higher investment (1.9 and 2.1 GWp respectively) and in turn higher residential PV electricity generation. Scenario PS2 that favours households with lower income achieves a higher expansion of PV using the same support volume as scenario PS1 that grants a subsidy of 30% to all households. This reflects the fact that the subsidy increases the investments of low- and medium-income households that are facing budget constraints, while it rather constitutes a deadweight effect for the highest income quintile.

4.2 Macroeconomic effects

Fig. 2 shows the average changes in real GDP in the period 2017 to 2030 in the two prosumer scenarios compared to the baseline by GDP component. Overall, the impacts of the investment in residential PV systems are very moderate, but positive in both prosumer scenarios. The highest positive contribution to GDP stems from private consumption, which includes household PV investment and the effects from shifting expenditure on electricity that is now provided by the PV systems to other consumption categories. The positive effect of the rise in private consumption is partly compensated by declining public consumption and a net increase in imports. The import effect is mainly related to the import shares of consumed commodities as well as PV investment.

4.3 Distributive effects

The distributive impacts of the two policy scenarios compared to the baseline scenario assuming no subsidies for residential PV systems are shown in Fig. 3. In PS1, with a common subsidy of 30% eligible to all households, household consumption rises over the income quintiles, i.e. households with higher incomes benefit more strongly than low income households. In PS2, gains compared to the baseline show for low- and medium-income households. Overall, in PS2 compared to PS1 disposable income increases for all income quintiles due to the macroeconomic feedback effects. However, due to the low level of investment compared to GDP, this effect is very small.

5 Conclusions

Due to the war in Ukraine—and its impact on the gas market—the challenges for the transformation of the European energy system have been instantly amplified. Against this background, as part of the “RE-PowerEU” initiative [16] in May 2022, the Commission developed options for an accelerated phase-out

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4 The net effect is moderate if counteracting impacts are simulated, e.g., the increase of consumption of non-energy goods equals the decrease of energy costs.

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Table 1 Development of residential PV generation, subsidies and investment by scenario

|                        | BS | PS1 | PS2 |
|------------------------|----|-----|-----|
| Additional electricity generation (TWh) | 7  | 1.7 | 1.9 |
| Subsidies (cumulative) (€) | 788 | 791 | 2329 |
| Investment in PV (cumulative) (€) | 2627 | 2966 | 2966 |
| Subsidies/kWp (€) | 420 | 373 | 373 |

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5 Higher consumption demand increases labour demand. In turn, wages increase which results in an increase in prices. Since the GDP components are represented in real terms (i.e. constant prices) this price level increase translates into the slightly negative impact on public consumption. In nominal terms public consumption is fixed exogenously in DYNK and does not differ from the baseline development.
of (Russian) natural gas, which had previously been regarded as a key bridging technology for achieving the climate targets. In addition to a higher degree of diversification of gas supply, central aspects of the proposal include a more rapid electrification and simultaneous substitution of fossil fuels by renewable energy sources (especially wind and solar energy) and heat pumps, as well as increases in energy efficiency.

Due to the increase in gas prices, electricity prices have risen significantly in Austria and other EU Member States. Households that own a PV system are significantly less affected by these price changes or might even be not affected at all in case they can fully cover their electricity consumption with their PV system.

For Austria, the data show that the ability of different household groups to participate in the electricity market as prosumers varies substantially, and depends particularly on the characteristics of the dwelling and on the household income. To ensure a fair participation of all groups of households in the energy transition, it will therefore be essential to reduce both legal barriers for the installation of PV systems on multi-family buildings and provide targeted support to low-income households to ensure broad affordability of residential PV systems. Enhancing citizen participation in renewable energy communities can also contribute to achieving a more equitable transformation of the electricity system.
Acknowledgements This research was conducted in the START2030 project that was funded by the Austrian Climate and Energy Fund and carried out in the Austrian Climate Research Program (ACRP). We are grateful for excellent research assistance provided by Eva Wretschitsch and Katharina Köberl.

Funding Open access funding provided by Österreichisches Institut für Wirtschaftsforschung (WIFO) – Austrian Institute of Economic Research.

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Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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