Forecasting the Diffusion of Residential Photovoltaic Systems in Austria: An Agent-Based Modeling Approach

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FCN | Future Energy Consumer Needs and Behavior
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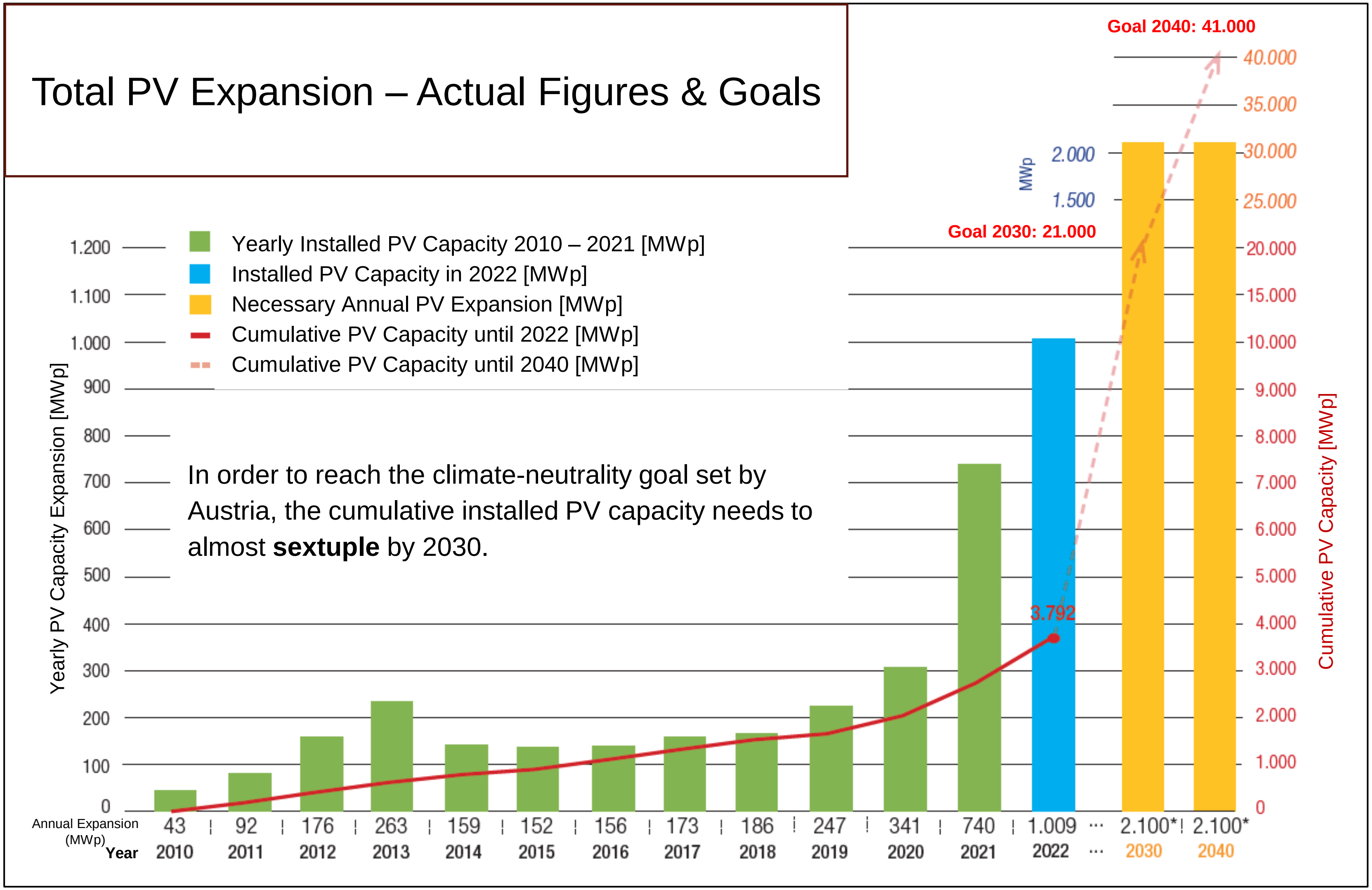
Agenda

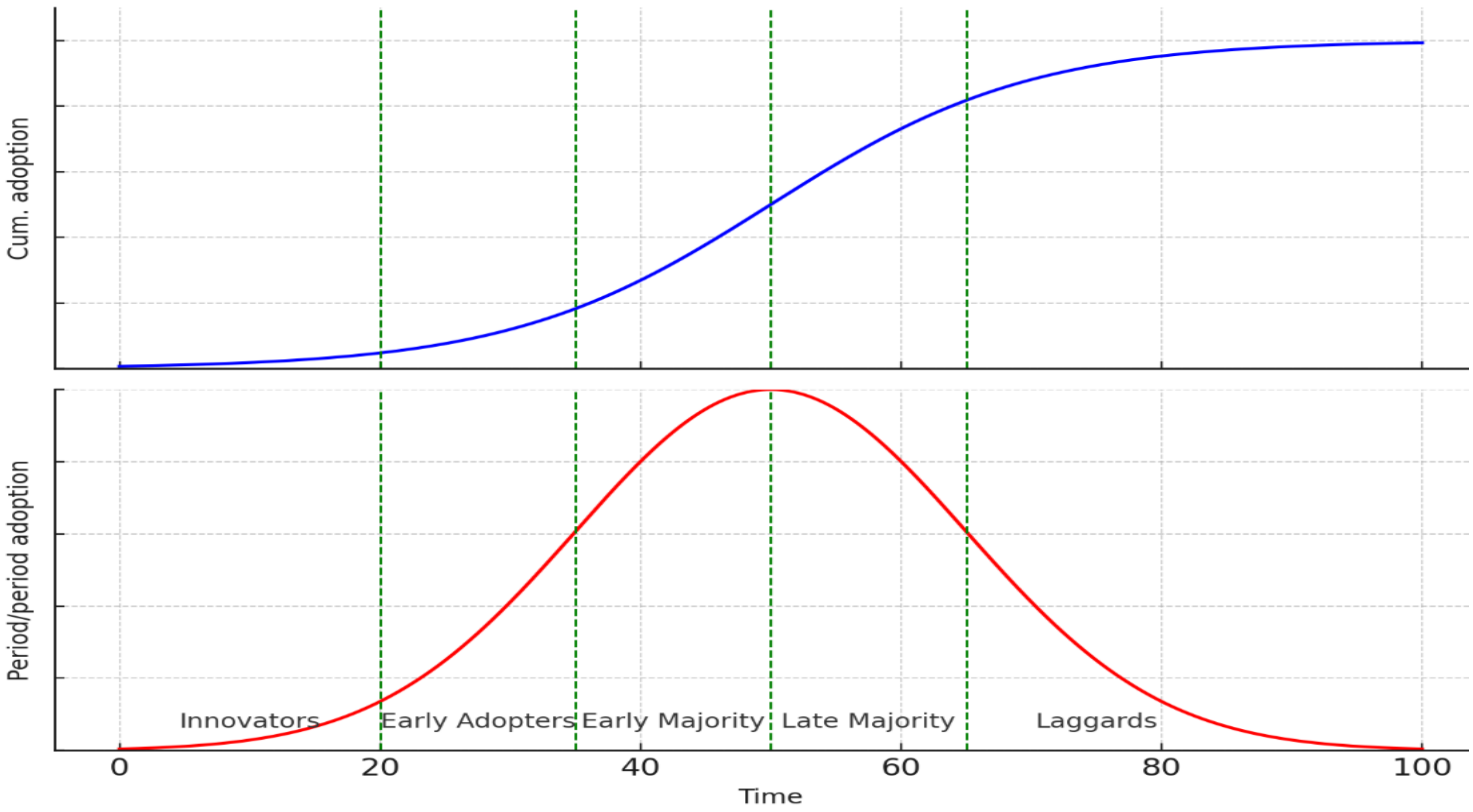
Introduction



PV Deployment Goals of Austria
Source: PV Austria (2023); Statistik Austria (2022)

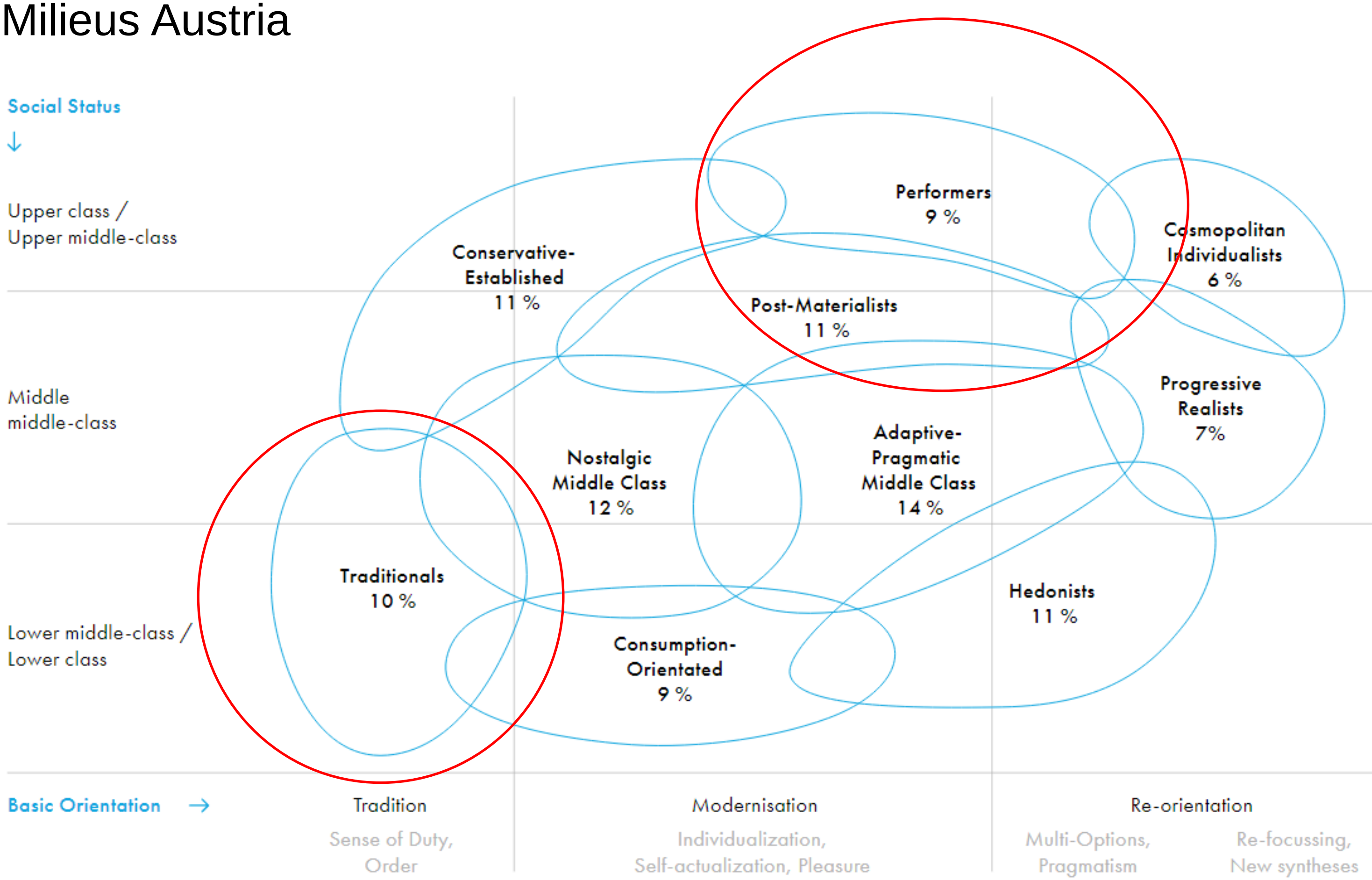
Agenda

Technological Diffusion & Agent-Based Modelling



Diffusion of Innovation Theory
Source: Own Illustration based on Rogers (1962)

Sinus-Milieus Austria



Sinus-Milieus of Austria
Source: Sinus-Milieus Austria (2022)

Solar Photovoltaics Policy in Austria – Summary of Recent Developments

Year	Feed-in-Tariff [€-cents/kWh]	Average Wholesale Electricity Selling Price [€-cents/kWh]	Capital Grants for PV systems [€/kWp]		Capital Grants for Batteries [€/kWh]
	5-10 kWp		< 5 kWp	5-10 kWp	
2008	39.99	7.28	2800	0	0
2009	39.98	4.72	2500	0	0
2010	38.00	4.66	1300	0	0
2011	38.00	5.66	1100	0	0
2012	27.60	4.87	800	0	0
2013	18.12	4.02	200	200	0
2014	12.50	3.53	200	200	0
2015	12.50	3.23	200	200	0
2016	8.24	2.70	275	375	0
2017	7.91	3.33	275	375	0
2018	7.91	4.45	250	250	500
2019	7.67	5.10	250	250	500
2020	7.67	3.99	250	250	200
2021	0.00	7.80	285	250	200
2022	0.00	33.43	285	285	200
2023	0.00	16.87	285	285	200

Sources: PV Austria (2024), IG Windkraft (2020), E-Control (2024), Klimafonds (2019)

Agenda

Why agent-based model?

- Bayesian, regression or system dynamics model rely on the availability of vast datasets
- Autoregressive models and neural networks rely on the availability of long time series data with repeating patterns

Data scarcity

- Limited time-series data for training but extensive sources of other categorical data
- Detailed investigation of individual investment decisions utilizing multi-categorical data is necessary

Methodology

Multi-Agent Segmentation

Initialization	All Austrian Households							
9 States	Burgenland	Lower Austria	Styria	....	Vienna			
X								
4 Age Groups	18 – 24	25 – 49	50 – 64	65+				
X								
8 Household Types	Single Person	Single Person with children	Two Adults	Two Adults with one Child	Two Adults with 2 Children	Two Adults with 3+ Children	Three or more Adults	Three+ adults with children
X								
3 Education levels	Primary Education	Secondary Education	Higher Education					
X								
4 Home Types	Owned House	Rented House	Owned Apartment	Rented Apartment				

=

3456 Subgroups

Agent Segmentation

Example Agent

General Attributes:

- State: Vienna
- Age class: 25-49
- Household type: Two Adults
- Education level: Secondary Education
- Home type: Rented House
- Year: 2015

Individual Attributes:

- Sinus Milieu: Post Materialist
- Household Income: 31,000 €/a
- Electricity Consumption: 3500 kWh/a
- Electricity Production: 3000 kWh/a

Example Agent Attributes

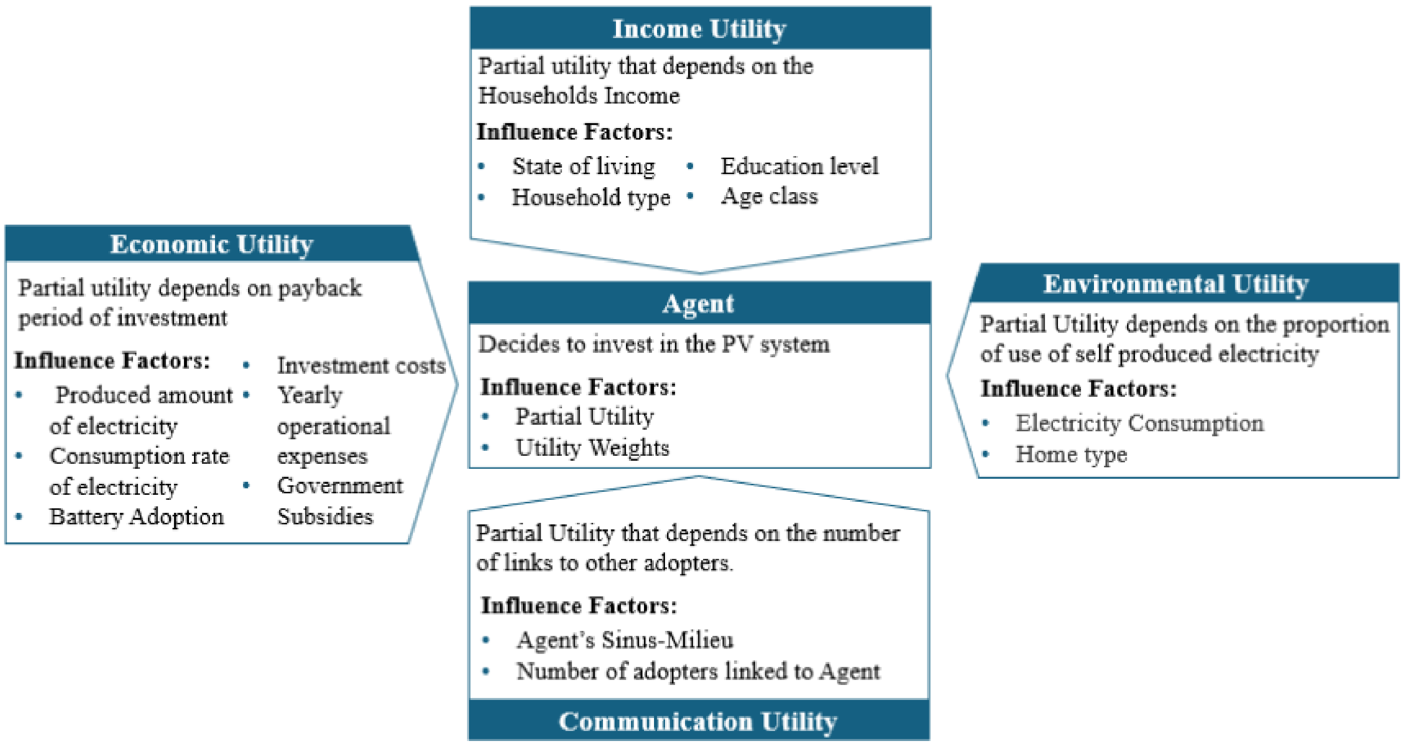
Methodology

Agent Adoption Decision

$$U_j = w_{econ}(sm_j) \cdot u_{econ}(j) + w_{com}(sm_j) \cdot u_{com}(j) + w_{inc}(sm_j) \cdot u_{inc}(j) + w_{env}(sm_j) \cdot u_{env}(j)$$

Where:

$$\sum_k w_k(sm_j) = 1 \; for \; k \in K: \{econ, com, inc, env\} \quad \textbf{and} \quad w_k(sm_j), U_j \in [0,1]$$



Partial Utilities and their Influence on Agents

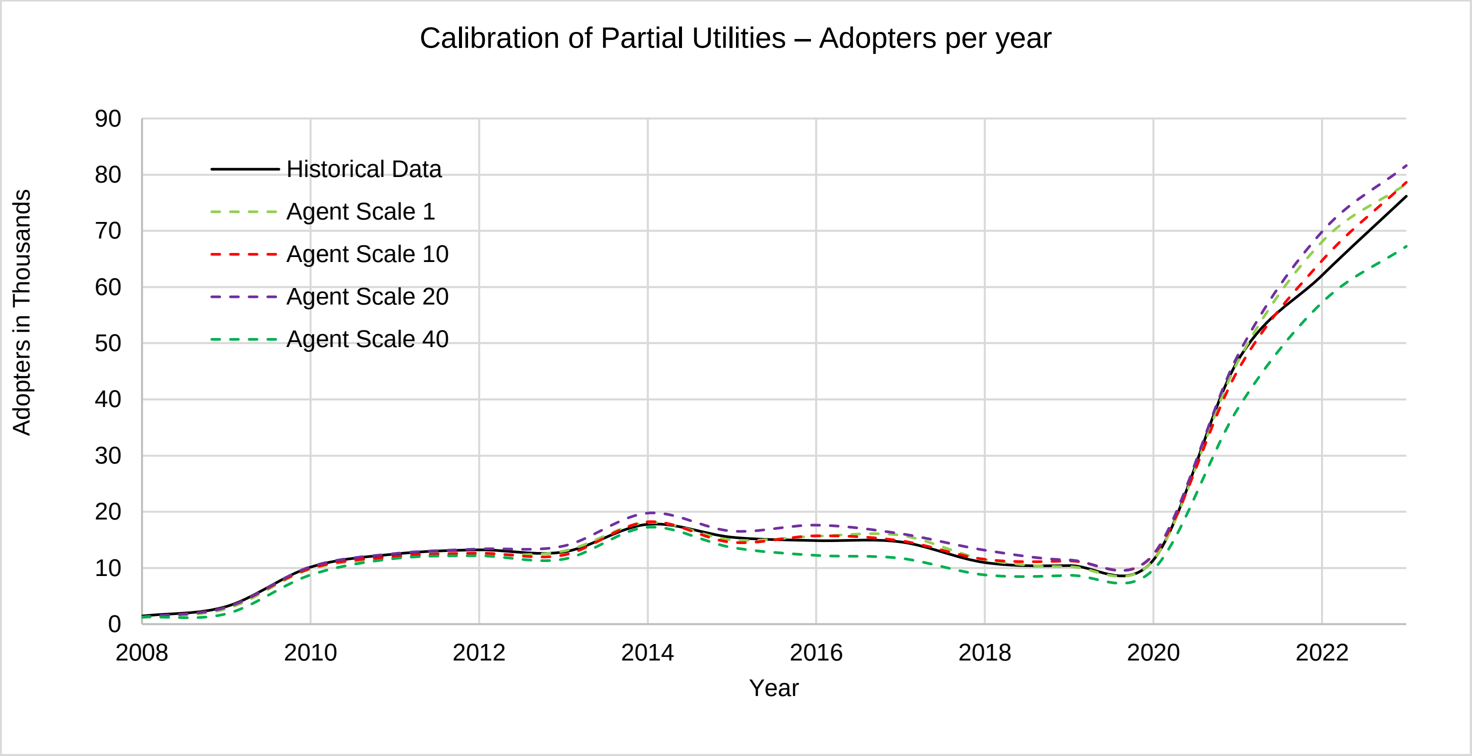
Source: Own Illustration, inspired by Palmer et al. (2015)

Methodology

Model Calibration – Partial Utilities

Runtimes (RWTH High-Performance Computing)

- 8 cores
- 256GB of RAM



- **Full population**: approx. 3 hours
- **Scaled down by 40**: 3 minutes
- **Scaled down to 10**: 12 minutes (optimal balance between computation time and accuracy)

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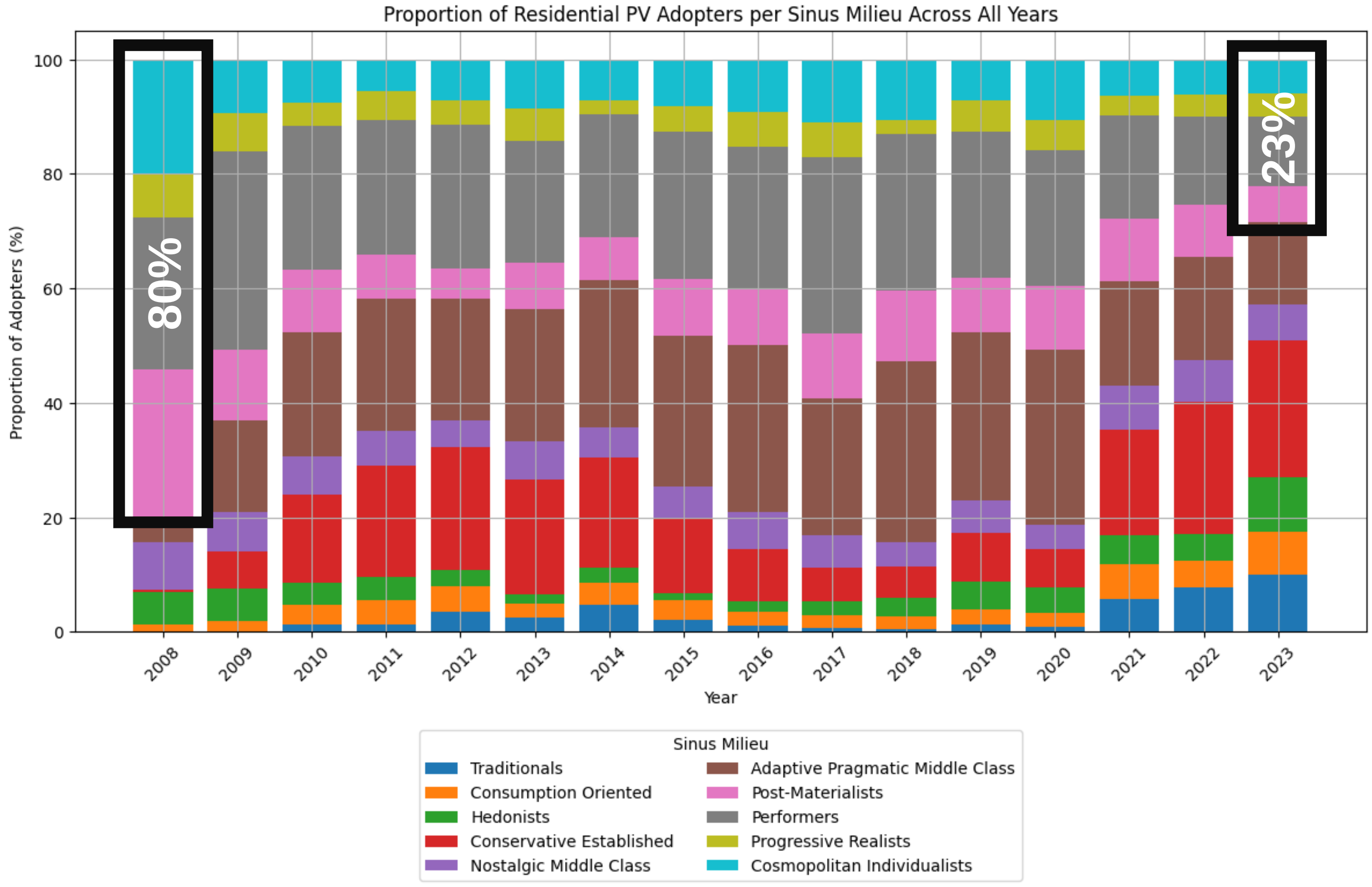
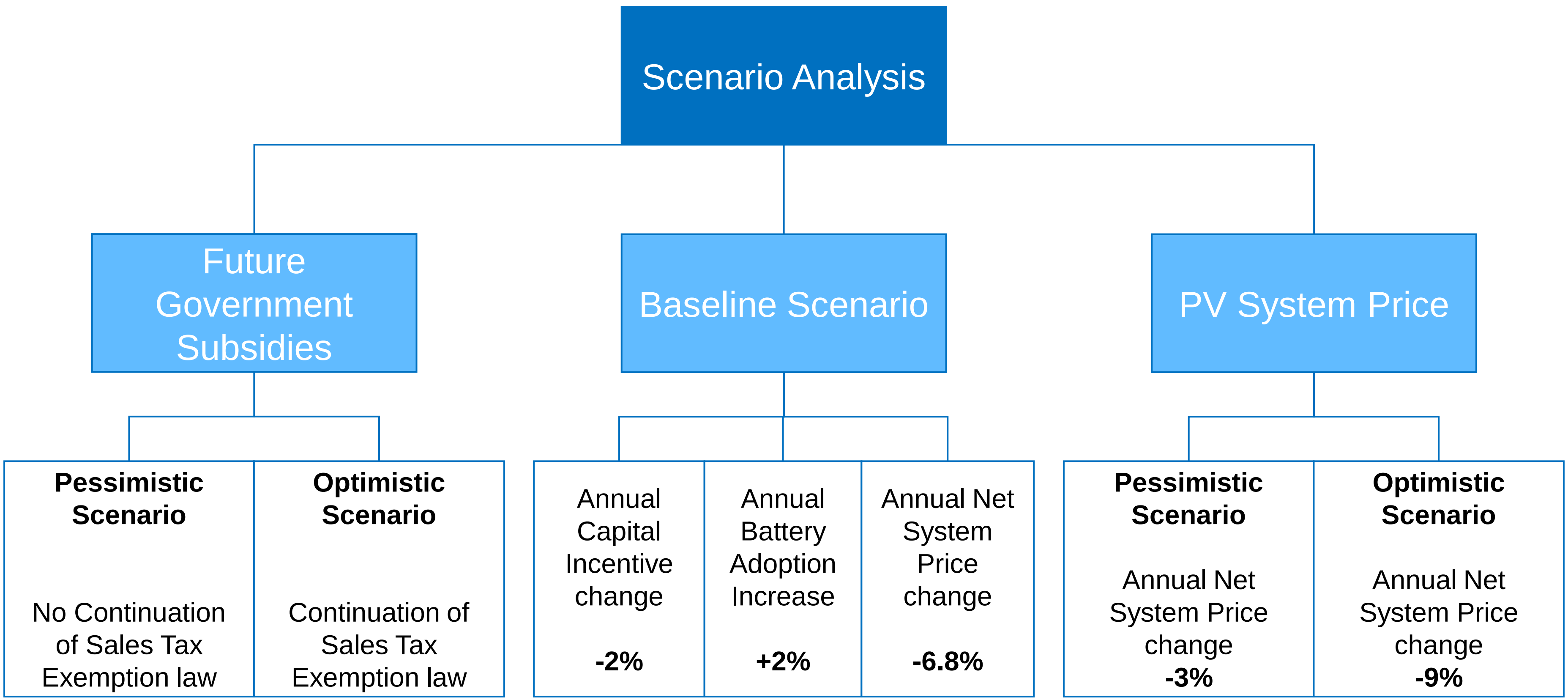
Proportion of Adopters per Sinus Milieu (Model Calibration)



Proportion of Residential PV Adopters per Sinus-Milieu

Forecasting Future Household PV Adoption – Scenario Analysis



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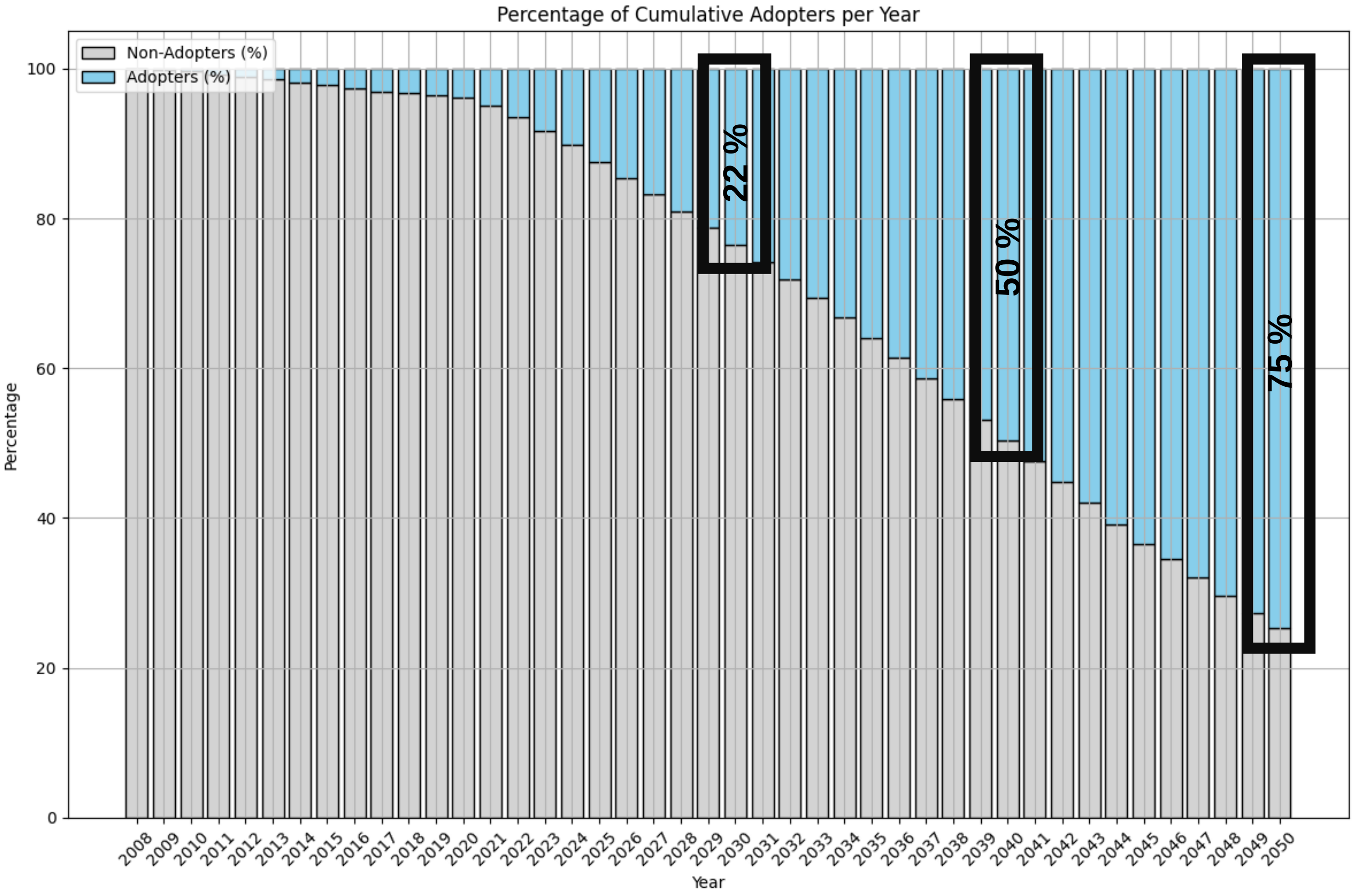
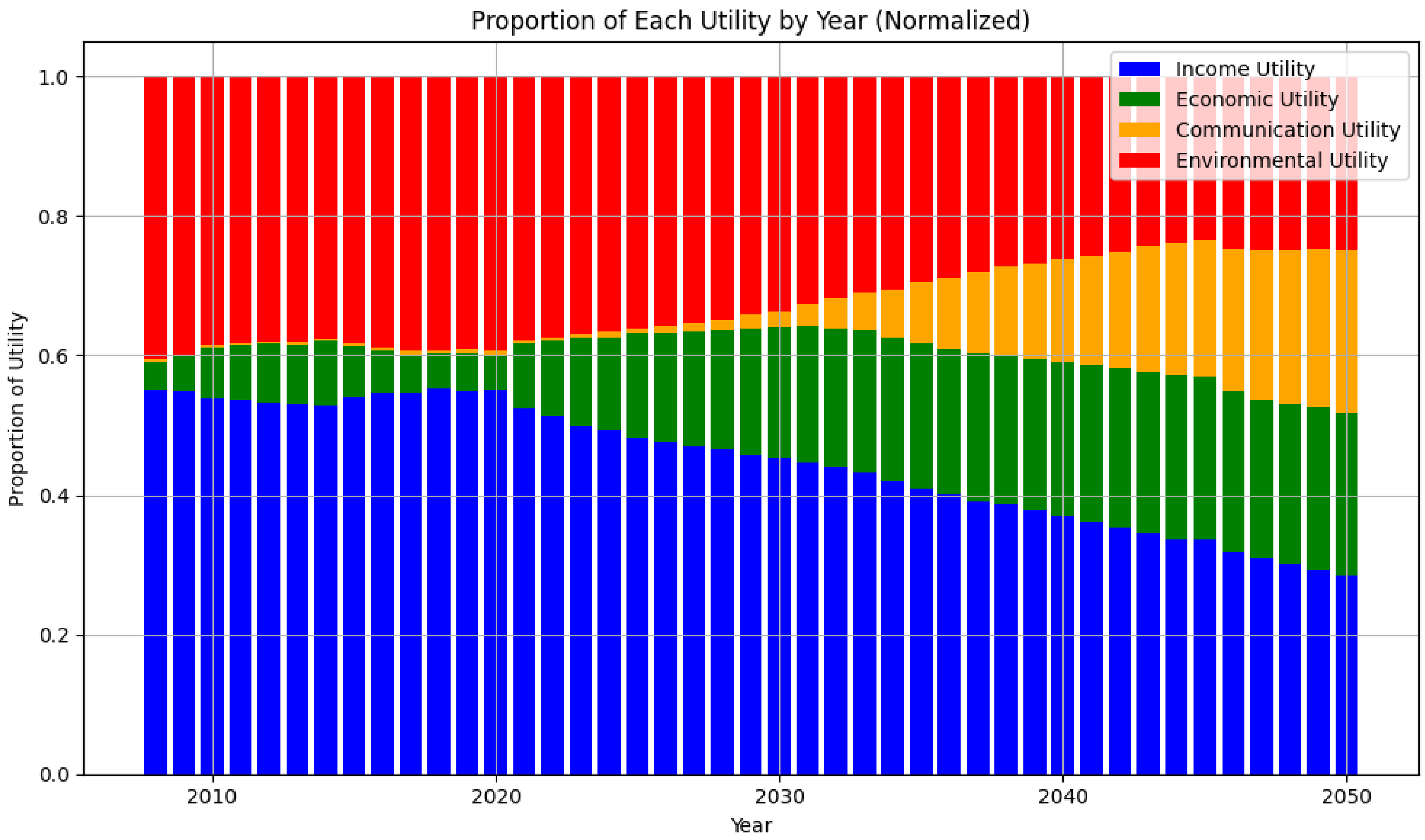
Projected Future Adoption – Baseline Scenario



Influence of Partial Utility on Adoption Over Time – Baseline Scenario

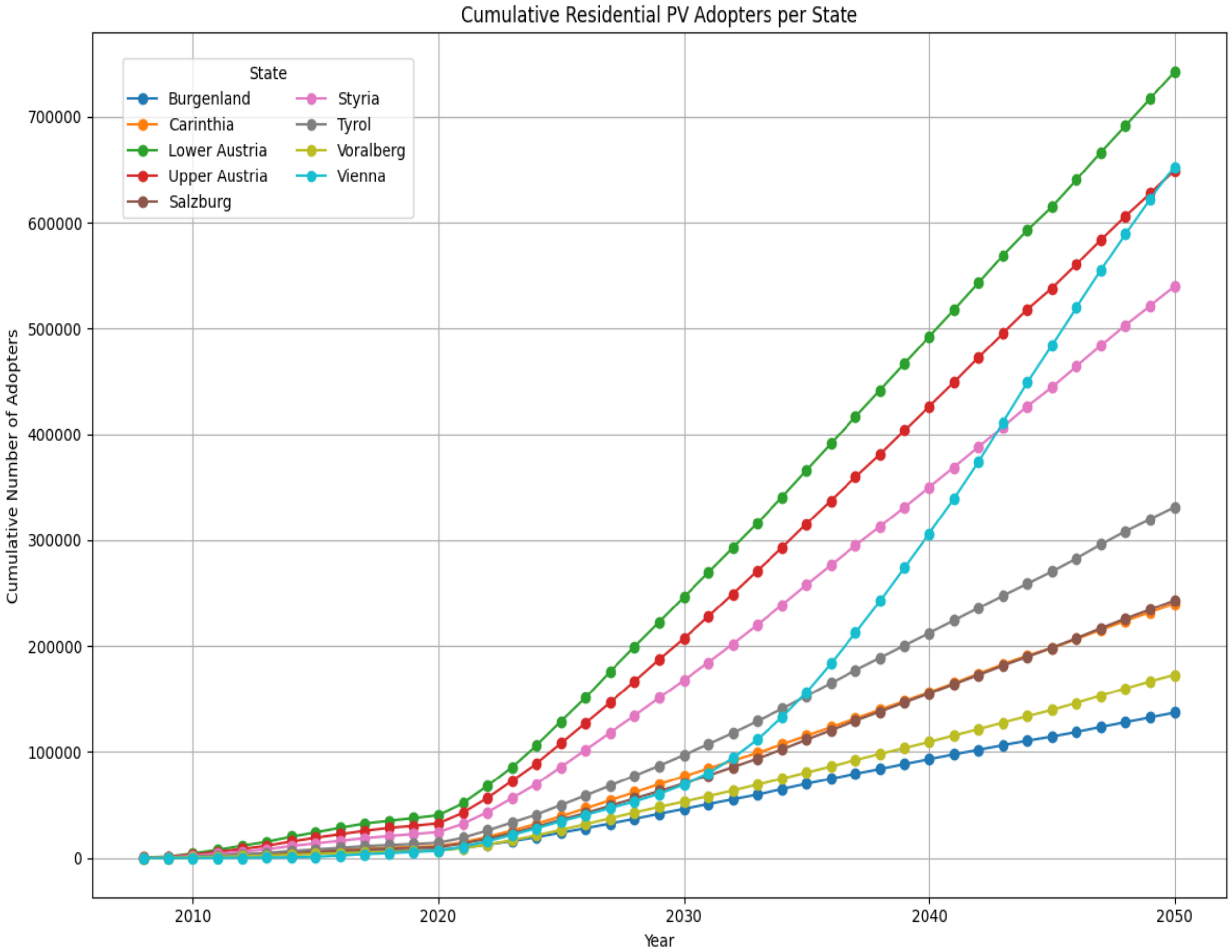


Results and Analysis

Results are cross-checked with surveys carried out **by third parties as well as our own** survey results

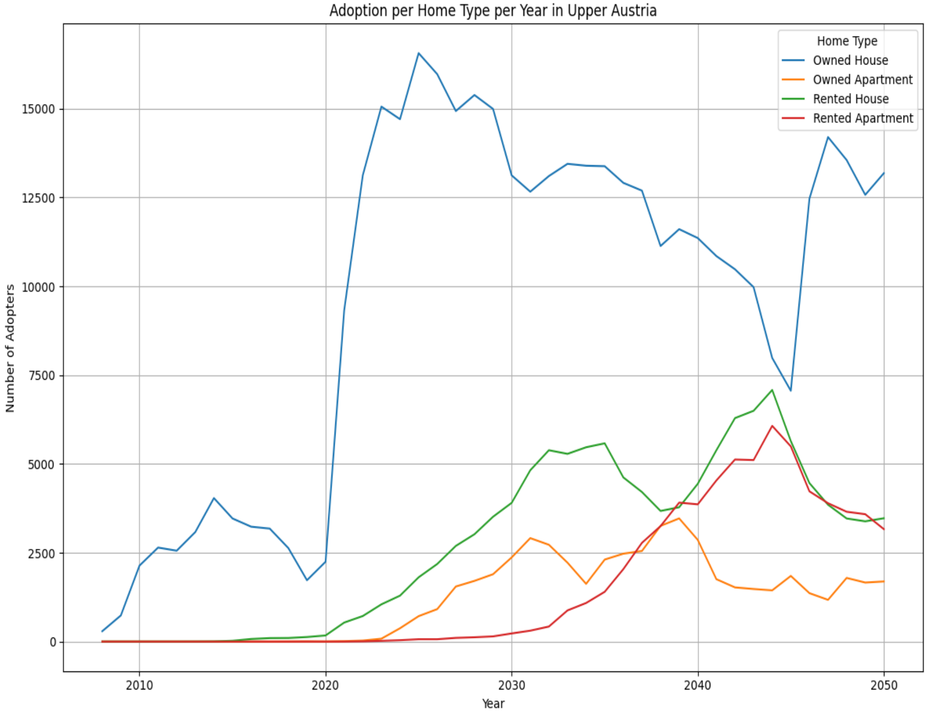
Results and Analysis

Cumulative Adoption per State – Baseline Scenario

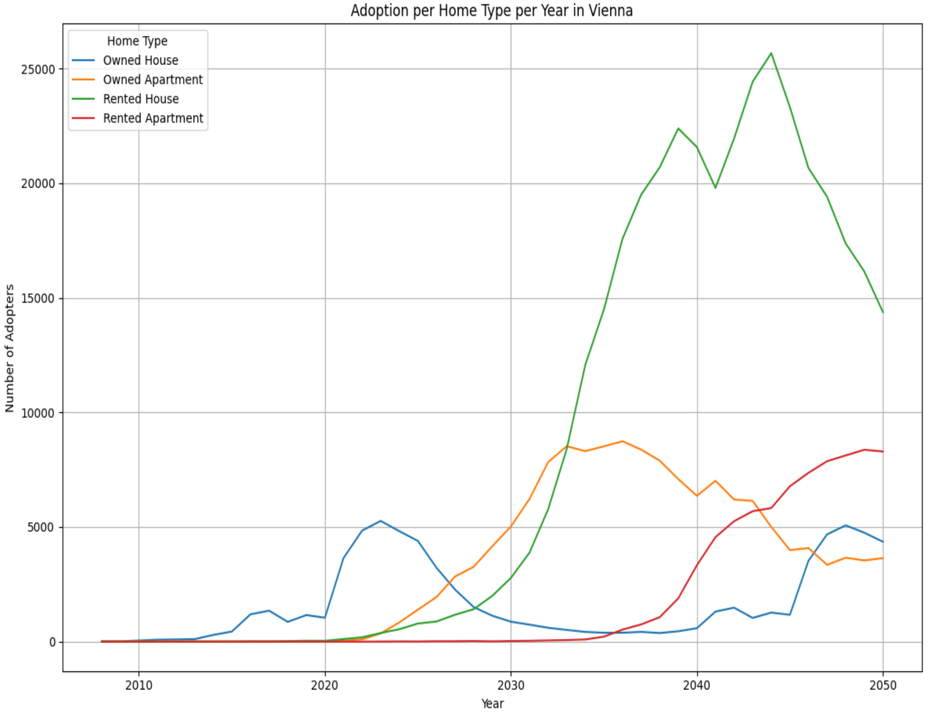


Adoption per Home Type in Different Federal States – Baseline Scenario

Upper Austria

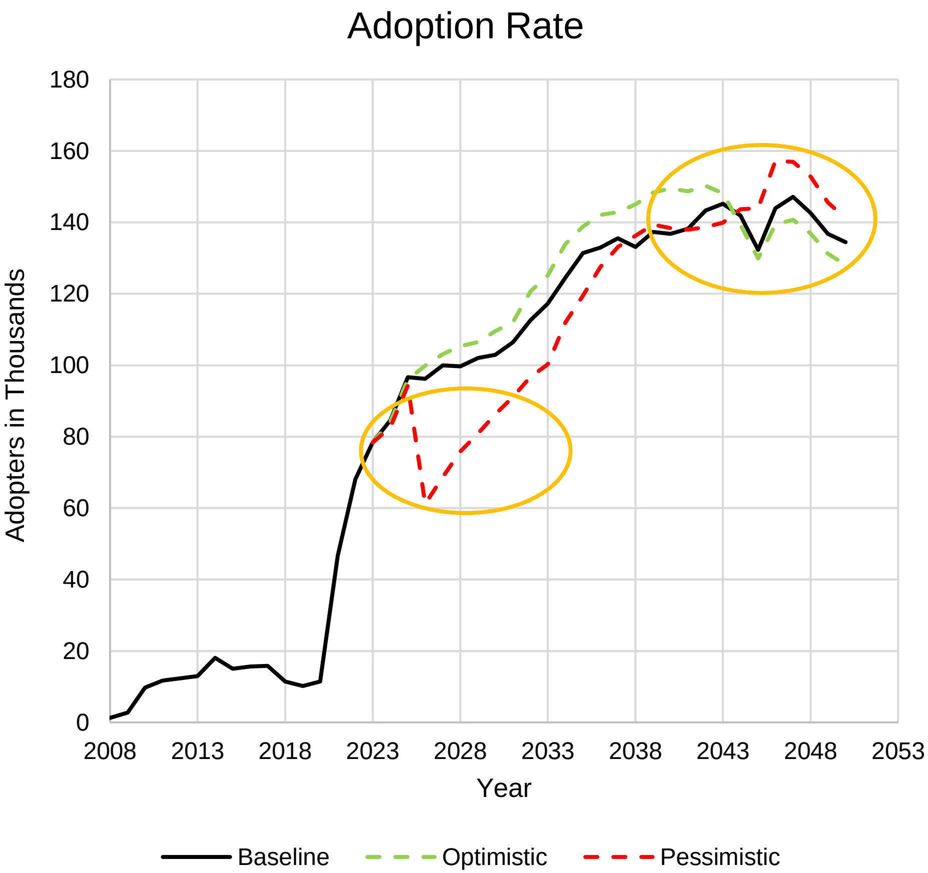


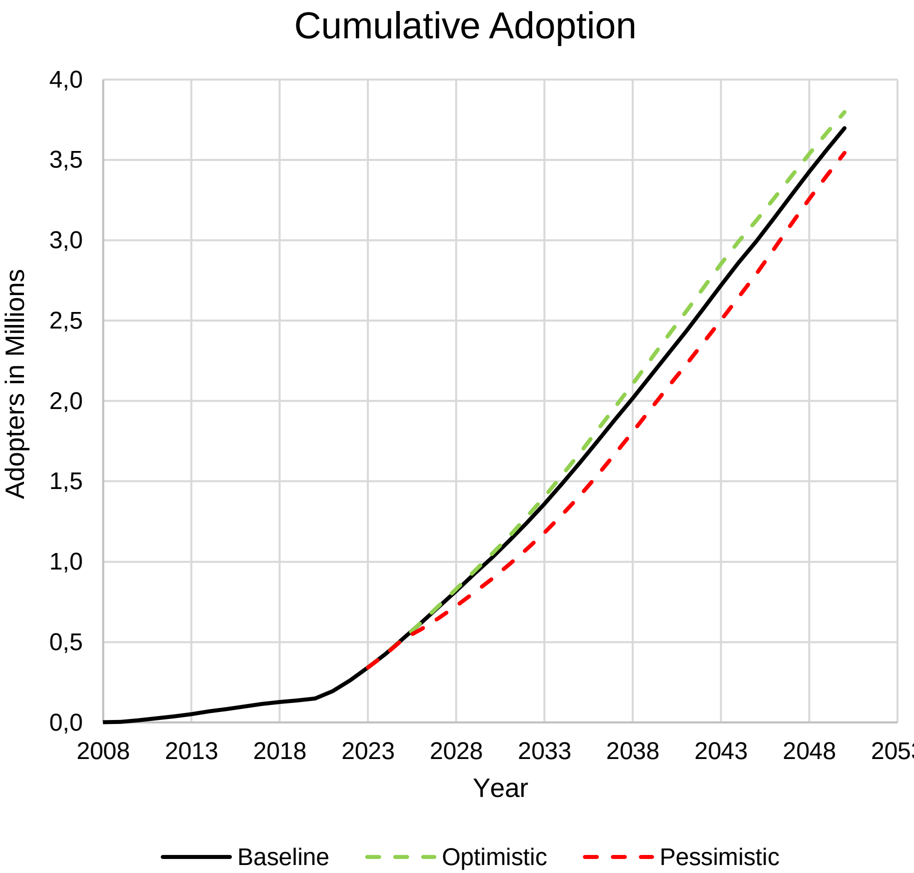
Vienna



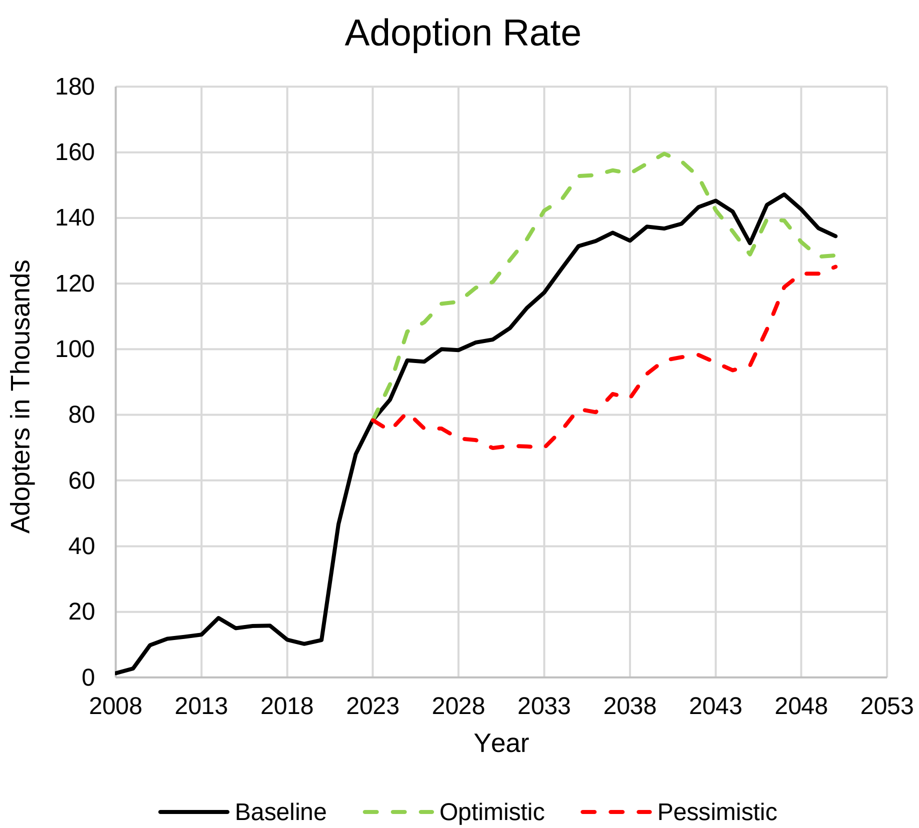
Results and Analysis

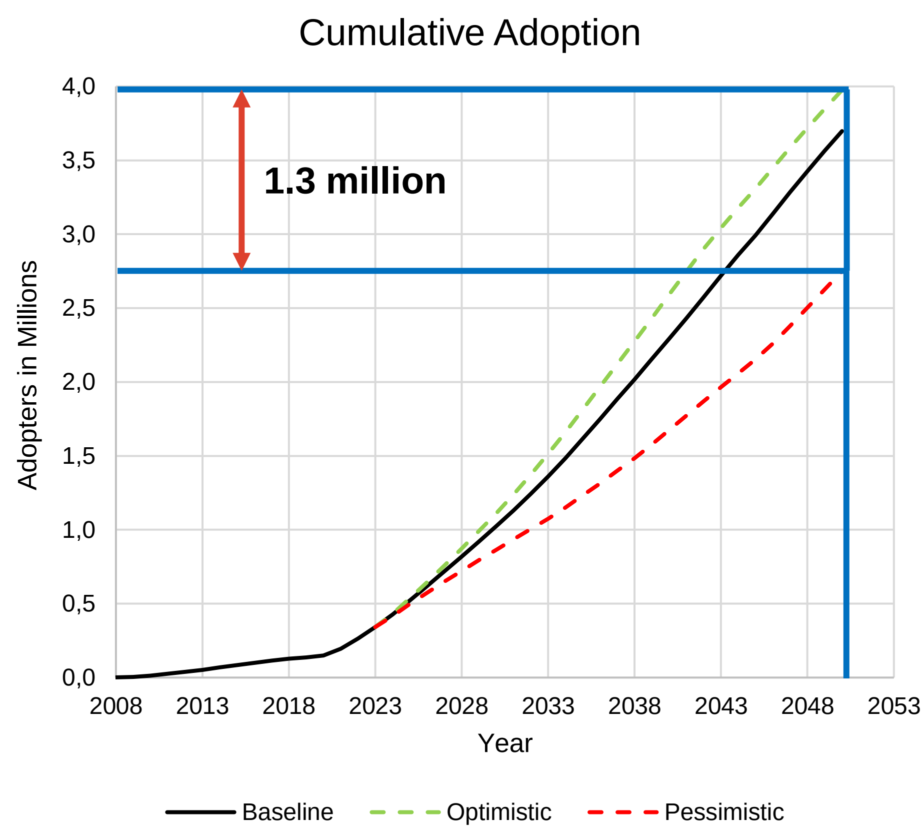
Projected Future Adoption – PV Regulation Developments





Projected Future Adoption – PV System Price Scenarios





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Conclusion and Outlook

- The model, expanding on Palmer et al. (2015), provides useful and a disaggregated investigation of PV adoption dynamics in Austria.
- Utilizing multi-categorical data enables better understanding of (state-level) market diffusion of residential PV systems in Austria.
- Sinus-Milieus are useful to reflect the socio-cultural dimensions of the Austrian population.
- House ownership loses ground as a primary factor for PV adoption. States with lower rates of homeownership are expected to catch up (e.g. Vienna).
- Changing the PV system price leads to market saturation faster than the offered subsidies.
- Incorporating state and district level policy heterogeneity into future models could enhance the predictive accuracy of the model (work in progress).

Work In Progress

■ “Zooming-In”: **State-Level** Subsidy Investigation

State	Owned / Rented	Available Subsidy (< 5 kWp)	Available Subsidy (5 kWp ≤ x ≤ 10 kWp)	Combination with EAG?	Notes
Carinthia	Owned	€323 (per kWp)	€194 (per kWp)	YES	Maximum 50% of costs covered
Carinthia	Rented	€200 (per kWp)	€200 (per kWp)	YES	
Salzburg	Owned	0	€1,000 (per kWp) 40% of total PV system cost	YES	Systems under €500 are ignored
Styria	Owned	15% of total PV system cost	€300 (per kWp) 15% of total PV cost	YES	
Styria	Rented	15% of total PV system cost	€300 (per kWp) 15% of total PV system cost	YES	
Tyrol	Owned	0	€250 (per kWp)	YES	Minimum 7 kWp
Vienna	Owned	€250 (per kWp) 30% of total PV system cost	€250 (per kWp) 30% of total PV system cost	NO	Minimum 1 kWp

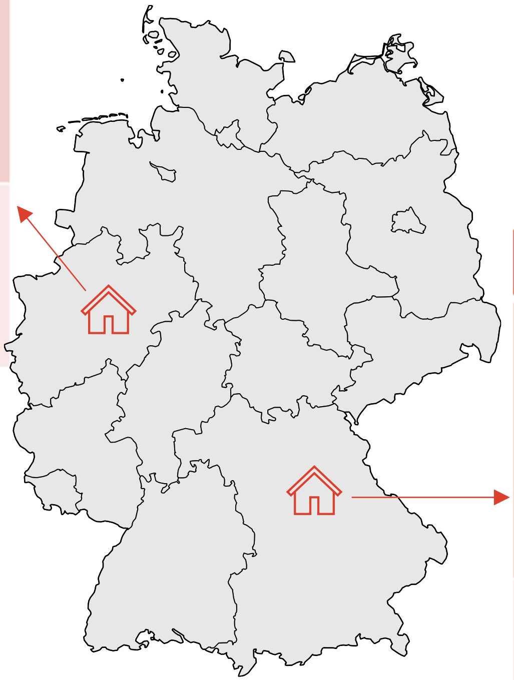
Work In Progress: Private E-Vehicle Charging Stations in Germany

"Plug-and-Play" Application for **Different Sustainable Residential Technologies**

Example Agent 1

General Attributes:
- **Year:** 2022
- **State:** North Rhine-Westphalia
- **Age Group:** 25 to 49 years
- **Education Level:** Tertiary Education
- **Household Type:** Two Adults
- **Degree of Urbanization:** Cities
- **Parking Lot Type:** Shared Garage

Individual Attributes:
- **Household Income:** 45,824 €/a
- **Annual Driving Distance:** 12,500 km/a
- **Powertrain:** Electric Motor
- **Sinus Milieu:** Performer Milieu



Example Agent 2

General Attributes:
- **Year:** 2022
- **State:** Bavaria
- **Age Group:** 65+ years
- **Education Level:** Primary Education
- **Household Type:** Three Adults
- **Degree of Urbanization:** Rural Areas
- **Parking Lot Type:** Lot on Private Ground

Individual Attributes:
- **Household Income:** 20,712 €/a
- **Annual Driving Distance:** 18,500 km/a
- **Powertrain:** Combustion Engine
- **Sinus Milieu:** Traditional Milieu

Thank you for your kind attention.
Any questions?

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