

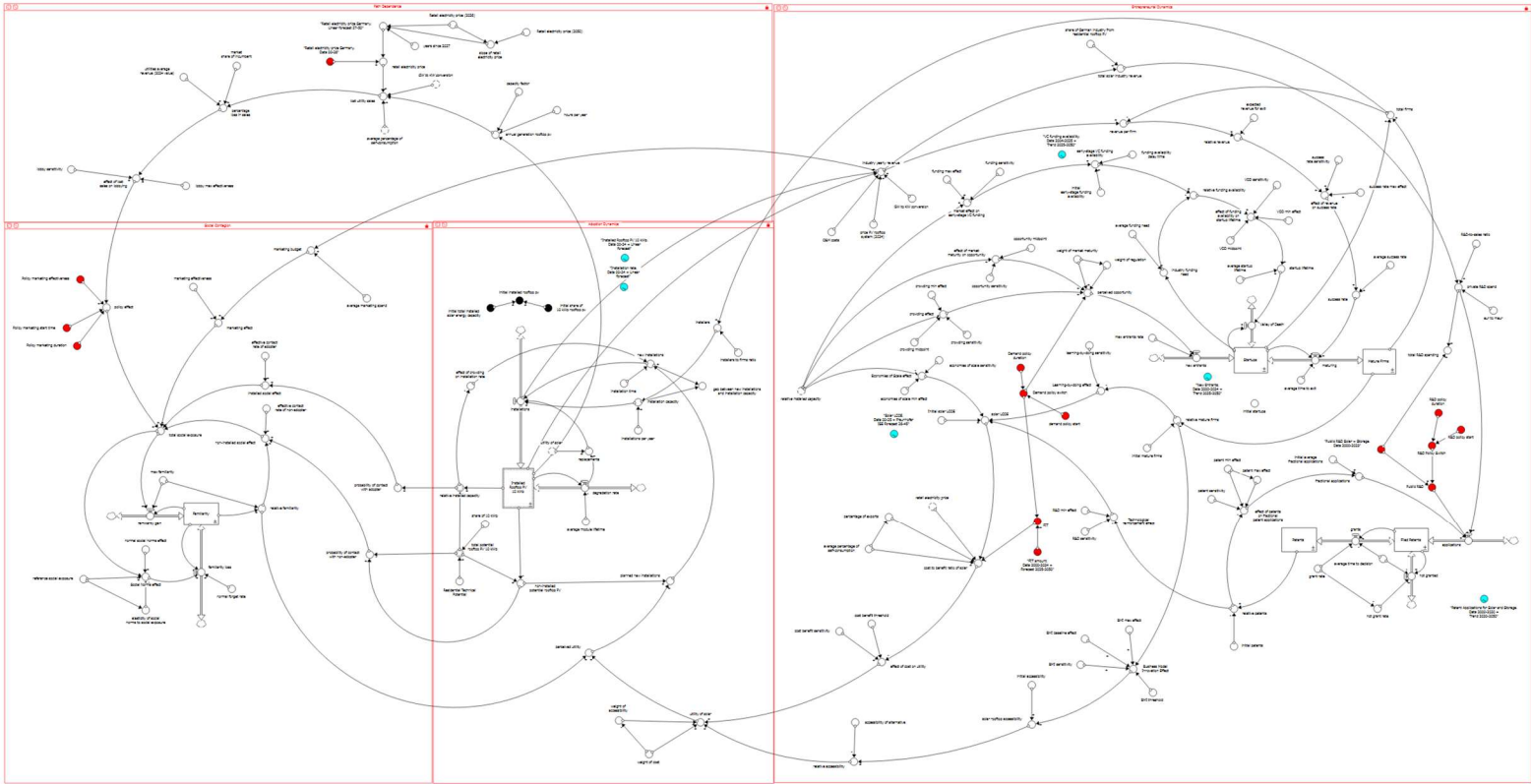
Submission to International System Dynamics Conference (ISDC) 2026

**Title: Positive Tipping Point Dynamics and
the role of Entrepreneurial Activity**

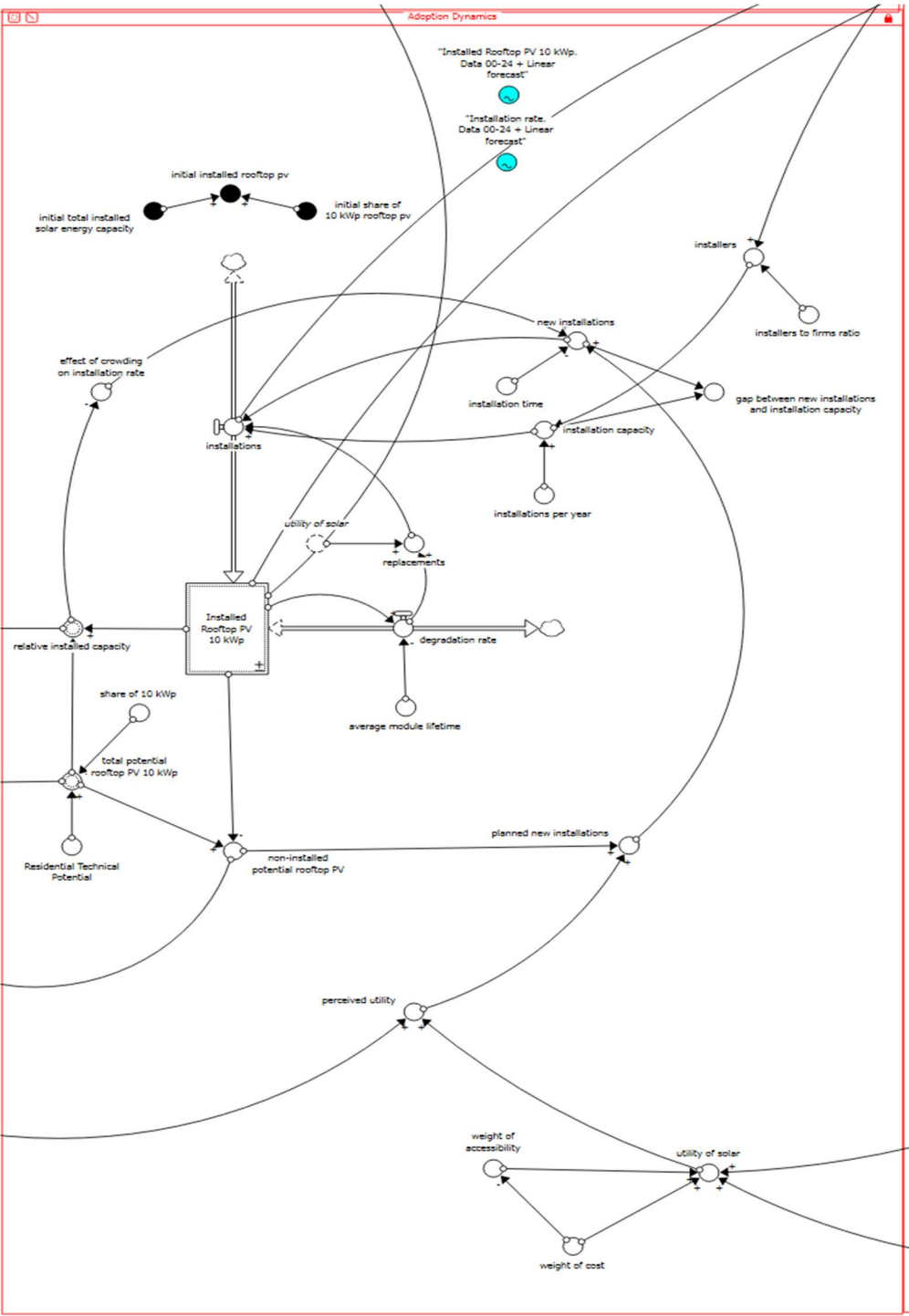
Appendix A-D

Appendix A: Model Structure

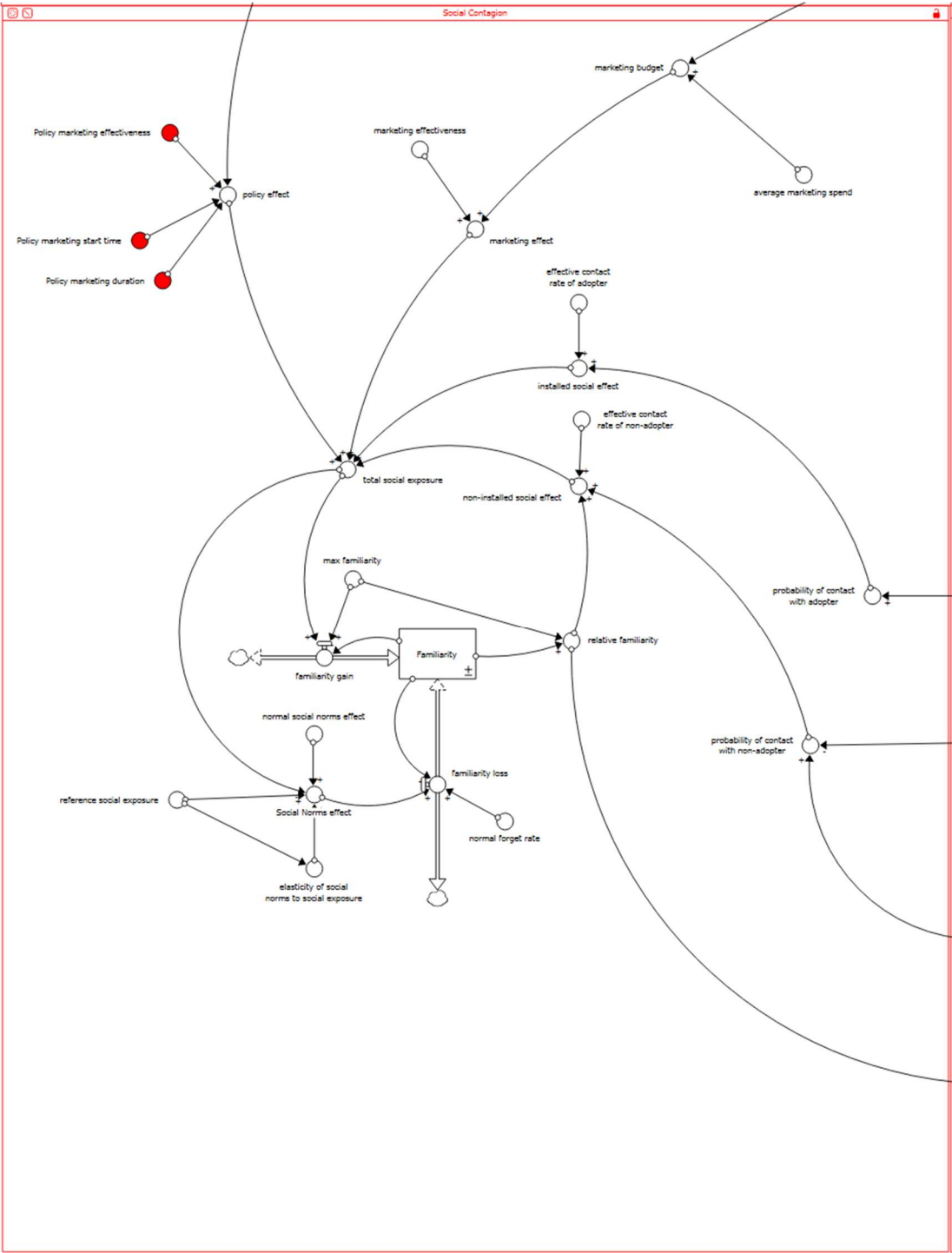
Full Model Structure. Model File and Code attached.



Adoption Dynamics (CENTER of model)



Social Contagion (LEFT of model)

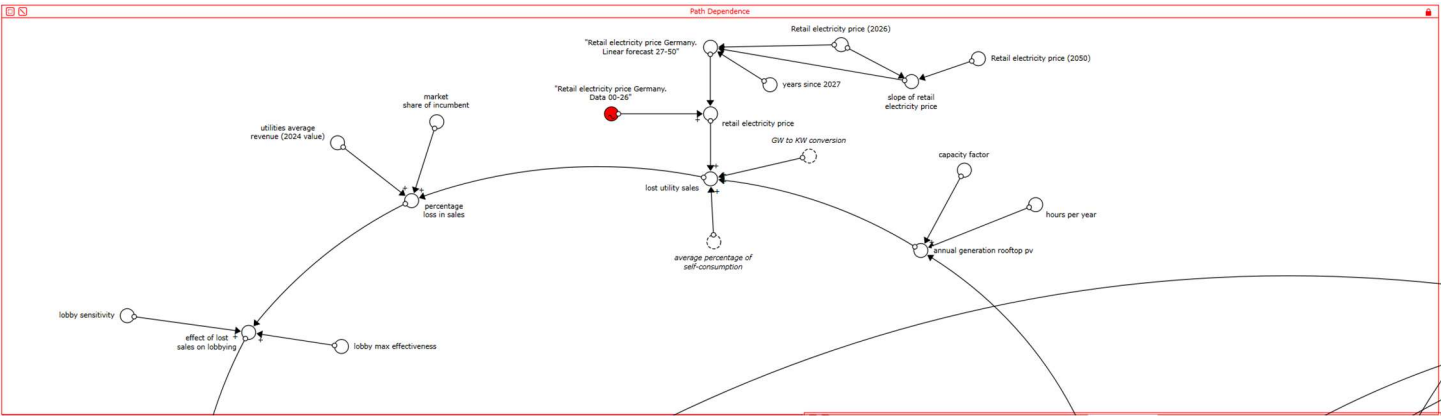


The diagram, titled "Entrepreneurial Dynamics", is a complex causal loop diagram illustrating the relationships between various factors in a startup ecosystem. It is organized into several interconnected sections:

- Funding and VC Dynamics:** This section includes nodes like "VC funding availability" (Data 2020-2024 = Trends 2020-2027), "funding max effect", "funding sensitivity", "VC funding availability", "initial average VC funding availability", "relative VC funding availability", "funding availability delay time", "relative VC funding availability", "VC sensitivity", "VC max effect", "VC min effect", "VC sensitivity", "VC max effect", "VC min effect", "VC sensitivity", "VC max effect", "VC min effect".
- R&D and Innovation:** This section includes nodes like "R&D-to-exit ratio", "private R&D spend", "R&D policy button", "R&D policy start", "R&D policy duration", "R&D policy effect", "R&D policy sensitivity", "R&D policy max effect", "R&D policy min effect", "R&D policy sensitivity", "R&D policy max effect", "R&D policy min effect".
- Patents and Intellectual Property:** This section includes nodes like "patents", "first patents", "patent max effect", "patent min effect", "patent sensitivity", "patent max effect", "patent min effect", "patent sensitivity", "patent max effect", "patent min effect", "patent sensitivity", "patent max effect", "patent min effect".
- Business Model Innovation:** This section includes nodes like "business model innovation effect", "BMC max effect", "BMC min effect", "BMC sensitivity", "BMC max effect", "BMC min effect", "BMC sensitivity", "BMC max effect", "BMC min effect", "BMC sensitivity".
- Market and Demand:** This section includes nodes like "market effect on average VC funding", "market effect on VC funding", "market effect on VC funding", "market effect on VC funding", "market effect on VC funding", "market effect on VC funding", "market effect on VC funding", "market effect on VC funding".

The diagram uses a combination of circles (nodes) and arrows (causal links) to represent the complex interactions between these factors. Some nodes are highlighted in red, indicating critical or high-impact areas. The overall structure suggests a dynamic system where changes in one area can have cascading effects on others, leading to different outcomes for startups.

Path Dependence (TOP of model)



Appendix B: Documentation

Documentation of model according to Reporting guidelines for simulation-based research in social sciences (Rahmandad, H., & Sterman, J. D., 2012, 396-411), and can be found in the following pages. The full XMILE code can be found on the pages following model documentation.

Simulation Settings

- Modelling Software: Stella Architect 4.0
- Start Time: 2000
- End Time: 2050
- Integration Method: Euler
- Time Units: Years
- DT: 1/16

	Equation	Units	Documentation
Adoption_Dynamics:			
"Installation_rate_Data_00-24+_Linear_forecast"	GRAPH(TIME) Points: (2000.00, 0.020), (2001.00, 0.05427), (2002.00, 0.0403), (2003.00, 0.0875), (2004.00, 0.1474), (2005.00, 0.22824), (2006.00, 0.22761), (2007.00, 0.26691), (2008.00, 0.3705), (2009.00, 0.53352), (2010.00, 0.6696), (2011.00, 0.7826), (2012.00, 0.71442), (2013.00, 0.42721), (2014.00, 0.223), (2015.00, 0.21654), (2016.00, 0.24833), (2017.00, 0.2992), (2018.00, 0.36834), (2019.00, 0.58684), (2020.00, 1.16046), (2021.00, 1.02204), (2022.00, 0.8195), (2023.00, 3.28656), (2024.00, 2.40976), (2025.00, 2.33735), (2026.00, 2.21925), (2027.00, 2.21925), (2028.00, 2.21925), (2029.00, 2.21925), (2030.00, 2.21925), (2031.00, 2.21925), (2032.00, 2.21925), (2033.00, 2.21925), (2034.00, 2.21925), (2035.00, 2.21925), (2036.00, 2.21925), (2037.00, 2.21925), (2038.00, 2.21925), (2039.00, 2.21925), (2040.00, 2.21925), (2041.00, 2.21925), (2042.00, 2.21925), (2043.00, 2.21925), (2044.00, 2.21925), (2045.00, 2.21925), (2046.00, 2.21925), (2047.00, 2.21925), (2048.00, 2.21925), (2049.00, 2.21925), (2050.00, 2.21925)	GW/year	The variable represents the estimated installation rate from 2000-2024 for the solar rooftop segment below 10 kWp and a linear forecast from 2025-2050 based on empirical data from Fraunhofer ISE (2025-a). The value from 2000-2024 is calculated by subtracting the installed capacity of a year by the preceding capacity and then multiplying the value by the percentage share of capacity additions from the building below 10 kWp segment. The value for 2025 is

			calculated by subtracting the total installed capacity forecasted value from the previous years, and then multiplying by a fixed 15% share of additions. This 15% is subject to uncertainty as a significantly lower share is possible due to increases in larger rooftop and utility-scale systems.
"Installed_Rooftop_PV_10_kWp_Data_00-24+_Linear_forecast"	GRAPH(TIME) Points: (2000.00, 0.10), (2001.00, 0.15427), (2002.00, 0.19457), (2003.00, 0.28207), (2004.00, 0.42947), (2005.00, 0.65771), (2006.00, 0.88532), (2007.00, 1.15223), (2008.00, 1.52273), (2009.00, 2.05625), (2010.00, 2.72585), (2011.00, 3.50845), (2012.00, 4.22287), (2013.00, 4.65008), (2014.00, 4.87308), (2015.00, 5.08962), (2016.00, 5.33795), (2017.00, 5.63715), (2018.00, 6.00549), (2019.00, 6.59233), (2020.00, 7.75279), (2021.00, 8.77483), (2022.00, 9.59433), (2023.00, 12.88089), (2024.00, 15.29065), (2025.00, 17.628), (2026.00, 19.84725), (2027.00, 22.0665), (2028.00, 24.28575), (2029.00, 26.505), (2030.00, 28.72425), (2031.00, 30.9435), (2032.00, 33.16275), (2033.00, 35.382), (2034.00, 37.60125), (2035.00, 39.8205), (2036.00, 42.03975), (2037.00, 44.259), (2038.00, 46.47825), (2039.00, 48.6975), (2040.00, 50.91675), (2041.00, 53.136), (2042.00, 55.35525), (2043.00, 57.5745), (2044.00, 59.79375), (2045.00, 62.013), (2046.00, 64.23225), (2047.00, 66.4515), (2048.00, 68.67075), (2049.00, 70.89), (2050.00, 73.10925)	GW	The variable represents the estimated installed capacity from 2000-2024 for the solar rooftop segment below 10 kWp and a linear forecast from 2025-2050 based on empirical data from Fraunhofer ISE (2025-a).

			The 2000 value is estimated at 0.1 GW based on the value of installed capacity in 2001 and the share of additions in the 10 kWp and below segment during these years. The value from 2001-2024 is calculated by adding the installation rate (see "Installation rate. Data 00-24 + Linear forecast") to the previous years value.
average_module_lifetime		30 year	This variable represents the average module lifetime, commonly set between 25-30 years in studies in Germany (Wirth, 2025).
degradation_rate	$\text{Installed_Rooftop_PV_10_kWp} / \text{average_module_lifetime}$	GW/year	This outflow represents the rate at which the installed rooftop PV stock is depleting. The value is determined by the total GW of installed capacity divided by the average module lifetime.

effect_of_crowding_on_installation_rate	$1 - (\text{relative_installed_capacity})^2$	dmnl	This variable represents an explicit crowding effect whereby new installation rate slows down as the total potential capacity is being reached, representing that the easiest sites and highest willingness households adopt first. This is consistent with the literature on innovation diffusion whereby adopter categories (innovators, early adopters, early majority, late majority and laggards) adopt at subsequently slower rates (Rogers, 2003).
gap_between_new_installations_and_installation_capacity	new_installations - installation_capacity	GW/year	This variable represents the gap between new installations to be made and the installation capacity.
initial_installed_rooftop_pv	initial_total_installed_solar_energy_capacity * initial_share_of_10_kWp_rooftop_pv	GW	This variable represents the initial amount of GW of installed rooftop solar PV systems of 10 kWp and below in Germany in the year 2000. The value is determined by the initial total installed solar energy capacity

			multiplied by the initial share of 10 kWp rooftop pv.
initial_share_of_10_kWp_rooftop_pv		0.8 dmnl	This variable represents the percentage share of total installed capacity from rooftop PV systems of 10 kWp and below in Germany in the year 2000. The value is estimated between 70% and 90% based on Fraunhofer ISE's Photovoltaics Report (2025-a).
initial_total_installed_solar_energy_capacity		0.114 GW	This variable represents the initial amount of GW of total installed solar energy capacity in Germany in 2000. The value is set at 0.114 GW (Our World in Data, 2025-a).
installation_capacity	installers*installations_per_year	GW/year	Installation capacity is a function of installers and installations per year, the value controls how many GW of installed capacity can be added to the system in a given year.

installation_time		1 year	This variable represents the amount of time from a purchasing decision of a rooftop PV system to the actual installation of that system. The value is estimated at 1 year.
installations	$\text{MIN}(\text{new_installations} + \text{replacements}, \text{installation_capacity})$	GW/year	This is an inflow which represents the rate at which installed rooftop PV stock increases per year. Installations consist of new installations and the replacements of previously installed PV systems past their lifetime, and is controlled by the installation capacity.
installations_per_year		0.0008 GW/installer/year	This represents the amount of installations in GW that one installer can complete per year. NREL report estimates that residential crew can install one system per day (Reiter & Margolis, 2023). Estimating from roughly 100 systems of 8 kWp and below systems comes out to 0.0008 GW per installer per year.

Installed_Rooftop_PV_10_kWp(t)	$\text{Installed_Rooftop_PV_10_kWp}(t - dt) + (\text{installations} - \text{degradation_rate}) * dt$	GW	This installed rooftop PV stock indicates the amount of GW of installed capacity of rooftop solar PV systems of 10 kWp and below in Germany. It is determined by an increase from the inflow of installation rate and the outflow of degradation rate. The initial value of this stock is determined by the initial installed rooftop PV.
installers	$\text{total_firms} * \text{installers_to_firms_ratio}$	installer	This variable represents installers, who are necessary to install residential rooftop pv systems. A recent workforce studies in Germany highlight the worker shortage of installers, underscoring the importance (Malin et al., 2022).
installers_to_firms_ratio		30 installer /firm	This variable represents the ratio of installer to total firms, startups and mature firms, in the modeled system. The value is uncertain and estimated at 30 based on comparing the historical ratio of venture-backed

			firms, modeled endogenously as firms, and installations in Germany (Fraunhofer ISE, 2025-a), taking into account the maximum installations per year (Reiter & Margolis, 2023).
new_installations	$((\text{planned_new_installations}/\text{installation_time}) * \text{effect_of_crowding_on_installation_rate})$	GW/year	This variable represents the new installations. It's value is determined by the planned installations divided by the installation time, and multiplied by a crowding effect.
"non-installed_potential_rooftop_PV"	$\text{total_potential_rooftop_PV_10_kWp} - \text{Installed_Rooftop_PV_10_kWp}$	GW	This variable represents the amount of potential adoption of solar PV at any point in time calculated as the total potential capacity less the total installed capacity.
perceived_utility	$\text{relative_familiarity} * \text{utility_of_solar}$	dmnl	This variable represents the perceived utility of rooftop PV. It is determined by multiplying utility and familiarity stock. In order for non-adopters to be willing to consider a new platform it must have sufficient utility as well as them being

			familiar with the platform.
planned_new_installations	perceived_utility*"non-installed_potential_rooftop_PV"	GW	This variable represents planned installations and its value is determined by multiplying the perceived utility by the amount of GW of non-installed potential rooftop PV.
relative_installed_capacity	Installed_Rooftop_PV_10_kWp // total_potential_rooftop_PV_10_kWp	dmnl	This variable represents the amount of installed rooftop PV relative to the total potential rooftop PV.
replacements	degradation_rate*utility_of_solar	GW/Years	This variable represents the amount of degraded rooftop solar PV systems which will be replaced per year. The value is determined by the degraded systems per year and the utility of rooftop solar PV. Those adopter who will make a replacement decision are assumed to be familiar with rooftop PV and thus will consider whether to replace their system based

			on the utility of the platform.
Residential_Technical_Potential	208	GW	This variable represents the total potential installed capacity of any size systems. The total technical potential for photovoltaic electricity generation on residential buildings' roofs in Germany has been calculated as 148 TWh, which translates to an installable capacity of roughly 208 GWp (Mainzer et al., 2014).
share_of_10_kWp	0.55	dmnl	This variable represents the share of total residential technical potential in Germany which is of systems of 10 kWp and below.

			According to studies of residential building sector 83% of Germany's residential building stock is single and two-family buildings (Real Ruiz et al., 2020). We assume that of these potential single and two-family homes, roughly 60-70% would install a system of 10 kWp or below, based on the 2024 share of installations by size in Germany (Fraunhofer ISE, 2025). Thus an uncertainty range of 50-60% is used.
total_potential_rooftop_PV_10_kWp	Residential_Technical_Potential * share_of_10_kWp	GW	This variable represents the total potential installed rooftop PV capacity of system of 10 kWp and below in Germany during the time horizon of the simulation.
utility_of_solar	(weight_of_cost*effect_of_cost_on_utility) + (weight_of_accessibility*relative_accessibility)	dmnl	This is a weighted utility function of rooftop solar photovoltaic adoption for German households, comprised of the effect of cost and accessibility, and their respective weights. It is a value between 0

			and 1, as effect of cost and accessibility can only reach 1 and the combined weights is equal to 1. The adoption decision of rooftop solar and other low-carbon technology platforms, such as electric vehicles or plant-based diets, is often considered as function of cost, performance (captured jointly in the model by LCOE) and accessibility (Lenton et al., 2023).
weight_of_accessibility	1-weight_of_cost	dmnl	This variable represents the weight of accessibility on utility and is calculated as weight of cost less from the maximum utility of 1.
weight_of_cost	0.5	dmnl	This variable represents the weight of cost on utility. It is an uncertain variable set at 50% and tested in the range of 25-75%.
Entrepreneurial_Dynamics:			

"FIT_amount._Data_2000-2024+_Forecast_2025-2050"	GRAPH(TIME) Points: (2000.00, 0.5100), (2001.00, 0.5100), (2002.00, 0.4800), (2003.00, 0.4500), (2004.00, 0.5700), (2005.00, 0.5400), (2006.00, 0.5200), (2007.00, 0.4900), (2008.00, 0.4700), (2009.00, 0.4300), (2010.00, 0.3700), (2011.00, 0.2800), (2012.00, 0.2000), (2013.00, 0.1500), (2014.00, 0.1300), (2015.00, 0.1300), (2016.00, 0.1300), (2017.00, 0.1300), (2018.00, 0.1250), (2019.00, 0.1100), (2020.00, 0.0900), (2021.00, 0.0700), (2022.00, 0.0700), (2023.00, 0.0800), (2024.00, 0.0800), (2025.00, 0.0784), (2026.00, 0.076832), (2027.00, 0.07529536), (2028.00, 0.073789453), (2029.00, 0.072313664), (2030.00, 0.07086739), (2031.00, 0.069450043), (2032.00, 0.068061042), (2033.00, 0.066699821), (2034.00, 0.065365825), (2035.00, 0.064058508), (2036.00, 0.062777338), (2037.00, 0.061521791), (2038.00, 0.060291355), (2039.00, 0.059085528), (2040.00, 0.057903818), (2041.00, 0.056745741), (2042.00, 0.055610826), (2043.00, 0.05449861), (2044.00, 0.053408638), (2045.00, 0.052340465), (2046.00, 0.051293656), (2047.00, 0.050267783), (2048.00, 0.049262427), (2049.00, 0.048277178), (2050.00, 0.047311635)	euro/(K W*Hour s)	The FIT amount if based on the actual development since 2000 and 2024 (Wirth, 2025). Since February 2024, the tariffs for newly commissioned PV systems are reduced 1% every half year, and this is how the 2025-2050 forecast is estimated in the model.
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"New_Entrants_Data_2000-2024+_Trend_2025-2050"	GRAPH(TIME) Points: (2000.00, 33.749997), (2001.00, 36.416667), (2002.00, 30.749996), (2003.00, 25.166663), (2004.00, 35.25), (2005.00, 29.0), (2006.00, 35.83334), (2007.00, 47.202388), (2008.00, 37.999997), (2009.00, 46.559523), (2010.00, 34.99286), (2011.00, 37.783497), (2012.00, 34.41392), (2013.00, 34.917296), (2014.00, 36.792718), (2015.00, 45.210207), (2016.00, 53.250199), (2017.00, 51.391787), (2018.00, 39.789208), (2019.00, 44.932949), (2020.00, 52.8858), (2021.00, 55.145235), (2022.00, 31.377488), (2023.00, 28.527752), (2024.00, 48.0434), (2025.00, 48.77), (2026.00, 49.4966), (2027.00, 50.2232), (2028.00, 50.9498), (2029.00, 51.6764), (2030.00, 52.403), (2031.00, 53.1296), (2032.00, 53.8562), (2033.00, 54.5828), (2034.00, 55.3094), (2035.00, 56.036), (2036.00, 56.7626), (2037.00, 57.4892), (2038.00, 58.2158), (2039.00, 58.9424), (2040.00, 59.669), (2041.00, 60.3956), (2042.00, 61.1222), (2043.00, 61.8488), (2044.00, 62.5754), (2045.00, 63.302), (2046.00, 64.0286), (2047.00, 64.7552), (2048.00, 65.4818), (2049.00, 66.2084), (2050.00, 66.935)	firm	This variable represents the empirical data of startups from 2000 to 2024 (International Energy Agency, 2025-a) and an estimated value from 2025 to 2050. Certain years data was missing and thus an estimated value was input based on the surrounding years values. The sectors included are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries.
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"Patent_Applications_for_Solar_and_Storage_Data_2000-2020+_Trend_2020-2050"	GRAPH(TIME) Points: (2000.00, 150.92), (2001.00, 198.95), (2002.00, 205.67), (2003.00, 197.11), (2004.00, 258.78), (2005.00, 272.57), (2006.00, 350.11), (2007.00, 502.31), (2008.00, 664.86), (2009.00, 970.05), (2010.00, 1057.82), (2011.00, 1043.59), (2012.00, 950.34), (2013.00, 742.5), (2014.00, 767.25), (2015.00, 690.89), (2016.00, 667.2), (2017.00, 790.36), (2018.00, 866.42), (2019.00, 776.64), (2020.00, 772.84), (2021.00, 817.921), (2022.00, 842.252), (2023.00, 866.583), (2024.00, 890.914), (2025.00, 915.245), (2026.00, 939.576), (2027.00, 963.907), (2028.00, 988.238), (2029.00, 1012.569), (2030.00, 1036.9), (2031.00, 1061.231), (2032.00, 1085.562), (2033.00, 1109.893), (2034.00, 1134.224), (2035.00, 1158.555), (2036.00, 1182.886), (2037.00, 1207.217), (2038.00, 1231.548), (2039.00, 1255.879), (2040.00, 1280.21), (2041.00, 1304.541), (2042.00, 1328.872), (2043.00, 1353.203), (2044.00, 1377.534), (2045.00, 1401.865), (2046.00, 1426.196), (2047.00, 1450.527), (2048.00, 1474.858), (2049.00, 1499.189), (2050.00, 1523.52)	patent/ year	This variable represents the empirical data from International Energy Agency for amount of patent applications per year in Germany for solar energy and battery storage technologies (2025-b).
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"Public_R&D_Solar+_Storage_Data_2000-2023"	GRAPH(TIME) Points: (2000.00, 70.149), (2001.00, 83.4), (2002.00, 75.4), (2003.00, 71.0), (2004.00, 44.347), (2005.00, 54.394), (2006.00, 54.546), (2007.00, 48.922), (2008.00, 65.937), (2009.00, 77.753), (2010.00, 91.503), (2011.00, 111.8), (2012.00, 115.409), (2013.00, 140.518), (2014.00, 136.25), (2015.00, 169.849), (2016.00, 187.841), (2017.00, 234.879), (2018.00, 204.521), (2019.00, 242.73), (2020.00, 213.742), (2021.00, 230.982), (2022.00, 197.092), (2023.00, 223.12)	meur/year	This variable represents the amount of millions of euros of public R&D funding into solar energy and battery storage technologies in Germany based on empirical data for 2000 to 2023 from International Energy Agency (2024).
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"Solar_LCOE_Data_00-25+_Fraunhofer_ISE_Forecast_26-45"	GRAPH(TIME) Points: (2000.00, 0.5000), (2001.00, 0.4700), (2002.00, 0.4400), (2003.00, 0.4100), (2004.00, 0.3800), (2005.00, 0.3500), (2006.00, 0.3300), (2007.00, 0.3100), (2008.00, 0.2900), (2009.00, 0.2700), (2010.00, 0.2500), (2011.00, 0.2000), (2012.00, 0.1500), (2013.00, 0.1200), (2014.00, 0.1100), (2015.00, 0.1000), (2016.00, 0.0980), (2017.00, 0.0960), (2018.00, 0.0950), (2019.00, 0.0900), (2020.00, 0.0850), (2021.00, 0.0800), (2022.00, 0.0880), (2023.00, 0.0940), (2024.00, 0.1000), (2025.00, 0.0980), (2026.00, 0.0960), (2027.00, 0.0940), (2028.00, 0.0920), (2029.00, 0.0900), (2030.00, 0.0880), (2031.00, 0.0860), (2032.00, 0.0840), (2033.00, 0.0830), (2034.00, 0.0810), (2035.00, 0.0800), (2036.00, 0.0790), (2037.00, 0.0790), (2038.00, 0.0780), (2039.00, 0.0780), (2040.00, 0.0770), (2041.00, 0.0770), (2042.00, 0.0760), (2043.00, 0.0760), (2044.00, 0.0750), (2045.00, 0.0750), (2046.00, 0.0750), (2047.00, 0.0750), (2048.00, 0.0750), (2049.00, 0.0750), (2050.00, 0.0750)	€/kwh	This represents the empirical data of solar LCOE from 2000-2025 and Fraunhofer ISE Forecast from 2026-2045. The behavior over time from 2000 to 2025 was compiled by examining Fraunhofer ISE's 5 LCOE reports from 2012 to 2024, and choosing the mean value for LCOE out of the specified uncertainty ranges (Kost et al., 2012; Kost et al., 2013; Kost et al., 2018; Kost et al., 2021; Kost et al., 2024). The forecast of LCOE is in the 2024 version of the report (Kost et al., 2024).
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"VC_funding_availability_Data_2004-2025+_Trend_2025-2050"	GRAPH(TIME) Points: (2000.00, 6e+06), (2001.00, 6e+06), (2002.00, 6e+06), (2003.00, 6e+06), (2004.00, 6017817), (2005.00, 5261457), (2006.00, 1778247), (2007.00, 9760563), (2008.00, 93825895), (2009.00, 25215182), (2010.00, 11016955), (2011.00, 22290823.1), (2012.00, 41026165), (2013.00, 28689650.7), (2014.00, 50243368.44), (2015.00, 35420290), (2016.00, 153151565), (2017.00, 70156637), (2018.00, 156163046), (2019.00, 73200699), (2020.00, 92316756.79), (2021.00, 270555236), (2022.00, 298030124), (2023.00, 252531662), (2024.00, 238029410), (2025.00, 1.6e+08), (2026.00, 1.7e+08), (2027.00, 1.8e+08), (2028.00, 1.9e+08), (2029.00, 2e+08), (2030.00, 2.1e+08), (2031.00, 2.2e+08), (2032.00, 2.3e+08), (2033.00, 2.4e+08), (2034.00, 2.5e+08), (2035.00, 2.6e+08), (2036.00, 2.7e+08), (2037.00, 2.8e+08), (2038.00, 2.9e+08), (2039.00, 3e+08), (2040.00, 3.1e+08), (2041.00, 3.2e+08), (2042.00, 3.3e+08), (2043.00, 3.4e+08), (2044.00, 3.5e+08), (2045.00, 3.6e+08), (2046.00, 3.7e+08), (2047.00, 3.8e+08), (2048.00, 3.9e+08), (2049.00, 4e+08), (2050.00, 4.1e+08)	USD/year	This variable represents the empirical data of early-stage VC funding availability in USD from 2004 to 2025 (International Energy Agency, n.d.) and an estimated value from 2000 to 2004, as well as the trendline for 2025 to 2050. The sectors included are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries. The total funding is the sum of these sectors at each given year multiplied by the share of early-stage funding of the total funding
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			in that year across all energy technologies. Early-stage funding is defined as initial coin offering, angel, convertible note, pre-seed, seed, series A and series B.
accessibility_of_alternative		1 accessibility	This variable represents the accessibility of purchasing electricity directly from the grid for residential households. It is estimated at a value of one, or perfect accessibility, because it is the incumbent standard way of purchasing electricity which is well-known and convenient. It is unlikely that rooftop solar pv will ever reach the same accessibility as the alternative because it will always require some effort from the consumer to install a rooftop system.

applications	$(\text{private_R\&D_spend} + \text{Public_R\&D}) * \text{fractional_applications}$	patent/ year	This inflow represents the amount of patent filings per year by the global solar industry, which determines the rate at which the filed patents stock increases. The value is determined by the patent filings per euro multiplied by the cumulative R&D spending of public and private sector. The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "Patent Applications for Solar and Storage. Data 2000-2020 + Trend 2020-2050".
average_funding_need	18100000	USD/firm	This variable represents average funding need per startup and it is based on the empirical data for energy technologies globally. The value 18.1M is calculated based on the median value for angel, pre-seed, seed, series A and series B rounds (International Energy Agency, 2025-a). The value

			is uncertain and the upper bound 40.3M is set based on the mean funding amount. It is more appropriate to use median values instead of mean because the funding need can be heavily skewed due to some lucrative funding rounds for certain startups.
"average_percentage_of_self-consumption"	0.35	dmnl	Percentage of self-consumption for household rooftop systems has increased over time and is roughly 17 percent in 2024 according to Fraunhofer ISE (2025-b).
average_startup_lifetime	5	year	The average startup lifetime is set at 5 years based on statistics of survival rates in Germany. Less than half of startups survive the first 5 years (IfM Bonn, 2023).
average_success_rate	0.029	dmnl	This variable represents that average success rate of startups for the average time to exit. According to International Energy Agency data, 2.9% startups in the energy sectors exit within 5 years (2025-a).

average_time_to_decision	2	year	This variable represents the average time it takes for a decision on a patent application to be made, and is set based on European Patent Office data (2025-a).
average_time_to_exit	5	Years	The average time to exit is based on empirical data of successful exits of German startups and set at 5 years (International Energy Agency, 2025-a).
BMI_baseline_effect	0.5	dmnl	This variable represents the initial effect of BMI on solar rooftop accessibility and therefore acts as a lower bound for the effect.
BMI_max_effect	4	dmnl	This variable represents the maximum effect of BMI on the solar rooftop accessibility. The variable is uncertain with an upper bound of 5 and lower bound of 3.
BMI_sensitivity	0.7	dmnl	This variable represents the sensitivity of BMI to the amount of mature firm. The value is subject to uncertainty and set at 0.7.

BMI_threshold		5	dmnl	This variable defines the inflection point of relative mature firms at which the business model innovation effect on accessibility is strongest; beyond this point, additional mature firms yield diminishing accessibility gains.
Business_Model_Innovation_Effect	$\text{BMI_baseline_effect} + \text{BMI_max_effect} * (1 / (1 + \text{EXP}(-\text{BMI_sensitivity} * (\text{relative_mature_firms} - \text{BMI_threshold}))))$		dmnl	This variable represents the effect of business model innovation on accessibility. Firms have an effect on improving accessibility of new technologies (Lenton et al., 2023). Novel business model innovations in solar PV have emerged according to market needs and customer pains. For example, business models, such as power purchase agreements and energy-as-a-service models can offload CAPEX and operating burdens from consumers (IRENA, 2019).

			The equation represents a logistic growth function, whereby initially accessibility increases exponentially towards the inflection point of relative firms is reached, set at 5. After the inflection point the business model effect diminishes for each additional mature firm.
cost_benefit_sensitivity		2 dmnl	This variable represents how sharply the effect changes around the threshold, thereby controlling the steepness of the logistic function.
cost_benefit_threshold		1.15 dmnl	This threshold represents the inflection point at which cost to benefit ratio, the effect is equal to 0.5
cost_to_benefit_ratio_of_solar	$\text{solar_LCOE} // ((\text{retail_electricity_price} * \text{average_percentage_of_self-consumption}) + (\text{FIT} * \text{percentage_of_exports}))$	dmnl	This is a ratio of how expensive solar electricity is compared to the monetary value of each kWh rooftop pv adopters generate. The numerator is solar LCOE, or the cost of how expensive the solar

			pv production is for the consumer. The denominator is made up of self-consumption benefit and export benefit. The self-consumption portion is the retail electricity price multiplied by the self-consumption portion, essentially the money you save not paying for electricity from the grid. The exported part is the portion of exports multiplied by the feed-in tariff. When the ratio is below 1, cost is lower than the economic value benefit, and thus the system is more attractive. Ratio of 1 is roughly break-even and a ratio above 1 means the cost of producing electricity are more than the economic benefit a consumer can gain from the system.
crowding_effect	$\text{crowding_min_effect} + ((1 - \text{crowding_min_effect}) / (1 + \text{EXP}(\text{crowding_sensitivity} * (\text{relative_installed_capacity} - \text{crowding_midpoint})))$	dmnl	This variable represents a crowding effect of perceived opportunity for entrepreneurs as

			the market reaches maturity and becomes less attractive for new entrants. Theory of organization ecology suggests that as an environment, in this case the solar PV market, exhausts its capacity the rate of growth of organizations in the population decreases (Hannan & Freeman 1977). Relative installed capacity serves as an effective proxy of carrying capacity of the environment.
crowding_midpoint	0.6	dmnl	This variable represents the relative installed capacity at which the crowding effect on perceived opportunity is at its inflection point, marking the transition from an emerging to a more saturated market.
crowding_min_effect	0.2	dmnl	This variable defines the lower bound of the crowding effect on perceived opportunity, ensuring that even in a very mature

			market some residual opportunity signal remains.
crowding_sensitivity		24 dmnl	This variable represents how sharply perceived entrepreneurial opportunity declines as the market approaches its carrying capacity, defining the steepness of the crowding effect around the midpoint installed capacity.
Demand_policy_duration		50 year	This variable represents the duration of the demand side policy. The user can test scenarios in which the policy duration lasts for varying amount of years from 0 to 50.
demand_policy_start		2000 year	This variable represents the start year of the demand side policy. The user can test scenarios in which the policy start at different point of the simulation time period from 2000 to 2049.

Demand_policy_switch	(STEP(1, demand_policy_start) - STEP(1, demand_policy_start+Demand_policy_duration))	dmnl	This demand policy switch controls when and for how long the feed-in tariff is implemented. The policy also affects the perceived opportunity.
"early-stage_VC_funding_availability"	SMTH1("initial_early-stage_funding_availability"*"market_effect_on_early-stage_VC_funding", funding_availability_delay_time)	USD	This variable represents VC funding availability as a function of the effect of market maturity and the initial funding availability. The dynamics behavior is consistent with empirical data of VC funding in Germany in solar and related sectors (International Energy Agency, n.d.). VC funding availability is subject to broad economic factors as well as the availability of funding from banks, pension funds, insurance companies, and corporate investors (MacMillan et al., 1989). The model's validity is partly tested by comparing the model produced solar LCOE with

			the real data see "VC funding availability. Data 2004-2025 + Trend 2025-2050".
Economies_of_Scale_effect	$\text{economies_of_scale_min_effect} + ((1 - \text{economies_of_scale_min_effect}) * \text{EXP}(-\text{economies_of_scale_sensitivity} * \text{relative_installed_capacity}))$	dmnl	Economies of scale are reported by PTP scholars to have a impact on improving price and performance of rooftop solar (Lenton et al., 2023; Ayoub and Geels, 2024). Nemet using technological forecasting methods found that one of the biggest factors that led to a drop in solar module prices was increasing plant size, or economies of scale (2006).
economies_of_scale_min_e ffect		0.3 dmnl	This variable represents the minimum effect of economies of scale on the LCOE. It is set at 0.3 lower than the minimum technological reinforcement effect based on empirical data from Nemet, which found plant size (economies of scale) to account for 50% more of the cost decreases in solar modules (2006).

economies_of_scale_sensitivity	15	dmnl	This variable represents the sensitivity of solar LCOE to cumulative installed capacity through economies of scale, controlling how quickly cost declines as relative installed capacity increases.
effect_of_cost_on_utility	1 // $(1 + \text{EXP}(\text{cost_benefit_sensitivity} * (\text{cost_to_benefit_ratio_of_solar} - \text{cost_benefit_threshold})))$	dmnl	This logistic utility function represents the effect of cost to benefit ratio, and thus solar LCOE, on the utility of rooftop solar. When solar is economically attractive and thus the cost-benefit ratio is small, the value of the effect approaches, or maximum effect on utility; and when unattractive the effect approaches 0.
effect_of_funding_availability_on_startup_lifetime	$\text{VOD_min_effect} + ((1 - \text{VOD_min_effect}) * (1 / (1 + \text{EXP}(-\text{VOD_sensitivity} * (\text{relative_funding_availability} - \text{VOD_midpoint}))))$	dmnl	This variable represents the effect of VC funding availability on startups lifetime. When early-stage VC funding availability matches the industry funding need, the effect on startup lifetime will 1, meaning startup lifetime is equal to the average of 5 years.

			This effect is uncertain and can be adjusted by adjusting the sensitivity of funding to lifetime and the minimum effect which controls the lower bound of startup lifetime.
effect_of_market_maturity_on_opportunity	$1 / (1 + \text{EXP}(-\text{opportunity_sensitivity} * (\text{relative_installed_capacity} - \text{opportunity_midpoint})))$	dmnl	This variable represents the effect of market maturity on opportunity. Startups in emerging industries often grapple with demand uncertainty, and thus intense uncertainty about potential opportunities (Guerra et al., 2025). As consumer adoption increases, characterized as installed capacity, this serves as a signal to entrepreneurs that uncertainty concerning opportunities is decreasing. Theory of organizational ecology maintains that more market maturity increases legitimacy and thus founding rates rise until the market reaches a

			saturation (Hannan & Freeman, 1977). The equation is a logistic function where effect of relative capacity on opportunity is strongest around the inflection point and sensitivity controls how steep the slope of the curve is at the inflection point.
effect_of_patents_on_fractional_patent_applications	$\text{patent_min_effect} + (\text{patent_max_effect} * \text{EXP}(-\text{patent_sensitivity} * \text{relative_patents}))$	dmnl	This variable represents how the rate of patent applications per million euro of R&D spending responds to the accumulated stock of patents, bounded between lower and upper limits and decreasing as the patent base grows.
effect_of_revenue_on_success_rate	$\text{success_rate_max_effect} / (1 + \text{EXP}(-\text{success_rate_sensitivity} * (\text{relative_revenue} - 1)))$	dmnl	This variable represents the effect of revenue per firm on success rates of startups. Revenue growth is an

			indicator of growth potential and highly influences the ability of a company to attract buyouts and IPOs. The equation is a logistic growth function scaled from minimum 0 to max effect of 2, meaning success rate can only double with higher revenues. The midpoint occurs when revenue is equal to the expected revenue for exit, or relative revenue of 1.
eur_to_meur	1000000	eur/meur	This variable converts amount of euros to millions of euros for ensuring unit consistency.
expected_revenue_for_exit	20000000	euro/firm/year	This variable represents an expected revenue from for a startup to make a successful exit, estimated at 10 million euros. Revenue growth is an indicator of growth potential and highly influences the ability of a company to attract buyouts and IPOs. Data from US found that median revenue at IPO

			was roughly \$67M (WilmerHale, 2024). The value is uncertain and set at half of the median amount because the system only accounts for revenues directly from rooftop pv systems below 10 kWp, and firms may well have other revenue channels, such as larger installations or other services.
Filed_Patents(t)	$\text{Filed_Patents}(t - dt) + (\text{applications} - \text{grants} - \text{not_granted}) * dt$	patent	This stock represents the amount of filed patents. It is determined by the inflow of applications and outflows of grants and not granted patent applications.
FIT	"FIT_amount._Data_2000-2024+_Forecast_2025-2050" * Demand_policy_switch	euro/(KW*Hours)	The feed-in tariff (FIT) is the principal policy lever that Germany has used since 2000 as part of the Renewable Energy Sources Act (EEG) to stimulate solar pv adoption and market

			development (EEG, 2000). Producers of rooftop solar pv can sell electricity back to the grid at the fixed price of the FIT. Therefore the Fit is part of the benefit calculation. It is controlled by the FIT amount and the demand policy switch, which can be toggled on or off.
fractional_applications	initial_average_fractional_applications * effect_of_patents_on_fractional_patent_applications	patent/ meur	This variable represents the fractional rate of applications in solar energy and battery storage technologies per million euro spent. It is determined by the initial fractional applications and the effect of patents on future filings. Eurostat data found that 400 patents on average are filed for every billion euros invested in R&D in Germany (2008).

funding_availability_delay_time		2 years	This variable represents the time it takes venture capital industry to react to changes in market maturity, estimated at 2 years based on empirical data of typical amount of time it takes to solicit money from limited partners and close a new fund (Gompers and Lerner 1998).
funding_max_effect		70 dmnl	Maximum VC funding relative to initial is calibrated to real-world data of how much the VC funding could grow in the solar energy sector relative to the initial funding availability.
funding_sensitivity		4 dmnl	This variable represents the sensitivity of VC availability to market maturity. When the value is higher, VC availability reacts strongly to small signals of market maturity around the inflection point; and when the value is low VC availability more risk-averse thus needing to see more evidence of market maturity

			before deploying significant amounts of additional capital.
grant_rate		0.7 dmnl	This variable represents the average percentage filed patents which are granted,. Based on EPO Patent Index data we calculate a grant rate of 71% for the time period 2015-2024 for Energy technologies (2025-b).
grants	$(\text{Filed_Patents} * \text{grant_rate}) / \text{average_time_to_decision}$	patent/ year	This flow is the outflow of filed patents and inflow of patents stocks. It represents the amount of granted patents per year, a function of the amount of filed patents, the grant rate and time for a grant or not grant decision to be made.
GW_to_KW_conversion		1000000 KW/GW	This variable converts between gigawatts and kilowatts.
industry_funding_need	$\text{Startups} * \text{average_funding_need}$	USD	This variable represent the total funding need of all the startups in the industry, a function of the

			amount of startups and the average funding need per startup.
industry_yearly_revenue	$(\text{installations} * \text{"price_PV_rooftop_system_}(2024)" * \text{GW_to_KW_conversion}) + (\text{Installed_Rooftop_PV_10_kWp} * (\text{"price_PV_rooftop_system_}(2024)" * \text{O\&M_costs} * \text{GW_to_KW_conversion}))$	euro/year	This value is the total revenue of the solar PV industry for the modeled segment of 10 kWp and below residential rooftop systems. Revenue is made up of price of PV rooftop system times installations per year, plus the operating and maintenance costs of the existing installed capacity.
initial_accessibility		0.1 accessibility	This variable represents the initial accessibility of rooftop solar pv for residential consumers. It is an uncertain value set at approximately one tenth of the accessibility of the alternative, direct purchase of electricity from the grid.
initial_average_fractional_applications		1.8 patent/meur	This variable represents the initial patent filings rate per million euros of public funding. The initial value is uncertain but estimated to be high due to the high amount of patenting activity around solar energy in 2000

			Eurostat data which found that 400 patents on average are filed for every billion euros invested in R&D in Germany (Félix, 2008).
"initial_early-stage_funding_availability"	6000000	USD	This variable represents the initial funding availability in 2000. Based on the the 2004 empirical value of 6.02M (International Energy Agency, 2025-a), the value of the parameter is estimated with an upper bound of 9.0M and a lower bound of 3.0M subject to uncertainty analysis.
initial_mature_firms	10	firm	This variable represents the initial amount of mature firms in Germany in the year 2000, estimated at 10 based on the immaturity of the industry at the time period, wit ha lower and upper bound of 5 and 15 respectively. Notable firms in early 2000s include, SolarWorld, IBC Solar, SOLARWATT and Q-Cells in pv

			manufacturing and SMA, KACO and VARTA in related segments.
initial_patents	200	patent	This variable represents the initial amount of patents, estimated at several hundreds based on the relatively modest historical behavior of patent applications for solar and battery storage technologies before 2000 (International Energy Agency, 2025-b).
Initial_solar_LCOE	0.565	eur/(KW *Hours)	The variable represents the initial LCOE, set at a realistic value between €0.5-0.5/kWh based on the feed-in tariff during those years (Kost et al., 2012) and German LCOE data (see "Solar LCOE. Data 00-25 + Fraunhofer ISE Forecast 26-45").
initial_startups	50	firm	This variable represents the initial amount of startup firms in the system, set at an estimated value of 50 based on startup creation data of Germany (International energy Agency, 2025-a). The sectors included in

			the dataset are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries.
"Learning-by-doing_effect"	$\text{relative_mature_firms}^{(-\text{"learning-by-doing_sensitivity"})}$	dmnl	This variable represents the learning-by-doing which is an effect of more firms in the market on the cost of solar energy. As a market matures, firms knowledge of the market, technology and consumers increases (Guerra et al., 2025). Learning-by-doing is cited to improve price and performance of low-carbon technologies and has been observed in the solar pv industry in Germany (Lenton et al., 2023; Ayoub and Geels, 2024).
"learning-by-doing_sensitivity"	0.2	dmnl	This variable represents how sensitive the solar LCOE is to the relative amount of firms in the system, through the learning-by-doing effect.

"market_effect_on_early-stage_VC_funding"	$\text{funding_max_effect} * (1 - \text{EXP}(-\text{funding_sensitivity} * \text{relative_installed_capacity}))$	dmnl	This variable represents the effect of relative installed capacity, or market maturity, on early-stage venture capital funding availability. Venture investors in energy sector typically want to invest only after most technical and market risks have been overcome (Murphy & Edwards, 2003). As the market becomes more mature, VC funding in a sector increases, which is also consistent with the data for solar energy in Germany (International Energy Agency, 2025-a).
Mature_Firms(t)	$\text{Mature_Firms}(t - dt) + (\text{maturing}) * dt$	firm	The stock of mature firms represents the startups which have successfully crossed the valley of death and either exited via IPO or M&A, or matured into stable businesses. It is determined by the inflow of exit rate.

maturing	$(\text{Startups} * \text{success_rate}) / \text{average_time_to_exit}$	firm/year	This is the outflow from startups and the inflow to mature firms, representing the rate at which startups mature. It's value is determined by multiplying the amount of startups by the success rate and dividing by the average time to exit.
max_entrants_rate		70 firm/year	This variable represents the maximum number of new entrants coming in to the system. It is treated as an exogenous parameter for modeling purposes, calibrated to the empirical data of new entrants - maximum new entrants rate was 55 in the year 2021, for the solar and related sectors of grid, energy efficiency and energy storage and batteries sectors in Germany (International Energy Agency, 2025-a). Since the perceived opportunity at the maximum historical entrants rate is unknown, this variable is

			highly uncertain. A lower bound of 50 and 150 are applied for uncertainty analysis.
new_entrants	$\text{max_entrants_rate} * \text{perceived_opportunity}$	firm/year	This inflow represents the rate at which startups stock increases and is determined by the maximum entrants rate and the perceived opportunity. The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "New Entrants. Data 2000-2024 + Trend 2025-2050".
not_grant_rate	$1 - \text{grant_rate}$	dmnl	This variable is the percentage of patent applications which are not granted, calculated as 100% less the grant rate.
not_granted	$(\text{Filed_Patents} * \text{not_grant_rate}) / \text{average_time_to_decision}$	patent/year	This is the outflow of not granted patents from the filed patents stock, calculated as a function of not

			granted percentage of the filed patents and time to decision.
O&M_costs	0.02	dmnl/year	Operating and maintenance costs of residential rooftop PV systems are on the order of 1-2% of the system's capex, or system price, according to NREL (2024).
opportunity_midpoint	0.15	dmnl	This variable represents what percentage of installed capacity relative to the total potential, corresponds with the highest increase in perceived opportunity. A higher inflection point, means that entrepreneurs are effectively more risk-averse, and prefer to see more demand before entering the market.
opportunity_sensitivity	40	dmnl	This variable represents how sensitive perceived opportunity of entrepreneurs is to installed capacity, conceptually entrepreneurs' risk appetite. Mathematically it controls how steep the slope of the curve is and is steepest at the

			inflection point. The variable is subject to uncertainty.
patent_max_effect	1-patent_min_effect	dmnl	This variable defines the maximum additional share that patent-driven application intensity can contribute above the lower bound, ensuring the fractional application effect remains bounded between 0 and 1.
patent_min_effect	0.23	dmnl	This variable defines the minimum fraction of the initial application intensity that persists even at high patent stocks, ensuring a floor to how low the responsiveness of new applications to patents can fall.
patent_sensitivity	0.05	dmnl	This variable represents how strongly the fractional patent-application rate responds to changes in the stock of patents; higher values imply that small changes in relative patents lead to larger shifts in

			application intensity.
Patents(t)	$\text{Patents}(t - dt) + (\text{grants}) * dt$	patent	This is the stock of granted patents, which have a positive R&D effect on levelized cost of electricity.
perceived_opportunity	$((\text{weight_of_market_maturity} * \text{effect_of_market_maturity_on_opportunity}) + (\text{weight_of_regulation} * \text{Demand_policy_switch})) * \text{crowding_effect}$	dmnl	This variable represents the perceived opportunity for entrepreneurs to enter the solar industry, which is a function of market maturity and regulation. Studies on the process of firm formation highlight the opportunity recognition stage of venture creation (Bhave, 1994). The role of market, technical and regulatory risks are often highlighted as affecting renewable energy entrepreneurs decision to enter a market (Dobrovolska et al., 2024; Guerra et al., 2025). Empirical evidence from the US underscores that there is a relationship between government policies that change cost and

			benefits and new firm formation in the solar market (Gao, 2021).
percentage_of_exports	1-"average_percentage_of_self-consumption"	dmnl	Percentage of exports is calculated as 100% minus percentage of self-consumption.
"price_PV_rooftop_system_(2024)"	1100	euro/kw	This variable is the price of PV rooftop system, set at the 2024 value of 1100 euro/kw based on the Fraunhofer ISE report (2025).
private_R&D_spend	(total_solar_industry_revenue/eur_to_meur)*"R&D-to-sales_ratio"	meur/year	This variable represents the total R&D spending of the private sector for solar energy and is determined by the total yearly revenue and an average R&D to sales ratio. Germany spent 88.7B EUR across all industries in private sector funding...

			https://www.gtai.de/en/invest/business-location-germany/rd-framework/germany-posts-commercial-r-d-investment-record-1843444
Public_R&D	"Public_R&D_Solar+_Storage_Data_2000-2023" * R&D_Policy_Switch	meur/year	This variable represents the public R&D spending determined by the R&D spending amount and policy switch, either on or off.
R&D_min_effect		0.45 dmnl	This variable represents the minimum effect of technological reinforcement on the LCOE. It is set at 0.45, 50% higher than the minimum economies of scale effect based on empirical data from Nemet, which found plant size (economies of scale) to account for 50% more of the cost decreases in solar modules (2006).
R&D_policy_duration		200 year	This variable represents the duration of the R&D policy. The user can test scenarios in which the policy duration lasts for varying

			amount of years from 0 to 50.
R&D_policy_start	2000	year	This variable represents the start year of the R&D policy. The user can test scenarios in which the policy start at different point of the simulation time period from 2000 to 2049.
R&D_Policy_Switch	(STEP(1, R&D_policy_start) - STEP(1, R&D_policy_start+R&D_policy_duration))	dmnl	This demand policy switch controls when and for how long the public R&D funding is implemented.
R&D_sensitivity	0.3	dmnl	This variable represents the sensitivity of the technological reinforcement effect to the amount of patents. When the value is higher, small changes in patents around the midpoint will have relatively larger effect, and visa versa.
"R&D-to-sales_ratio"	0.16	dmnl	This variable represents R&D-to-sales ratio of firms in the system, estimated at 16% based on the average of semiconductor (20.4% and software publishers (12.9%),

			a relevant comparison to IP-heavy venture-backed firms such as solar PV, average values from National Center for Science and Engineering (2024).
relative_accessibility	solar_rooftop_accessibility/accessibility_of_alternative	dmnl	This variable represents the accessibility of installing and operating solar rooftop solar PV relative to the alternative option of purchasing electricity directly from the grid.
relative_funding_availability	"early-stage_VC_funding_availability" / industry_funding_need	dmnl	This variable represents the VC funding availability in a given year relative to the funding need of the industry.
relative_mature_firms	Mature_Firms // initial_mature_firms	dmnl	This variable represents the relative amount of mature firms in the system compared to the initial amount.
relative_patents	Patents // initial_patents	dmnl	This variable represents the amount of patents in solar energy and battery storage technologies compared to the initial value.
relative_revenue	revenue_per_firm/expected_revenue_for_exit	dmnl	This variable represents the revenue per firm relative to the

			expected revenue to make a successful exit.
revenue_per_firm	industry_yearly_revenue / total_firms	Euros/firm/Years	This variable represents the revenue per firm from rooftop solar PV systems of 10 kWp and below, calculated as total industry revenue divided by amount of firms in the system. Because the model represents only venture-backed firms (startups and mature ventures) endogenously, we treat the modeled residential rooftop segment revenue as the relevant revenue base for these firms, and directly compute revenue per firm from total segment revenue and the number of venture-backed firms.
share_of_German_industry_from_residential_rooftop_PV	0.325	dmnl	This variable represents the share of total German solar industry revenue that is attributable to residential rooftop PV systems of 10 kWp and below, used to scale segment revenues up to the whole industry.

			It is calibrated as 0.325 based on Fraunhofer ISE's breakdown of cumulative capacity and system counts by size class, where rooftop systems below 10 constitute the majority of installation (66-67%), however given their smaller size a substantial minority of capacity (roughly 20%). This combined with higher specific prices for small rooftop systems compared to commercial rooftop and utility-scale plants justifies the estimated share of revenue in a range of 30-40% (Fraunhofer ISE, 2025-a; Wirth, 2025).
solar_LCOE	$\text{Initial_solar_LCOE} * \text{Economies_of_Scale_effect} * \text{Technological_reinforcement_effect} * \text{"Learning-by-doing_effect"}$	euro/(K W*Hours)	This variable represents the levelized cost of electricity (LCOE) of rooftop solar pv, a parameter often used in modeling studies and cited in reports (Nemet, 2006; Fraunhofer ISE, 2025-a). Solar LCOE in Germany has decreased 16% year on year

			between 2012-2024 (Fraunhofer ISE, 2025-a). The variable is crucial for the adoption of rooftop solar pv, as LCOE decreases, the relative utility of the platform increases. The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "Solar LCOE. Data 2000-2025 + Fraunhofer ISE Forecast 2026-2050".
solar_rooftop_accessibility	$\text{initial_accessibility} * \text{Business_Model_Innovation_Effect}$	accessibility	This variable represents the accessibility of solar rooftop, and is the function of initial accessibility and the business model innovation effect. Accessibility, along with price and performance, are cited to be important decision-making factors for the adoption of rooftop pv (Lenton et al., 2023).

startup_lifetime	average_startup_lifetime * effect_of_funding_availability_on_startup_lifetime	year	This variable represents the startup lifetime and is determined by the funding availability relative to the funding need and the average startup lifetime. The variable controls the rate of the valley of death outflow from startups.
Startups(t)	Startups(t - dt) + (new_entrants - Valley_of_Death - maturing) * dt	firm	This stock represents the amount of startup firms in the system. It is determined by the inflow of new entrants and the outflows of valley of death and the exit rate.
success_rate	average_success_rate * effect_of_revenue_on_success_rate	dmnl	This variable represents the average success rate, calculated as the average success rate by the effect of revenue growth on success rate. Success rate means the successful exit of a company via IPO or M&A.

success_rate_max_effect		2	dmnl	This variable defines the maximum multiplicative increase in startup success rate that can be achieved through higher revenue per firm, relative to the baseline average success rate. The value is uncertain and set at a plausible range between 1.5 and 2.5 based on success rates of startups from International Energy Agency (2025-a), indicating that success rate can only increase by 50-250% at even very high average revenues.
success_rate_sensitivity		4	dmnl	This variable represents how sensitive success rate is to changes in revenue.
Technological_reinforcement_effect	$R\&D_min_effect + ((1 - R\&D_min_effect) * \exp(-R\&D_sensitivity * relative_patents))$		dmnl	This variable represents the effect of cumulative patents on reinforcing technological progress beyond pure scale effects, reducing LCOE as the patent stock grows but with diminishing marginal impact. The effect of R&D, patent activity, on cost reductions in

			solar pv is documented in empirical studies (Nemet, 2006) as well as qualitative tipping points literature (Lenton et al., 2023; Ayoub and Geels, 2024).
total_firms	Mature_Firms+Startups	firm	This variable represents the total amount of venture-backed firms in the system, startups and mature firms.
total_R&D_spending	"Public_R&D_Solar+_Storage.Data_2000-2023"+private_R&D_spend	meur/year	This variable represents total annual R&D investment in solar energy and storage in Germany, combining public R&D support with private R&D spending by firms.
total_solar_industry_revenue	industry_yearly_revenue/share_of_German_industry_from_residential_rooftop_PV	euro/year	This variable represents the total annual revenue of the German solar industry across all segments, obtained by scaling the modeled residential rooftop segment by its estimated share of national industry revenue.

Valley_of_Death	Startups // startup_lifetime	firm/year	Valley of death represents the outflow of startups from the system. The value is determined by dividing the startups stock by the startup lifetime. If startup lifetime is higher the rate will decrease and visa versa. Valley of death is a common phenomenon among startups and technologies, and has been observed with renewable energy technologies as ell (Murphy & Edwards, 2003). Private investor financing is crucial for startups to cross the valley of death (Gbadegeshin et al., 2022; Markham, 2002).
VOD_midpoint		0.5 dmnl	This variable represents the relative funding availability at which the effect of VC funding on startup lifetime equals the midpoint of its logistic response, i.e. where lifetime is most sensitive to changes in funding.

VOD_min_effect		0.5	dmnl	This variable controls the lower bound of the funding effect on startup lifetime. Initially set at 0.2, representing that when funding availability is extremely low, startup lifetime approaches 20% of the average (1 year initially). The variable is subject to uncertainty and set based on (IfM Bonn, 2023).
VOD_sensitivity		14	dmnl	This variable represents the sensitivity of startup lifetime to funding. The higher K means the effect reacts more to funding availability and visa versa. The value is estimated and subject to uncertainty.
weight_of_market_maturity		0.5	dmnl	The weight of market maturity on perceived opportunity is uncertain and thus estimated as 50%.
weight_of_regulation	1-weight_of_market_maturity		dmnl	This variable represents the weight of regulation in shaping perceived entrepreneurial opportunity, defined as the complement of the market-maturity weight so that the

			two weights sum to one.
Path_Dependence:			
"Retail_electricity_price_Germany._Data_00-26"	GRAPH(TIME) Points: (2000.00, 0.1390), (2001.00, 0.1430), (2002.00, 0.1610), (2003.00, 0.1720), (2004.00, 0.1800), (2005.00, 0.1870), (2006.00, 0.1950), (2007.00, 0.2060), (2008.00, 0.2170), (2009.00, 0.2320), (2010.00, 0.2370), (2011.00, 0.2520), (2012.00, 0.2590), (2013.00, 0.2880), (2014.00, 0.2910), (2015.00, 0.2960), (2016.00, 0.2970), (2017.00, 0.3040), (2018.00, 0.3030), (2019.00, 0.3120), (2020.00, 0.3230), (2021.00, 0.3280), (2022.00, 0.4630), (2023.00, 0.4700), (2024.00, 0.4020), (2025.00, 0.3930), (2026.00, 0.3730)	euro/(KW*Hours)	This value represents the historical household electricity price in Germany from 2000 to 2026 (Open Energy Tracker, 2026).
"Retail_electricity_price_Germany._Linear_forecast_27-50"	"Retail_electricity_price_(2026)" + (slope_of_retail_electricity_price *years_since_2027)	euro/(KW*Hours)	This variable represents the linear forecast of retail electricity price for households in Germany from 2027 to 2050. It is calculated by adding the retail electricity price in 2026 to the slope of retail electricity price multiplied by

			the amount of time since the be
annual_generation_rooftop_pv	Installed_Rooftop_PV_10_kWp * capacity_factor * hours_per_year	(GW*hour)/year	This variable represents the annual generation, a function of the capacity factor and hours per year, of the installed capacity.
capacity_factor	0.11	dmnl	This variable represents the average capacity factor of residential rooftop PV systems in Germany, capturing the ratio of actual annual generation to generation at full nameplate capacity. The value is set based on empirical data (Wirth, 2025).
effect_of_lost_sales_on_lobbying	(1-EXP(-lobby_sensitivity*percentage_loss_in_sales)) * - lobby_max_effectiveness	1/year	This variable represents the effect of lobbying by the incumbent regime on policy. The equation defines how strong lobbying becomes as incumbents lose sales, saturating at a maximum effectiveness. It's non-linear, as initial increases in lobbying budget will increase

			effectiveness more. Increased energy generation by private individuals is a threat to utilities' business models and leads to an erosion of their revenues. In response, utility companies, particularly the big four in German, spend high sums on lobbying efforts (Engelken et al., 2014; Sühlsen & Hisschemöller, 2014).
hours_per_year	8760	hour/year	This variable represents the hours in the year.
lobby_max_effectiveness	0.09	1/year	This variable represents the maximum lobby effectiveness to which the incumbent lobbying variable saturates to. The variable is set higher than policy and firms marketing effectiveness because of the political power that the incumbent regime has due to their

			economic impact. The value is uncertain and can be set higher or lower, signaling the incumbent regime's power.
lobby_sensitivity	40	dmnl	This variable represents the sensitivity of lobbying efforts to lost sales of the incumbents and defines the slope of incumbent lobbying. It is uncertain set at 40.
lost_utility_sales	$\text{annual_generation_rooftop_pv} * \\ \text{"average_percentage_of_self-consumption"} * \\ \text{GW_to_KW_conversion} * (\text{retail_electricity_price})$	euro/year	This variable represents the lost revenue of utilities from households consuming their own electricity. The remaining portion not part of self-consumption is sold back to utilities at the fixed feed-in tariff rate.
market_share_of_incumbent	0.59	dmnl	This value, 0.59, represents the percentage of market share held by the four largest private utility companies in 2014 (RAP, 2015). The value is uncertain and held constant throughout the simulation.
percentage_loss_in_sales	$(\text{lost_utility_sales} * \text{market_share_of_incumbent}) / \\ \text{"utilities_average_revenue_}(2024_value)\text{"}$	dmnl	This variable represents the percentage in lost sales of the

			incumbent relative to their total yearly revenue.
retail_electricity_price	IF TIME < 2027 THEN "Retail_electricity_price_Germany._Data_00-26" ELSE "Retail_electricity_price_Germany._Linear_forecast_27-50"	eur/(KW*Hours)	This variable represents the retail electricity price. From 2000 to 2026 it takes the value of "Retail electricity price Germany. Data 00-26" and from 2027 to 2050 it takes the value of "Retail electricity price Germany. Linear forecast 27-50".
"Retail_electricity_price_(2026)"		0.373 euro/(KW*Hours)	This value represents the historical household electricity price in Germany in 2026 (Open Energy Tracker, 2026).
"Retail_electricity_price_(2050)"		0.45 euro/(KW*Hours)	The variable represents the retail electricity price in 2050, which is used to calculate the slope of retail electricity price. The value is uncertain and is set at the same value at 0.45, representing a moderate increase based on the assumption from Fraunhofer ISE's study by Henning and Palzer (2015).

slope_of_retail_electricity_price	("Retail_electricity_price_(2050)" - "Retail_electricity_price_(2026)") / 24	euro/(KW*Hours)	This variable represent the slope of the linearly forecasted retail electricity price in Germany from 2027-2050. The value is calculated by subtracting the price in 2026 by the price in 2050 and divided by 24 (the number of years between 2050 and 2026).
"utilities_average_revenue_(2024_value)"	1.65E+11	euro/year	This variable is the 2024 yearly revenue of the big four utilities in Germany based on annual reports (Vattenfall AB, 2025; E.ON SE, 2025; EnBW Energie Baden-Württemberg AG, 2025; RWE AG, 2025).
years_since_2027	TIME-2027	dmnl	This variable represents the years since 2027 for calculating the linearly forecasted retail electricity price.
Social_Contagion:			
average_marketing_spend	0.05	dmnl	This variable represents the percentage of the total industry revenue spent on marketing of the platform. An uncertain variable set at a conservative 5% based on a generic

			marketing budget benchmark for high tech firms (Thanh Thuy & Klymova 2022).
effective_contact_rate_of_a dopter		0.25 1/year	This variable is the strength of word-of-mouth between non-adopters and adopters of rooftop solar PV. The value is uncertain and estimated at 0.25 based on previous modeling studies of adoption of alternative fuel vehicles (Struben and Sterman, 2008). Similar peer effects have been observed in the diffusion of solar photovoltaics (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015).
"effective_contact_rate_of_non-adopter"		0.15 1/year	This variable is the strength of word-of-mouth between non-adopters of rooftop solar PV when familiarity is at its maximum. The value is uncertain and estimated at 0.15 based on previous modeling studies of adoption of alternative fuel vehicles (Struben and Sterman,

			2008). Similar peer effects have been observed in the diffusion of solar photovoltaics (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015).
elasticity_of_social_norms_to_social_exposure	$1 / (2 * \text{reference_social_exposure})$	year	This variable represents the elasticity of the familiarity loss rate with respect to social exposure to rooftop PV around 1 at the reference. The value is normalized to exposure at 1 so that local changes in exposure have a proportionate effect on familiarity loss.
Familiarity(t)	$\text{Familiarity}(t - dt) + (\text{familiarity_gain} - \text{familiarity_loss}) * dt$	familiarity	The familiarity stock indicates how familiar the population is with the new platform. Its value is between 0 and 1 and controlled by inflow of familiarity gain and outflow of familiarity loss.
familiarity_gain	$\text{MAX}(0, \text{total_social_exposure} * (\text{max_familiarity} - \text{Familiarity}))$	familiarity/year	This inflow represents the rate at which familiarity stock increases. The equation describes a bounded growth inflow whereby social exposure increases familiarity at a rate proportional to

			current exposure and the remaining gap to maximum familiarity, but never allows the inflow to go negative.
familiarity_loss	$\text{Social_Norms_effect} * \text{Familiarity} * \text{normal_forget_rate}$	familiarity/year	This outflow represents the rate at which familiarity stock depletes. The familiarity loss rate is proportional to the familiarity stock and modulated by the social norms effect and the normal forget rate. When social norms effect is high familiarity loss rate is at the normal rate; when social norms effect is weak, the outflow is weak and familiarity persists. It takes effort to stay up to date with developments in solar photovoltaics and thus familiarity erodes unless there is consistent social exposure and marketing.
installed_social_effect	$\text{effective_contact_rate_of_adopter} * \text{probability_of_contact_with_adopter}$	1/year	This variable represents the effect of word-of-mouth contacts between non-adopters and adopters on the total social exposure. This

			direct exposure depends on the frequency of contacts between an adopter and a non-adopter and the effective contact rate. This term captures word-of-mouth about rooftop solar PV on social exposure acquired by seeing them and talking to their owners (Struben & Sterman, 2008).
marketing_budget	average_marketing_spend * industry_yearly_revenue	euro/year	This variable represents the total annual marketing expenditure of firms active in the modeled rooftop PV segment, computed as a fixed share of industry yearly revenue.
marketing_effect	marketing_budget * marketing_effectiveness	1/year	This variable represents the total marketing effect of firms on social exposure. Previous studies treat marketing exogenously, but here marketing effect is endogenized (Struben & Sterman, 2008).
marketing_effectiveness	8.5E-11	1/euro	This variable represents the effectiveness of each euro spent

			on marketing to the total exposure of the platform. It is highly uncertain, estimated at 8.5e-11 per euro spent.
max_familiarity		1 familiarity	This variable is conceptually the maximum familiarity of 1, or 100 percent familiarity.
"non-installed_social_effect"	relative_familiarity * "effective_contact_rate_of_non-adopter" * "probability_of_contact_with_non-adopter"	1/year	This variable represents the effect of word-of-mouth contacts between non-adopters and other non-adopters on the total social exposure. The value depends on the probability of contact with non-adopter and the effective contact rate, normalized to the maximum familiarity of the platform. This term captures the word-of-mouth about rooftop solar PV arising from those not using solar PV and learning about the platform from others not using solar PV (Struben & Sterman, 2008).

normal_forget_rate	0.65	1/year	This variable is the normal familiarity loss rate if the social norms effect would be at the maximum value of 1, which occurs when there is a complete absence of social exposure. The total social exposure thus modulates this rate via the social norm effect. The value is estimated based on adoption dynamics for alternative fuel vehicles by Struben and Sterman (2008).
normal_social_norms_effect	0.5	dmnl	This variable is an anchor for the social norms effect implying that when total social exposure is equal to the reference social exposure, social norms effect is medium, 0.5 on a scale of 0-1. Rooftop PV ownership is a visible status and can become part of ones identity, similar to that of a road vehicles and thus a similar value to previous studies is justified (Struben & Sterman, 2008).

policy_effect	(STEP(Policy_marketing_effectiveness, Policy_marketing_start_time) - STEP(Policy_marketing_effectiveness, Policy_marketing_start_time+Policy_marketing_duration)) + effect_of_lost_sales_on_lobbying	1/year	This variable represents the effect of the policy on social exposure, determined by the political landscape and the effect of incumbent lobbying efforts.
Policy_marketing_duration	50	year	The variable represents the duration of the policy marketing. It is set at 50 years in the base run under the assumption that policy will be in favor of solar energy until 2050.
Policy_marketing_effectiveness	0.0015	1/year	This variable represents the effectiveness of policy marketing of solar energy. The value is highly uncertain and estimated based on behavioral calibration to data. While the value is uncertain, it enables scenario analysis in relative increases or decreases in policy effectiveness. The German government has actively marketed solar energy to consumers since 2000 (German

			Bundestag, 2014/2023).
Policy_marketing_start_time	2000	year	This variable represents the start time of the policy to market solar pv as a platform. It is set at 2000 based on the start time of the EEG act (German Bundestag, 2014/2023).
probability_of_contact_with_adopter	relative_installed_capacity	dmnl	This variable represents the probability of a contact being with an adopter of rooftop solar PV. Initially, with low installed rooftop PV, the probability is low, and as more adopt, the probability of meeting an adopter increases.
"probability_of_contact_with_non-adopter"	"non-installed_potential_rooftop_PV"/total_potential_rooftop_PV_10_kWp	dmnl	This variable represents the probability of a contact being with a non-adopter of rooftop solar PV. Initially, with low installed rooftop PV, the probability is high, and as more adopt, the probability of meeting a non-adopter falls.

reference_social_exposure	0.05	1/year	This variable serves as a baseline level of social exposure. At this level of exposure, the social norms effect takes the value of 0.5. If total social exposure is above this value, social norms effect will move below 0.5 and if it is below this value, it will move above 0.5, effecting the familiarity loss rate. Value is an assumption based on adoption dynamics of alternative fuel vehicles by Struben and Sterman (2008).
relative_familiarity	Familiarity / max_familiarity	dmnl	This variable represents the current familiarity of the platform relative to the maximum familiarity.
Social_Norms_effect	$\text{MIN}(1, \text{MAX}(0, \text{elasticity_of_social_norms_to_social_exposure} * \text{reference_social_exposure} + \text{normal_social_norms_effect} - \text{elasticity_of_social_norms_to_social_exposure} * \text{total_social_exposure}))$	dmnl	This variable captures the effect of social exposure on familiarity loss and is a value between 0 and 1. When total social exposure is equal to the reference value, the effect modulates familiarity loss at exactly half of the baseline forget rate and the slope of social norms

		effect is equal to the sensitivity. When social exposure is higher than the reference, the effect is below 0.5 and if lower than reference then the effect is greater than 0.5. As social norms effect approaches 0 with consistent social exposure, it signifies the new norm emergence and familiarity loss flow also approaches 0. The social norms effect of a new technology platform is highly nonlinear. When exposure is infrequent familiarity decays rapidly, but once it is sufficiently intense and adoption of rooftop PV becomes the new "social norm" there is no decay of consideration. The social norms effect has been observed with other technological transitions such as from horses to internal combustion engines (Struben & Sterman, 2008).
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total_social_exposure	$\text{MIN}(1, \text{policy_effect} + \text{marketing_effect} + \text{installed_social_effect} + \text{"non-installed_social_effect"})$	1/year	This variable represents the total social exposure to rooftop solar PV. It is a function of total marketing effectiveness, installed social effect and non-installed social effect. Social exposure to a new technology platform arises from three components: marketing, word-of-mouth contacts with platform adopters, and word-of-mouth about the platform among non-adopters (Struben & Sterman, 2008).
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XMILE MODEL CODE:

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xmlns:isee="http://iseesystems.com/XMILE">
```

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```

```
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    <vendor>isee systems, inc.</vendor>
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Architect</product>
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  </header>
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enabled="false"/>
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<default_format/>

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<isee:sensi_specs name="Average time to exit" method="sobol_sequence" runs="50">
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name="average_time_to_exit" num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="Market share of incumbent" method="sobol_sequence" runs="50">
    <isee:variable type="normal" mean="0.6" std_dev="0.04" min="0.5" max="0.7" seed="12345"
name="market_share_of_incumbent" num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="BMI baseline effect" method="sobol_sequence" runs="50">
    <isee:variable type="uniform" min="0.3" max="0.7" seed="12345" name="BMI_baseline_effect"
num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="BMI max effect" method="sobol_sequence" runs="50">
    <isee:variable type="uniform" min="3" max="5" seed="12345" name="BMI_max_effect"
num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="BMI sensitivity" method="sobol_sequence" runs="50">
    <isee:variable type="uniform" min="0.5" max="0.9" seed="12345" name="BMI_sensitivity"
num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="BMI threshold" method="sobol_sequence" runs="50">
    <isee:variable type="uniform" min="2.5" max="7.5" seed="12345" name="BMI_threshold"
num_samples="5"/>
</isee:sensi_specs>

<isee:sensi_specs name="Cost benefit sensitivity" method="sobol_sequence" runs="50"/>

<isee:sensi_specs name="Cost benefit threshold" method="sobol_sequence" runs="50">
    <isee:variable type="uniform" min="1" max="1.3" seed="12345" name="cost_benefit_threshold"
num_samples="5"/>
</isee:sensi_specs>
```

```

    <isee:sensi_specs name="Crowding midpoint" method="sobol_sequence" runs="50">
        <isee:variable type="uniform" min="0.4" max="0.8" seed="12345" name="crowding_midpoint"
num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Crowding min effect" method="sobol_sequence" runs="50">
        <isee:variable type="uniform" min="0.1" max="0.3" seed="12345" name="crowding_min_effect"
num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Crowding sensitivity" method="sobol_sequence" runs="50">
        <isee:variable type="uniform" min="20" max="28" seed="12345" name="crowding_sensitivity"
num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Economies of scale min effect" method="sobol_sequence" runs="50">
        <isee:variable type="uniform" min="0.2" max="0.4" seed="12345"
name="economies_of_scale_min_effect" num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Economies of scale sensitivity" method="sobol_sequence" runs="50">
        <isee:variable type="uniform" min="10" max="20" seed="12345"
name="economies_of_scale_sensitivity" num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Effective contact rate of adopter" method="sobol_sequence" runs="50">
        <isee:variable type="normal" mean="0.25" std_dev="0.02" min="0.2" max="0.3" seed="12345"
name="effective_contact_rate_of_adopter" num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Effective contact rate of non-adopter" method="sobol_sequence" runs="50">
        <isee:variable type="normal" mean="0.15" std_dev="0.02" min="0.1" max="0.2" seed="12345"
name=""effective_contact_rate_of_non-adopter"" num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Expected revenue for exit" method="sobol_sequence" runs="50">
        <isee:variable type="normal" mean="20000000" std_dev="8000000" min="10000000"
max="50000000" seed="12345" name="expected_revenue_for_exit" num_samples="5"/>
    </isee:sensi_specs>

    <isee:sensi_specs name="Funding availability delay time" method="sobol_sequence" runs="50">

```

```

        <isee:variable type="normal" mean="2" std_dev="0.4" min="1" max="3" seed="12345"
name="funding_availability_delay_time" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Funding max effect" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="40" max="80" seed="12345" name="funding_max_effect"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Funding sensitivity" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="2" max="6" seed="12345" name="funding_sensitivity"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Grant rate" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.7" std_dev="0.08" min="0.5" max="0.9" seed="12345"
name="grant_rate" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial accessibility" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.1" max="0.3" seed="12345" name="initial_accessibility"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial average fractional applications" method="sobol_sequence" runs="50"/>

    <isee:sensi_specs name="Initial early-stage funding availability" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="6000000" std_dev="1200000" min="3000000"
max="9000000" seed="12345" name="initial_early-stage_funding_availability" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial mature firms" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="10" std_dev="2" min="5" max="15" seed="12345"
name="initial_mature_firms" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial patents" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="300" std_dev="80" min="100" max="500" seed="12345"
name="initial_patents" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial share of 10 kWp" method="sobol_sequence" runs="50">

```

```

    <isee:variable type="triangular" lower="0.7" upper="0.9" mode="0.8" min="0.7" max="0.9"
seed="12345" name="initial_share_of_10_kWp_rooftop_pv" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Initial startups" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="20" max="80" seed="12345" name="initial_startups"
num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Installation time" method="sobol_sequence" runs="50">

    <isee:variable type="normal" mean="1" std_dev="0.08" min="0.8" max="1.2" seed="12345"
name="installation_time" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Installations per year" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="0.0007" max="0.0009" seed="12345"
name="installations_per_year" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Installers to firms ratio" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="10" max="50" seed="12345"
name="installers_to_firms_ratio" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Learning-by-doing sensitivity" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="0.1" max="2" seed="12345" name="learning-by-
doing_sensitivity" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="marketing effectiveness" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="6e-11" max="1e-10" seed="12345"
name="marketing_effectiveness" num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Max entrants rate" method="sobol_sequence" runs="50">

    <isee:variable type="uniform" min="50" max="90" seed="12345" name="max_entrants_rate"
num_samples="5"/>

</isee:sensi_specs>

<isee:sensi_specs name="Normal forget rate" method="sobol_sequence" runs="50">

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        <isee:variable type="uniform" min="0.6" max="0.7" seed="12345" name="normal_forget_rate"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Normal social norms effect" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.4" max="0.6" seed="12345"
name="normal_social_norms_effect" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Opportunity midpoint" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.1" max="0.5" seed="12345"
name="opportunity_midpoint" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Opportunity sensitivity" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="30" max="50" seed="12345"
name="opportunity_sensitivity" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Patent min effect" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.1" max="0.3" seed="12345" name="patent_min_effect"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Patent sensitivity" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.02" max="0.08" seed="12345" name="patent_sensitivity"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Policy marketing effectiveness" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.001" max="0.002" seed="12345"
name="Policy_marketing_effectiveness" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="R&D min effect" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.3" max="0.5" seed="12345"
name=""R&D_min_effect"" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="R&D sensitivity" method="sobol_sequence" runs="50">

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        <isee:variable type="uniform" min="0.2" max="0.4" seed="12345"
name=""R&D_sensitivity"" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="R&D to sales ratio" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.15" std_dev="0.02" min="0.1" max="0.2" seed="12345"
name=""R&D-to-sales_ratio"" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Reference social exposure" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.05" std_dev="0.038" min="0.01" max="0.2"
seed="12345" name="reference_social_exposure" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Share of 10 kWp" method="sobol_sequence" runs="50">

        <isee:variable type="triangular" lower="0.5" upper="0.6" mode="0.55" min="0.5" max="0.6"
seed="12345" name="share_of_10_kWp" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Share of German industry from residential rooftop PV"
method="sobol_sequence" runs="50">

        <isee:variable type="triangular" lower="0.3" upper="0.4" mode="0.35" min="0.3" max="0.4"
seed="12345" name="share_of_German_industry_from_residential_rooftop_PV" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial Solar LCOE " method="sobol_sequence" runs="50">

        <isee:variable type="triangular" lower="0.5" upper="0.6" mode="0.55" min="0.5" max="0.6"
seed="12345" name="Initial_solar_LCOE" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Success rate max effect" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="1.5" max="2.5" seed="12345"
name="success_rate_max_effect" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="VOD midpoint" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.4" max="0.6" seed="12345" name="VOD_midpoint"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="VOD min effect" method="sobol_sequence" runs="50">

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        <isee:variable type="uniform" min="0.1" max="0.5" seed="12345" name="VOD_min_effect"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="VOD sensitivity" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="10" max="20" seed="12345" name="VOD_sensitivity"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Weight of cost" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.5" std_dev="0.16" min="0.3" max="0.7" seed="12345"
name="weight_of_cost" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Weight of market maturity" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.5" std_dev="0.1" min="0.3" max="0.7" seed="12345"
name="weight_of_market_maturity" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Lobby max effectiveness" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="0.06" max="0.12" seed="12345"
name="lobby_max_effectiveness" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Lobby sensitivity" method="sobol_sequence" runs="50">

        <isee:variable type="uniform" min="35" max="45" seed="12345" name="lobby_sensitivity"
num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Retail Electricity Price (2050)" method="sobol_sequence" runs="50">

        <isee:variable type="normal" mean="0.45" std_dev="0.1" min="0.25" max="0.75" seed="12345"
name=""Retail_electricity_price_(2050)"" num_samples="5"/>

    </isee:sensi_specs>

    <isee:sensi_specs name="Initial installed rooftop pv" method="sobol_sequence" runs="50"/>
</isee:sensi_specs_list>

<isee:optimizer_specs_list active_index="0">

    <isee:optimizer_specs name="Optimization" method="Powell" use_additional_starts_file="false"
additional_starts="0" report_interval="1" confidence_range="0"/>

</isee:optimizer_specs_list>

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<isee:payoff_specs_list>
  <isee:payoff_specs name="Payoff"/>
</isee:payoff_specs_list>
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  <unit name="Dimensionless">
    <eqn>1</eqn>
    <alias>dmnl</alias>
    <alias>unitless</alias>
    <alias>fraction</alias>
  </unit>
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    <eqn/>
    <alias>$US</alias>
    <alias>USD</alias>
```

<alias>US\$</alias>

</unit>

</model_units>

<model>

<variables>

<stock name="Installed\nRooftop PV\n10 kWp" access="output" isee:autocreated="true">

<doc>This installed rooftop PV stock indicates the amount of GW of installed capacity of rooftop solar PV systems of 10 kWp and below in Germany. It is determined by an increase from the inflow of installation rate and the outflow of degradation rate. The initial value of this stock is determined by the initial installed rooftop PV.

</doc>

<eqn>initial_installed_rooftop_pv</eqn>

<inflow>installations</inflow>

<outflow>degradation_rate</outflow>

<units>GW</units>

</stock>

<aux name="average module lifetime">

<doc>\${Uncertain}

This variable represents the average module lifetime, commonly set between 25-30 years in studies in Germany (Wirth, 2025).</doc>

<eqn>30</eqn>

<range min="25" max="35"/>

<units>year</units>

</aux>

<flow name="installations">

<doc>This is an inflow which represents the rate at which installed rooftop PV stock increases per year. Installations consist of new installations and the replacements of previously installed PV systems past their lifetime, and is controlled by the installation capacity. </doc>

<eqn>MIN(new_installations

+
replacements, installation_capacity)</eqn>

<units>GW/year</units>

</flow>

<stock name="Familiarity">

<doc>The familiarity stock indicates how familiar the population is with the new platform. Its value is between 0 and 1 and controlled by inflow of familiarity gain and outflow of familiarity loss. </doc>

<eqn>0</eqn>

<inflow>familiarity_gain</inflow>

<outflow>familiarity_loss</outflow>

<units>familiarity</units>

</stock>

<aux name="probability of contact\nwith adopter">

<doc>This variable represents the probability of a contact being with an adopter of rooftop solar PV. Initially, with low installed rooftop PV, the probability is low, and as more adopt, the probability of meeting an adopter increases. </doc>

<eqn>relative_installed_capacity</eqn>

<units>dmnl</units>

</aux>

<flow name="familiarity gain">

<doc>This inflow represents the rate at which familiarity stock increases. The equation describes a bounded growth inflow whereby social exposure increases familiarity at a rate proportional to current exposure and the remaining gap to maximum familiarity, but never allows the inflow to go negative.</doc>

<eqn>MAX(0, total_social_exposure

*
(max_familiarity-Familiarity))</eqn>

<units>familiarity/year</units>

</flow>

<flow name="familiarity loss">

<doc>This outflow represents the rate at which familiarity stock depletes. The familiarity loss rate is proportional to the familiarity stock and modulated by the social norms effect and the normal forget rate. When social norms effect is high familiarity loss rate is at the normal rate; when social norms effect is weak, the outflow is weak and familiarity persists.

It takes effort to stay up to date with developments in solar photovoltaics and thus familiarity erodes unless there is consistent social exposure and marketing. </doc>

<eqn>Social_Norms_effect

*

Familiarity

*

normal_forget_rate</eqn>

<units>familiarity/year</units>

</flow>

<aux name="effective contact\nrate of adopter">

<doc>\${Uncertain}

This variable is the strength of word-of-mouth between non-adopters and adopters of rooftop solar PV.

The value is uncertain and estimated at 0.25 based on previous modeling studies of adoption of alternative fuel vehicles (Struben and Sterman, 2008). Similar peer effects have been observed in the diffusion of solar photovoltaics (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015). </doc>

<eqn>0.25</eqn>

<format precision="0.01"/>

<range min="0.2" max="0.3"/>

<units>1/year</units>

</aux>

<aux name="installed social effect">

<doc>This variable represents the effect of word-of-mouth contacts between non-adopters and adopters on the total social exposure. This direct exposure depends on the frequency of contacts between an adopter and a non-adopter and the effective contact rate.

This term captures word-of-mouth about rooftop solar PV on social exposure acquired by seeing them and talking to their owners (Struben & Sterman, 2008). </doc>

<eqn>effective_contact_rate_of_adopter

*

probability_of_contact_with_adopter</eqn>

<units>1/year</units>

</aux>

<aux name="total social exposure">

<doc>This variable represents the total social exposure to rooftop solar PV. It is a function of total marketing effectiveness, installed social effect and non-installed social effect.

Social exposure to a new technology platform arises from three components: marketing, word-of-mouth contacts with platform adopters, and word-of-mouth about the platform among non-adopters (Struben & Stermann, 2008). </doc>

<eqn>MIN(1, policy_effect

+

marketing_effect

+

installed_social_effect

+

"non-installed_social_effect")</eqn>

<units>1/year</units>

</aux>

<aux name="effective contact\nrate of non-adopter">

<doc>\${Uncertain}

This variable is the strength of word-of-mouth between non-adopters of rooftop solar PV when familiarity is at its maximum.

The value is uncertain and estimated at 0.15 based on previous modeling studies of adoption of alternative fuel vehicles (Struben and Stermann, 2008). Similar peer effects have been observed in the diffusion of solar photovoltaics (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015). </doc>

<eqn>0.15</eqn>

<format precision="0.01"/>

<range min="0.1" max="0.2"/>

<units>1/year</units>

</aux>

<aux name="non-installed social effect">

<doc>This variable represents the effect of word-of-mouth contacts between non-adopters and other non-adopters on the total social exposure. The value depends on the probability of contact with non-adopter and the effective contact rate, normalized to the maximum familiarity of the platform.

This term captures the word-of-mouth about rooftop solar PV arising from those not using solar PV and learning about the platform from others not using solar PV (Struben & Sterman, 2008).

$$\begin{aligned} & \times \\ & \times \text{effective_contact_rate_of_non-adopter} \\ & \times \text{probability_of_contact_with_non-adopter} \\ & \text{1/year} \\ & \text{"Social Norms effect"} \end{aligned}$$

This variable captures the effect of social exposure on familiarity loss and is a value between 0 and 1. When total social exposure is equal to the reference value, the effect modulates familiarity loss at exactly half of the baseline forget rate and the slope of social norms effect is equal to the sensitivity. When social exposure is higher than the reference, the effect is below 0.5 and if lower than reference then the effect is greater than 0.5. As social norms effect approaches 0 with consistent social exposure, it signifies the new norm emergence and familiarity loss flow also approaches 0.

The social norms effect of a new technology platform is highly nonlinear. When exposure is infrequent familiarity decays rapidly, but once it is sufficiently intense and adoption of rooftop PV becomes the new "social norm" there is no decay of consideration. The social norms effect has been observed with other technological transitions such as from horses to internal combustion engines (Struben & Sterman, 2008).

$$\begin{aligned} & \text{MIN}(1, \\ & \text{MAX}(0, \\ & \text{elasticity_of_social_norms_to_social_exposure} \times \text{reference_social_exposure} \\ & + \text{normal_social_norms_effect} \\ & - \text{elasticity_of_social_norms_to_social_exposure} \times \text{total_social_exposure} \\ &) \\ &) \end{aligned}$$

dmnl

"normal forget rate"

<doc>\${Uncertain}

This variable is the normal familiarity loss rate if the social norms effect would be at the maximum value of 1, which occurs when there is a complete absence of social exposure. The total social exposure thus modulates this rate via the social norm effect. The value is estimated based on adoption dynamics for alternative fuel vehicles by Struben and Sterman (2008).</doc>

<eqn>0.65</eqn>

<range min="0.6" max="0.7"/>

<units>1/year</units>

</aux>

<aux name="probability of contact\nwith non-adopter">

<doc>This variable represents the probability of a contact being with a non-adopter of rooftop solar PV. Initially, with low installed rooftop PV, the probability is high, and as more adopt, the probability of meeting a non-adopter falls. </doc>

<eqn>"non-
installed_potential_rooftop_PV"/total_potential_rooftop_PV_10_kWp</eqn>

<units>dmnl</units>

</aux>

<aux name="initial installed rooftop pv">

<doc>This variable represents the initial amount of GW of installed rooftop solar PV systems of 10 kWp and below in Germany in the year 2000. The value is determined by the initial total installed solar energy capacity multiplied by the initial share of 10 kWp rooftop pv. </doc>

<eqn>initial_total_installed_solar_energy_capacity

*

initial_share_of_10_kWp_rooftop_pv</eqn>

<range min="0.7" max="0.95"/>

<units>GW</units>

</aux>

<aux name="total potential\nrooftop PV 10 kWp" access="output" isec:autocreated="true">

<doc>This variable represents the total potential installed rooftop PV capacity of system of 10 kWp and below in Germany during the time horizon of the simulation. </doc>

<eqn>Residential_Technical_Potential

*

share_of_10_kWp</eqn>

<units>GW</units>

</aux>

<aux name="non-installed\npotential rooftop PV">

<doc>This variable represents the amount of potential adoption of solar PV at any point in time calculated as the total potential capacity less the total installed capacity.</doc>

<eqn>total_potential_rooftop_PV_10_kWp-Installed_Rooftop_PV_10_kWp</eqn>

<units>GW</units>

</aux>

<flow name="degradation rate">

<doc>This outflow represents the rate at which the installed rooftop PV stock is depleting. The value is determined by the total GW of installed capacity divided by the average module lifetime. </doc>

<eqn>Installed_Rooftop_PV_10_kWp/average_module_lifetime</eqn>

<units>GW/year</units>

</flow>

<aux name="replacements">

<doc>This variable represents the amount of degraded rooftop solar PV systems which will be replaced per year. The value is determined by the degraded systems per year and the utility of rooftop solar PV. Those adopter who will make a replacement decision are assumed to be familiar with rooftop PV and thus will consider whether to replace their system based on the utility of the platform. </doc>

<eqn>degradation_rate*utility_of_solar</eqn>

<units>GW/Years</units>

</aux>

<aux name="installation time">

<doc>\${Uncertain}

This variable represents the amount of time from a purchasing decision of a rooftop PV system to the actual installation of that system. The value is estimated at 1 year.</doc>

<eqn>1</eqn>

<format precision="0.1"/>

<range min="0.8" max="1.2"/>

<units>year</units>

</aux>

<aux name="elasticity of social\nnorms to social exposure">

<doc>This variable represents the elasticity of the familiarity loss rate with respect to social exposure to rooftop PV around 1 at the reference. The value is normalized to exposure at 1 so that local changes in exposure have a proportionate effect on familiarity loss. </doc>

<eqn>1

/

(2*reference_social_exposure)</eqn>

<units>year</units>

</aux>

<aux name="reference social exposure">

<doc>\${Uncertain}

This variable serves as a baseline level of social exposure. At this level of exposure, the social norms effect takes the value of 0.5. If total social exposure is above this value, social norms effect will move below 0.5 and if it is below this value, it will move above 0.5, effecting the familiarity loss rate. Value is an assumption based on adoption dynamics of alternative fuel vehicles by Struben and Sterman (2008).</doc>

<eqn>0.05</eqn>

<format precision="0.001"/>

<range min="0.01" max="0.2"/>

<units>1/year</units>

</aux>

<aux name="relative installed capacity" access="output" isee:autocreated="true">

<doc>This variable represents the amount of installed rooftop PV relative to the total potential rooftop PV. </doc>

<eqn>Installed_Rooftop_PV_10_kWp

//

total_potential_rooftop_PV_10_kWp</eqn>

<units>dmnl</units>

</aux>

<aux name="planned new installations">

<doc>This variable represents planned installations and its value is determined by multiplying the perceived utility by the amount of GW of non-installed potential rooftop PV.</doc>

<eqn>perceived_utility*"non-installed_potential_rooftop_PV"</eqn>

<units>GW</units>

</aux>

<aux name="cost to benefit ratio of solar">

<doc>This is a ratio of how expensive solar electricity is compared to the monetary value of each kWh rooftop pv adopters generate. </doc>

The numerator is solar LCOE, or the cost of how expensive the solar pv production is for the consumer.

The denominator is made up of self-consumption benefit and export benefit. The self-consumption portion is the retail electricity price multiplied by the self-consumption portion, essentially the money you save not paying for electricity from the grid. The exported part is the portion of exports multiplied by the feed-in tariff.

When the ratio is below 1, cost is lower than the economic value benefit, and thus the system is more attractive. Ratio of 1 is roughly break-even and a ratio above 1 means the cost of producing electricity are more than the economic benefit a consumer can gain from the system. </doc>

<eqn>solar_LCOE

//

((retail_electricity_price

*"average_percentage_of_self-consumption")

+(FIT*percentage_of_exports)

)</eqn>

<units>dmnl</units>

</aux>

<aux name="perceived utility">

<doc>This variable represents the perceived utility of rooftop PV. It is determined by multiplying utility and familiarity stock. In order for non-adopters to be willing to consider a new platform it must have sufficient utility as well as them being familiar with the platform. </doc>

<eqn>relative_familiarity*utility_of_solar</eqn>

<units>dmnl</units>

</aux>

<aux name="max familiarity">

<doc>This variable is conceptually the maximum familiarity of 1, or 100 percent familiarity. </doc>

<eqn>1</eqn>

<units>familiarity</units>

</aux>

<aux name="Initial solar LCOE">

<doc>\${Uncertain}

The variable represents the initial LCOE, set at a realistic value between €0.5-0.5/kWh based on the feed-in tariff during those years (Kost et al., 2012) and German LCOE data (see "Solar LCOE. Data 00-25 + Fraunhofer ISE Forecast 26-45").

<eqn>0.565</eqn>

<range min="0.5" max="0.6"/>

<units>eur/(KW*Hours)</units>

</aux>

<aux name="policy effect">

<doc>This variable represents the effect of the policy on social exposure, determined by the political landscape and the effect of incumbent lobbying efforts. </doc>

<eqn>(STEP(Policy_marketing_effectiveness, Policy_marketing_start_time)

-

STEP(Policy_marketing_effectiveness, Policy_marketing_start_time+Policy_marketing_duration))

+

effect_of_lost_sales_on_lobbying</eqn>

<format precision="0.0001"/>

<range min="0" max="0.1"/>

<units>1/year</units>

</aux>

<aux name="solar LCOE">

<doc>This variable represents the levelized cost of electricity (LCOE) of rooftop solar pv, a parameter often used in modeling studies and cited in reports (Nemet, 2006; Fraunhofer ISE, 2025-a). Solar LCOE in Germany has decreased 16% year on year between 2012-2024 (Fraunhofer ISE, 2025-a).

The variable is crucial for the adoption of rooftop solar pv, as LCOE decreases, the relative utility of the platform increases. The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "Solar LCOE. Data 2000-2025 + Fraunhofer ISE Forecast 2026-2050".

<eqn>Initial_solar_LCOE

*

Economies_of_Scale_effect

*

Technological_reinforcement_effect

*

"Learning-by-doing_effect"</eqn>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="utility of solar">

<doc>This is a weighted utility function of rooftop solar photovoltaic adoption for German

households, comprised of the effect of cost and accessibility, and their respective weights. It is a value between 0 and 1, as effect of cost and accessibility can only reach 1 and the combined weights is equal to 1.

The adoption decision of rooftop solar and other low-carbon technology platforms, such as electric vehicles or plant-based diets, is often considered as function of cost, performance (captured jointly in the model by LCOE) and accessibility (Lenton et al., 2023). </doc>

<eqn>(weight_of_cost*effect_of_cost_on_utility)

+

(weight_of_accessibility*relative_accessibility)</eqn>

<units>dmnl</units>

</aux>

<aux name="accessibility of alternative">

<doc>\${Uncertain}

This variable represents the accessibility of purchasing electricity directly from the grid for residential households. It is estimated at a value of one, or perfect accessibility, because it is the incumbent standard way of purchasing electricity which is well-known and convenient. It is unlikely that rooftop solar pv will ever reach the same accessibility as the alternative because it will always require some effort from the consumer to install a rooftop system. </doc>

<eqn>1</eqn>

<range min="0.8" max="1"/>

<units>accessibility</units>

</aux>

<aux name="initial accessibility">

<doc>\${Uncertain}

This variable represents the initial accessibility of rooftop solar pv for residential consumers. It is an uncertain value set at approximately one tenth of the accessibility of the alternative, direct purchase of electricity from the grid. </doc>

<eqn>0.1</eqn>

<range min="0.1" max="0.3"/>

<units>accessibility</units>

</aux>

<flow name="Valley of Death">

<doc>Valley of death represents the outflow of startups from the system. The value is determined by dividing the startups stock by the startup lifetime. If startup lifetime is higher the rate will decrease and visa versa.</doc>

Valley of death is a common phenomenon among startups and technologies, and has been observed with renewable energy technologies as ell (Murphy & Edwards, 2003). Private investor financing is crucial for startups to cross the valley of death (Gbadegeshin et al., 2022; Markham, 2002).</doc>

<eqn>Startups

//

startup_lifetime</eqn>

<units>firm/year</units>

</flow>

<flow name="new entrants">

<doc>This inflow represents the rate at which startups stock increases and is determined by the maximum entrants rate and the perceived opportunity.</doc>

The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "New Entrants. Data 2000-2024 + Trend 2025-2050"</doc>

<eqn>max_entrants_rate

*

perceived_opportunity</eqn>

<units>firm/year</units>

</flow>

<stock name="Startups">

$\langle \text{doc} \rangle$ This stock represents the amount of startup firms in the system. It is determined by the inflow of new entrants and the outflows of valley of death and the exit rate. $\langle / \text{doc} \rangle$

$\langle \text{eqn} \rangle$ initial_startups $\langle / \text{eqn} \rangle$

$\langle \text{inflow} \rangle$ new_entrants $\langle / \text{inflow} \rangle$

$\langle \text{outflow} \rangle$ Valley_of_Death $\langle / \text{outflow} \rangle$

$\langle \text{outflow} \rangle$ maturing $\langle / \text{outflow} \rangle$

$\langle \text{units} \rangle$ firm $\langle / \text{units} \rangle$

$\langle / \text{stock} \rangle$

$\langle \text{aux name} = \text{"average success rate"} \rangle$

$\langle \text{doc} \rangle$ $\{ \text{Uncertain} \}$

This variable represents that average success rate of startups for the average time to exit. According to International Energy Agency data, 2.9% startups in the energy sectors exit within 5 years (2025-a). $\langle / \text{doc} \rangle$

$\langle \text{eqn} \rangle$ 0.029 $\langle / \text{eqn} \rangle$

$\langle \text{range min} = \text{"0.01"} \text{ max} = \text{"0.05"} \rangle$

$\langle \text{units} \rangle$ dmnl $\langle / \text{units} \rangle$

$\langle / \text{aux} \rangle$

$\langle \text{aux name} = \text{"solar rooftop accessibility"} \rangle$

$\langle \text{doc} \rangle$ This variable represents the accessibility of solar rooftop, and is the function of initial accessibility and the business model innovation effect. Accessibility, along with price and performance, are cited to be important decision-making factors for the adoption of rooftop pv (Lenton et al., 2023). $\langle / \text{doc} \rangle$

$\langle \text{eqn} \rangle$ initial_accessibility * Business_Model_Innovation_Effect $\langle / \text{eqn} \rangle$

$\langle \text{units} \rangle$ accessibility $\langle / \text{units} \rangle$

$\langle / \text{aux} \rangle$

$\langle \text{aux name} = \text{"relative accessibility"} \rangle$

$\langle \text{doc} \rangle$ This variable represents the accessibility of installing and operating solar rooftop solar PV relative to the alternative option of purchasing electricity directly from the grid. $\langle / \text{doc} \rangle$

$\langle \text{eqn} \rangle$ solar_rooftop_accessibility / accessibility_of_alternative $\langle / \text{eqn} \rangle$

$\langle \text{units} \rangle$ dmnl $\langle / \text{units} \rangle$

$\langle / \text{aux} \rangle$

$\langle \text{aux name} = \text{"marketing effectiveness"} \rangle$

$\langle \text{doc} \rangle$ $\{ \text{Uncertain} \}$

This variable represents the effectiveness of each euro spent on marketing to the total exposure of the platform. It is highly uncertain, estimated at $8.5e-11$ per euro spent. </doc>

<eqn>0.000000000085</eqn>

<format precision="full"/>

<range min="6e-11" max="1e-10"/>

<units>1/euro</units>

</aux>

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 </group>
 <stock name="Mature Firms">

<doc>The stock of mature firms represents the startups which have successfully crossed the valley of death and either exited via IPO or M&A, or matured into stable businesses. It is determined by the inflow of exit rate. </doc>

<eqn>initial_mature_firms</eqn>

<inflow>maturing</inflow>

<units>firm</units>

</stock>

<flow name="maturing">

<doc>This is the outflow from startups and the inflow to mature firms, representing the rate at which startups mature. It's value is determined by multiplying the amount of startups by the success rate and dividing by the average time to exit. </doc>

<eqn>(Startups

*

success_rate)

/

average_time_to_exit</eqn>

<units>firm/year</units>

</flow>

<aux name="initial mature firms">

<doc>\${Uncertain}

This variable represents the initial amount of mature firms in Germany in the year 2000, estimated at 10 based on the immaturity of the industry at the time period, with a lower and upper bound of 5 and 15 respectively.

Notable firms in early 2000s include, SolarWorld, IBC Solar, SOLARWATT and Q-Cells in pv manufacturing and SMA, KACO and VARTA in related segments.</doc>

<eqn>10</eqn>

<range min="5" max="15"/>

<units>firm</units>

</aux>

<aux name="marketing effect">

<doc>This variable represents the total marketing effect of firms on social exposure.

Previous studies treat marketing exogenously, but here marketing effect is endogenized (Struben & Sterman, 2008).</doc>

<eqn>marketing_budget

*

marketing_effectiveness</eqn>

<units>1/year</units>

</aux>

<aux name="perceived opportunity">

<doc>This variable represents the perceived opportunity for entrepreneurs to enter the solar industry, which is a function of market maturity and regulation. Studies on the process of firm formation highlight the opportunity recognition stage of venture creation (Bhave, 1994). The role of market, technical and regulatory risks are often highlighted as affecting renewable energy entrepreneurs decision to enter a market (Dobrovolska et al., 2024; Guerra et al., 2025). Empirical evidence from the US underscores that there is a relationship between government policies that change cost and benefits and new firm formation in the solar market (Gao, 2021).

</doc>

<eqn>((weight_of_market_maturity*effect_of_market_maturity_on_opportunity)+(weight_of_regulation*Demand_policy_switch))

*

crowding_effect</eqn>

<units>dmnl</units>

</aux>

<aux name="industry yearly revenue">

<doc>This value is the total revenue of the solar PV industry for the modeled segment of 10 kWp and below residential rooftop systems. Revenue is made up of price of PV rooftop system times installations per year, plus the operating and maintenance costs of the existing installed capacity. </doc>

<eqn>(installations

*

"price_PV_rooftop_system_(2024)";

*

GW_to_KW_conversion)

+

(Installed_Rooftop_PV_10_kWp

*

("price_PV_rooftop_system_(2024)"*"O&M_costs"*GW_to_KW_conversion))</eqn>

<units>euro/year</units>

</aux>

<aux name="price PV rooftop\nsystem (2024)">

<doc>This variable is the price of PV rooftop system, set at the 2024 value of 1100 euro/kw based on the Fraunhofer ISE report (2025).</doc>

<eqn>1100</eqn>

<units>euro/kw</units>

</aux>

<aux name="GW to KW conversion">

<doc>This variable converts between gigawatts and kilowatts. </doc>

<eqn>1000000</eqn>

<units>KW/GW</units>

</aux>

<aux name="O&M costs">

<doc>Operating and maintenance costs of residential rooftop PV systems are on the order or 1-2% of the system's capex, or system price, according to NREL (2024).</doc>

<eqn>0.02</eqn>

<units>dmnl/year</units>

</aux>

<aux name="revenue per firm">

<doc>This variable represents the revenue per firm from rooftop solar PV systems of 10 kWp and below, calculated as total industry revenue divided by amount of firms in the system.

Because the model represents only venture-backed firms (startups and mature ventures) endogenously, we treat the modeled residential rooftop segment revenue as the relevant revenue base for these firms, and directly compute revenue per firm from total segment revenue and the number of venture-backed firms.</doc>

<eqn>industry_yearly_revenue

/

total_firms</eqn>

<units>Euros/firm/Years</units>

</aux>

<aux name="max entrants rate">

<doc>\${Uncertain}

This variable represents the maximum number of new entrants coming in to the system. It is treated as an exogenous parameter for modeling purposes, calibrated to the empirical data of new entrants - maximum new entrants rate was 55 in the year 2021, for the solar and related sectors of grid, energy efficiency and energy storage and batteries sectors in Germany (International Energy Agency, 2025-a). Since the perceived opportunity at the maximum historical entrants rate is unknown, this variable is highly uncertain. A lower bound of 50 and 150 are applied for uncertainty analysis.

$$70$$

1

50 90

firm/year

average startup lifetime

{Uncertain}

The average startup lifetime is set at 5 years based on statistics of survival rates in Germany. Less than half of startups survive the first 5 years (IfM Bonn, 2023).

$$5$$

4 6

year

average time to exit

{Uncertain}

The average time to exit is based on empirical data of successful exits of German startups and set at 5 years (International Energy Agency, 2025-a).

$$5$$

4 10

Years

FIT amount. Data 2000-2024 + Forecast 2025-2050

The FIT amount is based on the actual development since 2000 and 2024 (Wirth, 2025). Since February 2024, the tariffs for newly commissioned PV systems are reduced 1% every half year, and this is how the 2025-2050 forecast is estimated in the model.

$$TIME$$

gf

<yscale min="0" max="0.6"/>

<xpts>2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050</xpts>

<ypts>0.51,0.51,0.48,0.45,0.57,0.54,0.52,0.49,0.47,0.43,0.37,0.28,0.2,0.15,0.13,0.13,0.13,0.13,0.125,0.11,0.09,0.07,0.07,0.08,0.08,0.0784,0.076832,0.07529536,0.073789453,0.072313664,0.07086739,0.069450043,0.068061042,0.066699821,0.065365825,0.064058508,0.062777338,0.061521791,0.060291355,0.059085528,0.057903818,0.056745741,0.055610826,0.05449861,0.053408638,0.052340465,0.051293656,0.050267783,0.049262427,0.048277178,0.047311635</ypts>

</gf>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="average percentage of nself-consumption">

<doc>\${Uncertain}

Percentage of self-consumption for household rooftop systems has increased over time and is roughly 17 percent in 2024 according to Fraunhofer ISE (2025-b). </doc>

<eqn>0.35</eqn>

<range min="0.2" max="0.5"/>

<units>dmnl</units>

</aux>

<aux name="percentage of exports">

<doc>Percentage of exports is calculated as 100% minus percentage of self-consumption.

</doc>

<eqn>1-"average_percentage_of_self-consumption"</eqn>

<units>dmnl</units>

</aux>

<aux name="FIT">

<doc>\${Policy}

The feed-in tariff (FIT) is the principal policy lever that Germany has used since 2000 as part of the Renewable Energy Sources Act (EEG) to stimulate solar pv adoption and market development (EEG, 2000).

Producers of rooftop solar pv can sell electricity back to the grid at the fixed price of the FIT. Therefore the FIT is part of the benefit calculation. It is controlled by the FIT amount and the demand policy switch, which can be toggled on or off.

$$\text{"FIT_amount._Data_2000-2024_+_Forecast_2025-2050"}$$

*

Demand_policy_switch

$$\text{euro/(KW*Hours)}$$

Demand policy switch

This demand policy switch controls when and for how long the feed-in tariff is implemented. The policy also affects the perceived opportunity.

$$\text{(STEP(1, demand_policy_start)}$$

-

STEP(1, demand_policy_start+Demand_policy_duration))

$$\text{format precision="1"}$$

$$\text{range min="0" max="1"}$$

$$\text{dmnl}$$

weight of market maturity

$$\text{\$ \{Uncertain\}}$$

The weight of market maturity on perceived opportunity is uncertain and thus estimated as 50%.

$$0.5$$

$$\text{range min="0.3" max="0.7"}$$

$$\text{dmnl}$$

capacity factor

This variable represents the average capacity factor of residential rooftop PV systems in Germany, capturing the ratio of actual annual generation to generation at full nameplate capacity. The value is set based on empirical data (Wirth, 2025).

$$0.11$$

$$\text{dmnl}$$

<aux name="hours per year">

<doc>This variable represents the hours in the year. </doc>

<eqn>8760</eqn>

<units>hour/year</units>

</aux>

<aux name="annual generation rooftop pv">

<doc>This variable represents the annual generation, a function of the capacity factor and hours per year, of the installed capacity. </doc>

<eqn>Installed_Rooftop_PV_10_kWp

*

capacity_factor

*

hours_per_year</eqn>

<units>(GW*hour)/year</units>

</aux>

<aux name="lost utility sales">

<doc>This variable represents the lost revenue of utilities from households consuming their own electricity. The remaining portion not part of self-consumption is sold back to utilities at the fixed feed-in tariff rate.

</doc>

<eqn>annual_generation_rooftop_pv

*

"average_percentage_of_self-consumption";

*

GW_to_KW_conversion

*

(retail_electricity_price)</eqn>

<units>euro/year</units>

</aux>

<aux name="weight of naccessibility">

$$\text{weight_of_cost} = 1 - \text{weight_of_accessibility}$$

This variable represents the weight of accessibility on utility and is calculated as weight of cost less from the maximum utility of 1.

$$1 - \text{weight_of_cost}$$

range min="0" max="1"

units: dmnl

aux name="weight of cost"

$\{\text{Uncertain}\}$

This variable represents the weight of cost on utility. It is an uncertain variable set at 50% and tested in the range of 25-75%.

$$0.5$$

format precision="0.1"

range min="0.3" max="0.7"

units: dmnl

aux name="Demand policy\nduration"

This variable represents the duration of the demand side policy.

The user can test scenarios in which the policy duration lasts for varying amount of years from 0 to 50.

$$50$$

format precision="1"

range min="0" max="50"

units: year

aux name="demand policy start"

This variable represents the start year of the demand side policy.

The user can test scenarios in which the policy start at different point of the simulation time period from 2000 to 2049.

$$2000$$

format precision="1"

<range min="2000" max="2049"/>

<units>year</units>

</aux>

<aux name="retail electricity price">

<doc>This variable represents the retail electricity price. From 2000 to 2026 it takes the value of "Retail electricity price Germany. Data 00-26" and from 2027 to 2050 it takes the value of "Retail electricity price Germany. Linear forecast 27-50".</doc>

<eqn>IF TIME < 2027 THEN "Retail_electricity_price_Germany._Data_00-26" ELSE "Retail_electricity_price_Germany._Linear_forecast_27-50"</eqn>

<units>eur/(KW*Hours)</units>

</aux>

<aux name="Retail electricity price Germany.\nData 00-26">

<doc>\${Data}

This value represents the historical household electricity price in Germany from 2000 to 2026 (Open Energy Tracker, 2026).</doc>

<eqn>TIME</eqn>

<gf>

<yscale min="0.1" max="0.5"/>

<xpts>2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026</xpts>

<ypts>0.139,0.143,0.161,0.172,0.18,0.187,0.195,0.206,0.217,0.232,0.237,0.252,0.259,0.288,0.291,0.296,0.297,0.304,0.303,0.312,0.323,0.328,0.463,0.47,0.402,0.393,0.373</ypts>

</gf>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="success rate">

<doc>This variable represents the average success rate, calculated as the average success rate by the effect of revenue growth on success rate. Success rate means the successful exit of a company via IPO or M&A.</doc>

<eqn>average_success_rate

effect_of_revenue_on_success_rate</eqn>

<units>dmnl</units>

</aux>

<stock name="Patents">

<doc>This is the stock of granted patents, which have a positive R&D effect on levelized cost of electricity.

</doc>

<eqn>initial_patents</eqn>

<inflow>grants</inflow>

<units>patent</units>

</stock>

<flow name="applications">

<doc>This inflow represents the amount of patent filings per year by the global solar industry, which determines the rate at which the filed patents stock increases. The value is determined by the patent filings per euro multiplied by the cumulative R&D spending of public and private sector.

The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "Patent Applications for Solar and Storage. Data 2000-2020 + Trend 2020-2050".</doc>

<eqn>("private_R&D_spend"+"Public_R&D")*fractional_applications</eqn>

<units>patent/year</units>

</flow>

<aux name="fractional applications">

<doc>This variable represents the fractional rate of applications in solar energy and battery storage technologies per million euro spent. It is determined by the initial fractional applications and the effect of patents on future filings.

Eurostat data found that 400 patents on average are filed for every billion euros invested in R&D in Germany (2008).</doc>

<eqn>initial_average_fractional_applications

*

effect_of_patents_on_fractional_patent_applications</eqn>

<units>patent/meur</units>

</aux>

<aux name="R&D-to-sales ratio">

<doc>\${Uncertain}

This variable represents R&D-to-sales ratio of firms in the system, estimated at 16% based on the average of semiconductor (20.4% and software publishers (12.9%), a relevant comparison to IP-heavy venture-backed firms such as solar PV, average values from National Center for Science and Engineering (2024). </doc>

<eqn>0.16</eqn>

<range min="0.1" max="0.2"/>

<units>dmnl</units>

</aux>

<aux name="private R&D spend">

<doc>This variable represents the total R&D spending of the private sector for solar energy and is determined by the total yearly revenue and an average R&D to sales ratio.

Germany spent 88.7B EUR across all industries in private sector funding...

<https://www.gtai.de/en/invest/business-location-germany/rd-framework/germany-posts-commercial-r-d-investment-record-1843444></doc>

<eqn>(total_solar_industry_revenue/eur_to_meur)*"R&D-to-sales_ratio"</eqn>

<format scale_by="1"/>

<units>meur/year</units>

</aux>

<aux name="initial patents">

<doc>\${Uncertain}

This variable represents the initial amount of patents, estimated at several hundreds based on the relatively modest historical behavior of patent applications for solar and battery storage technologies before 2000 (International Energy Agency, 2025-b). </doc>

<eqn>200</eqn>

<range min="100" max="500"/>

<units>patent</units>

</aux>

<aux name="relative patents">

<doc>This variable represents the amount of patents in solar energy and battery storage technologies compared to the initial value.</doc>

<eqn>Patents

//

initial_patents</eqn>

<units>dmnl</units>

</aux>

<aux name="relative mature firms">

<doc>This variable represents the relative amount of mature firms in the system compared to the initial amount. </doc>

<eqn>Mature_Firms

//

initial_mature_firms</eqn>

<units>dmnl</units>

</aux>

<aux name="early-stage VC funding\navailability">

<doc>This variable represents VC funding availability a function of the effect of market maturity and the initial funding availability. The dynamics behavior is consistent with empirical data of VC funding in Germany in solar and related sectors (International Energy Agency, n.d.).

VC funding availability is subject to broad economic factors as well as the availability of funding from banks, pension funds, insurance companies, and corporate investors (MacMillan et al., 1989).

The model's validity is partly tested by comparing the model produced solar LCOE with the real data see "VC funding availability. Data 2004-2025 + Trend 2025-2050".</doc>

<eqn>SMTH1("initial_early-stage_funding_availability"*"market_effect_on_early-stage_VC_funding"; funding_availability_delay_time)</eqn>

<units>USD</units>

</aux>

<aux name="initial\nearly-stage funding\navailability">

<doc>\${Uncertain}

This variable represents the initial funding availability in 2000. Based on the the 2004 empirical value of 6.02M (International Energy Agency, 2025-a), the value of the parameter is estimated with an upper bound of 9.0M and a lower bound of 3.0M subject to uncertainty analysis. </doc>

```
<eqn>6000000</eqn>

<format precision="100000" scale_by="1"/>

<range min="3000000" max="9000000"/>

<units>USD</units>
```

```
</aux>

<aux name="VC funding availability.\nData 2004-2025 +\nTrend 2025-2050">

  <doc>${Data}
```

This variable represents the empirical data of early-stage VC funding availability in USD from 2004 to 2025 (International Energy Agency, n.d.) and an estimated value from 2000 to 2004, as well as the trendline for 2025 to 2050.

The sectors included are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries. The total funding is the sum of these sectors at each given year multiplied by the share of early-stage funding of the total funding in that year across all energy technologies. Early-stage funding is defined as initial coin offering, angel, convertible note, pre-seed, seed, series A and series B. </doc>

```
<eqn>TIME</eqn>

<gf>

  <xscale min="2000" max="2050"/>

  <yscale min="5000000" max="410000000"/>
```

```
<ypts>6000000,6000000,6000000,6000000,6017817,5261457,1778247,9760563,93825895,25215182,11016955,
22290823.1,41026165,28689650.7,50243368.44,35420290,153151565,70156637,156163046,73200699,92316756.79,27
0555236,298030124,252531662,238029410,160000000,170000000,180000000,190000000,200000000,210000000,2200
00000,230000000,240000000,250000000,260000000,270000000,280000000,290000000,300000000,310000000,320000
000,330000000,340000000,350000000,360000000,370000000,380000000,390000000,400000000,410000000</ypts>
```

```
</gf>

<units>USD/year</units>
```

```
</aux>

<aux name="industry funding\nneed">
```

<doc>This variable represent the total funding need of all the startups in the industry, a function of the amount of startups and the average funding need per startup. </doc>

```
<eqn>Startups*average_funding_need</eqn>
```

<units>USD</units>

</aux>

<aux name="relative funding availability">

<doc>This variable represents the VC funding availability in a given year relative to the funding need of the industry. </doc>

<eqn>"early-stage_VC_funding_availability"

/

industry_funding_need</eqn>

<units>dmnl</units>

</aux>

<aux name="average funding need">

<doc>\${Uncertain}

This variable represents average funding need per startup and it is based on the empirical data for energy technologies globally. The value 18.1M is calculated based on the median value for angel, pre-seed, seed, series A and series B rounds (International Energy Agency, 2025-a). The value is uncertain and the upper bound 40.3M is set based on the mean funding amount. It is more appropriate to use median values instead of mean because the funding need can be heavily skewed due to some lucrative funding rounds for certain startups. </doc>

<eqn>18100000</eqn>

<range min="10000000" max="40000000"/>

<units>USD/firm</units>

</aux>

<aux name="startup lifetime">

<doc>This variable represents the startup lifetime and is determined by the funding availability relative to the funding need and the average startup lifetime. The variable controls the rate of the valley of death outflow from startups. </doc>

<eqn>average_startup_lifetime

*

effect_of_funding_availability_on_startup_lifetime</eqn>

<units>year</units>

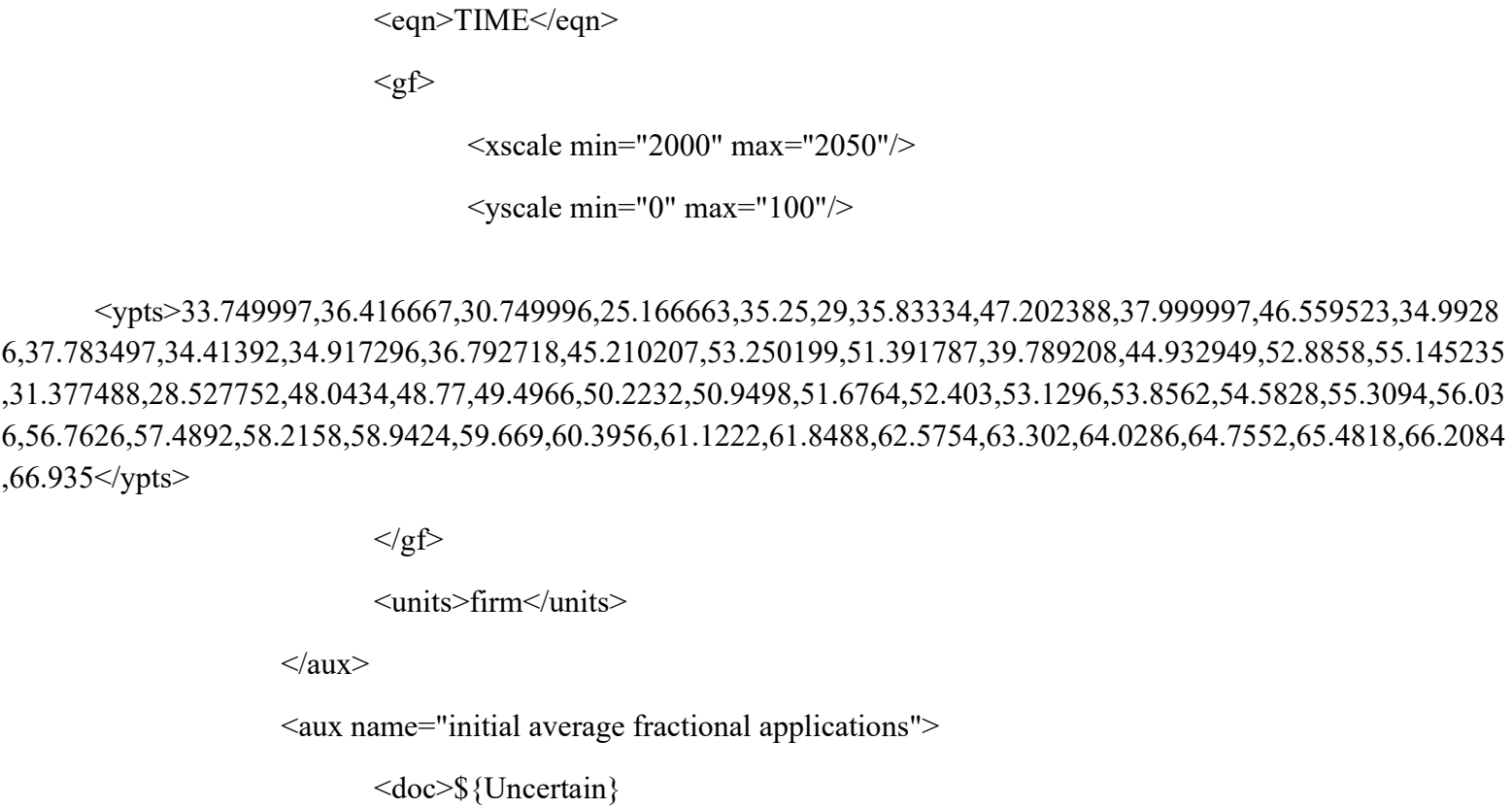
</aux>

<aux name="New Entrants.\nData 2000-2024 +\nTrend 2025-2050">

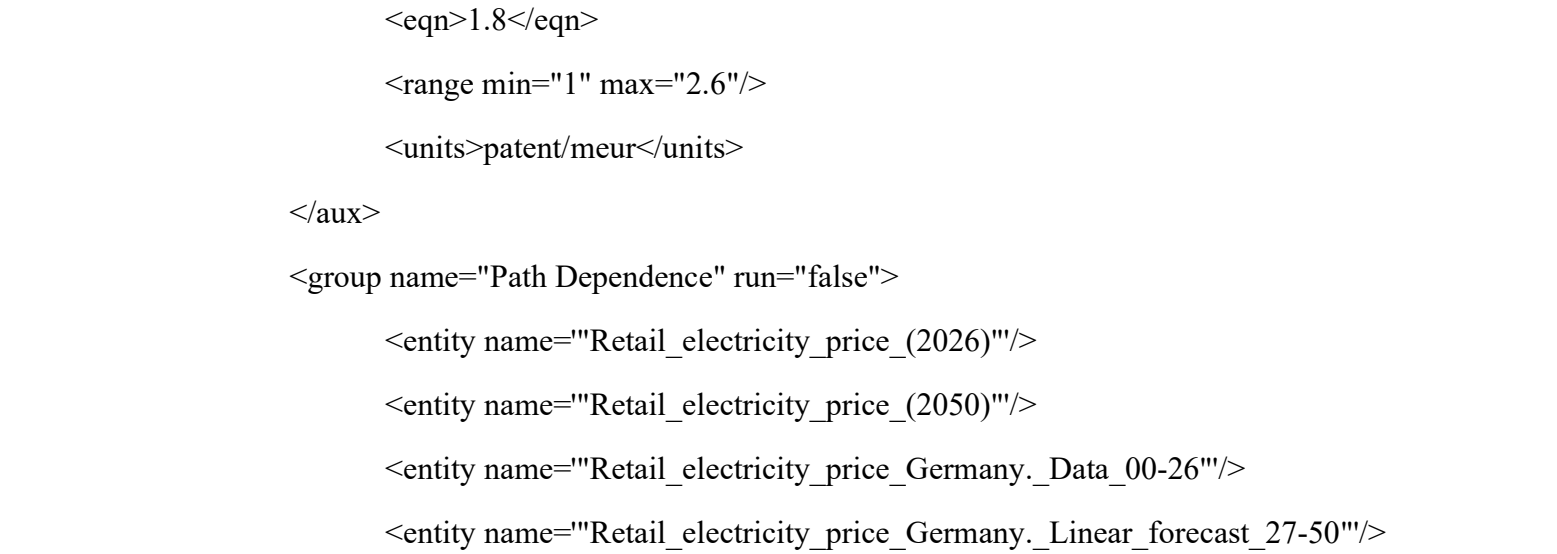
<doc>\${Data}

This variable represents the empirical data of startups from 2000 to 2024 (International Energy Agency, 2025-a) and an estimated value from 2025 to 2050. Certain years data was missing and thus an estimated value was input based on the surrounding years values.

The sectors included are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries.



This variable represents the initial patent filings rate per million euros of public funding. The initial value is uncertain but estimated to be high due to the high amount of patenting activity around solar energy in 2000 Eurostat data which found that 400 patents on average are filed for every billion euros invested in R&D in Germany (Félix, 2008).



<entity name="utilities_average_revenue_(2024_value)"/>
 <entity name="annual_generation_rooftop_pv"/>
 <entity name="capacity_factor"/>
 <entity name="effect_of_lost_sales_on_lobbying"/>
 <entity name="hours_per_year"/>
 <entity name="lobby_max_effectiveness"/>
 <entity name="lobby_sensitivity"/>
 <entity name="lost_utility_sales"/>
 <entity name="market_share_of_incumbent"/>
 <entity name="percentage_loss_in_sales"/>
 <entity name="retail_electricity_price"/>
 <entity name="slope_of_retail_electricity_price"/>
 <entity name="years_since_2027"/>
 </group>
 <aux name="Residential Technical\nPotential">

<doc>This variable represents the total potential installed capacity of any size systems. The total technical potential for photovoltaic electricity generation on residential buildings' roofs in Germany has been calculated as 148 TWh, which translates to an installable capacity of roughly 208 GWp (Mainzer et al., 2014).</doc>

<eqn>208</eqn>
 <format precision="1"/>
 <range min="188" max="228"/>
 <units>GW</units>
 </aux>
 <aux name="share of 10 kWp">
 <doc>\${Uncertain}

This variable represents the share of total residential technical potential in Germany which is of systems of 10 kWp and below.

According to studies of residential building sector 83% of Germany's residential building stock is single and two-family buildings (Real Ruiz et al., 2020). We assume that of these potential single and two-family homes, roughly 60-70% would install a system of 10 kWp or below, based on the 2024 share of installations by size in Germany (Fraunhofer ISE, 2025). Thus an uncertainty range of 50-60% is used. </doc>

$$0.55$$

 format precision="0.01"

 range min="0.5" max="0.6"

 units>dmnl</units>

 </aux>

 <aux name="Installed Rooftop PV 10 kWp.\nData 00-24 + Linear\nforecast">

 <doc>\${Data}

The variable represents the estimated installed capacity from 2000-2024 for the solar rooftop segment below 10 kWp and a linear forecast from 2025-2050 based on empirical data from Fraunhofer ISE (2025-a).

The 2000 value is estimated at 0.1 GW based on the value of installed capacity in 2001 and the share of additions in the 10 kWp and below segment during these years. The value from 2001-2024 is calculated by adding the installation rate (see "Installation rate. Data 00-24 + Linear forecast") to the previous years value. </doc>

$$TIME$$

 <gf>

 yscale min="0" max="74"

 <xpts>2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050</xpts>

 <ypts>0.1,0.15427,0.19457,0.28207,0.42947,0.65771,0.88532,1.15223,1.52273,2.05625,2.72585,3.50845,4.22287,4.65008,4.87308,5.08962,5.33795,5.63715,6.00549,6.59233,7.75279,8.77483,9.59433,12.88089,15.29065,17.628,19.84725,22.0665,24.28575,26.505,28.72425,30.9435,33.16275,35.382,37.60125,39.8205,42.03975,44.259,46.47825,48.6975,50.91675,53.136,55.35525,57.5745,59.79375,62.013,64.23225,66.4515,68.67075,70.89,73.10925</ypts>

 </gf>

 units>GW</units>

 </aux>

 <aux name="Installation rate.\nData 00-24 + Linear\nforecast">

 <doc>\${Data}

The variable represents the estimated installation rate from 2000-2024 for the solar rooftop segment below 10 kWp and a linear forecast from 2025-2050 based on empirical data from Fraunhofer ISE (2025-a).

The value from 2000-2024 is calculated by subtracting the installed capacity of a year by the preceding capacity and then multiplying the value by the percentage share of capacity additions from the building below 10 kWp segment. The value for 2025 is calculated by subtracting the total installed capacity forecasted value from the previous years, and then multiplying by a fixed 15% share of additions. This 15% is subject to uncertainty as a significantly lower share is possible due to increases in larger rooftop and utility-scale systems.

 TIME $\langle gf \rangle$

<xscale min="2000" max="2050"/>

<yscale min="0" max="3.7"/>

<ypts>0.02,0.05427,0.0403,0.0875,0.1474,0.22824,0.22761,0.26691,0.3705,0.53352,0.6696,0.7826,0.71442,0.42
721,0.223,0.21654,0.24833,0.2992,0.36834,0.58684,1.16046,1.02204,0.8195,3.28656,2.40976,2.33735,2.21925,2.21925
,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,
5,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925,2.21925</ypts>

<units>GW/year</units>

<aux name="utilities average\nrevenue (2024 value)">

<doc>This variable is the 2024 yearly revenue of the big four utilities in Germany based on annual reports (Vattenfall AB, 2025; E.ON SE, 2025; EnBW Energie Baden-Württemberg AG, 2025; RWE AG, 2025).</doc>

$$165000000000$$

```
<range min="150000000000" max="180000000000"/>
```

<units>euro/year</units>

<aux name="percentage\nloss in sales">

<doc>This variable represents the percentage in lost sales of the incumbent relative to their total yearly revenue. </doc>

$$\text{lost utility sales} \times \text{market share of incumbent}$$

/

"utilities average revenue (2024 value)"

`<units>dmnl</units>`

<aux name="Solar LCOE.\nData 00-25 + Fraunhofer\nISE Forecast 26-45">

<doc>\${Data}

This represents the empirical data of solar LCOE from 2000-2025 and Fraunhofer ISE Forecast from 2026-2045. The behavior over time from 2000 to 2025 was compiled by examining Fraunhofer ISE's 5 LCOE reports from 2012 to 2024, and choosing the mean value for LCOE out of the specified uncertainty ranges (Kost et al., 2012; Kost et al., 2013; Kost et al., 2018; Kost et al., 2021; Kost et al., 2024). The forecast of LCOE is in the 2024 version of the report (Kost et al., 2024).

<eqn>TIME</eqn>

<gf>

<yscale min="0" max="0.5"/>

<xpts>2000,2001,2002,2003,2004,2005,2006,2007,2008,2009,2010,2011,2012,2013,2014,2015,2016,2017,2018,2019,2020,2021,2022,2023,2024,2025,2026,2027,2028,2029,2030,2031,2032,2033,2034,2035,2036,2037,2038,2039,2040,2041,2042,2043,2044,2045,2046,2047,2048,2049,2050</xpts>

<ypts>0.5,0.47,0.44,0.41,0.38,0.35,0.33,0.31,0.29,0.27,0.25,0.2,0.15,0.12,0.11,0.1,0.098,0.096,0.095,0.09,0.085,0.08,0.088,0.094,0.1,0.098,0.096,0.094,0.092,0.09,0.088,0.086,0.084,0.083,0.081,0.08,0.079,0.079,0.078,0.078,0.077,0.077,0.076,0.076,0.075,0.075,0.075,0.075,0.075,0.075,0.075</ypts>

</gf>

<units>€/kwh</units>

</aux>

<aux name="total firms">

<doc>This variable represents the total amount of venture-backed firms in the system, startups and mature firms. </doc>

<eqn>Mature_Firms+Startups</eqn>

<units>firm</units>

</aux>

<aux name="initial total installed solar energy capacity">

<doc>This variable represents the initial amount of GW of total installed solar energy capacity in Germany in 2000. The value is set at 0.114 GW (Our World in Data, 2025-a).</doc>

<eqn>0.114</eqn>

<units>GW</units>

</aux>

<aux name="initial share of 10 kWp rooftop pv">

<doc>\${Uncertain}

This variable represents the percentage share of total installed capacity from rooftop PV systems of 10 kWp and below in Germany in the year 2000. The value is estimated between 70% and 90% based on Fraunhofer ISE's Photovoltaics Report (2025-a).

$$0.8$$

$$0.001$$

$$0.7 \text{ } 0.9$$

$$\text{dmnl}$$

This variable represents the new installations. Its value is determined by the planned installations divided by the installation time, and multiplied by a crowding effect.

$$\frac{\text{planned_new_installations}}{\text{installation_time}} \times \text{effect_of_crowding_on_installation_rate}$$

$$\text{GW/year}$$

normal social norms effect

Uncertain

This variable is an anchor for the social norms effect implying that when total social exposure is equal to the reference social exposure, social norms effect is medium, 0.5 on a scale of 0-1.

Rooftop PV ownership is a visible status and can become part of ones identity, similar to that of a road vehicles and thus a similar value to previous studies is justified (Struben & Sterman, 2008).

$$0.5$$

$$0.01$$

$$0.4 \text{ } 0.6$$

$$\text{dmnl}$$

effect of crowding\ non installation rate

This variable represents an explicit crowding effect whereby new installation rate slows down as the total potential capacity is being reached, representing that the easiest sites and highest willingness households adopt first. This is consistent with the literature on innovation diffusion whereby adopter categories (innovators, early adopters, early majority, late majority and laggards) adopt at subsequently slower rates (Rogers, 2003).

$$<eqn>1-(relative_installed_capacity^2)</eqn>$$

<units>dmnl</units>

</aux>

<aux name="installations per year">

<doc>\${Uncertain}

This represents the amount of installations in GW that one installer can complete per year. NREL report estimates that residential crew can install one system per day (Reiter & Margolis, 2023). Estimating from roughly 100 systems of 8 kWp and below systems comes out to 0.0008 GW per installer per year.</doc>

$$<eqn>0.0008</eqn>$$

<range min="0.0007" max="0.0009"/>

<units>GW/installer/year</units>

</aux>

<aux name="installation capacity">

<doc>Installation capacity is a function of installers and installations per year, the value controls how many GW of installed capacity can be added to the system in a given year. </doc>

$$<eqn>installers*installations_per_year</eqn>$$

<units>GW/year</units>

</aux>

<aux name="installers to firms ratio">

<doc>\${Uncertain}

This variable represents the ratio of installer to total firms, startups and mature firms, in the modeled system. The value is uncertain and estimated at 30 based on comparing the historical ratio of venture-backed firms, modeled endogenously as firms, and installations in Germany (Fraunhofer ISE, 2025-a), taking into account the maximum installations per year (Reiter & Margolis, 2023). </doc>

$$<eqn>30</eqn>$$

<range min="10" max="50"/>

<units>installer/firm</units>

</aux>

<aux name="installers">

<doc>This variable represents installers, who are necessary to install residential rooftop pv systems. A recent workforce studies in Germany highlight the worker shortage of installers, underscoring the importance (Malin et al., 2022). </doc>

$$<eqn>total_firms*installers_to_firms_ratio</eqn>$$

<units>installer</units>

</aux>

<aux name="relative familiarity">

<doc>This variable represents the current familiarity of the platform relative to the maximum familiarity.</doc>

<eqn>Familiarity

/

max_familiarity</eqn>

<units>dmnl</units>

</aux>

<aux name="average marketing spend">

<doc>\${Uncertain}

This variable represents the percentage of the total industry revenue spent on marketing of the platform. An uncertain variable set at a conservative 5% based on a generic marketing budget benchmark for high tech firms (Thanh Thuy & Klymova 2022). </doc>

<eqn>0.05</eqn>

<range min="0.03" max="0.15"/>

<units>dmnl</units>

</aux>

<aux name="marketing budget">

<doc>This variable represents the total annual marketing expenditure of firms active in the modeled rooftop PV segment, computed as a fixed share of industry yearly revenue.

</doc>

<eqn>average_marketing_spend

*

industry_yearly_revenue</eqn>

<units>euro/year</units>

</aux>

<aux name="lobby max effectiveness">

<doc>\${Uncertain}

This variable represents the maximum lobby effectiveness to which the incumbent lobbying variable saturates to. The variable is set higher than policy and firms marketing effectiveness because of the political power that the incumbent

regime has due to their economic impact. The value is uncertain and can be set higher or lower, signaling the incumbent regime's power.

0.09
 $\text{range min}="0.06" \text{ max}="0.12"$
 $\text{units} \text{1/year}$

$\text{aux name}="lobby \text{ sensitivity}"$
 $\text{doc} \{Uncertain\}$

This variable represents the sensitivity of lobbying efforts to lost sales of the incumbents and defines the slope of incumbent lobbying. It is uncertain set at 40.

40
 $\text{range min}="35" \text{ max}="45"$
 $\text{units} \text{dmnl}$

$\text{aux name}="effect \text{ of lost sales on lobbying}"$

doc This variable represents the effect of lobbying by the incumbent regime on policy. The equation defines how strong lobbying becomes as incumbents lose sales, saturating at a maximum effectiveness. It's non-linear, as initial increases in lobbying budget will increase effectiveness more.

Increased energy generation by private individuals is a threat to utilities' business models and leads to an erosion of their revenues. In response, utility companies, particularly the big four in German, spend high sums on lobbying efforts (Engelken et al., 2014; Sühlsen & Hisschemöller, 2014).

$(1-\text{EXP}(-\text{lobby_sensitivity}*\text{percentage_loss_in_sales}))$

$\text{lobby_max_effectiveness}$

$\text{units} \text{1/year}$

$\text{aux name}="Policy \text{ marketing duration}"$

doc The variable represents the duration of the policy marketing. It is set at 50 years in the base run under the assumption that policy will be in favor of solar energy until 2050.

50
 $\text{format precision}="1"$

<range min="0" max="50"/>

<units>year</units>

</aux>

<aux name="Policy marketing start time">

<doc>This variable represents the start time of the policy to market solar pv as a platform. It is set at 2000 based on the start time of the EEG act (German Bundestag, 2014/2023). </doc>

<eqn>2000</eqn>

<format precision="1"/>

<range min="2000" max="2040"/>

<units>year</units>

</aux>

<aux name="Policy marketing effectiveness">

<doc>\${Uncertain}

This variable represents the effectiveness of policy marketing of solar energy. The value is highly uncertain and estimated based on behavioral calibration to data. While the value is uncertain, it enables scenario analysis in relative increases or decreases in policy effectiveness.

The German government has actively marketed solar energy to consumers since 2000 (German Bundestag, 2014/2023). </doc>

<eqn>0.0015</eqn>

<format precision="full"/>

<range min="0.001" max="0.002"/>

<units>1/year</units>

</aux>

<aux name="market\nshare of incumbent">

<doc>\${Uncertain}

This value, 0.59, represents the percentage of market share held by the four largest private utility companies in 2014 (RAP, 2015). The value is uncertain and held constant throughout the simulation.</doc>

<eqn>0.59</eqn>

<range min="0.5" max="0.7"/>

<units>dmnl</units>

</aux>

<aux name="eur to meur">

<doc>This variable converts amount of euros to millions of euros for ensuring unit consistency.</doc>

<eqn>1000000</eqn>

<units>eur/meur</units>

</aux>

<aux name="expected\nrevenue for exit">

<doc>\${Uncertain}

This variable represents an expected revenue from for a startup to make a successful exit, estimated at 10 million euros. Revenue growth is an indicator of growth potential and highly influences the ability of a company to attract buyouts and IPOs. Data from US found that median revenue at IPO was roughly \$67M (WilmerHale, 2024).

The value is uncertain and set at half of the median amount because the system only accounts for revenues directly from rooftop pv systems below 10 kWp, and firms may well have other revenue channels, such as larger installations or other services.

</doc>

<eqn>20000000</eqn>

<format precision="100"/>

<range min="10000000" max="50000000"/>

<units>euro/firm/year</units>

</aux>

<aux name="relative revenue">

<doc>This variable represents the revenue per firm relative to the expected revenue to make a successful exit. </doc>

<eqn>revenue_per_firm/expected_revenue_for_exit</eqn>

<units>dmnl</units>

</aux>

<aux name="effect of revenue\nnon success rate">

<doc>This variable represents the effect of revenue per firm on success rates of startups. Revenue growth is an indicator of growth potential and highly influences the ability of a company to attract buyouts and IPOs.

The equation is a logistic growth function scaled from minimum 0 to max effect of 2, meaning success rate can only double with higher revenues. The midpoint occurs when revenue is equal to the expected revenue for exit, or relative revenue of 1.

$$\frac{\text{success_rate_max_effect}}{(1+\text{EXP}((- \text{success_rate_sensitivity} * (\text{relative_revenue} - 1))))}$$

dmnl

success rate sensitivity

This variable represents how sensitive success rate is to changes in revenue.

4

range min="2" max="6"

dmnl

market effect on nearly-stage VC funding

This variable represents the effect of relative installed capacity, or market maturity, on early-stage venture capital funding availability.

Venture investors in energy sector typically want to invest only after most technical and market risks have been overcome (Murphy & Edwards, 2003). As the market becomes more mature, VC funding in a sector increases, which is also consistent with the data for solar energy in Germany (International Energy Agency, 2025-a).

$$\text{funding_max_effect} * (1 - \text{EXP}(- \text{funding_sensitivity} * \text{relative_installed_capacity}))$$

dmnl

funding max effect

{Uncertain}

Maximum VC funding relative to initial is calibrated to real-world data of how much the VC funding could grow in the solar energy sector relative to the initial funding availability.

$$70$$

range min="40" max="80"

dmnl

</aux>

<aux name="effect of market maturity on opportunity">

<doc>This variable represents the effect of market maturity on opportunity. Startups in emerging industries often grapple with demand uncertainty, and thus intense uncertainty about potential opportunities (Guerra et al., 2025). As consumer adoption increases, characterized as installed capacity, this serves as a signal to entrepreneurs that uncertainty concerning opportunities is decreasing. Theory of organizational ecology maintains that more market maturity increases legitimacy and thus founding rates rise until the market reaches a saturation (Hannan & Freeman, 1977).

The equation is a logistic function where effect of relative capacity on opportunity is strongest around the inflection point and sensitivity controls how steep the slope of the curve is at the inflection point.</doc>

<eqn>1

/

(1+EXP(-opportunity_sensitivity*(relative_installed_capacity-opportunity_midpoint)))</eqn>

<units>dmnl</units>

</aux>

<aux name="opportunity sensitivity">

<doc>\${Uncertain}

This variable represents how sensitive perceived opportunity of entrepreneurs is to installed capacity, conceptually entrepreneurs' risk appetite. Mathematically it controls how steep the slope of the curve is and is steepest at the inflection point. The variable is subject to uncertainty.</doc>

<eqn>40</eqn>

<range min="30" max="50"/>

<units>dmnl</units>

</aux>

<aux name="crowding effect">

<doc>This variable represents a crowding effect of perceived opportunity for entrepreneurs as the market reaches maturity and becomes less attractive for new entrants.

Theory of organization ecology suggests that as an environment, in this case the solar PV market, exhausts its capacity the rate of growth of organizations in the population decreases (Hannan & Freeman 1977). Relative installed capacity serves as an effective proxy of carrying capacity of the environment. </doc>

<eqn>crowding_min_effect

+

$$\frac{((1-\text{crowding_min_effect})}{(1+\text{EXP}(\text{crowding_sensitivity}*(\text{relative_installed_capacity}-\text{crowding_midpoint})))}$$

<units>dmnl</units>

</aux>

<aux name="crowding sensitivity">

<doc>\${Uncertain}

This variable represents how sharply perceived entrepreneurial opportunity declines as the market approaches its carrying capacity, defining the steepness of the crowding effect around the midpoint installed capacity.</doc>

<eqn>24</eqn>

<range min="20" max="28"/>

<units>dmnl</units>

</aux>

<aux name="Economies of Scale effect">

<doc>Economies of scale are reported by PTP scholars to have a impact on improving price and performance of rooftop solar (Lenton et al., 2023; Ayoub and Geels, 2024). Nemet using technological forecasting methods found that one of the biggest factors that led to a drop in solar module prices was increasing plant size, or economies of scale (2006). </doc>

$$\text{economies_of_scale_min_effect}+((1-\text{economies_of_scale_min_effect})*\text{EXP}(-\text{economies_of_scale_sensitivity}*\text{relative_installed_capacity}))$$

<units>dmnl</units>

</aux>

<aux name="economies of scale sensitivity">

<doc>\${Uncertain}

This variable represents the sensitivity of solar LCOE to cumulative installed capacity through economies of scale, controlling how quickly cost declines as relative installed capacity increases.</doc>

<eqn>15</eqn>

<range min="10" max="20"/>

<units>dmnl</units>

</aux>

<aux name="Learning-by-doing effect">

$$\text{relative_mature_firms}^{\text{learning-by-doing sensitivity}}$$

dmnl

This variable represents the learning-by-doing which is an effect of more firms in the market on the cost of solar energy. As a market matures, firms knowledge of the market, technology and consumers increases (Guerra et al., 2025). Learning-by-doing is cited to improve price and performance of low-carbon technologies and has been observed in the solar pv industry in Germany (Lenton et al., 2023; Ayoub and Geels, 2024).

learning-by-doing sensitivity

Uncertain

This variable represents how sensitive the solar LCOE is to the relative amount of firms in the system, through the learning-by-doing effect.

0.2

range min="0.1" max="2"

dmnl

initial startups

Uncertain

This variable represents the initial amount of startup firms in the system, set at an estimated value of 50 based on startup creation data of Germany (International energy Agency, 2025-a). The sectors included in the dataset are Solar and related technologies which effect the dynamics of rooftop PV adoption including Grid, Energy Efficiency and Energy Storage and Batteries.

50

range min="20" max="80"

firm

effect of funding availability on startup lifetime

This variable represents the effect of VC funding availability on startups lifetime. When early-stage VC funding availability matches the industry funding need, the effect on startup lifetime will 1, meaning startup lifetime is equal to the average of 5 years.

This effect is uncertain and can be adjusted by adjusting the sensitivity of funding to lifetime and the minimum effect which controls the lower bound of startup lifetime.

$$\text{VOD_min_effect} +$$

$$((1-VOD_min_effect)*$$

$$(1/(1+EXP(-VOD_sensitivity*(relative_funding_availability-VOD_midpoint))$$

$$)))</eqn>$$

<units>dmnl</units>

</aux>

<aux name="VOD sensitivity">

<doc>\${Uncertain}

This variable represents the sensitivity of startup lifetime to funding. The higher K means the effect reacts more to funding availability and visa versa. The value is estimated and subject to uncertainty. </doc>

$$<eqn>14</eqn>$$

<range min="10" max="20"/>

<units>dmnl</units>

</aux>

<aux name="VOD min effect">

<doc>\${Uncertain}

This variable controls the lower bound of the funding effect on startup lifetime. Initially set at 0.2, representing that when funding availability is extremely low, startup lifetime approaches 20% of the average (1 year initially). The variable is subject to uncertainty and set based on (IfM Bonn, 2023).</doc>

$$<eqn>0.5</eqn>$$

<range min="0.1" max="0.5"/>

<units>dmnl</units>

</aux>

<aux name="opportunity midpoint">

<doc>\${Uncertain}

This variable represents what percentage of installed capacity relative to the total potential, corresponds with the highest increase in perceived opportunity. A higher inflection point, means that entrepreneurs are effectively more risk-averse, and prefer to see more demand before entering the market. </doc>

$$<eqn>0.15</eqn>$$

<range min="0.1" max="0.5"/>

<units>dmnl</units>

</aux>

<aux name="funding sensitivity">

<doc>\${Uncertain}

This variable represents the sensitivity of VC availability to market maturity. When the value is higher, VC availability reacts strongly to small signals of market maturity around the inflection point; and when the value is low VC availability more risk-averse thus needing to see more evidence of market maturity before deploying significant amounts of additional capital. </doc>

<eqn>4</eqn>

<range min="2" max="6"/>

<units>dmnl</units>

</aux>

<aux name="weight of regulation">

<doc>This variable represents the weight of regulation in shaping perceived entrepreneurial opportunity, defined as the complement of the market-maturity weight so that the two weights sum to one.</doc>

<eqn>1-weight_of_market_maturity</eqn>

<units>dmnl</units>

</aux>

<aux name="share of German industry from\nresidential rooftop PV">

<doc>\${Uncertain}

This variable represents the share of total German solar industry revenue that is attributable to residential rooftop PV systems of 10 kWp and below, used to scale segment revenues up to the whole industry.

It is calibrated as 0.325 based on Fraunhofer ISE's breakdown of cumulative capacity and system counts by size class, where rooftop systems below 10 constitute the majority of installation (66-67%), however given their smaller size a substantial minority of capacity (roughly 20%). This combined with higher specific prices for small rooftop systems compared to commercial rooftop and utility-scale plants justifies the estimated share of revenue in a range of 30-40% (Fraunhofer ISE, 2025-a; Wirth, 2025).</doc>

<eqn>0.325</eqn>

<range min="0.3" max="0.4"/>

<units>dmnl</units>

</aux>

<aux name="total solar industry revenue">

<doc>This variable represents the total annual revenue of the German solar industry across all segments, obtained by scaling the modeled residential rooftop segment by its estimated share of national industry revenue.</doc>

<eqn>industry_yearly_revenue/share_of_German_industry_from_residential_rooftop_PV</eqn>

<units>euro/year</units>

</aux>

<aux name="grant rate">

<doc>\${Uncertain}

This variable represents the average percentage filed patents which are granted,. Based on EPO Patent Index data we calculate a grant rate of 71% for the time period 2015-2024 for Energy technologies (2025-b). </doc>

<eqn>0.7</eqn>

<range min="0.5" max="0.9"/>

<units>dmnl</units>

</aux>

<aux name="average time to decision">

<doc>\${Uncertain}

This variable represents the average time it takes for a decision on a patent application to be made, and is set based on European Patent Office data (2025-a). </doc>

<eqn>2</eqn>

<range min="1" max="3"/>

<units>year</units>

</aux>

<stock name="Filed Patents">

<doc>This stock represents the amount of filed patents. It is determined by the inflow of applications and outflows of grants and not granted patent applications. </doc>

<eqn>initial_patents</eqn>

<inflow>applications</inflow>

<outflow>grants</outflow>

<outflow>not_granted</outflow>

<units>patent</units>

</stock>

<flow name="grants">

<doc>This flow is the outflow of filed patents and inflow of patents stocks. It represents the amount of granted patents per year, a function of the amount of filed patents, the grant rate and time for a grant or not grant decision to be made. </doc>

<eqn>(Filed_Patents*grant_rate)
/
average_time_to_decision</eqn>

<units>patent/year</units>

</flow>

<aux name="Patent Applications for Solar and Storage.\nData 2000-2020 +\nTrend 2020-2050">

<doc>\${Data}

This variable represents the empirical data from International Energy Agency for amount of patent applications per year in Germany for solar energy and battery storage technologies (2025-b).

</doc>

<eqn>TIME</eqn>

<gf isee:roll_forward="true">

<xscale min="2000" max="2050"/>

<yscale min="0" max="1600"/>

<ypts>150.92,198.95,205.67,197.11,258.78,272.57,350.11,502.31,664.86,970.05,1057.82,1043.59,950.34,742.5,
767.25,690.89,667.2,790.36,866.42,776.64,772.84,817.921,842.252,866.583,890.914,915.245,939.576,963.907,988.238,
1012.569,1036.9,1061.231,1085.562,1109.893,1134.224,1158.555,1182.886,1207.217,1231.548,1255.879,1280.21,1304
.541,1328.872,1353.203,1377.534,1401.865,1426.196,1450.527,1474.858,1499.189,1523.52</ypts>

</gf>

<units>patent/year</units>

</aux>

<aux name="Public R&D Solar + Storage.\nData 2000-2023">

<doc>\${Data}

This variable represents the amount of millions of euros of public R&D funding into solar energy and battery storage technologies in Germany based on empirical data for 2000 to 2023 from International Energy Agency (2024).</doc>

<eqn>TIME</eqn>

<gf>

<xscale min="2000" max="2023"/>

<yscale min="0" max="240"/>

<ypts>70.149,83.4,75.4,71,44.347,54.394,54.546,48.922,65.937,77.753,91.503,111.8,115.409,140.518,136.25,16
9.849,187.841,234.879,204.521,242.73,213.742,230.982,197.092,223.12</ypts>

</gf>

<units>meur/year</units>

</aux>

<flow name="not granted">

<doc>This is the outflow of not granted patents from the filed patents stock, calculated as a
function of not granted percentage of the filed patents and time to decision. </doc>

<eqn>(Filed_Patents*not_grant_rate)

/
average_time_to_decision</eqn>

<units>patent/year</units>

</flow>

<aux name="not grant rate">

<doc>This variable is the percentage of patent applications which are not granted,
calculated as 100% less the grant rate. </doc>

<eqn>1-grant_rate</eqn>

<units>dmnl</units>

</aux>

<aux name="Business Model\nInnovation Effect">

<doc>This variable represents the effect of business model innovation on accessibility.
Firms have an effect on improving accessibility of new technologies (Lenton et al., 2023). Novel business model
innovations in solar PV have emerged according to market needs and customer pains. For example, business models,
such as power purchase agreements and energy-as-a-service models can offload CAPEX and operating burdens from
consumers (IRENA, 2019).

The equation represents a logistic growth function, whereby initially accessibility increases exponentially towards the
inflection point of relative firms is reached, set at 5. After the inflection point the business model effect diminishes for
each additional mature firm. </doc>

<eqn>BMI_baseline_effect+

BMI_max_effect*(1/(1+EXP(-BMI_sensitivity*(relative_mature_firms-BMI_threshold))))</eqn>

<units>dmnl</units>

</aux>

<aux name="total R&D spending">

<doc>This variable represents total annual R&D investment in solar energy and storage in Germany, combining public R&D support with private R&D spending by firms.</doc>

<eqn>"Public_R&D_Solar+_Storage._Data_2000-2023"+"private_R&D_spend"</eqn>

<units>meur/year</units>

</aux>

<aux name="BMI baseline effect">

<doc>\${Uncertain}

This variable represents the initial effect of BMI on solar rooftop accessibility and therefore acts as a lower bound for the effect.</doc>

<eqn>0.5</eqn>

<range min="0.3" max="0.7"/>

<units>dmnl</units>

</aux>

<aux name="BMI max effect">

<doc>\${Uncertain}

This variable represents the maximum effect of BMI on the solar rooftop accessibility. The variable is uncertain with an upper bound of 5 and lower bound of 3. </doc>

<eqn>4</eqn>

<format precision="0.01"/>

<range min="3" max="5"/>

<units>dmnl</units>

</aux>

<aux name="BMI sensitivity">

<doc>\${Uncertain}

This variable represents the sensitivity of BMI to the amount of mature firm. The value is subject to uncertainty and set at 0.7.</doc>

<eqn>0.7</eqn>

<range min="0.5" max="0.9"/>

<units>dmnl</units>

</aux>

<aux name="BMI threshold">

<doc>\${Uncertain}

This variable defines the inflection point of relative mature firms at which the business model innovation effect on accessibility is strongest; beyond this point, additional mature firms yield diminishing accessibility gains.</doc>

<eqn>5</eqn>

<range min="2.5" max="7.5"/>

<units>dmnl</units>

</aux>

<aux name="effect of patents\non fractional\npatent applications">

<doc>This variable represents how the rate of patent applications per million euro of R&D spending responds to the accumulated stock of patents, bounded between lower and upper limits and decreasing as the patent base grows.</doc>

<eqn>patent_min_effect+(patent_max_effect*EXP(-patent_sensitivity*relative_patents))</eqn>

<units>dmnl</units>

</aux>

<aux name="patent min effect">

<doc>\${Uncertain}

This variable defines the minimum fraction of the initial application intensity that persists even at high patent stocks, ensuring a floor to how low the responsiveness of new applications to patents can fall.</doc>

<eqn>0.23</eqn>

<range min="0.1" max="0.3"/>

<units>dmnl</units>

</aux>

<aux name="patent max effect">

<doc>This variable defines the maximum additional share that patent-driven application intensity can contribute above the lower bound, ensuring the fractional application effect remains bounded between 0 and 1.</doc>

<eqn>1-patent_min_effect</eqn>

<units>dmnl</units>

</aux>

<aux name="patent sensitivity">

<doc>\${Uncertain}

This variable represents how strongly the fractional patent-application rate responds to changes in the stock of patents; higher values imply that small changes in relative patents lead to larger shifts in application intensity.</doc>

<eqn>0.05</eqn>

<range min="0.02" max="0.08"/>

<units>dmnl</units>

</aux>

<aux name="effect of cost on utility">

<doc>This logistic utility function represents the effect of cost to benefit ratio, and thus solar LCOE, on the utility of rooftop solar. When solar is economically attractive and thus the cost-benefit ratio is small, the value of the effect approaches, or maximum effect on utility; and when unattractive the effect approaches 0. </doc>

<eqn>1

//

(1+EXP(cost_benefit_sensitivity*(cost_to_benefit_ratio_of_solar-cost_benefit_threshold)))</eqn>

<units>dmnl</units>

</aux>

<aux name="cost benefit threshold">

<doc>\${Uncertain}

This threshold represents the inflection point at which cost to benefit ratio, the effect is equal to 0.5 </doc>

<eqn>1.15</eqn>

<range min="1" max="1.3"/>

<units>dmnl</units>

</aux>

<aux name="cost benefit sensitivity">

<doc>\${Uncertain}

This variable represents how sharply the effect changes around the threshold, thereby controlling the steepness of the logistic function. </doc>

<eqn>2</eqn>

<range min="1" max="3"/>

<units>dmnl</units>

</aux>

<aux name="VOD midpoint">

<doc>\${Uncertain}

This variable represents the relative funding availability at which the effect of VC funding on startup lifetime equals the midpoint of its logistic response, i.e. where lifetime is most sensitive to changes in funding.</doc>

<eqn>0.5</eqn>

<range min="0.4" max="0.6"/>

<units>dmnl</units>

</aux>

<aux name="success rate max effect">

<doc>\${Uncertain}

This variable defines the maximum multiplicative increase in startup success rate that can be achieved through higher revenue per firm, relative to the baseline average success rate. The value is uncertain and set at a plausible range between 1.5 and 2.5 based on success rates of startups from International Energy Agency (2025-a), indicating that success rate can only increase by 50-250% at even very high average revenues. </doc>

<eqn>2</eqn>

<range min="1.5" max="2.5"/>

<units>dmnl</units>

</aux>

<aux name="crowding min effect">

<doc>\${Uncertain}

This variable defines the lower bound of the crowding effect on perceived opportunity, ensuring that even in a very mature market some residual opportunity signal remains.</doc>

<eqn>0.2</eqn>

<range min="0.1" max="0.3"/>

<units>dmnl</units>

</aux>

<aux name="crowding midpoint">

<doc>\${Uncertain}

This variable represents the relative installed capacity at which the crowding effect on perceived opportunity is at its inflection point, marking the transition from an emerging to a more saturated market.</doc>

$$<eqn>0.6</eqn>$$

$$<range\ min="0.4"\ max="0.8"/>$$

$$<units>dmnl</units>$$

</aux>

<aux name="Technological\nreinforcement effect">

<doc>This variable represents the effect of cumulative patents on reinforcing technological progress beyond pure scale effects, reducing LCOE as the patent stock grows but with diminishing marginal impact. The effect of R&D, patent activity, on cost reductions in solar pv is documented in empirical studies (Nemet, 2006) as well as qualitative tipping points literature (Lenton et al., 2023; Ayoub and Geels, 2024).</doc>

$$<eqn>\text{"R\&D_min_effect"}+$$

$$((1-\text{"R\&D_min_effect"})*$$

$$\text{EXP}(-\text{"R\&D_sensitivity"}*\text{relative_patents}))</eqn>$$

$$<units>dmnl</units>$$

</aux>

<aux name="R&D min effect">

<doc>\${Uncertain}

This variable represents the minimum effect of technological reinforcement on the LCOE. It is set at 0.45, 50% higher than the minimum economies of scale effect based on empirical data from Nemet, which found plant size (economies of scale) to account for 50% more of the cost decreases in solar modules (2006). </doc>

$$<eqn>0.45</eqn>$$

$$<range\ min="0.3"\ max="0.5"/>$$

$$<units>dmnl</units>$$

</aux>

<aux name="R&D sensitivity">

<doc>\${Uncertain}

This variable represents the sensitivity of the technological reinforcement effect to the amount of patents. When the value is higher, small changes in patents around the midpoint will have relatively larger effect, and visa versa.</doc>

$$<eqn>0.3</eqn>$$

$$<range\ min="0.2"\ max="0.4"/>$$

$$<units>dmnl</units>$$

</aux>

<aux name="economies of scale min effect">

<doc>\${Uncertain}

This variable represents the minimum effect of economies of scale on the LCOE. It is set at 0.3 lower than the minimum technological reinforcement effect based on empirical data from Nemet, which found plant size (economies of scale) to account for 50% more of the cost decreases in solar modules (2006). </doc>

<eqn>0.3</eqn>

<range min="0.2" max="0.4"/>

<units>dmnl</units>

</aux>

<aux name="funding availability\ndelay time">

<doc>\${Uncertain}

This variable represents the time it takes venture capital industry to react to changes in market maturity, estimated at 2 years based on empirical data of typical amount of time it takes to solicit money from limited partners and close a new fund (Gompers and Lerner 1998).

</doc>

<eqn>2</eqn>

<range min="1" max="3"/>

<units>years</units>

</aux>

<aux name="Retail electricity price (2026)">

<doc>This value represents the historical household electricity price in Germany in 2026 (Open Energy Tracker, 2026).</doc>

<eqn>0.373</eqn>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="slope of retail electricity price">

<doc>This variable represent the slope of the linearly forecasted retail electricity price in Germany from 2027-2050. The value is calculated by subtracting the price in 2026 by the price in 2050 and divided by 24 (the number of years between 2050 and 2026). </doc>

<eqn>("Retail_electricity_price_(2050)"-
"Retail_electricity_price_(2026)")

/

24</eqn>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="Retail electricity price Germany.\nLinear forecast 27-50">

<doc>This variable represents the linear forecast of retail electricity price for households in Germany from 2027 to 2050. It is calculated by adding the retail electricity price in 2026 to the slope of retail electricity price multiplied by the amount of time since the be</doc>

<eqn>"Retail_electricity_price_(2026)"

+

(slope_of_retail_electricity_price

*years_since_2027)</eqn>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="years since 2027">

<doc>This variable represents the years since 2027 for calculating the linearly forecasted retail electricity price.</doc>

<eqn>TIME-2027</eqn>

<units>dmnl</units>

</aux>

<aux name="Retail electricity price (2050)">

<doc>\${Uncertain}

The variable represents the retail electricity price in 2050, which is used to calculate the slope of retail electricity price. The value is uncertain and is set at the same value at 0.45, representing a moderate increase based on the assumption from Fraunhofer ISE's study by Henning and Palzer (2015). </doc>

<eqn>0.45</eqn>

<range min="0.3" max="0.7"/>

<units>euro/(KW*Hours)</units>

</aux>

<aux name="gap between new installations and installation capacity">

<doc>This variable represents the gap between new installations to be made and the installation capacity.</doc>

<eqn>new_installations

-

installation_capacity</eqn>

<units>GW/year</units>

</aux>

<aux name="R&D Policy Switch">

<doc>This demand policy switch controls when and for how long the public R&D funding is implemented. </doc>

<eqn>(STEP(1, "R&D_policy_start")

-

STEP(1, "R&D_policy_start"+"R&D_policy_duration"))</eqn>

<units>dmnl</units>

</aux>

<aux name="R&D policy\nduration">

<doc>This variable represents the duration of the R&D policy.

The user can test scenarios in which the policy duration lasts for varying amount of years from 0 to 50. </doc>

<eqn>200</eqn>

<format precision="1"/>

<range min="0" max="50"/>

<units>year</units>

</aux>

<aux name="R&D policy start">

<doc>This variable represents the start year of the R&D policy.

The user can test scenarios in which the policy start at different point of the simulation time period from 2000 to 2049. </doc>

<eqn>2000</eqn>

<format precision="1"/>

<range min="2000" max="2049"/>

<units>year</units>

</aux>

<aux name="Public R&D">

<doc>This variable represents the public R&D spending determined by the R&D spending amount and policy switch, either on or off. </doc>

<eqn>"Public_R&D_Solar+_Storage._Data_2000-2023"

*

"R&D_Policy_Switch"</eqn>

<units>meur/year</units>

</aux>

</variables>

<views>

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<aux x="1402.84" y="1280.83" name="average module lifetime"/>

<flow x="1246.67" y="990.566" name="installations">

<pts>

<pt x="1246.67" y="820.333"/>

<pt x="1246.67" y="1151.8"/>

</pts>

</flow>

<stock label_side="center" x="439.416" y="1234.69" width="83" height="54" name="Familiarity"/>

<aux label_side="left" x="952.219" y="1198.41" name="probability of contact\nwith adopter"/>

<flow label_side="bottom" x="358.5" y="1265.86" name="familiarity gain">

<pts>

<pt x="265.583" y="1265.86"/>

<pt x="439.416" y="1265.86"/>

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</flow>

<flow label_side="right" label_angle="45" x="480.916" y="1402.35" name="familiarity loss">

<pts>

<pt x="480.916" y="1288.69"/>

<pt x="480.916" y="1525"/>

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        </pts>
    </flow>
    <aux label_side="top" x="634.166" y="882.529" name="effective contact\nrate of
adopter"/>

    <aux x="634.166" y="953.194" name="installed social effect"/>
    <connector uid="2" polarity="+" isee:polarity_placement="outside" angle="104.843">
        <from>probability_of_contact_with_adopter</from>
        <to>installed_social_effect</to>
    </connector>
    <connector uid="3" polarity="+" isee:polarity_placement="outside" angle="270">
        <from>effective_contact_rate_of_adopter</from>
        <to>installed_social_effect</to>
    </connector>
    <aux label_side="right" label_angle="315" x="383.583" y="1062.19" name="total social
exposure"/>
    <aux label_side="right" x="637.166" y="1008.57" name="effective contact\nrate of non-
adopter"/>
    <aux label_side="left" label_angle="225" x="634.166" y="1080.19" name="non-installed
social effect"/>

    <connector uid="5" polarity="+" isee:polarity_placement="outside" angle="267.602">
        <from>&quot;effective_contact_rate_of_non-adopter&quot;</from>
        <to>&quot;non-installed_social_effect&quot;</to>
    </connector>
    <connector uid="6" polarity="+" isee:polarity_placement="outside" angle="147.322">
        <from>&quot;non-installed_social_effect&quot;</from>
        <to>total_social_exposure</to>
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    <aux x="347.583" y="1413.19" name="Social Norms effect"/>
    <connector uid="7" polarity="-" isee:polarity_placement="outside" angle="181.033">
        <from>total_social_exposure</from>
        <to>Social_Norms_effect</to>

```

</connector>

<connector uid="8" polarity="+" isee:polarity_placement="outside" angle="176.104">

<from>installed_social_effect</from>

<to>total_social_exposure</to>

</connector>

<connector uid="9" polarity="+" isee:polarity_placement="outside" angle="229.853">

<from>total_social_exposure</from>

<to>familiarity_gain</to>

</connector>

<connector uid="10" polarity="-" isee:polarity_placement="outside" angle="161.509">

<from>Familiarity</from>

<to>familiarity_gain</to>

</connector>

<aux x="554.166" y="1442.08" name="normal forget rate"/>

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<from>normal_forget_rate</from>

<to>familiarity_loss</to>

</connector>

<connector uid="12" polarity="+" isee:polarity_placement="outside" angle="339.452">

<from>Social_Norms_effect</from>

<to>familiarity_loss</to>

</connector>

<connector uid="13" polarity="+" isee:polarity_placement="outside" angle="225">

<from>Familiarity</from>

<to>familiarity_loss</to>

</connector>

<aux label_side="left" x="884.996" y="1360.2" name="probability of contact\nwith non-adopter"/>

<aux background="black" label_side="top" x="1243.84" y="749.75" name="initial installed rooftop pv"/>

```

    <aux label_side="right" label_angle="45" x="1100.17" y="1356.74" name="total
potential\nrooftop PV 10 kWp"/>

    <aux label_side="right" label_angle="315" x="1246.67" y="1428.83" name="non-
installed\npotential rooftop PV"/>

    <connector uid="14" polarity="+" isee:polarity_placement="outside" angle="333.799">

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        <to>&quot;non-installed_potential_rooftop_PV&quot;</to>

    </connector>

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    </flow>

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        <from>Installed_Rooftop_PV_10_kWp</from>

        <to>degradation_rate</to>

    </connector>

    <connector uid="16" polarity="-" isee:polarity_placement="outside" angle="271.455">

        <from>Installed_Rooftop_PV_10_kWp</from>

        <to>&quot;non-installed_potential_rooftop_PV&quot;</to>

    </connector>

    <aux x="1410.26" y="1110.92" name="replacements"/>

    <connector uid="17" polarity="+" isee:polarity_placement="outside" angle="51.0856">

        <from>degradation_rate</from>

        <to>replacements</to>

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    <connector uid="18" angle="105.094">

        <from>replacements</from>

        <to>installations</to>

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```

</connector>

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    <to>new_installations</to>
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    <to>&quot;probability_of_contact_with_non-adopter&quot;</to>
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<connector uid="23" polarity="-" isee:polarity_placement="outside" angle="180.92">
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    <to>&quot;probability_of_contact_with_non-adopter&quot;</to>
</connector>

<connector uid="24" polarity="+" isee:polarity_placement="outside" angle="103.735">
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    <to>&quot;non-installed_social_effect&quot;</to>
</connector>

<aux x="347.583" y="1492.86" name="elasticity of social\nnorms to social exposure"/>
<connector uid="26" polarity="+" isee:polarity_placement="outside" angle="90">
    <from>elasticity_of_social_norms_to_social_exposure</from>
    <to>Social_Norms_effect</to>
</connector>

<aux label_side="left" x="198.833" y="1418.83" name="reference social exposure"/>
<connector uid="27" polarity="+" isee:polarity_placement="outside" angle="2.17267">
    <from>reference_social_exposure</from>
    <to>Social_Norms_effect</to>
</connector>

<connector uid="31" polarity="-" isee:polarity_placement="outside" angle="91.6235">
    <from>average_module_lifetime</from>

```

```

        <to>degradation_rate</to>
    </connector>
    <aux x="1101.17" y="1198.41" name="relative installed capacity"/>
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        <from>Installed_Rooftop_PV_10_kWp</from>
        <to>relative_installed_capacity</to>
    </connector>
    <connector uid="33" polarity="-" isee:polarity_placement="outside" angle="89.6381">
        <from>total_potential_rooftop_PV_10_kWp</from>
        <to>relative_installed_capacity</to>
    </connector>
    <aux label_side="left" label_angle="135" x="1605.17" y="1423.08" name="planned new
installations"/>
    <aux label_side="left" label_angle="225" x="2343.32" y="1380.83" name="cost to benefit
ratio of solar"/>
    <connector uid="52" polarity="+" isee:polarity_placement="outside" angle="45.0348">
        <from>planned_new_installations</from>
        <to>new_installations</to>
    </connector>
    <aux label_side="left" label_angle="135" x="1410.26" y="1594.53" name="perceived
utility"/>
    <connector uid="68" polarity="+" isee:polarity_placement="outside" angle="19.7238">
        <from>perceived_utility</from>
        <to>planned_new_installations</to>
    </connector>
    <connector uid="80" polarity="+" isee:polarity_placement="outside" angle="180">
        <from>relative_installed_capacity</from>
        <to>probability_of_contact_with_adopter</to>
    </connector>
    <aux label_side="top" x="389.583" y="1180.41" name="max familiarity"/>
    <connector uid="116" polarity="+" isee:polarity_placement="outside" angle="250.01">

```

LCOE"/>

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<from>max_familiarity</from>
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  <to>solar_LCOE</to>
</connector>
<aux label_side="right" x="253.916" y="766.529" name="policy effect"/>
<connector uid="150" polarity="+" isee:polarity_placement="outside" angle="0.918891">
  <from>&quot;non-installed_potential_rooftop_PV&quot;</from>
  <to>planned_new_installations</to>
</connector>
<aux label_side="right" label_angle="45" x="2359.49" y="1036.67" name="solar
LCOE"/>
<aux label_side="top" x="1677.51" y="1760.25" name="utility of solar"/>
<aux label_side="right" x="2048.51" y="1760.25" name="accessibility of alternative"/>
<aux label_side="top" x="2471.82" y="1671.49" name="initial accessibility"/>
<flow label_side="right" x="2998.83" y="809.75" name="Valley of Death">
  <pts>
    <pt x="2998.83" y="862.333"/>
    <pt x="2998.83" y="748.167"/>
  </pts>
</flow>
<flow label_side="bottom" x="2866.42" y="887.499" name="new entrants">
  <pts>
    <pt x="2764.17" y="887.499"/>
    <pt x="2956.67" y="887.499"/>
  </pts>
</flow>
```

```

name="Startups"/>
<stock label_side="center" x="2956.67" y="862.333" width="80.3333" height="61"

<connector uid="138" polarity="+" isee:polarity_placement="outside" angle="150.842">
    <from>Startups</from>
    <to>Valley_of_Death</to>
</connector>

<aux label_side="top" x="3331.11" y="665" name="average success rate"/>
<connector uid="143" polarity="+" isee:polarity_placement="outside_stem"
angle="220.927">
    <from>average_success_rate</from>
    <to>success_rate</to>
</connector>

<aux label_side="left" label_angle="135" x="2471.82" y="1765.33" name="solar rooftop
accessibility"/>

<aux label_side="left" label_angle="225" x="2045.27" y="1854.08" name="relative
accessibility"/>

<connector uid="203" polarity="+" isee:polarity_placement="outside_stem" angle="270">
    <from>initial_accessibility</from>
    <to>solar_rooftop_accessibility</to>
</connector>

<aux label_side="top" x="461.916" y="717.417" name="marketing effectiveness"/>
<connector uid="226" polarity="+" isee:polarity_placement="outside" angle="305.021">
    <from>marketing_effectiveness</from>
    <to>marketing_effect</to>
</connector>

<group locked="false" x="9.7778" y="583.834" width="1024.69" height="1452.36"
name="Social Contagion"/>

<group locked="true" x="1854.12" y="57.2507" width="1816.08" height="1982.41"
name="Entrepreneurial Dynamics">
    <item uid="131"/>
    <item uid="538"/>
</group>

```

```

    <group locked="false" x="1036.92" y="575.917" width="816.203" height="1459.84"
name="Adoption Dynamics">

    <item uid="261"/>

</group>

<connector uid="280" polarity="+" isee:polarity_placement="outside" angle="0">

    <from>

        <alias uid="261"/>

    </from>

    <to>replacements</to>

</connector>

<stock label_side="center" x="3265.34" y="866.666" width="79" height="59"
name="Mature Firms"/>

<flow label_side="right" label_angle="315" x="3151.17" y="892.833" name="maturing">

    <pts>

        <pt x="3037" y="892.833"/>

        <pt x="3265.34" y="892.833"/>

    </pts>

</flow>

<connector uid="305" polarity="+" isee:polarity_placement="outside" angle="29.7445">

    <from>Startups</from>

    <to>maturing</to>

</connector>

<aux label_side="bottom" x="2748" y="1103.05" name="initial mature firms"/>

<aux label_side="right" label_angle="315" x="522.123" y="803.333" name="marketing
effect"/>

<connector uid="337" polarity="+" isee:polarity_placement="outside" angle="223.549">

    <from>marketing_effect</from>

    <to>total_social_exposure</to>

</connector>

<aux label_side="right" x="2605.5" y="731.666" name="perceived opportunity"/>

<aux label_side="top" x="2110.05" y="441.888" name="industry yearly revenue"/>

```

(2024)"/>

<aux label_side="bottom" x="2092.05" y="567.75" name="price PV rooftop\nsystem

<aux label_side="bottom" x="2184.83" y="505.667" name="GW to KW conversion"/>

<connector uid="353" polarity="+" isee:polarity_placement="outside" angle="139.54">

<from>GW_to_KW_conversion</from>

<to>industry_yearly_revenue</to>

</connector>

<connector uid="354" polarity="+" isee:polarity_placement="outside" angle="81.8611">

<from>"price_PV_rooftop_system_(2024)"</from>

<to>industry_yearly_revenue</to>

</connector>

<connector uid="364" polarity="+" isee:polarity_placement="outside" angle="58.2778">

<from>installations</from>

<to>industry_yearly_revenue</to>

</connector>

<connector uid="365" polarity="+" isee:polarity_placement="outside" angle="64.2344">

<from>Installed_Rooftop_PV_10_kWp</from>

<to>industry_yearly_revenue</to>

</connector>

<aux label_side="bottom" x="1992.05" y="585.75" name="O&M costs"/>

<connector uid="366" polarity="+" isee:polarity_placement="outside" angle="50.6404">

<from>"O&M_costs"</from>

<to>industry_yearly_revenue</to>

</connector>

<aux label_side="bottom" x="2691.29" y="325.833" name="revenue per firm"/>

<connector uid="372" polarity="+" isee:polarity_placement="outside" angle="22.9952">

<from>industry_yearly_revenue</from>

<to>revenue_per_firm</to>

</connector>

<aux label_side="left" x="2760.83" y="839.5" name="max entrants rate"/>

```
<connector uid="387" polarity="+" isee:polarity_placement="outside" angle="335.554">
  <from>max_entrants_rate</from>
  <to>new_entrants</to>
</connector>

<aux label_side="top" x="2970.67" y="700.333" name="average startup\nlifetime"/>
<connector uid="389" polarity="+" isee:polarity_placement="outside" angle="14.9192">
  <from>average_startup_lifetime</from>
  <to>startup_lifetime</to>
</connector>

<aux label_side="bottom" x="3116.79" y="940.5" name="average time to exit"/>
<connector uid="403" polarity="-" isee:polarity_placement="outside" angle="54.1975">
  <from>average_time_to_exit</from>
  <to>maturing</to>
</connector>

<aux background="red" label_side="bottom" x="2485.48" y="1353.67" name="FIT
amount.\nData 2000-2024 + Forecast 2025-2050"/>

<aux label_side="left" x="2081.34" y="1346.75" name="average percentage of\nself-
consumption"/>

<aux label_side="left" x="2129.13" y="1268.83" name="percentage of exports"/>
<connector uid="406" polarity="-" isee:polarity_placement="outside" angle="58.4777">
  <from>&quot;average_percentage_of_self-consumption&quot;</from>
  <to>percentage_of_exports</to>
</connector>

<connector uid="411" polarity="+" isee:polarity_placement="outside" angle="285.13">
  <from>solar_LCOE</from>
  <to>cost_to_benefit_ratio_of_solar</to>
</connector>

<connector uid="413" polarity="+" isee:polarity_placement="outside" angle="332.395">
  <from>percentage_of_exports</from>
  <to>cost_to_benefit_ratio_of_solar</to>
</connector>
```

```
<connector uid="414" polarity="+" isee:polarity_placement="outside" angle="90">
    <from>"FIT_amount._Data_2000-2024+_Forecast_2025-
2050"</from>

    <to>FIT</to>
</connector>

<aux background="red" label_side="right" label_angle="315" x="2485.48" y="1279.84"
name="FIT"/>

<connector uid="415" polarity="-" isee:polarity_placement="outside" angle="215.391">
    <from>FIT</from>

    <to>cost_to_benefit_ratio_of_solar</to>
</connector>

<aux background="red" label_side="right" x="2451.96" y="972.499" name="Demand
policy switch"/>

<connector uid="416" angle="276.224">
    <from>Demand_policy_switch</from>

    <to>FIT</to>
</connector>

<aux label_side="top" x="2581.05" y="651" name="weight of market maturity"/>
<connector uid="423" polarity="+" isee:polarity_placement="outside" angle="286.86">
    <from>weight_of_market_maturity</from>

    <to>perceived_opportunity</to>
</connector>

<aux label_side="top" x="1242.08" y="249.875" name="capacity factor"/>
<aux label_side="right" label_angle="315" x="1333.51" y="294" name="hours per
year"/>

<aux label_side="right" x="1186.33" y="352.57" name="annual generation rooftop pv"/>
<connector uid="461" polarity="+" isee:polarity_placement="outside" angle="43.041">
    <from>Installed_Rooftop_PV_10_kWp</from>

    <to>annual_generation_rooftop_pv</to>
</connector>

<connector uid="462" polarity="+" isee:polarity_placement="outside" angle="201.701">
```

sales"/>

```
<from>hours_per_year</from>
<to>annual_generation_rooftop_pv</to>
</connector>
<connector uid="463" polarity="+" isee:polarity_placement="outside" angle="241.504">
  <from>capacity_factor</from>
  <to>annual_generation_rooftop_pv</to>
</connector>
<aux label_side="left" label_angle="225" x="916.833" y="261" name="lost utility
sales"/>
<connector uid="467" polarity="+" isee:polarity_placement="outside" angle="148.469">
  <from>annual_generation_rooftop_pv</from>
  <to>lost_utility_sales</to>
</connector>
<connector uid="468" polarity="+" isee:polarity_placement="outside" angle="93.0174">
  <from>
    <alias uid="465"/>
  </from>
  <to>lost_utility_sales</to>
</connector>
<connector uid="470" polarity="+" isee:polarity_placement="outside" angle="192.952">
  <from>
    <alias uid="471"/>
  </from>
  <to>lost_utility_sales</to>
</connector>
<connector uid="510" polarity="+" isee:polarity_placement="outside" angle="203.354">
  <from>solar_rooftop_accessibility</from>
  <to>relative_accessibility</to>
</connector>
<aux label_side="top" x="1482.18" y="1755.83" name="weight of\accessibility"/>
```

```
<aux label_side="bottom" x="1554.34" y="1836.08" name="weight of cost"/>
<connector uid="513" polarity="+" isee:polarity_placement="outside" angle="358.704">
  <from>weight_of_accessibility</from>
  <to>utility_of_solar</to>
</connector>
```

```
<connector uid="514" polarity="+" isee:polarity_placement="outside" angle="31.6194">
  <from>weight_of_cost</from>
  <to>utility_of_solar</to>
</connector>
```

```
<connector uid="515" polarity="-" isee:polarity_placement="outside" angle="131.963">
  <from>weight_of_cost</from>
  <to>weight_of_accessibility</to>
</connector>
```

```
<connector uid="522" polarity="-" isee:polarity_placement="inside_stem"
angle="268.022">
  <from>accessibility_of_alternative</from>
  <to>relative_accessibility</to>
</connector>
```

```
<connector uid="523" polarity="+" isee:polarity_placement="outside" angle="182.834">
  <from>relative_accessibility</from>
  <to>utility_of_solar</to>
</connector>
```

```
<connector uid="524" polarity="+" isee:polarity_placement="outside" angle="160.185">
  <from>utility_of_solar</from>
  <to>perceived_utility</to>
</connector>
```

```
<aux background="red" label_side="top" x="2444.99" y="910.833" name="Demand
policy\nduration"/>
<connector uid="530" angle="276.452">
  <from>Demand_policy_duration</from>
  <to>Demand_policy_switch</to>
```

</connector>

<aux background="red" label_side="bottom" x="2552.38" y="1026" name="demand
policy start"/>

<connector uid="531" angle="151.953">

<from>demand_policy_start</from>

<to>Demand_policy_switch</to>

</connector>

<aux label_side="right" label_angle="315" x="916.833" y="177.888" name="retail
electricity price"/>

<connector uid="537" polarity="+" isee:polarity_placement="outside" angle="270">

<from>retail_electricity_price</from>

<to>lost_utility_sales</to>

</connector>

<aux background="red" label_side="top" x="789.834" y="177.888" name="Retail
electricity price Germany.\nData 00-26"/>

<connector uid="540" polarity="+" isee:polarity_placement="outside" angle="0">

<from>"Retail_electricity_price_Germany._Data_00-26"</from>

<to>retail_electricity_price</to>

</connector>

<connector uid="541" angle="308.526">

<from>

<alias uid="538"/>

</from>

<to>cost_to_benefit_ratio_of_solar</to>

</connector>

<connector uid="412" polarity="+" isee:polarity_placement="outside" angle="352.588">

<from>"average_percentage_of_self-consumption"</from>

<to>cost_to_benefit_ratio_of_solar</to>

</connector>

<aux label_side="left" label_angle="225" x="3248.84" y="736.333" name="success
rate"/>

```

name="Patents"/>
<stock label_side="center" x="3070.59" y="1296.5" width="83.6667" height="57"

name="Patents"/>
<flow label_side="left" label_angle="225" x="3518.5" y="1327" name="applications">
    <pts>
        <pt x="3627" y="1327"/>
        <pt x="3422" y="1327"/>
    </pts>
</flow>
<aux label_side="left" label_angle="225" x="3256.34" y="1171.16" name="fractional
applications"/>
<connector uid="568" polarity="+" isee:polarity_placement="inside" angle="344.476">
    <from>fractional_applications</from>
    <to>applications</to>
</connector>
<aux label_side="top" x="3536.98" y="613.914" name="R&D-to-sales ratio"/>
<aux label_side="right" x="3494.45" y="718.333" name="private R&D spend"/>
<connector uid="572" polarity="+" isee:polarity_placement="outside_stem"
angle="247.839">
    <from>&quot;R&D-to-sales_ratio&quot;</from>
    <to>&quot;private_R&D_spend&quot;</to>
</connector>
<connector uid="573" polarity="+" isee:polarity_placement="outside" angle="287.766">
    <from>&quot;private_R&D_spend&quot;</from>
    <to>applications</to>
</connector>
<connector uid="576" polarity="+" isee:polarity_placement="outside" angle="37.4697">
    <from>industry_yearly_revenue</from>
    <to>total_solar_industry_revenue</to>
</connector>
<aux label_side="right" x="2956.33" y="1579.33" name="initial patents"/>

```

```

patents"/>
<aux label_side="right" label_angle="315" x="2956.33" y="1489.33" name="relative
patents"/>
<connector uid="577" polarity="+" isee:polarity_placement="inside" angle="258.55">
    <from>Patents</from>
    <to>relative_patents</to>
</connector>
<connector uid="578" polarity="-" isee:polarity_placement="inside" angle="90">
    <from>initial_patents</from>
    <to>relative_patents</to>
</connector>
<aux label_side="right" x="2819.75" y="1036.67" name="relative mature firms"/>
<connector uid="584" polarity="-" isee:polarity_placement="outside" angle="38.0053">
    <from>initial_mature_firms</from>
    <to>relative_mature_firms</to>
</connector>
<aux label_side="top" x="2623.5" y="423.888" name="early-stage VC
funding\navailability"/>
<aux label_side="left" x="2637.29" y="491.23" name="initial\nearly-stage
funding\navailability"/>
<connector uid="590" polarity="+" isee:polarity_placement="outside" angle="101.573">
    <from>&quot;initial_early-stage_funding_availability&quot;</from>
    <to>&quot;early-stage_VC_funding_availability&quot;</to>
</connector>
<aux background="aqua" label_side="top" x="2544.05" y="400.388" name="VC funding
availability.\nData 2004-2025 +\nTrend 2025-2050"/>
<aux label_side="right" x="2787.83" y="683" name="industry funding\nneed"/>
<aux label_side="right" label_angle="45" x="2859.5" y="497.667" name="relative
funding availability"/>
<connector uid="597" polarity="+" isee:polarity_placement="outside" angle="356.339">
    <from>&quot;early-stage_VC_funding_availability&quot;</from>
    <to>relative_funding_availability</to>
</connector>

```

<connector uid="598" polarity="-" isee:polarity_placement="outside" angle="111.363">
 <from>industry_funding_need</from>
 <to>relative_funding_availability</to>
</connector>

<aux label_side="top" x="2713" y="590.58" name="average funding need"/>

<connector uid="601" polarity="+" isee:polarity_placement="outside" angle="308.996">
 <from>average_funding_need</from>
 <to>industry_funding_need</to>
</connector>

angle="256.403">
 <connector uid="614" polarity="+" isee:polarity_placement="outside_stem"

 <from>success_rate</from>
 <to>maturing</to>

</connector>

<aux label_side="right" x="3069.5" y="674" name="startup lifetime"/>

<connector uid="617" polarity="-" isee:polarity_placement="outside" angle="258.366">
 <from>startup_lifetime</from>
 <to>Valley_of_Death</to>
</connector>

<aux background="aqua" label_side="bottom" x="2893.33" y="932.333" name="New
Entrants.\nData 2000-2024 +\nTrend 2025-2050"/>

<aux label_side="left" x="3193.42" y="1130.75" name="initial average fractional
applications"/>

<connector uid="625" polarity="+" isee:polarity_placement="outside" angle="327.29">
 <from>initial_average_fractional_applications</from>
 <to>fractional_applications</to>
</connector>

<group locked="true" x="8.37" y="55.0125" width="1841.42" height="507.417"
name="Path Dependence">

 <item uid="465"/>

 <item uid="471"/>

</group>

<aux x="1100.17" y="1424.08" name="Residential Technical\nPotential"/>

<connector uid="634" polarity="+" isee:polarity_placement="outside" angle="90">

<from>Residential_Technical_Potential</from>

<to>total_potential_rooftop_PV_10_kWp</to>

</connector>

<aux label_side="top" x="1161.42" y="1286.41" name="share of 10 kWp"/>

<connector uid="635" polarity="+" isee:polarity_placement="outside" angle="228.949">

<from>share_of_10_kWp</from>

<to>total_potential_rooftop_PV_10_kWp</to>

</connector>

<aux background="aqua" label_side="top" x="1496.25" y="647.861" name="Installed
Rooftop PV 10 kWp.\nData 00-24 + Linear\nforecast"/>

<aux background="aqua" label_side="top" x="1494.25" y="717.417" name="Installation
rate.\nData 00-24 + Linear\nforecast"/>

<aux label_side="left" label_angle="135" x="438.916" y="214.888" name="utilities
average\nrevenue (2024 value)"/>

<aux label_side="right" label_angle="315" x="533.751" y="288.875"
name="percentage\nloss in sales"/>

<connector uid="636" polarity="+" isee:polarity_placement="outside" angle="322.04">

<from>"utilities_average_revenue_(2024_value)"</from>

<to>percentage_loss_in_sales</to>

</connector>

<connector uid="637" polarity="+" isee:polarity_placement="outside" angle="168.359">

<from>lost_utility_sales</from>

<to>percentage_loss_in_sales</to>

</connector>

<aux background="aqua" label_side="top" x="2141.63" y="1069.21" name="Solar
LCOE.\nData 00-25 + Fraunhofer\nISE Forecast 26-45"/>

<connector uid="643" angle="349.631">

<from>perceived_opportunity</from>

<to>new_entrants</to>

</connector>

<connector uid="644" polarity="+" isee:polarity_placement="outside" angle="241.135">

<from>Mature_Firms</from>

<to>relative_mature_firms</to>

</connector>

<aux label_side="right" label_angle="45" x="3331.11" y="305.721" name="total firms"/>

<connector uid="646" polarity="+" isee:polarity_placement="outside" angle="49.5512">

<from>Mature_Firms</from>

<to>total_firms</to>

</connector>

<connector uid="647" polarity="+" isee:polarity_placement="inside"
isee:label_placement="outside_mid_arc" angle="40.0198">

<from>Startups</from>

<to>total_firms</to>

</connector>

<aux background="black" label_side="left" label_angle="225" x="1174.42" y="767.75"
name="initial total installed solar energy capacity"/>

<aux background="black" label_side="right" x="1312.68" y="767.75" name="initial share
of 10 kWp rooftop pv"/>

<connector uid="652" polarity="+" isee:polarity_placement="outside" angle="165.346">

<from>initial_share_of_10_kWp_rooftop_pv</from>

<to>initial_installed_rooftop_pv</to>

</connector>

<connector uid="653" polarity="+" isee:polarity_placement="outside" angle="14.5355">

<from>initial_total_installed_solar_energy_capacity</from>

<to>initial_installed_rooftop_pv</to>

</connector>

<aux label_side="top" x="1557.92" y="901.5" name="new installations"/>

<connector uid="654" angle="173.934">

<from>new_installations</from>

<to>installations</to>

</connector>

<connector uid="656" angle="333.542">

<from>reference_social_exposure</from>

<to>elasticity_of_social_norms_to_social_exposure</to>

</connector>

<aux label_side="top" x="347.583" y="1348.19" name="normal social norms effect"/>

<connector uid="657" polarity="+" isee:polarity_placement="outside" angle="261.423">

<from>normal_social_norms_effect</from>

<to>Social_Norms_effect</to>

</connector>

<aux label_side="top" x="1126.75" y="954.499" name="effect of crowding\

installation rate"/>

<connector uid="658" polarity="-" isee:polarity_placement="outside" angle="100.484">

<from>relative_installed_capacity</from>

<to>effect_of_crowding_on_installation_rate</to>

</connector>

<connector uid="659" polarity="+" isee:polarity_placement="outside" angle="42.8868">

<from>effect_of_crowding_on_installation_rate</from>

<to>new_installations</to>

</connector>

<aux label_side="bottom" x="1528.17" y="1060.83" name="installations per year"/>

<aux label_side="right" x="1528.17" y="993.666" name="installation capacity"/>

<connector uid="665" polarity="+" isee:polarity_placement="outside" angle="90">

<from>installations_per_year</from>

<to>installation_capacity</to>

</connector>

<aux label_side="bottom" x="1768.03" y="874.833" name="installers to firms ratio"/>

<aux label_side="left" label_angle="135" x="1718.09" y="815.333" name="installers"/>

<connector uid="668" angle="130.008">

<from>installers_to_firms_ratio</from>

```
<to>installers</to>

</connector>

<connector uid="669" polarity="+" isee:polarity_placement="outside" angle="140.798">

  <from>total_firms</from>

  <to>installers</to>

</connector>

<connector uid="671" polarity="+" isee:polarity_placement="outside" angle="243.997">

  <from>installers</from>

  <to>installation_capacity</to>

</connector>

<connector uid="673" polarity="+" isee:polarity_placement="outside" angle="189.646">

  <from>installation_capacity</from>

  <to>installations</to>

</connector>

<connector uid="528" angle="165.93">

  <from>industry_yearly_revenue</from>

  <to>marketing_budget</to>

</connector>

<aux label_side="right" x="626.166" y="1247.86" name="relative familiarity"/>

<connector uid="686" polarity="+" isee:polarity_placement="outside" angle="356.498">

  <from>Familiarity</from>

  <to>relative_familiarity</to>

</connector>

<connector uid="687" angle="344.088">

  <from>max_familiarity</from>

  <to>relative_familiarity</to>

</connector>

<connector uid="688" polarity="+" isee:polarity_placement="outside" angle="71.5006">

  <from>relative_familiarity</from>

  <to>&quot;non-installed_social_effect&quot;</to>
```

</connector>

<connector uid="689" polarity="+" isee:polarity_placement="outside" angle="269.3">

<from>relative_familiarity</from>

<to>perceived_utility</to>

</connector>

<connector uid="692" polarity="+" isee:polarity_placement="outside" angle="278.154">

<from>policy_effect</from>

<to>total_social_exposure</to>

</connector>

<aux label_side="bottom" x="877.751" y="744.75" name="average marketing spend"/>

<connector uid="698" polarity="+" isee:polarity_placement="outside" angle="139.338">

<from>average_marketing_spend</from>

<to>marketing_budget</to>

</connector>

<aux label_side="left" x="744" y="629.861" name="marketing budget"/>

<connector uid="699" polarity="+" isee:polarity_placement="outside" angle="206.629">

<from>marketing_budget</from>

<to>marketing_effect</to>

</connector>

<aux label_side="right" x="443.916" y="475.333" name="lobby max effectiveness"/>

<connector uid="711" polarity="+" isee:polarity_placement="outside" angle="171.393">

<from>lobby_max_effectiveness</from>

<to>effect_of_lost_sales_on_lobbying</to>

</connector>

<aux label_side="left" x="169.369" y="436" name="lobby sensitivity"/>

<aux label_side="left" label_angle="225" x="325" y="457.333" name="effect of lost sales
on lobbying"/>

<connector uid="712" angle="206.3">

<from>percentage_loss_in_sales</from>

<to>effect_of_lost_sales_on_lobbying</to>

</connector>

<connector uid="713" polarity="+" isee:polarity_placement="outside" angle="352.195">

<from>lobby_sensitivity</from>

<to>effect_of_lost_sales_on_lobbying</to>

</connector>

<aux color="black" background="red" label_side="left" x="183.369" y="858.667"

name="Policy marketing duration"/>

<aux color="black" background="red" label_side="left" x="158.5" y="815.527"

name="Policy marketing start time"/>

<aux color="black" background="red" label_side="left" x="191.167" y="699.417"

name="Policy marketing effectiveness"/>

<connector uid="716" polarity="+" isee:polarity_placement="outside" angle="313.076">

<from>Policy_marketing_effectiveness</from>

<to>policy_effect</to>

</connector>

<connector uid="717" angle="27.1816">

<from>Policy_marketing_start_time</from>

<to>policy_effect</to>

</connector>

<connector uid="718" angle="52.5599">

<from>Policy_marketing_duration</from>

<to>policy_effect</to>

</connector>

<connector uid="719" angle="241.912">

<from>effect_of_lost_sales_on_lobbying</from>

<to>policy_effect</to>

</connector>

<aux label_side="top" x="566" y="187.98" name="market\nshare of incumbent"/>

<connector uid="720" angle="252.275">

<from>market_share_of_incumbent</from>

<to>percentage_loss_in_sales</to>

```

</connector>
<aux x="3578.25" y="773.917" name="eur to meur"/>
<connector uid="721" polarity="-" isee:polarity_placement="outside" angle="146.443">
    <from>eur_to_meur</from>
    <to>&quot;private_R&amp;D_spend&quot;</to>
</connector>
<connector uid="735" polarity="+" isee:polarity_placement="outside" angle="6.53282">
    <from>revenue_per_firm</from>
    <to>relative_revenue</to>
</connector>
<connector uid="648" polarity="-" isee:polarity_placement="outside" angle="155.4">
    <from>total_firms</from>
    <to>revenue_per_firm</to>
</connector>
<aux label_side="top" x="3004.33" y="312.166" name="expected\nrevenue for exit"/>
<aux label_side="left" label_angle="225" x="2965.05" y="358.666" name="relative
revenue"/>
<connector uid="736" polarity="-" isee:polarity_placement="outside" angle="229.811">
    <from>expected_revenue_for_exit</from>
    <to>relative_revenue</to>
</connector>
<aux label_side="bottom" x="3173.79" y="497.667" name="effect of revenue\non success
rate"/>
<connector uid="738" polarity="+" isee:polarity_placement="inside_stem"
angle="338.582">
    <from>relative_revenue</from>
    <to>effect_of_revenue_on_success_rate</to>
</connector>
<aux label_side="left" x="3207" y="413.055" name="success\nrate sensitivity"/>
<connector uid="740" polarity="+" isee:polarity_placement="inside_stem"
angle="248.57">

```

<from>success_rate_sensitivity</from>
 <to>effect_of_revenue_on_success_rate</to>
 </connector>
 <connector uid="741" polarity="+" isee:polarity_placement="inside_stem"
 angle="304.721">
 <from>effect_of_revenue_on_success_rate</from>
 <to>success_rate</to>
 </connector>
 <aux x="2316.82" y="515.667" name="market effect on\nearly-stage VC funding"/>
 <connector uid="742" polarity="+" isee:polarity_placement="outside" angle="69.4367">
 <from>
 <alias uid="131"/>
 </from>
 <to>"market_effect_on_early-stage_VC_funding"</to>
 </connector>
 <connector uid="744" polarity="+" isee:polarity_placement="outside" angle="32.8596">
 <from>"market_effect_on_early-stage_VC_funding"</from>
 <to>"early-stage_VC_funding_availability"</to>
 </connector>
 <aux label_side="top" x="2268.15" y="459.888" name="funding max effect"/>
 <connector uid="745" polarity="+" isee:polarity_placement="outside" angle="311.106">
 <from>funding_max_effect</from>
 <to>"market_effect_on_early-stage_VC_funding"</to>
 </connector>
 <aux label_side="left" label_angle="135" x="2385.32" y="651" name="effect of
 market\nmaturity on opportunity"/>
 <connector uid="746" polarity="+" isee:polarity_placement="inside_stem"
 angle="65.534">
 <from>
 <alias uid="131"/>
 </from>

```

        <to>effect_of_market_maturity_on_opportunity</to>
    </connector>
    <connector uid="747" polarity="+" isee:polarity_placement="inside_stem"
angle="358.643">

        <from>effect_of_market_maturity_on_opportunity</from>

        <to>perceived_opportunity</to>
    </connector>
    <aux x="2371.49" y="696.333" name="opportunity sensitivity"/>
    <connector uid="748" angle="73.0306">

        <from>opportunity_sensitivity</from>

        <to>effect_of_market_maturity_on_opportunity</to>
    </connector>
    <aux label_side="left" x="2259.32" y="783" name="crowding effect"/>
    <connector uid="749" polarity="-" isee:polarity_placement="outside" angle="40.056">

        <from>

            <alias uid="131"/>

        </from>

        <to>crowding_effect</to>
    </connector>
    <aux label_side="bottom" x="2316.82" y="832" name="crowding sensitivity"/>
    <connector uid="751" polarity="+" isee:polarity_placement="inside_stem"
angle="21.0943">

        <from>crowding_effect</from>

        <to>perceived_opportunity</to>
    </connector>
    <connector uid="752" angle="139.563">

        <from>crowding_sensitivity</from>

        <to>crowding_effect</to>
    </connector>
    <aux label_side="left" x="2208.3" y="930.333" name="Economies of Scale effect"/>
    <connector uid="754" polarity="-" isee:polarity_placement="outside" angle="31.6256">

```

```

    <from>
        <alias uid="131"/>
    </from>
    <to>Economies_of_Scale_effect</to>
</connector>
<aux label_side="right" label_angle="315" x="2249.63" y="892.833" name="economies
of scale sensitivity"/>
<connector uid="755" angle="222.218">
    <from>economies_of_scale_sensitivity</from>
    <to>Economies_of_Scale_effect</to>
</connector>
<connector uid="756" angle="351.416">
    <from>Economies_of_Scale_effect</from>
    <to>solar_LCOE</to>
</connector>
<aux label_side="left" label_angle="135" x="2637.29" y="966.333" name="Learning-by-
doing effect"/>
<connector uid="757" polarity="-" isee:polarity_placement="outside" angle="120.737">
    <from>relative_mature_firms</from>
    <to>&quot;Learning-by-doing_effect&quot;</to>
</connector>
<aux label_side="bottom" x="2609.96" y="857.5" name="learning-by-doing sensitivity"/>
<connector uid="759" angle="270.555">
    <from>&quot;learning-by-doing_sensitivity&quot;</from>
    <to>&quot;Learning-by-doing_effect&quot;</to>
</connector>
<connector uid="760" polarity="+" isee:polarity_placement="outside" angle="206.654">
    <from>&quot;Learning-by-doing_effect&quot;</from>
    <to>solar_LCOE</to>
</connector>
<aux label_side="bottom" x="3006" y="996.333" name="initial startups"/>

```

<connector uid="763" angle="148.37">

<from>Startups</from>

<to>industry_funding_need</to>

</connector>

<aux label_side="left" x="2996.84" y="549.75" name="effect of funding\navailability

on\nstartup lifetime"/>

<connector uid="764" polarity="+" isee:polarity_placement="outside" angle="355.012">

<from>relative_funding_availability</from>

<to>effect_of_funding_availability_on_startup_lifetime</to>

</connector>

<aux label_side="left" label_angle="135" x="3059.5" y="473.23" name="VOD

sensitivity"/>

<connector uid="766" angle="230.685">

<from>VOD_sensitivity</from>

<to>effect_of_funding_availability_on_startup_lifetime</to>

</connector>

<aux label_side="top" x="3087.5" y="558.416" name="VOD min effect"/>

<connector uid="767" angle="174.54">

<from>VOD_min_effect</from>

<to>effect_of_funding_availability_on_startup_lifetime</to>

</connector>

<connector uid="779" polarity="+" isee:polarity_placement="outside" angle="342.033">

<from>effect_of_funding_availability_on_startup_lifetime</from>

<to>startup_lifetime</to>

</connector>

<aux label_side="top" x="2469.96" y="624.167" name="opportunity midpoint"/>

<connector uid="780" angle="197.59">

<from>opportunity_midpoint</from>

<to>effect_of_market_maturity_on_opportunity</to>

</connector>

<aux label_side="top" x="2395.49" y="441.888" name="funding sensitivity"/>

```
<connector uid="781" angle="223.162">
  <from>funding_sensitivity</from>
  <to>&quot;market_effect_on_early-stage_VC_funding&quot;</to>
</connector>
```

```
<aux label_side="right" label_angle="45" x="2651.5" y="665" name="weight of
regulation"/>
```

```
<connector uid="782" angle="235.396">
  <from>weight_of_regulation</from>
  <to>perceived_opportunity</to>
</connector>
```

```
<connector uid="783" angle="356.102">
  <from>weight_of_market_maturity</from>
  <to>weight_of_regulation</to>
</connector>
```

```
<connector uid="790" angle="57.481">
  <from>Demand_policy_switch</from>
  <to>perceived_opportunity</to>
</connector>
```

```
<aux label_side="top" x="2612.48" y="135.667" name="share of German industry
from\nresidential rooftop PV"/>
```

```
<connector uid="795" angle="329.896">
  <from>share_of_German_industry_from_residential_rooftop_PV</from>
  <to>total_solar_industry_revenue</to>
</connector>
```

```
<aux x="2684.67" y="194" name="total solar industry revenue"/>
```

```
<aux label_side="bottom" x="3157.42" y="1393.75" name="grant rate"/>
```

```
<aux label_side="left" label_angle="225" x="3313.63" y="1370.5" name="average time to
decision"/>
```

```
<connector uid="799" angle="10.205">
  <from>total_solar_industry_revenue</from>
  <to>&quot;private_R&amp;D_spend&quot;</to>
```

</connector>

<stock label_side="center" x="3341" y="1297.5" width="81" height="55" name="Filed

Patents"/>

<flow label_side="top" x="3247.63" y="1328" name="grants">

<pts>

<pt x="3341" y="1328"/>

<pt x="3154.26" y="1328"/>

</pts>

</flow>

<connector uid="800" polarity="+" isee:polarity_placement="inside" angle="153.173">

<from>Filed_Patents</from>

<to>grants</to>

</connector>

<connector uid="801" polarity="-" isee:polarity_placement="inside" angle="147.222">

<from>average_time_to_decision</from>

<to>grants</to>

</connector>

<connector uid="802" polarity="+" isee:polarity_placement="outside" angle="36.0871">

<from>grant_rate</from>

<to>grants</to>

</connector>

<aux background="aqua" x="3556" y="1465.83" name="Patent Applications for Solar and Storage.\nData 2000-2020 +\nTrend 2020-2050"/>

<aux background="red" label_side="left" label_angle="135" x="3309.11" y="1106.5" name="Public R&D Solar + Storage.\nData 2000-2023"/>

<connector uid="803" polarity="+" isee:polarity_placement="outside" angle="313.52">

<from>"Public_R&D_Solar+_Storage._Data_2000-2023"</from>

<to>"Public_R&D"</to>

</connector>

<flow label_side="right" x="3382" y="1411.75" name="not granted">

```

        <pts>
            <pt x="3382" y="1352.5"/>
            <pt x="3382" y="1480"/>
        </pts>
    </flow>
    <aux x="3300.42" y="1489.33" name="not grant rate"/>
    <connector uid="805" polarity="-" isee:polarity_placement="outside" angle="326.242">
        <from>grant_rate</from>
        <to>not_grant_rate</to>
    </connector>
    <connector uid="806" polarity="+" isee:polarity_placement="outside" angle="43.5603">
        <from>not_grant_rate</from>
        <to>not_granted</to>
    </connector>
    <connector uid="807" polarity="-" isee:polarity_placement="outside" angle="328.897">
        <from>average_time_to_decision</from>
        <to>not_granted</to>
    </connector>
    <connector uid="808" polarity="+" isee:polarity_placement="inside" angle="313.082">
        <from>Filed_Patents</from>
        <to>not_granted</to>
    </connector>
    <aux label_side="right" x="2714.92" y="1633" name="Business Model\nInnovation
Effect"/>
    <connector uid="817" angle="285.092">
        <from>relative_mature_firms</from>
        <to>Business_Model_Innovation_Effect</to>
    </connector>
    <aux label_side="left" label_angle="225" x="3468.5" y="869.499" name="total
R&D spending"/>
    <connector uid="818" polarity="+" isee:polarity_placement="outside" angle="56.078">

```

2023"Public_R&D_Solar+_Storage._Data_2000-

"total_R&D_spending"

</connector>

<connector uid="819" polarity="+" isee:polarity_placement="outside" angle="260.259">

<from>"private_R&D_spend"</from>

<to>"total_R&D_spending"</to>

</connector>

<aux label_side="left" label_angle="135" x="2599.17" y="1561.33" name="BMI baseline effect"/>

<connector uid="823" polarity="+" isee:polarity_placement="outside_mid_arc" angle="328.237">

<from>BMI_baseline_effect</from>

<to>Business_Model_Innovation_Effect</to>

</connector>

<aux label_side="top" x="2705.42" y="1539.17" name="BMI max effect"/>

<connector uid="824" polarity="+" isee:polarity_placement="outside_mid_arc" angle="275.781">

<from>BMI_max_effect</from>

<to>Business_Model_Innovation_Effect</to>

</connector>

<aux label_side="left" x="2588.67" y="1622.83" name="BMI sensitivity"/>

<connector uid="825" polarity="+" isee:polarity_placement="outside_mid_arc" angle="355.396">

<from>BMI_sensitivity</from>

<to>Business_Model_Innovation_Effect</to>

</connector>

<connector uid="826" polarity="+" isee:polarity_placement="outside_stem" angle="226.756">

<from>Business_Model_Innovation_Effect</from>

<to>solar_rooftop_accessibility</to>

</connector>

```

<aux x="2762.16" y="1689.49" name="BMI threshold"/>
<connector uid="829" angle="129.904">
    <from>BMI_threshold</from>
    <to>Business_Model_Innovation_Effect</to>
</connector>

<aux label_side="right" label_angle="315" x="2980.5" y="1252.84" name="effect of
patents\non fractional\npatent applications"/>
<connector uid="831" polarity="-" isee:polarity_placement="outside" angle="108.628">
    <from>relative_patents</from>
    <to>effect_of_patents_on_fractional_patent_applications</to>
</connector>

<aux label_side="top" x="2942" y="1153.16" name="patent min effect"/>
<connector uid="832" angle="291.119">
    <from>patent_min_effect</from>
    <to>effect_of_patents_on_fractional_patent_applications</to>
</connector>

<aux label_side="top" x="3011.83" y="1179.33" name="patent max effect"/>
<connector uid="833" angle="246.914">
    <from>patent_max_effect</from>
    <to>effect_of_patents_on_fractional_patent_applications</to>
</connector>

<connector uid="834" angle="339.459">
    <from>patent_min_effect</from>
    <to>patent_max_effect</to>
</connector>

<aux label_side="top" x="2902.5" y="1225.5" name="patent sensitivity"/>
<connector uid="835" angle="340.686">
    <from>patent_sensitivity</from>
    <to>effect_of_patents_on_fractional_patent_applications</to>
</connector>

```

<connector uid="837" polarity="+" isee:polarity_placement="outside" angle="43.1431">
 <from>effect_of_patents_on_fractional_patent_applications</from>
 <to>fractional_applications</to>
</connector>

<aux label_side="right" label_angle="315" x="2111.94" y="1616.53" name="effect of
cost on utility"/>

<connector uid="838" polarity="-" isee:polarity_placement="inside_stem"
angle="244.26">

 <from>cost_to_benefit_ratio_of_solar</from>
 <to>effect_of_cost_on_utility</to>
</connector>

<aux label_side="top" x="2087.77" y="1525.17" name="cost benefit threshold"/>

<connector uid="841" angle="284.816">
 <from>cost_benefit_threshold</from>
 <to>effect_of_cost_on_utility</to>

</connector>

<aux label_side="left" x="2010.83" y="1543.17" name="cost benefit sensitivity"/>

<connector uid="842" polarity="+" isee:polarity_placement="outside" angle="324.034">
 <from>cost_benefit_sensitivity</from>
 <to>effect_of_cost_on_utility</to>

</connector>

<connector uid="843" polarity="+" isee:polarity_placement="inside_stem"
angle="214.519">

 <from>effect_of_cost_on_utility</from>
 <to>utility_of_solar</to>

</connector>

<aux x="2947.67" y="606.167" name="VOD midpoint"/>

<connector uid="844" angle="48.9264">
 <from>VOD_midpoint</from>
 <to>effect_of_funding_availability_on_startup_lifetime</to>

</connector>

```

max effect"/>

<aux label_side="right" label_angle="45" x="3259.51" y="491.23" name="success rate

angle="184.294">

    <from>success_rate_max_effect</from>

    <to>effect_of_revenue_on_success_rate</to>

</connector>

<aux label_side="top" x="2231.63" y="736.333" name="crowding min effect"/>

<connector uid="846" angle="300.683">

    <from>crowding_min_effect</from>

    <to>crowding_effect</to>

</connector>

<aux x="2190.3" y="850" name="crowding midpoint"/>

<connector uid="847" angle="44.1492">

    <from>crowding_midpoint</from>

    <to>crowding_effect</to>

</connector>

<aux label_side="right" label_angle="315" x="2667.96" y="1268.83"
name="Technological\nreinforcement effect"/>

<connector uid="848" polarity="-" isee:polarity_placement="outside" angle="175.622">

    <from>relative_patents</from>

    <to>Technological_reinforcement_effect</to>

</connector>

<aux label_side="left" x="2599.17" y="1252.84" name="R&D min effect"/>

<connector uid="849" angle="346.914">

    <from>"R&D_min_effect"</from>

    <to>Technological_reinforcement_effect</to>

</connector>

<aux x="2599.17" y="1305.17" name="R&D sensitivity"/>

<connector uid="850" angle="27.8497">

    <from>"R&D_sensitivity"</from>

```

```

        <to>Technological_reinforcement_effect</to>
    </connector>
    <connector uid="852" angle="116.6">
        <from>Technological_reinforcement_effect</from>
        <to>solar_LCOE</to>
    </connector>
    <aux x="2166.83" y="966.333" name="economies of scale min effect"/>
    <connector uid="854" angle="40.9612">
        <from>economies_of_scale_min_effect</from>
        <to>Economies_of_Scale_effect</to>
    </connector>
    <aux label_side="right" x="2713" y="400.388" name="funding availability\ndelay time"/>
    <connector uid="855" polarity="-" isee:polarity_placement="outside" angle="194.712">
        <from>funding_availability_delay_time</from>
        <to>&quot;early-stage_VC_funding_availability&quot;</to>
    </connector>
    <aux label_side="top" x="1084.33" y="89.4163" name="Retail electricity price (2026)"/>
    <aux x="1174.42" y="136.667" name="slope of retail electricity price"/>
    <aux label_side="left" x="916.833" y="92.7497" name="Retail electricity price
Germany.\nLinear forecast 27-50"/>
    <connector uid="859" angle="181.14">
        <from>&quot;Retail_electricity_price_(2026)&quot;</from>
        <to>&quot;Retail_electricity_price_Germany._Linear_forecast_27-50&quot;</to>
    </connector>
    <connector uid="860" angle="170.324">
        <from>slope_of_retail_electricity_price</from>
        <to>&quot;Retail_electricity_price_Germany._Linear_forecast_27-50&quot;</to>
    </connector>
    <connector uid="862" angle="268.068">
        <from>&quot;Retail_electricity_price_Germany._Linear_forecast_27-
50&quot;</from>

```

<to>retail_electricity_price</to>

</connector>

<aux label_side="right" x="993.087" y="140.667" name="years since 2027"/>

<aux label_side="right" x="1260.08" y="107.416" name="Retail electricity price

(2050)"/>

<connector uid="864" angle="198.854">

<from>"Retail_electricity_price_(2050)"</from>

<to>slope_of_retail_electricity_price</to>

</connector>

<connector uid="865" angle="332.323">

<from>"Retail_electricity_price_(2026)"</from>

<to>slope_of_retail_electricity_price</to>

</connector>

<aux label_side="right" label_angle="315" x="1682.09" y="954.499" name="gap between

new installations and installation capacity"/>

<connector uid="866" angle="336.886">

<from>new_installations</from>

<to>gap_between_new_installations_and_installation_capacity</to>

</connector>

<connector uid="867" angle="14.2767">

<from>installation_capacity</from>

<to>gap_between_new_installations_and_installation_capacity</to>

</connector>

<connector uid="863" angle="147.855">

<from>years_since_2027</from>

<to>"Retail_electricity_price_Germany._Linear_forecast_27-50"</to>

</connector>

<aux background="red" x="3431" y="1097.3" name="R&D Policy Switch"/>

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R&amp;D"/>

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    </alias>

    <alias font_style="italic" label_side="bottom" uid="465" x="912.08" y="332.57"
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Appendix C: Sensitivity Analysis

Local and global sensitivity analysis was performed.

Local Sensitivity Analysis

For this model, all parameters were tested that were uncertain values using Stella’s sensitivity analysis tool using Sobol Sequence of 50 runs with either normal, uniform or triangular distributions. An extended time horizon of 2000 to 2100 is taken for sensitivity analysis to differentiate behavioral and numerical sensitivity. Table 2 showcases all the parameters that were tested and the sensitivity of those parameters.

Table 1. Full list of uncertain parameters (Auping et al., 2024).

Model Sector	Parameter	Unit	Min	Max	Mean / Mode	Std. Dev.	Distribution	Sensitivity	Reference
Adoption_Dynamics	average_module_lifetime	Year	25	35	30		Triangular	Numerical, insignificant	(Wirth, 2025)
	average_percentage_of_self-consumption	Dimensionless	0.2	0.5	0.35	0.06	Normal	Numerical, significant	(Fraunhofer ISE, 2025-b)
	initial_share_of_10_kWp_rooftop_pv	Dimensionless	0.7	0.9	0.8		Triangular	Not sensitive	(Fraunhofer ISE, 2025-a)
	installation_time	Year	0.8	1.2	1	0.08	Normal	Numerical, significant	Assumption
	installations_per_year	GW/installer/year	0.0007	0.0009			Uniform	Not sensitive 2000-2035, Numerical, insignificant 2035-2050	(Reiter & Margolis, 2023)
	installers_to_firms_ratio	Installer/firm	10	50			Uniform	Behavioral	(Fraunhofer ISE, 2025-a; Reiter & Margolis, 2023)
	share_of_10_kWp	Dimensionless	0.5	0.6	0.55		Triangular	Numerical, insignificant	(Real Ruiz et al., 2020; Fraunhofer ISE, 2025-a)
	weight_of_cost	Dimensionless	0.3	0.7	0.5	0.16	Normal	Behavioral	Assumption
Entrepreneurial_Dynamics	accessibility_of_alternative	Accessibility	0.8	1	0.9	0.04	Normal	Numerical, insignificant	Assumption
	average_funding_need	USD/firm	10m	40m	18m		Triangular	Numerical, insignificant	(International Energy Agency, 2025-a)
	average_startup_lifetime	Year	4	6	5	0.4	Normal	Numerical, insignificant	(IfM Bonn, 2023)
	average_success_rate	Dimensionless	0.01	0.05	0.03	0.008	Normal	Numerical, insignificant	(International Energy Agency, 2025-a)
	average_time_to_decision	Year	1	3	2	0.4	Normal	Numerical, insignificant	(European Patent Office data, 2025-a)
	average_time_to_exit	Year	4	10	7	1.2	Normal	Not sensitive 2000-2025, Numerical, insignificant 2025-2050	(International Energy Agency, 2025-a)
	BMI_baseline_effect	Dimensionless	0.3	0.7			Uniform	Numerical, insignificant	Assumption
	BMI_max_effect	Dimensionless	3	5			Uniform	Not sensitive	Assumption
	BMI_sensitivity	Dimensionless	0.5	0.9			Uniform	Numerical, insignificant	Assumption
	BMI_threshold	Dimensionless	2.5	7.5			Uniform	Numerical, insignificant	Assumption
	cost_benefit_sensitivity	Dimensionless	1	3			Uniform	Numerical, significant	Assumption
	cost_benefit_threshold	Dimensionless	1	1.3			Uniform	Numerical, significant	Assumption
	crowding_midpoint	Dimensionless	0.4	0.8			Uniform	Not sensitive 2000-2035, Numerical, significant 2035-2100	Assumption
	crowding_min_effect	Dimensionless	0.1	0.3			Uniform	Not sensitive	Assumption
	crowding_sensitivity	Dimensionless	20	80			Uniform	Not sensitive	Assumption
	economies_of_scale_min_effect	Dimensionless	0.2	0.4			Uniform	Numerical, insignificant	Assumption based on Nemet (2006)
	economies_of_scale_sensitivity	Dimensionless	10	20			Uniform	Numerical, insignificant	Assumption
	expected_revenue_for_exit	Euro/firm/year	10m	50m	20m	800,000	Normal	Numerical, insignificant	(WilmerHale, 2024)
	funding_availability_delay_time	Year	1	3	2	0.4	Normal	Not sensitive	(Gompers and Lerner, 1998)
	funding_max_effect	Dimensionless	40	80			Uniform	Not sensitive	Assumption
	funding_sensitivity	Dimensionless	2	6			Uniform	Not sensitive	Assumption
	grant_rate	Dimensionless	0.5	0.9	0.7	0.08	Normal	Numerical, insignificant	(European Patent Office data, 2025-b)
	initial_accessibility	Accessibility	0.1	0.3			Uniform	Numerical, insignificant	Assumption
	initial_average_fractional_applications	Patent/meur	1	2.6			Uniform	Numerical, insignificant	(Félix, 2008)
	initial_early-stage_funding_availability	USD	3m	9m	6m	1.2m	Normal	Numerical, insignificant	(International Energy Agency, 2025-a)
	initial_mature_firms	Firm	5	15	10	2	Normal	Not sensitive	Assumption
	initial_patents	Patent	100	500	300	80	Normal	Numerical, insignificant	(Wirth, 2025)
	Initial_solar_LCOE	Euro/(kW*Hours)	0.5	0.6	0.55		Triangular	Numerical, insignificant	(Kost et al., 2012; Wirth, 2025)
	initial_startups	Firm	20	80			Uniform	Not sensitive	(International Energy Agency, 2025-a)
	learning-by-doing_sensitivity	Dimensionless	0.1	2			Uniform	Numerical, insignificant	Assumption
	max_entrantrs_rate	Firm/year	50	90			Uniform	Not sensitive 2000-2026, Numerical, significant 2026-2100	(International Energy Agency, 2025-a)
	opportunity_midpoint	Dimensionless	0.1	0.5			Uniform	Not sensitive 2000-2026, Behavioral 2026-2100	Assumption
	opportunity_sensitivity	Dimensionless	30	50			Uniform	Not sensitive	Assumption
	patent_min_effect	Dimensionless	0.1	0.3			Uniform	Not sensitive	Assumption
	patent_sensitivity	Dimensionless	0.02	0.08			Uniform	Not sensitive	Assumption
	R&D-to-sales_ratio	Dimensionless	0.1	0.2	0.15	0.02	Normal	Not sensitive	(National Center for Science and Engineering, 2024)
	R&D_min_effect	Dimensionless	0.3	0.5			Uniform	Numerical, insignificant	Assumption based on Nemet (2006)
	R&D_sensitivity	Dimensionless	0.2	0.4			Uniform	Numerical, insignificant	Assumption
	share_of_German_industry_from_residential_rooftop_PV	Dimensionless	0.3	0.4	0.35		Triangular	Not sensitive	(Fraunhofer ISE, 2025-a; Wirth, 2025)
	success_rate_max_effect	Dimensionless	1.5	2.5			Uniform	Not sensitive 2000-2025, Numerical, insignificant 2025-2050	Assumption based on International Energy Agency (2025-a)
	VDD_midpoint	Dimensionless	0.4	0.6			Uniform	Not sensitive	Assumption
	VDD_min_effect	Dimensionless	0.1	0.5			Uniform	Not sensitive 2000-2018, Behavioral 2018-2100	Assumption based on IfM Bonn (2023)
	VDD_sensitivity	Dimensionless	10	20			Uniform	Not sensitive	Assumption
	weight_of_market_maturity	Dimensionless	0.3	0.7	0.5	0.1	Normal	Not sensitive	Assumption
Social Contagion	average_marketing_spend	Dimensionless	0.03	0.15	0.05		Triangular	Numerical, insignificant	(Thanh Thy & Klymova 2022)
	effective_contact_rate_of_adopter	1/Year	0.2	0.3	0.25	0.02	Normal	Numerical, significant	Struben and Sterman, 2008; (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015)
	effective_contact_rate_of_non-adopter	1/Year	0.1	0.2	0.15	0.02	Normal	Numerical, insignificant	Struben and Sterman, 2008; (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015)
	marketing_effectiveness	1/Euro	6e^-11	1e^-10			Uniform	Numerical, significant	Assumption
	normal_forget_rate	1/Year	0.6	0.7			Uniform	Numerical, insignificant	Assumption based on Struben and Sterman (2008)
	normal_social_norms_effect	Dimensionless	0.4	0.6			Uniform	Numerical, significant	Assumption based on Struben and Sterman (2008)
	Policy_marketing_effectiveness	1/Year	0.001	0.002			Uniform	Numerical, significant	Assumption
	reference_social_exposure	1/Year	0.01	0.2	0.05	0.038	Normal	Behavioral	Assumption based on Struben and Sterman (2008)
Path_Dependence	lobby_max_effectiveness	1/Year	0.06	0.12			Uniform	Behavioral	Assumption
	lobby_sensitivity	Dimensionless	35	45			Uniform	Numerical, insignificant	Assumption
	market_share_of_incumbent	Dimensionless	0.5	0.7	0.6	0.04	Normal	Numerical, insignificant	(RAP, 2015)
	Retail_electricity_price_(2050)	Euro/(kW*Hours)	0.25	0.75	0.45	0.1	Normal	Not sensitive	(Henning & Palzer, 2015)

The parameters to which installed capacity is behaviorally sensitive or numerically significantly sensitive are expanded on further below.

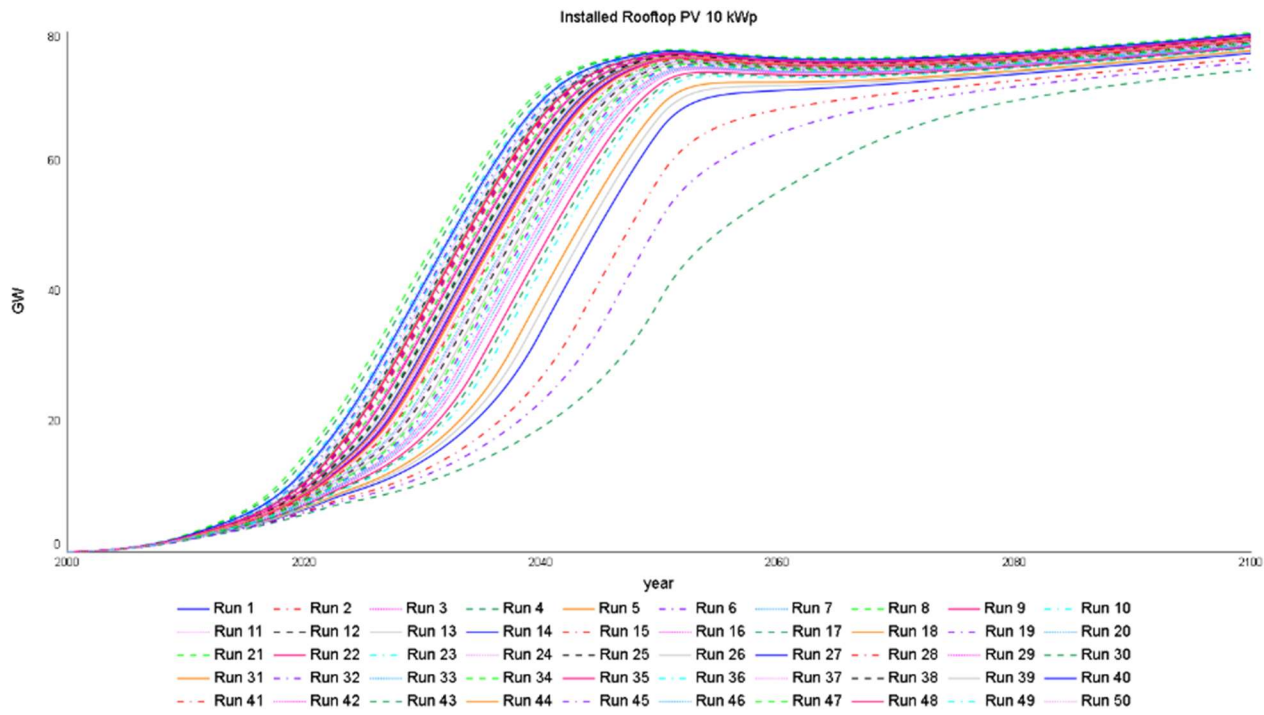


Figure 1. displays the comparative line graphs for “average percentage of self-consumption” to which installed capacity is significantly numerically sensitive.

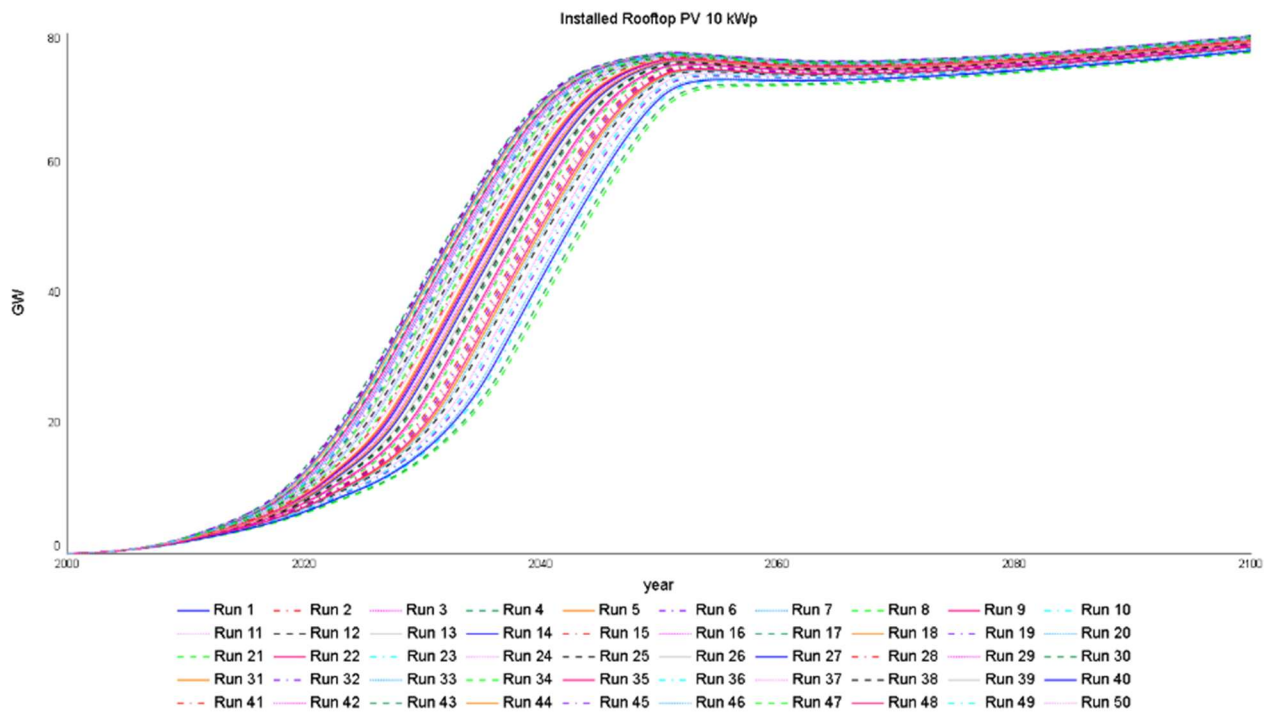


Figure 2. displays the comparative line graphs for “Cost benefit sensitivity” to which installed capacity is significantly numerically sensitive.

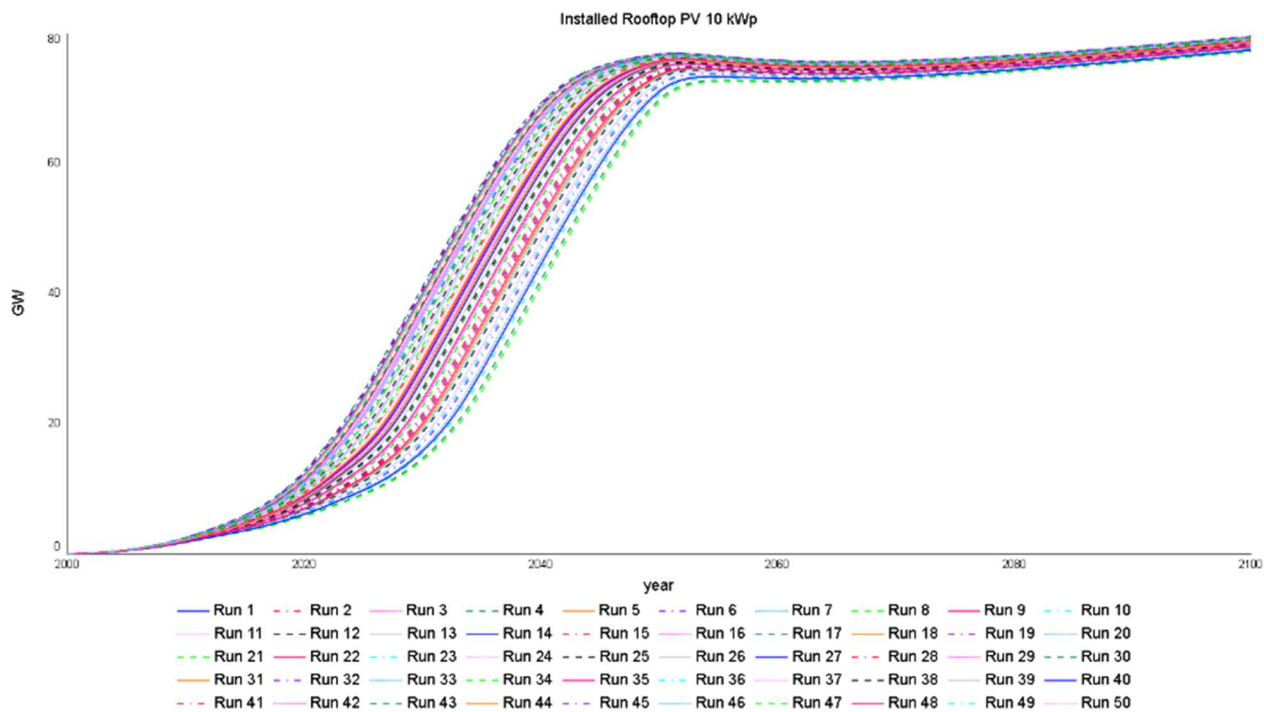


Figure 3. displays the comparative line graphs for "Cost benefit threshold" to which installed capacity is significantly numerically sensitive.

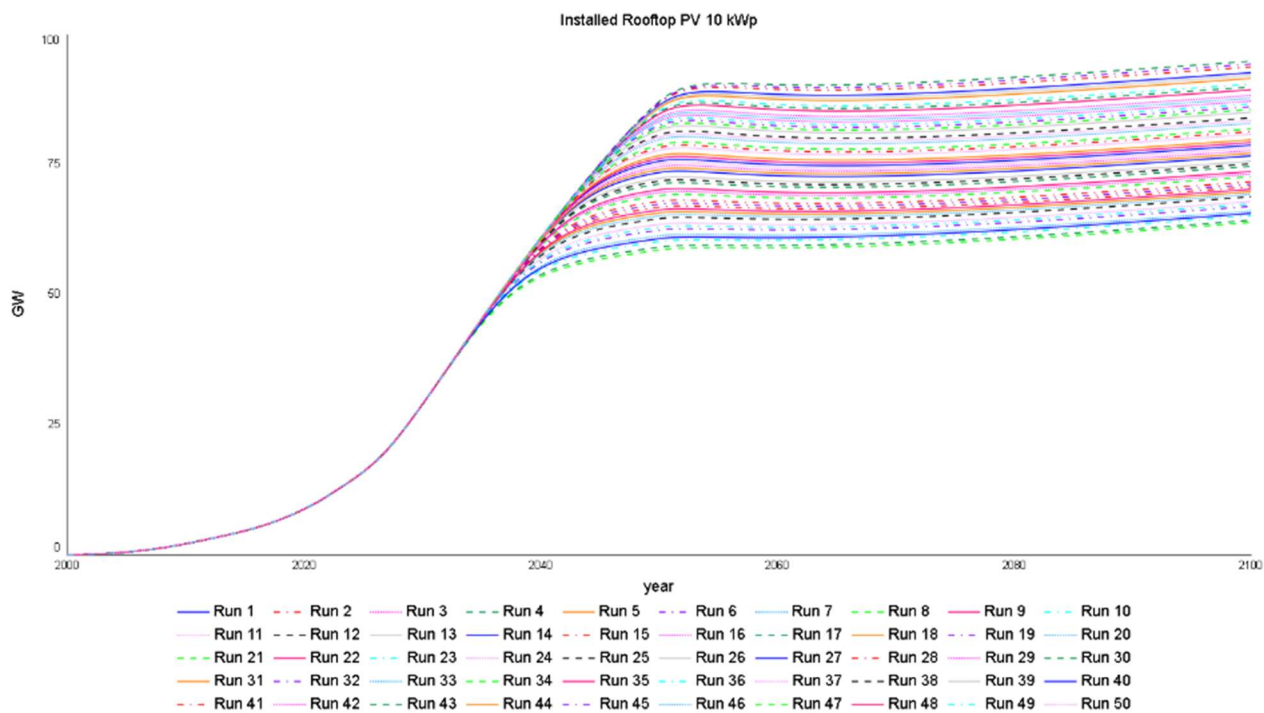


Figure 4. displays the comparative line graphs for "crowding midpoint" to which installed capacity is not sensitive between 2000-2035 but significantly numerically sensitive from 2035-2100.

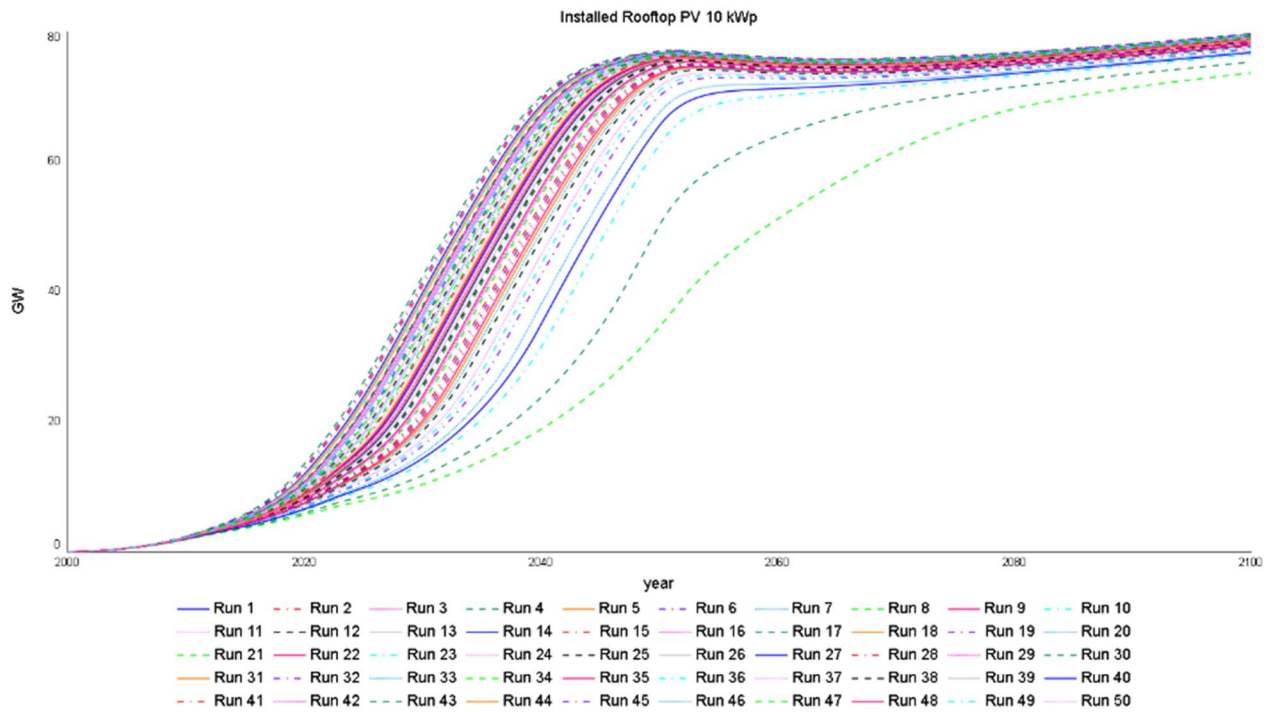


Figure 5. displays the comparative line graphs for “Effective contact rate of adopter” to which installed capacity is significantly numerically sensitive.

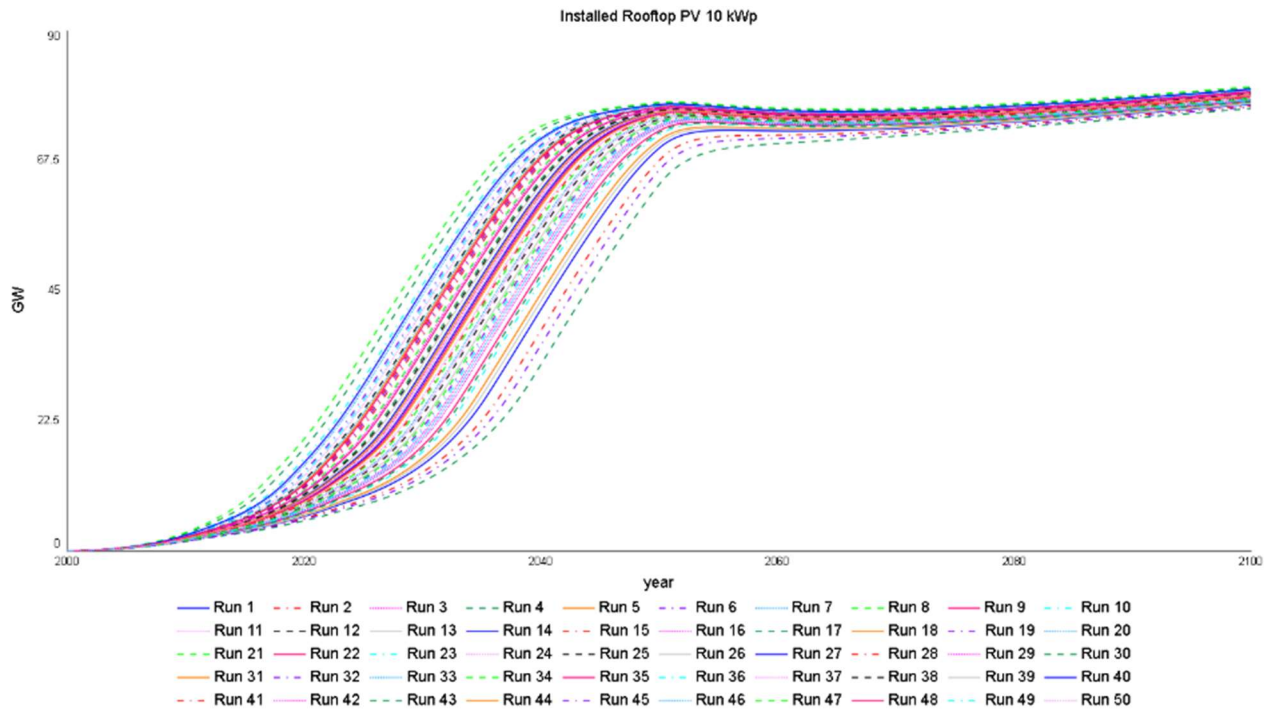


Figure 6. displays the comparative line graphs for “Installation time” to which installed capacity is significantly numerically sensitive.

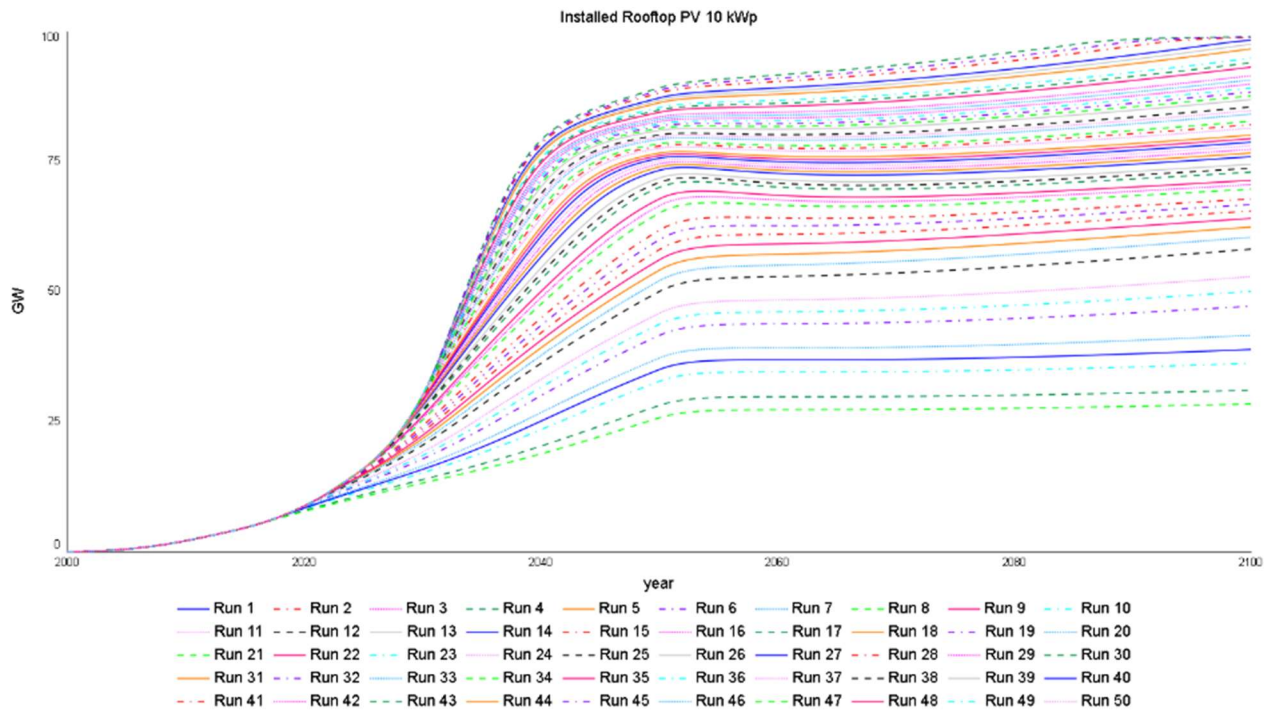


Figure 7. displays the comparative line graphs for "Installers to firms ratio" to which installed capacity is behaviorally sensitive.

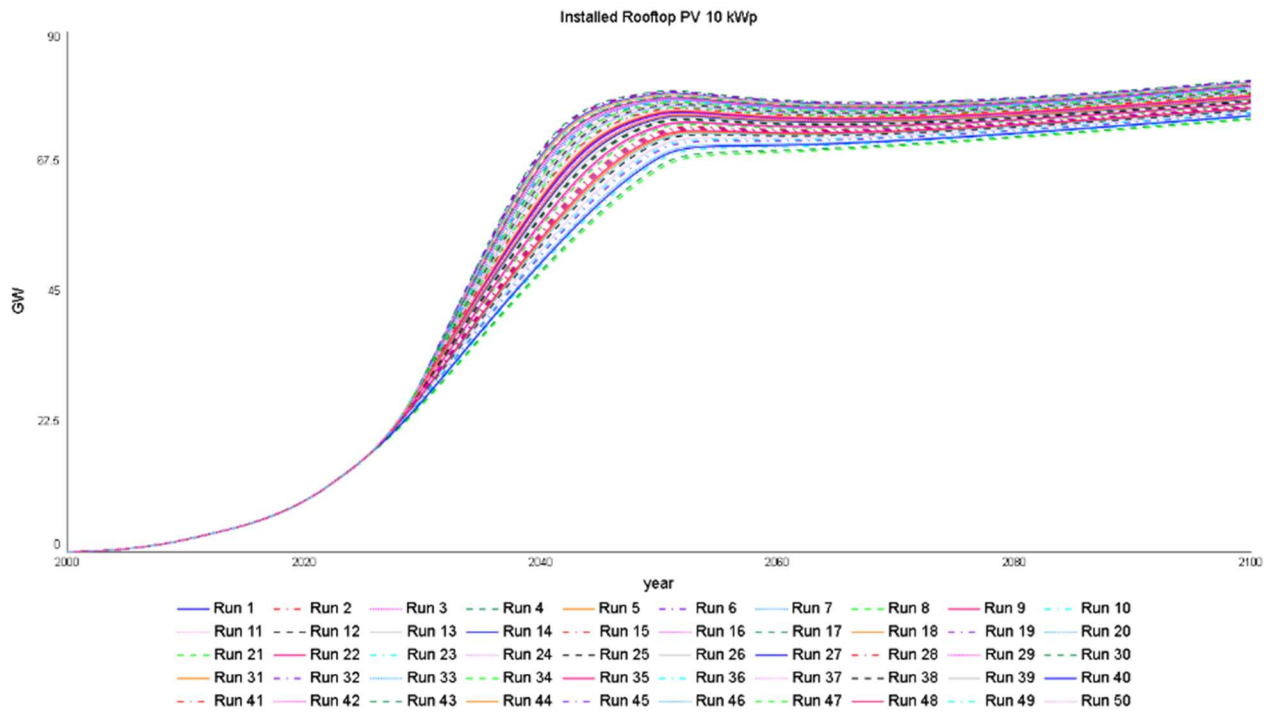


Figure 8. displays the comparative line graphs for "Max entrants rate" to which installed capacity is not sensitive between 2000-2026 but significantly numerically sensitive from 2026-2100.

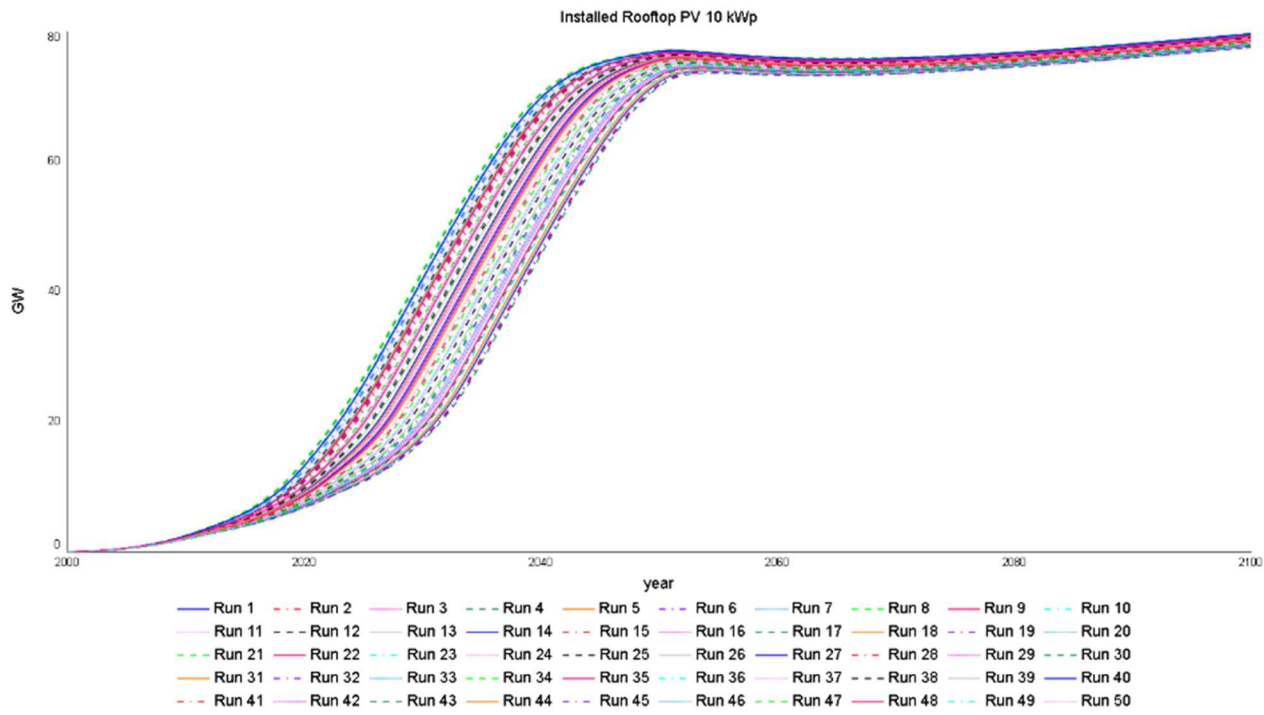


Figure 9. displays the comparative line graphs for "Normal social norms effect" to which installed capacity is significantly numerically sensitive.

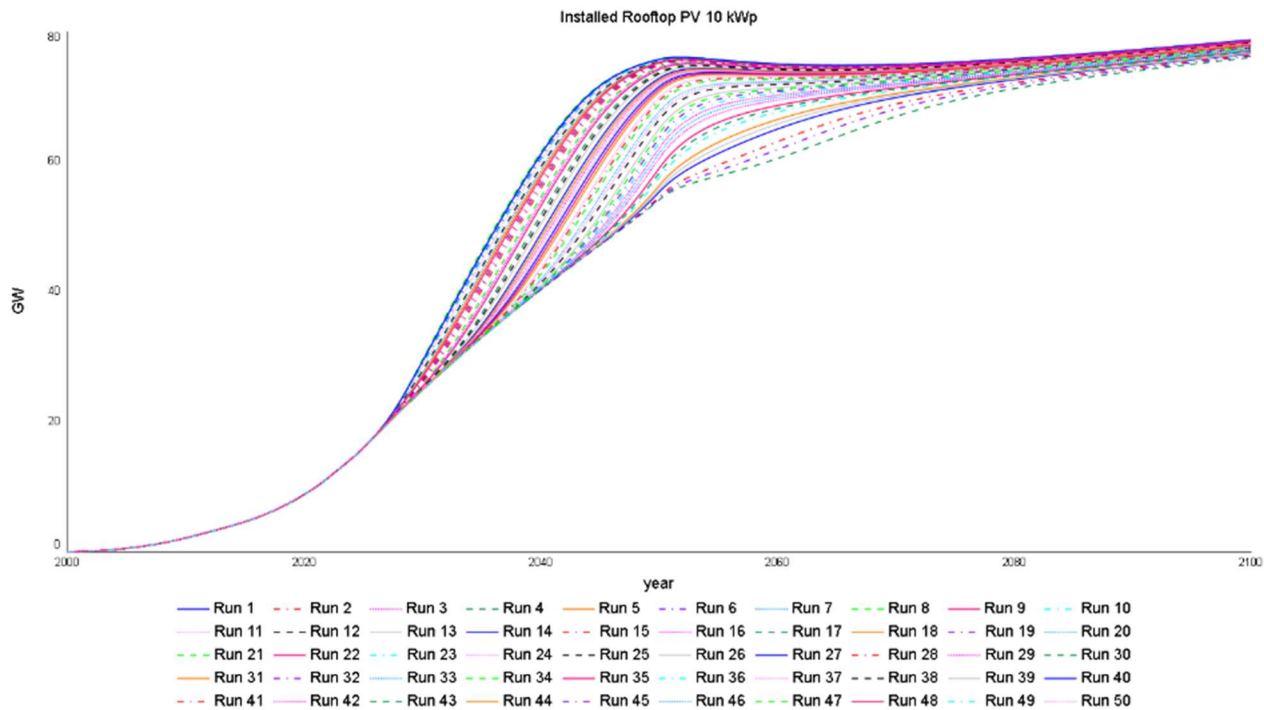


Figure 10. displays the comparative line graphs for "Opportunity midpoint" to which installed capacity is not sensitive between 2000-2026 but behaviorally sensitive from 2026-2100.

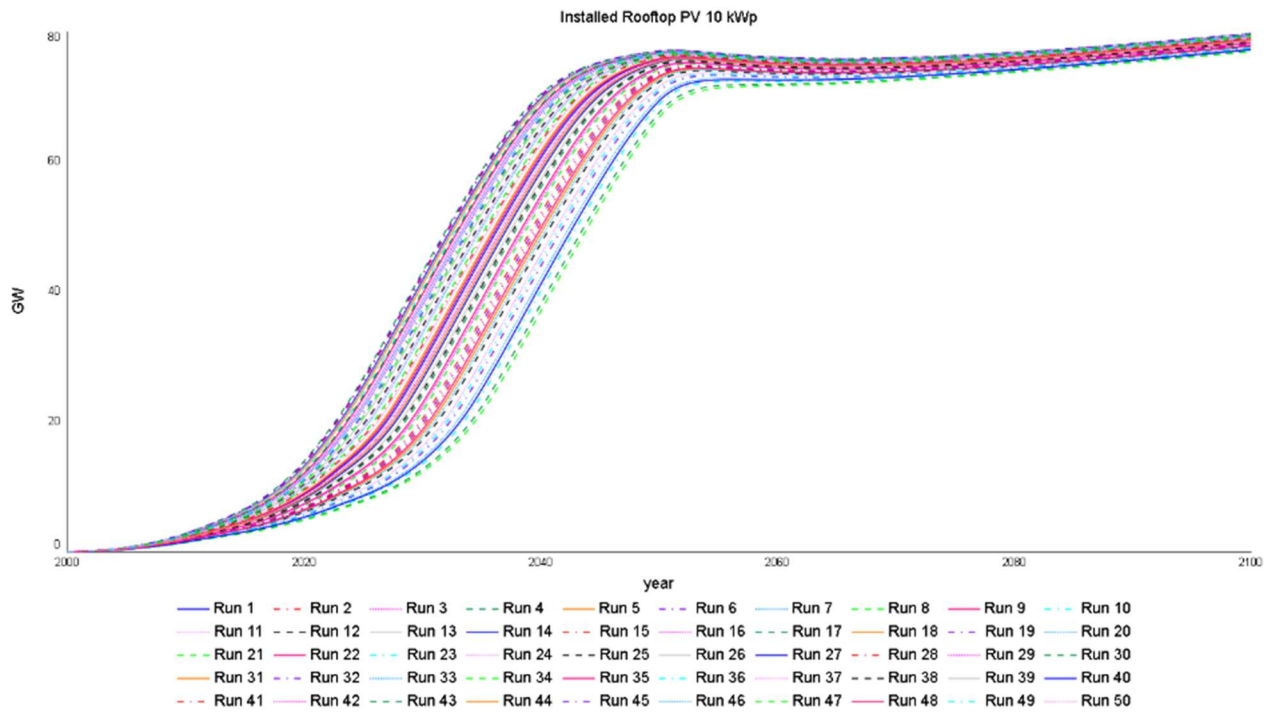


Figure 11. displays the comparative line graphs for “Policy marketing effectiveness” to which installed capacity is significantly numerically sensitive.

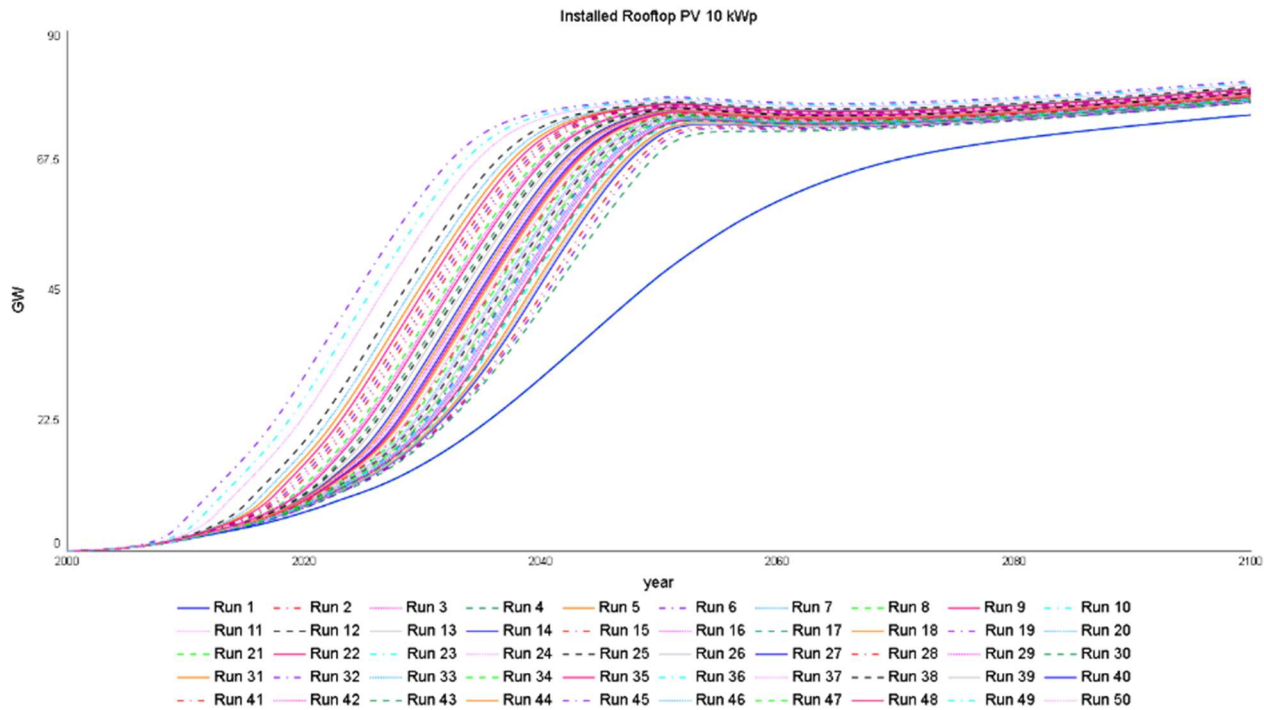


Figure 12. displays the comparative line graphs for “reference social exposure” to which installed capacity is behaviorally sensitive.

VOD Min effect (effect on lifetime)

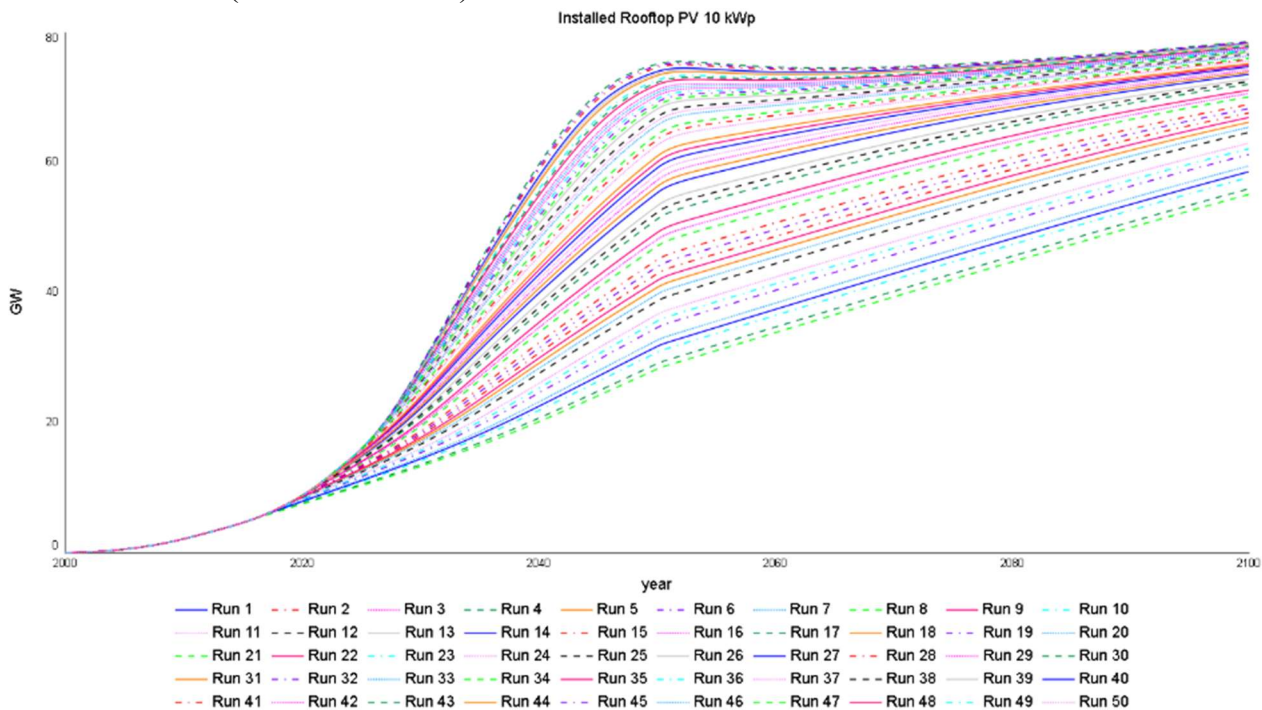


Figure 13. displays the comparative line graphs for“Opportunity midpoint” to which installed capacity is not sensitive between 2000-2018 but behaviorally sensitive from 2018-2100.

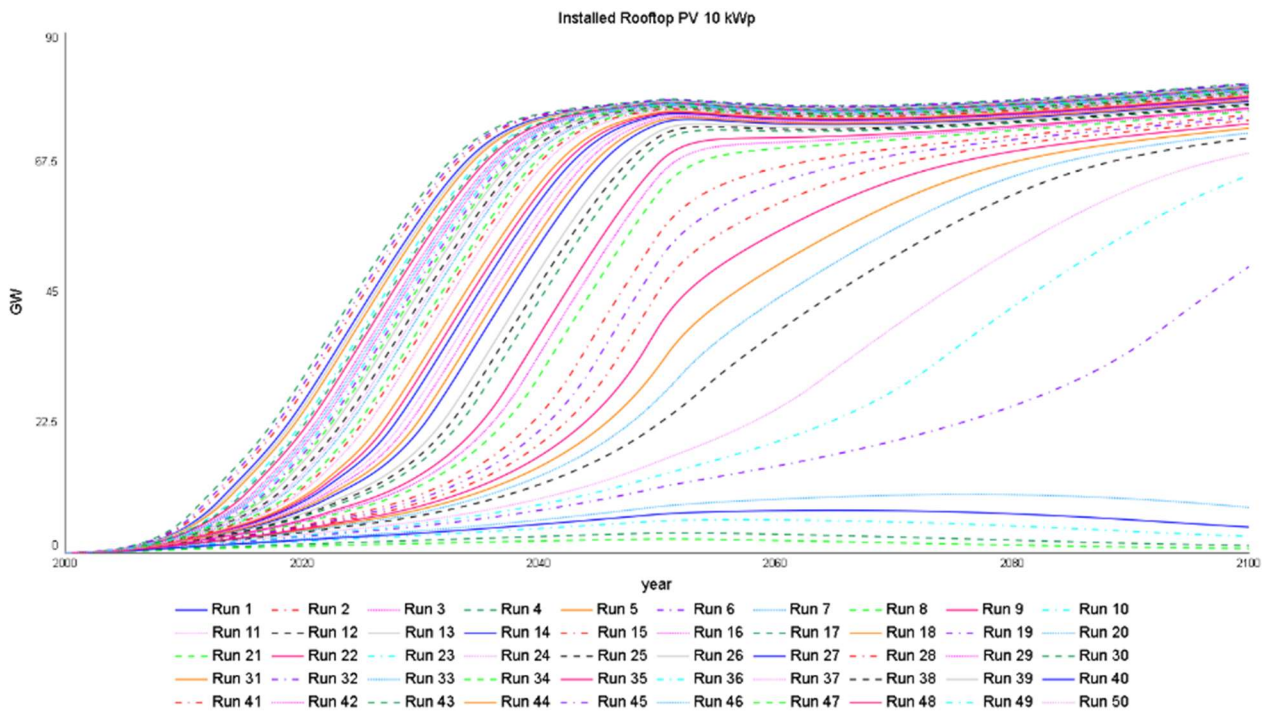


Figure 14. displays the comparative line graphs for“Weight of Cost” to which installed capacity is behaviorally sensitive.

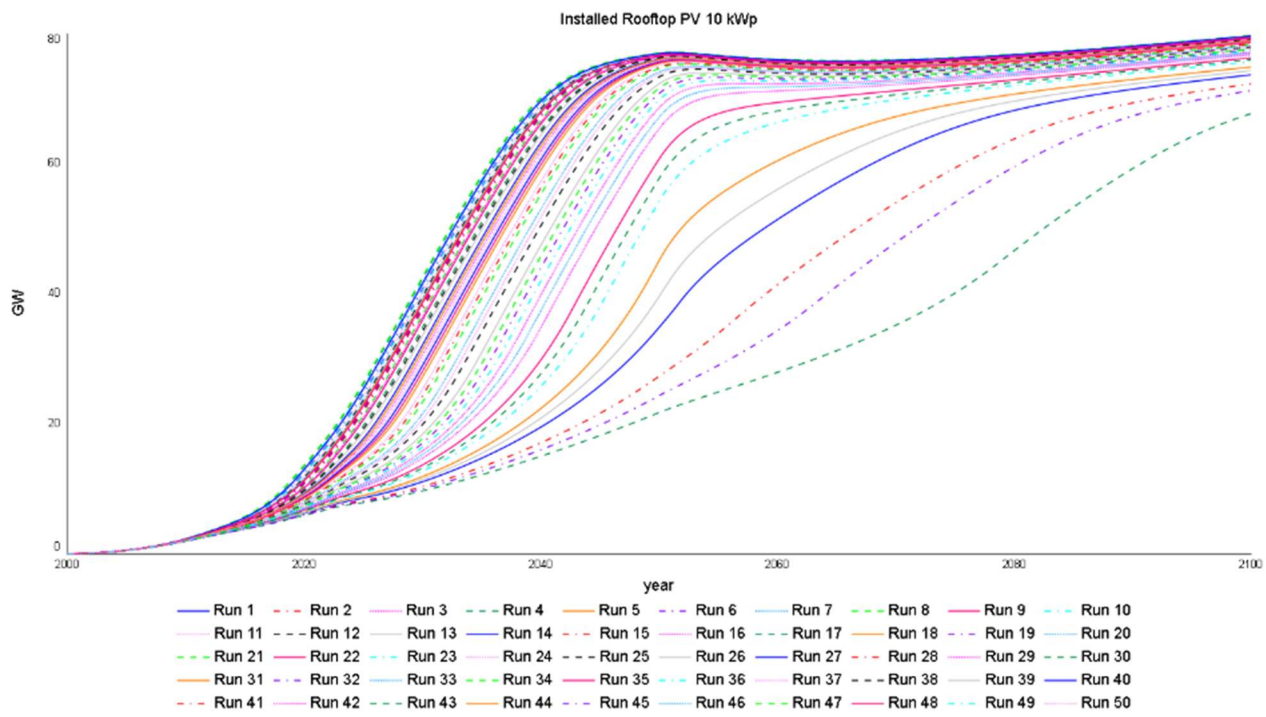


Figure 15. displays the comparative line graphs for “lobby max effectiveness to which installed capacity is behaviorally sensitive.

Global Sensitivity Analysis

A global sensitivity analysis on Sobol sequence across 10,000 runs of random variations of values from uncertainty ranges specified in Table 1 was performed to determine the confidence in the model creating different modes of behavior with random variations of uncertain parameters.

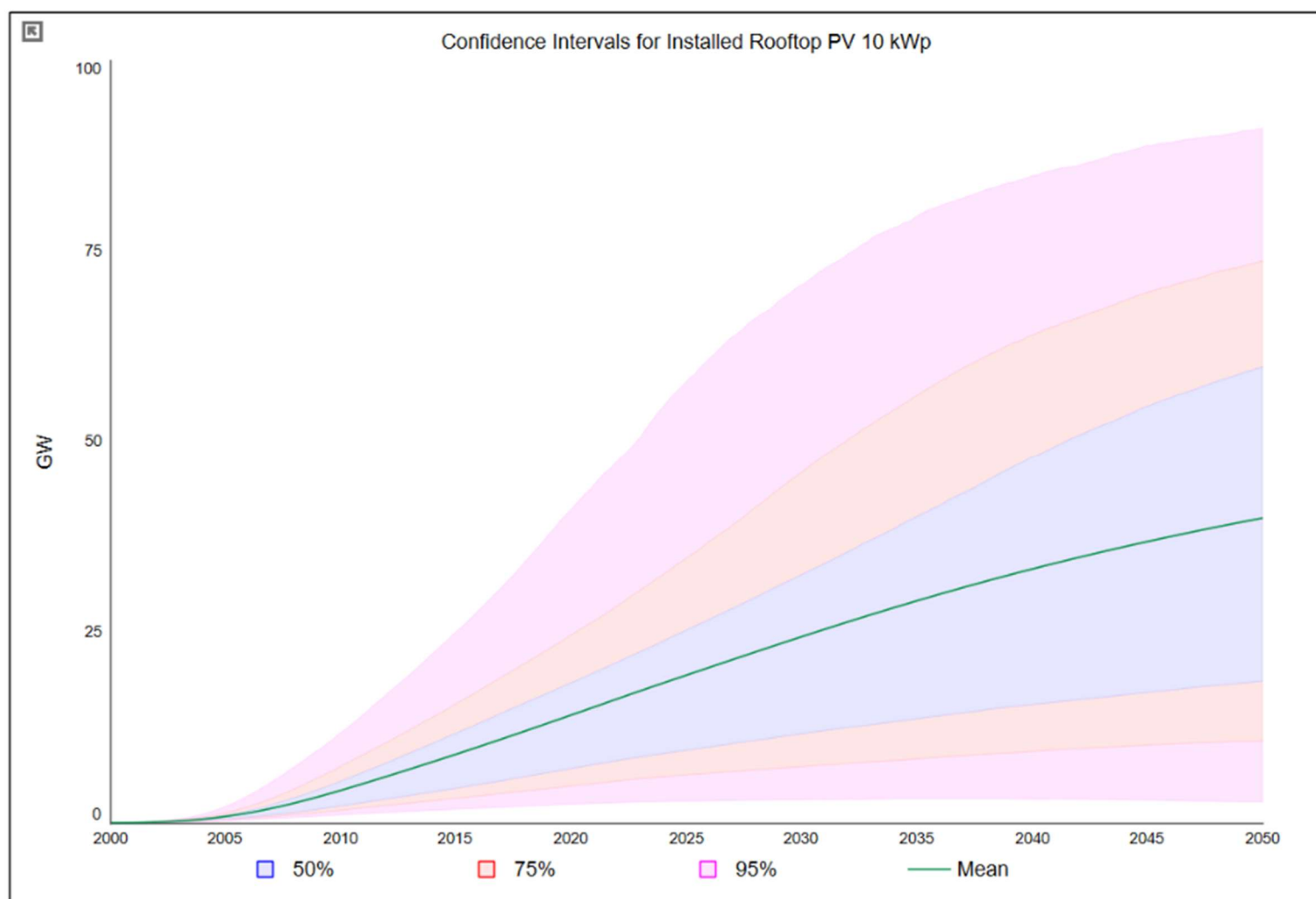


Figure 16. Displays the confidence Intervals for Installed Rooftop PV 10 kWp. The broad range of behavior modes is suspected under such uncertainty. Despite the base run scenario producing the desired behavior mode, the mean of the global sensitivity analysis and the 50% range between 15 and 55 GW of installed capacity suggests that a positive tipping point has not been crossed. Interpretation of the 75% and 95% range means that a high installed capacity above 55GW is equally likely as a very low installed capacity below 15 GW.

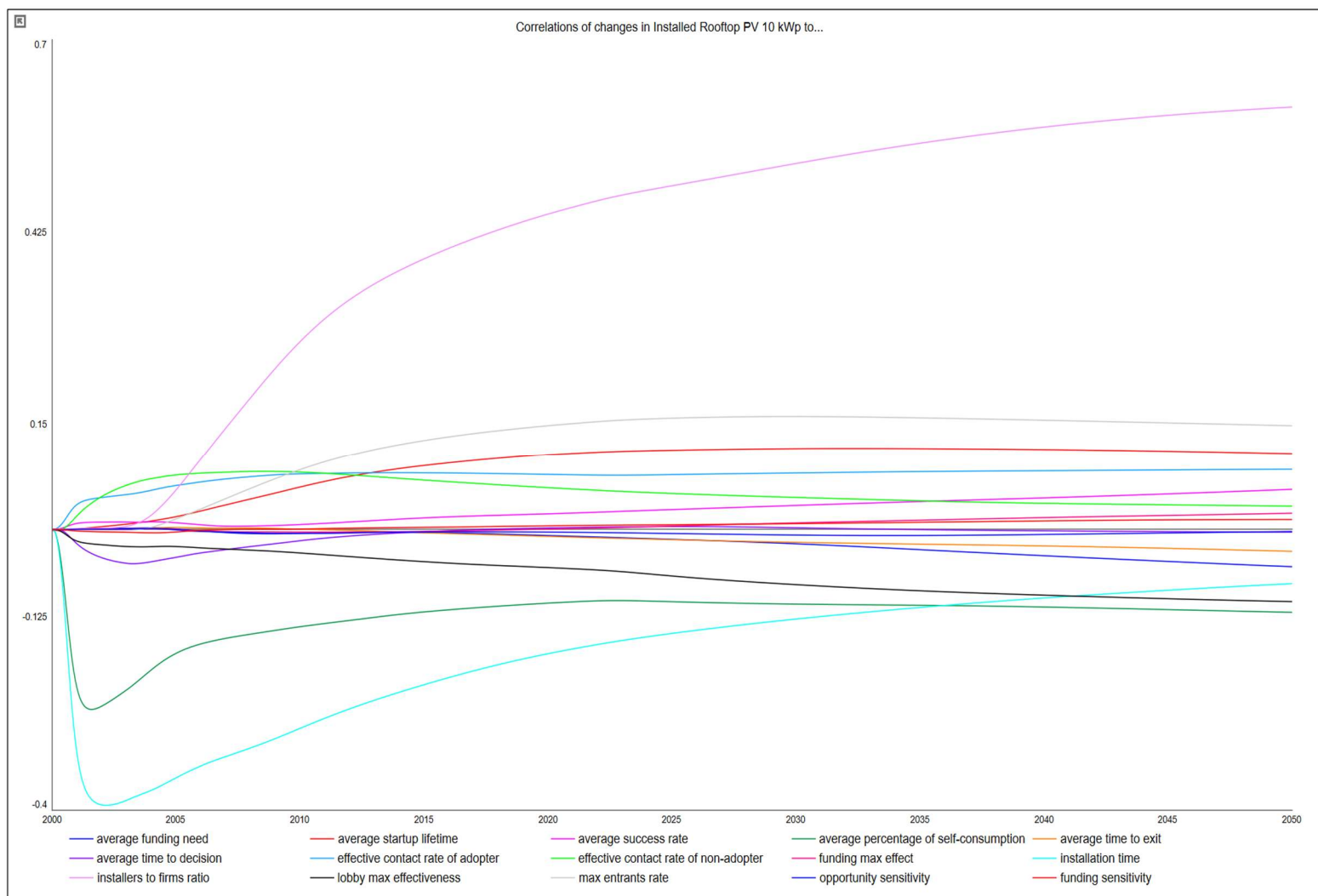


Figure 17. Displays the correlation across runs graph of installed capacity to selected variables. Installed capacity is most positively correlated with installers to firms ratio, suggesting that increasing the amount of installers could be an effective policy to increase installed capacity and strengthen reinforcing feedbacks. Also, max entrants rate and funding sensitivity show strong positive correlation as the simulation progresses. Installed capacity is most negatively correlated with installation time and average percentage of self-consumption and as the simulation progresses on lobby max effectiveness. Therefore, cutting down installation time, decreasing self-consumption and limiting lobbying would be effective to reduce negative feedbacks.

Appendix D: Validation Interviews

Interview 1: Extantia Capital, Personal Communication, 2026

Speaker 1: Author

Speaker 2: Representative at Extantia Capital

Transcript

00:00:00 Speaker 1

agenda.

00:00:01 Speaker 1

So yeah, I explained a bit about the backstory.

00:00:06 Speaker 1

So researching in my master's the tipping points in low carbon technologies.

00:00:16 Speaker 1

And I chose as the use case, as you know, Germany and solar PV because it first of all, it's been reported to have crossed some sort of tipping point that if we continue even

00:00:29 Speaker 1

by removing regulations and policies to support it.

00:00:34 Speaker 1

I think the feed in tariff in Germany, for example, has been it's getting it's getting removed completely, I believe in 2028.

00:00:41 Speaker 2

It's upstage.

00:00:41 Speaker 2

Yeah.

00:00:42 Speaker 1

Yeah.

00:00:42 Speaker 1

So basically the the assumption is that it will continue to the deployment will continue to increase all the way to the to the desired level in Germany, which is

00:00:59 Speaker 1

Yeah, the 27% I think is technically feasible for solar PV to cover of the energy mix.

00:01:05 Speaker 1

And I think it's about 400 gigawatts roughly of energy.

00:01:12 Speaker 1

For my case, I decided to focus on the so in system dynamics modeling is obviously what we're doing.

00:01:18 Speaker 1

So we create a computer simulation model that takes into account feedback within the system.

00:01:27 Speaker 1

It's a little bit different to linear regression modeling because we take into account the, you know, accumulations and delays and different kind of measures of time in the system.

00:01:45 Speaker 1

And not sure how familiar you are with system dynamics.

00:01:48 Speaker 1

That's why I give you the brief overview.

00:01:51 Speaker 2

A long time ago.

00:01:52 Speaker 2

I studied economics so many years ago, but it's a while ago.

00:01:56 Speaker 1

Okay, so it can be, everything that we do can be done in an Excel sheet.

00:02:01 Speaker 1

It would just be really difficult to understand and conceptualize.

00:02:06 Speaker 1

So that's why we create these diagrams.

00:02:08 Speaker 1

So we use a software called Stellar Architect.

00:02:10 Speaker 1

It has, it's easy to understand.

00:02:13 Speaker 1

So you can think about this as the equations behind an Excel sheet.

00:02:19 Speaker 1

When you look at an Excel sheet, you just see numbers, which is great.

00:02:23 Speaker 1

And then if you click on the cell, you can see the equation behind it.

00:02:28 Speaker 1

Here, we can essentially see the equation.

00:02:33 Speaker 1

So this installation rate, for example, increases the installed PV.

00:02:38 Speaker 1

And it's a function of utility.

00:02:41 Speaker 1

And this is a simplified CLD.

00:02:43 Speaker 1

So there are other variables involved as well.

00:02:46 Speaker 1

And then if we want to see the output,

00:02:52 Speaker 1

Then we do a simulation, we run it, and then we can see the outputs, like I showed you the graphs, and we can see the numbers behind it.

00:02:59 Speaker 1

So it's kind of like the inverse of an Excel sheet.

00:03:03 Speaker 1

And all of these, this is kind of the information is kind of flowing through this diagram.

00:03:13 Speaker 1

So, and you mentioned that you had one question.

00:03:19 Speaker 1

or some questions?

00:03:20 Speaker 2

You're just expanding it to be honest already.

00:03:22 Speaker 1

Okay, great, great.

00:03:23 Speaker 1

Yeah.

00:03:23 Speaker 1

So if anything is unclear, please let me know and we'll cover it.

00:03:29 Speaker 1

So I'll just go through the feedback loops first on a general level and then we can focus on this startup and VC entrepreneurial sector a little bit more in depth because I think this is where you have the most expertise.

00:03:47 Speaker 1

But what we have here is basically we have the interplay of social contagion and adoption, as well as these more industrial effects, which improved the utility.

00:04:03 Speaker 1

So first, as installed PV increases, there's more social exposure.

00:04:07 Speaker 1

This is a commonly seen phenomenon with new platforms.

00:04:14 Speaker 1

take electric vehicles or solar PV in this case, that it increases kind of this familiarity or willingness to consider amongst the non-adopters.

00:04:26 Speaker 1

So as people who have not adopted come into contact with people that have adopted, they may talk about the benefits of having a rooftop solar panel, and then they will consider the platform.

00:04:40 Speaker 1

And then this will increase the perceived utility, which increases the installation rate.

00:04:44 Speaker 1

And then we get more installations, more contacts, right?

00:04:48 Speaker 1

And then more installations that way.

00:04:50 Speaker 1

So that's why we see this kind of exponential curve.

00:04:54 Speaker 1

So that's the social contagion curve.

00:04:56 Speaker 1

The reinforcing loop two, so R2 loop, also commonly understood phenomenon of economies of scale.

00:05:04 Speaker 1

So as the installations increase,

00:05:09 Speaker 1

the factory sizes increase, the production amount increases, and that'll decrease the production cost, which reduces the cost for the consumer as well.

00:05:20 Speaker 1

And we get more installations, et cetera.

00:05:23 Speaker 1

Pretty easy to understand.

00:05:24 Speaker 1

Learning by doing.

00:05:25 Speaker 1

So this goes through the firms.

00:05:31 Speaker 1

So as we have more firms coming into the market,

00:05:37 Speaker 1

They come up with better ideas, more business model innovation, and more complimentary products.

00:05:43 Speaker 1

And through these processes, the cost for the consumer again decreases, we get more, okay?

00:05:52 Speaker 1

Reinforcing loop.

00:05:54 Speaker 1

Increasing R&D, so as we get more industry revenue, so industry revenue is a direct function of the amount of installations, that means the industry in general is getting more revenue.

00:06:06 Speaker 1

The private sector, they invest some amount into R&D, and that R&D translates roughly into some amount of patents, right?

00:06:17 Speaker 1

There's a lot of other knowledge being created, but patents is one measurable way that we can look at this.

00:06:25 Speaker 1

And then, of course, public side R&D funding also increases the total

00:06:33 Speaker 1

Total amount of funding, which increases the total patents, okay?

00:06:38 Speaker 1

The technological innovation, so let's think about the improvements in PV cells.

00:06:46 Speaker 1

The module efficiency has increased by some double digit amount since 2000, I believe so.

00:06:57 Speaker 1

And that's kind of a direct correlation with the amount of R&D funding.

00:07:01 Speaker 1

So there's a study by

00:07:04 Speaker 1

A study done by Gregory Nemet, a low carbon technology researcher in the US who even calculated the amount of increase in module efficiency that came from R&D.

00:07:22 Speaker 1

It was about nine out of 12 of the technological innovations had some public R&D funding included.

00:07:33 Speaker 1

and the cost for consumers again decreases, perceived utility increases.

00:07:38 Speaker 1

Then then we have R.

00:07:40 Speaker 1

5.

00:07:40 Speaker 1

So importantly.

00:07:44 Speaker 1

how do startups enter the market?

00:07:46 Speaker 1

How do we get firms into the market that that engage in in improving, improving the utility for for consumers?

00:07:56 Speaker 1

There's a

00:07:57 Speaker 1

perceived market opportunity.

00:07:58 Speaker 1

So entrepreneurs perceive that, hey, there's a market here for us to enter.

00:08:05 Speaker 1

And that perceived market opportunity is somewhat influenced by previous exits.

00:08:13 Speaker 1

So you think, you know, successful entrepreneurs in the market.

00:08:19 Speaker 1

I think it was Solar World was the major one in Germany, for example, and then this can spark

00:08:26 Speaker 1

more entrance into the market.

00:08:28 Speaker 1

And this is kind of a reinforcing feedback loop as well.

00:08:32 Speaker 1

Then we have the marketing effect.

00:08:33 Speaker 1

So as more industry revenue comes in, some amount is invested into marketing.

00:08:40 Speaker 1

So solar PV becomes more present in public discourse, maybe on through newspaper articles or marketing and this kind of thing.

00:08:56 Speaker 1

increase.

00:08:57 Speaker 1

Then funding availability.

00:09:00 Speaker 1

So startups don't all survive.

00:09:03 Speaker 1

As you know, they encounter a valley of death.

00:09:05 Speaker 1

And this is a gross, well, estimation and approximation as a model is.

00:09:14 Speaker 1

However, VC funding availability is very important for companies to get past this valley of death.

00:09:21 Speaker 1

Therefore, if we have more VC funding,

00:09:24 Speaker 1

more companies will get through the valley of death and less of them will die.

00:09:30 Speaker 1

Then we have declining market share.

00:09:32 Speaker 1

So there's a there's a finite amount of industry revenue that you can kind of create.

00:09:40 Speaker 1

If we have too many companies being created and joining, then on average, the market share decreases per company, which will reduce the exit rate.

00:09:53 Speaker 1

So the average revenue will decrease as we have more firms.

00:09:56 Speaker 1

That's the B2 or B1.

00:09:59 Speaker 1

And then B2, the crowding effect.

00:10:01 Speaker 1

So essentially, yeah, as we have more installed capacity, the perceived market opportunity for entrepreneurs increases.

00:10:09 Speaker 1

However, at some point, the market will get crowded.

00:10:14 Speaker 1

So it will no longer be as interesting as it previously was to enter

00:10:21 Speaker 1

because it's already been, you know, kind of saturated.

00:10:25 Speaker 2

You need some type of innovation.

00:10:27 Speaker 1

Yeah, yeah.

00:10:30 Speaker 1

Then finally, the counter lobby efforts.

00:10:33 Speaker 1

So what we've what we've seen in Germany, you know, it's not all so perfect and rosy that that that things happen like this in reality for low carbon technologies, but there is an incumbent

00:10:48 Speaker 1

incumbent market, in this case, for example, utilities or fossil fuel firms, that may engage in some counter lobby efforts.

00:10:55 Speaker 1

And we have seen that as well, even more recently with, with the new, I think the AFD party and these ones.

00:11:06 Speaker 1

So that's what the counter lobby efforts is.

00:11:08 Speaker 1

And as more, as the incumbent industry decreases their revenue, the counter lobby efforts will get more, more strong and more powerful.

00:11:20 Speaker 1

to some extent in Germany.

00:11:21 Speaker 1

We've seen that utility companies have started to adapt their business models as well to this disruption.

00:11:30 Speaker 1

but there has also been some some backlash.

00:11:34 Speaker 1

So that's the general.

00:11:37 Speaker 1

Yeah, that's the that's the causal of diagram.

00:11:40 Speaker 1

And then I have as well kind of I I zoomed in a bit on the

00:11:50 Speaker 1

The startup sector.

00:11:52 Speaker 1

So this was supposed to be the same.

00:11:55 Speaker 1

So the perceived opportunity increases the entrance.

00:11:59 Speaker 1

As we have more successful cases, the market opportunity increases.

00:12:03 Speaker 1

Market crowding decreases this perceived market opportunity.

00:12:07 Speaker 1

And there's VC funding availability.

00:12:10 Speaker 1

is driven by the installed rooftop PV, which kind of is a market maturity indicator.

00:12:19 Speaker 1

And with more VC funding, this startup lifetime increases valley of death.

00:12:27 Speaker 1

Less companies will fall into valley of death.

00:12:28 Speaker 1

And then this industry revenue impacts the profits per firm, which increases the average success rate.

00:12:36 Speaker 2

Yeah.

00:12:37 Speaker 1

So that's the gist.

00:12:44 Speaker 1

Do you have any specific questions on the causal loop diagram or does it all make sense?

00:12:48 Speaker 1

Then we can move on to validation questions.

00:12:52 Speaker 2

It, yeah, it makes sense.

00:12:55 Speaker 2

It makes sense.

00:12:56 Speaker 2

Let's go.

00:12:56 Speaker 2

We'll move on.

00:12:57 Speaker 1

Okay.

00:13:00 Speaker 1

Sounds good.

00:13:23 Speaker 1

Just one second.

00:13:27 Speaker 1

Okay, so this one I also sent to you about the results.

00:13:33 Speaker 1

So one thing about the simulation time, so these are preliminary simulations and they shouldn't change too much, but the model may change.

00:13:48 Speaker 1

But these will roughly

00:13:50 Speaker 1

be the scenario.

00:13:51 Speaker 1

So what we're looking for is different scenarios.

00:13:53 Speaker 1

We change different variables in the model.

00:13:56 Speaker 1

And this is a different scenario.

00:13:58 Speaker 1

So let's say.

00:14:00 Speaker 1

So now, because we're taking a retrospective view, we're looking at.

00:14:03 Speaker 1

Okay, what if feed in tariffs were removed at some point, right?

00:14:09 Speaker 1

What if they didn't last until they have as long as they have?

00:14:12 Speaker 1

What would what would happen in that scenario?

00:14:14 Speaker 1

And hopefully, these will yield some insights for

00:14:19 Speaker 1

future technologies and the policies that we that we put in place.

00:14:22 Speaker 1

And we can also experience with different scenarios like, oh, what if, you know, some, yeah, for example, for example, with install, with rooftop solar, we saw that, you know, what if supply chains get disrupted or something like that in the future, what would what would the scenario be?

00:14:44 Speaker 1

What we're simulating here is from 2000 to 2050,

00:14:48 Speaker 1

and the blue line is on the desired desired scenario compared with the the actual real data.

00:14:56 Speaker 1

So the model is able to create roughly the the the data that we saw in in reality.

00:15:04 Speaker 1

And then what we see from 2025 and beyond is more or less a trend.

00:15:08 Speaker 1

So a trended forecast.

00:15:09 Speaker 1

It's not.

00:15:11 Speaker 2

No.

00:15:12 Speaker 1

Yeah, it's probably not going to look like that.

00:15:15 Speaker 1

In reality, you know, data looks more like it's more, there's more variance and then the undesired scenario.

00:15:22 Speaker 1

So first of all, do you agree with the assertion that solar PV adoption has crossed the positive tipping point in Germany and globally?

00:15:39 Speaker 2

That's good.

00:15:39 Speaker 2

It's a good question.

00:15:41 Speaker 2

Complex one, to be honest as well.

00:15:43 Speaker 2

I mean, definitely, it always depends on where you are, to be honest, and how high your system integration cost of that solar PV and EC minute.

00:15:53 Speaker 2

It's dirty, right?

00:15:53 Speaker 2

Let me clean this camera here.

00:15:54 Speaker 2

No, better.

00:15:56 Speaker 2

How high that system integration cost is as well.

00:16:00 Speaker 2

And then it has a lot to do with market design as well.

00:16:04 Speaker 2

But generally speaking, of course, solar PV has come down in cost very significantly.

00:16:09 Speaker 2

And that's a, that's generally a very, very good thing.

00:16:16 Speaker 2

One second here, my wife's calling me for whatever reason.

00:16:20 Speaker 1

No problem.

00:16:29 Speaker 2

That's how I call later.

00:17:11 Speaker 2

Okay, that's it.

00:17:13 Speaker 2

So, I mean, clearly, cost curves come down, solar significantly down.

00:17:18 Speaker 2

It's the cheapest source of energy today for certain hours of the day.

00:17:23 Speaker 2

Obviously, we have the intermittency topic of solar remains.

00:17:27 Speaker 2

And then, like I said, the market design topic is also an important one.

00:17:30 Speaker 2

It's actually being currently discussed in Germany at a proposed change by the minister, which has caused a lot of upheaval.

00:17:39 Speaker 2

So that's, where is the problem at the moment?

00:17:46 Speaker 2

Even if you're not contributing to the grid, you're still being paid.

00:17:54 Speaker 2

Because the grid also needs a certain amount of stability and the so-called sort of re-dispatching,

00:18:04 Speaker 2

you're being compensated for it.

00:18:07 Speaker 2

So you have it, which means for the investor, you have a pretty stable case where you're saying, no matter how much sunshine there is, I'm always being somehow compensated for my ability to produce when desired, let's say.

00:18:24 Speaker 2

If you change that, changes the case for solar quite a bit.

00:18:27 Speaker 2

If you change redispatching regulations and saying, oh, I'm only now paying for capacity,

00:18:35 Speaker 2

and don't care about the grid as much.

00:18:40 Speaker 2

You look at it differently, it's a political question, but it could, of course, could change the business case for intermittent sources significantly.

00:18:51 Speaker 2

So, all of a sudden, you are very exposed to the potential congestion in the grid, because

00:19:03 Speaker 2

You cannot just look at solar.

00:19:04 Speaker 2

I mean, it's easy to look at behind the meter.

00:19:07 Speaker 2

And I have my own battery, I have my rooftop solar, easy.

00:19:10 Speaker 2

I'm not using the grid.

00:19:12 Speaker 2

I may be feeding something into the grid, but then you're already part of the grid again.

00:19:18 Speaker 2

The grid makes things in the energy transition extremely complex.

00:19:22 Speaker 2

It's not the generation capacity as much.

00:19:27 Speaker 2

So, also, in Germany, we have a specific law.

00:19:29 Speaker 2

You're probably aware of the...

00:19:39 Speaker 2

the tax, all the Germans have been paying for the.

00:19:42 Speaker 1

Surcharge that they pay on their energy bill.

00:19:44 Speaker 2

Exactly, the surcharge paying the energy bill.

00:19:49 Speaker 2

That's

00:19:50 Speaker 2

also can sometimes make cases complicated because, for example, if I have a home device that stores energy, I might be charged twice that surcharge on the way in and on the way out again.

00:20:07 Speaker 2

If I feed back into the grid, that's the current design of the market.

00:20:11 Speaker 2

Why?

00:20:12 Speaker 2

Because it was thought back then, it was designed by a socialist government that sort of owning a

00:20:20 Speaker 2

storage device should not be a form of aggregating more wealth.

00:20:25 Speaker 2

So kind of tax it twice.

00:20:27 Speaker 2

So you don't make really any money out of it.

00:20:30 Speaker 2

But the downside on the system is that nobody does it because it has no economic case to do it.

00:20:35 Speaker 2

And therefore, for like more home style systems, it doesn't make much sense currently to feed previously

00:20:49 Speaker 2

stored energy into the grid.

00:20:52 Speaker 2

It makes sense to store your own energy if you use it your own, but anything below that, not really.

00:20:59 Speaker 2

So anyway, so you see it's a complex, it's a complex beast, the market design as well.

00:21:06 Speaker 2

And depending on how you take decisions, it can influence A lot.

00:21:10 Speaker 2

That's what I've been criticizing with the German politics quite a bit, that there is a basically a North Star missing.

00:21:18 Speaker 2

by which is our overriding principle what we want to achieve.

00:21:23 Speaker 2

And yet it's not to provide just energy to a system and have a stable grid, which is, I think, the current government's view.

00:21:32 Speaker 2

But geopolitically, we should have learned our lesson that always, with the case of Germany, will require energy sources

00:21:43 Speaker 2

which require importing a significant amount of import of energy, meaning there's no resilience or sovereignty or security built into the system right now.

00:21:56 Speaker 2

They have some of it, but it's very little in the end of the day.

00:22:00 Speaker 2

I mean, we have for natural gas, for example, we have a storage capacity of five, six months or something.

00:22:07 Speaker 2

Okay, that's a certain amount of resilience, 5, six months.

00:22:10 Speaker 2

But if you look at it from a

00:22:14 Speaker 2

how the US is, for example, looking at it.

00:22:18 Speaker 2

It's a very clear, or France, it doesn't even go so far, yeah.

00:22:22 Speaker 2

France is a very clear goal.

00:22:24 Speaker 2

70% of the energy we consume in this country needs to be produced in France and cannot be relying on anything else.

00:22:33 Speaker 2

And it's quite a simple, simple law of the US

00:22:37 Speaker 2

doesn't have it in the law as much, but the reality is lived like it.

00:22:40 Speaker 2

They don't want to, they want to be 100% resilient economy.

00:22:45 Speaker 2

And that's a political decision at the end of the day, and China's on its way to it, right?

00:22:50 Speaker 2

And Germany is still not taking that decision in this direction, leading to another birth mistake, to be honest, currently.

00:22:58 Speaker 2

We are building a huge gas infrastructure now, but we don't have any gas.

00:23:04 Speaker 2

And the gas infrastructure is to support the solar, right, and the wind.

00:23:07 Speaker 2

That's clear.

00:23:07 Speaker 2

It's supposed to be peakers in the system, but even peakers, if you don't control the peakers and the input for the peakers, a system running only on renewables and batteries is not feasible for a country like Germany.

00:23:22 Speaker 2

It is feasible for some other countries, for example, probably electricity only.

00:23:28 Speaker 2

If you combine energy with transport fuels and heat, then it's, I think there's literally no country that could run on renewables only.

00:23:38 Speaker 2

But for electricity, look at Denmark, for example, with the low amount of wind energy in the system, they, but it's very specific use case.

00:23:48 Speaker 2

You know, you have a population which lives only by the coast.

00:23:54 Speaker 2

or all the entire countries, only coastline kind of, very, very specific country where it's not so replicable for others.

00:24:04 Speaker 1

Okay.

00:24:05 Speaker 2

So just see for this graph is market design, market conditions, policy depend a lot.

00:24:11 Speaker 2

It can make a huge difference.

00:24:12 Speaker 2

Even if it's very clear that solar is the cheapest source of energy, but it's only in generation the cheapest source, you have to always think about the full system integration cost.

00:24:24 Speaker 1

Yeah, okay.

00:24:25 Speaker 1

Yeah.

00:24:26 Speaker 1

So it's a bit optimistic to say, it's crossed the positive tipping point.

00:24:30 Speaker 1

We can remove all of the regulations.

00:24:32 Speaker 1

Like there's still market design.

00:24:34 Speaker 1

that we need to take care of to keep the...

00:24:36 Speaker 2

In certain scenarios, in the grid, off grid, behind the meter, no doubt.

00:24:41 Speaker 2

And I think we'll see a lot more behind the meter projects coming to life or stuff like data centers.

00:24:48 Speaker 2

Some areas are not allowing it right now, some states in the US or some areas.

00:24:55 Speaker 2

But I think that trend will change.

00:24:57 Speaker 2

We'll see more and more behind the meter just also

00:25:00 Speaker 2

Of course, the grid is super complex the tourist is slow to build out because of its complexity.

00:25:09 Speaker 2

it's not just people are stupid and they don't find enough cables or not enough people who can erect a tower and put a cable on.

00:25:17 Speaker 2

That's not the issue it's just the planning and all the proper...

00:25:22 Speaker 2

resourcing of a grid is just generally very, very complex animal.

00:25:27 Speaker 2

And then again, yes, solar itself, great.

00:25:31 Speaker 2

Enormous future for sure.

00:25:34 Speaker 2

Grid integration is complicated.

00:25:36 Speaker 1

Got it.

00:25:37 Speaker 1

Okay.

00:25:37 Speaker 1

That makes sense.

00:25:38 Speaker 1

That makes sense.

00:25:41 Speaker 1

Then does the, you know, does the causal loop diagram, in your view,

00:25:48 Speaker 1

So the bigger one, does it accurately represent how, you know, rooftop solar PV adoption behavior and the business activity interact, for example, to drive down?

00:26:05 Speaker 2

I think generally speaking, these are the right levers.

00:26:07 Speaker 2

I think you can discuss now which lever has more effect than the other, and it might vary from time to time as well.

00:26:13 Speaker 2

But in generally speaking, yes, I think the overall feedback loops are right.

00:26:17 Speaker 2

The more activity comes to the market, the higher the social contagion is, the more activity comes, the more the businesses start becoming larger businesses, they will invest more into marketing, into R&D.

00:26:31 Speaker 2

And the bigger it becomes also, the more sort of it becomes on the radar of the larger competitors who see, hey, you know, my turf is being attacked here.

00:26:42 Speaker 2

Yeah.

00:26:43 Speaker 2

And the war they will fight against it, which they're doing a lot.

00:26:48 Speaker 2

I mean, all the time, the utilities who are in gas business are have no interest at all in renewables, you know.

00:26:58 Speaker 1

Okay.

00:26:59 Speaker 1

Cool.

00:26:59 Speaker 1

Yeah, we can dive deeper into, you know, some, the strength of some of these levers specifically related to the startup sector just in a sec.

00:27:09 Speaker 1

About the, so the behavior of these, so new entrants and then kind of the mature firms, you know, this one you can kind of memorize that it goes, that it goes up to some extent and the startups, you know, it,

00:27:29 Speaker 1

It represents much.

00:27:31 Speaker 1

I think the interesting flow here is the new entrance.

00:27:34 Speaker 1

So how do companies enter the market?

00:27:37 Speaker 1

If we have more companies in the market, obviously we're going to have more, you know, we will have more exits to some extent and we will have more startups.

00:27:46 Speaker 1

The data I found was based on, so the red curve is from Crunchbase.

00:27:52 Speaker 1

So Crunchbase has a database of, you know, startups, as you know, and

00:27:59 Speaker 1

There is a lot of variance.

00:28:00 Speaker 1

So you can see that each year.

00:28:02 Speaker 1

It may change a lot, depending a lot also on the market conditions in general.

00:28:08 Speaker 2

Yeah, and on the teams, to be honest, you know, a lot of the teams, we actually barely ever see technology or markets fail.

00:28:15 Speaker 2

It's typically teams that fail.

00:28:17 Speaker 1

Okay.

00:28:19 Speaker 2

Because we haven't seen many markets who said like, oh, market collapse, go on.

00:28:22 Speaker 2

We had one case in the portfolio where it did happen with the sort of in the US with the

00:28:27 Speaker 2

the advent of the Trump administration, certain things got changed on the carbon removal side, and that company literally lost its market.

00:28:34 Speaker 2

So the technology was good, but then a lot of it was riding on a certain setup in the agricultural market.

00:28:43 Speaker 2

There was no longer available, but that's a rare case now.

00:28:47 Speaker 2

That's really the rare case.

00:28:48 Speaker 2

The normal case is that team sale simply don't get along, doesn't don't execute well enough.

00:28:55 Speaker 1

Okay.

00:28:55 Speaker 1

Okay.

00:28:56 Speaker 1

Is there, do you see any?

00:28:57 Speaker 2

In the early stages now we're talking, right?

00:28:58 Speaker 2

I mean, the changes, this is relevant for up to series B companies, I would say.

00:29:04 Speaker 2

Series B onwards, that team failing risk because the companies are much larger now, you know, than there are 100 or 200 employees.

00:29:11 Speaker 2

It doesn't mean so much if even if the CEO leaves, right, the companies are rolling.

00:29:16 Speaker 2

But in the early stages, pre-seen to B, team is the biggest risk.

00:29:21 Speaker 1

Okay.

00:29:21 Speaker 1

Okay.

00:29:22 Speaker 1

Fair.

00:29:24 Speaker 1

Does this kind of curve, is this something that you observe in markets?

00:29:32 Speaker 1

So do you observe like, okay, as the market becomes more, you know, interesting to enter, more companies will kind of enter up to a certain point and then, you know, then you start to see like a decrease in kind of entrance.

00:29:48 Speaker 2

Of course, absolutely, absolutely, because we also then see consolidation, people buying up each other and so on.

00:29:54 Speaker 2

So, and of course, once you have 3, 4, 5, like, let's take the solar market, once you have like NPAL and Wines come up and Tamondo in the market, and they all have a certain, and of course, all the local mom and pop shops and installers.

00:30:10 Speaker 2

Right.

00:30:10 Speaker 2

It gets less attractive.

00:30:12 Speaker 2

Also, the VC funding, the VCs have taken their bets at that stage.

00:30:15 Speaker 2

They've backed a few teams.

00:30:18 Speaker 2

They're not going to back another five teams unless you come up with significant business model innovation, which for example, Einstein have tried.

00:30:25 Speaker 2

I mean, there was already quite a few mature entrants already and Einstein said, okay, we'll make a buy and build case out of it.

00:30:31 Speaker 2

We'll buy up this because they thought, I think it's actually wrong assumption in the end.

00:30:37 Speaker 2

They thought that the biggest shortage will be insulation capacity.

00:30:44 Speaker 2

But in the end, insulation capacity in a market which is not growing as dynamically as they thought is not the bottleneck.

00:30:57 Speaker 2

And then the buy and build case probably makes no sense.

00:31:01 Speaker 2

But yes, generally speaking, either a very innovative approach or a new technology, or let's say if you can come tomorrow and do full automated installation of PV using robots or whatever, that of course would change.

00:31:18 Speaker 2

Or in the US, for example, we've seen one company, forgot the name now, that's doing a super low tech approach.

00:31:25 Speaker 2

What's it called?

00:31:27 Speaker 2

I forgot the name.

00:31:30 Speaker 2

And they're not installing and they do utility now, not homes, but utility style sort of larger solar projects.

00:31:38 Speaker 2

And they have a cost leadership model where they use this very, very simple, cheap materials, have no trackers and nothing installed because it all has to cost, but in the end of the day, it's good enough.

00:31:56 Speaker 2

reduces the total cost of build and hence the LCOE.

00:32:00 Speaker 2

Speed is also important.

00:32:01 Speaker 2

They can be very fast.

00:32:03 Speaker 1

Okay, okay.

00:32:05 Speaker 2

But yes, I mean, generally, this is the normal curve.

00:32:07 Speaker 2

You have a hype cycle.

00:32:08 Speaker 2

People are seeing opportunity when they come into market.

00:32:10 Speaker 2

And at some stage, it drops off because, yeah, there's no more venture capital available for another bet.

00:32:21 Speaker 1

Okay, great.

00:32:23 Speaker 1

Okay, at this point, I can

00:32:26 Speaker 1

I can stop sharing.

00:32:27 Speaker 1

We can just have a conversation.

00:32:30 Speaker 1

So how does the entrepreneurial activity affect the adoption of technologies such as in renewables?

00:32:40 Speaker 1

Very general question.

00:32:42 Speaker 2

Yeah, very much.

00:32:43 Speaker 2

Of course, very much.

00:32:44 Speaker 2

If you have a market where you have good entrepreneurs and good people who know how to build companies,

00:32:50 Speaker 2

who have the right sense or attitude to build companies, it makes a huge difference.

00:32:55 Speaker 2

Because the founders make a huge difference, huge difference.

00:33:03 Speaker 2

Even in the deepest of the deep tech place where you think what an amazing innovation, whatever, if the founder is not commercially savvy and able to sell his idea, he will get nowhere.

00:33:19 Speaker 2

And then the market doesn't take off for that reason, because there's not enough smart people in the market.

00:33:24 Speaker 2

So I think people make an absolutely gigantic difference.

00:33:28 Speaker 2

And what's the old Warren Buffett saying?

00:33:32 Speaker 2

What did he say?

00:33:34 Speaker 2

I forgot what he said.

00:33:44 Speaker 1

Something about cost?

00:33:45 Speaker 2

I can't put the code together now, but something that direction he said.

00:33:48 Speaker 1

I'll have to look it up after the call.

00:33:49 Speaker 2

I can't put the code together, but it's managers matter.

00:33:54 Speaker 2

Of course, if the market is structurally flawed, then it also doesn't matter with the managers.

00:33:59 Speaker 2

That's also true.

00:34:00 Speaker 2

If there are structurally flaws in the market and the market can't take off for whatever other reason, because there's geopolitical constraint.

00:34:10 Speaker 2

For example, if you're an AI,

00:34:12 Speaker 2

You can see a lot of cases where you would probably think this has a large security risk.

00:34:20 Speaker 2

Then you're constrained by that, no matter how good the manager is.

00:34:25 Speaker 1

Yeah, And then you probably wouldn't see new entrants for very long, right?

00:34:29 Speaker 1

Or at least not very good entrepreneurs going in there.

00:34:32 Speaker 2

Yeah, exactly.

00:34:33 Speaker 2

No, you want to be in markets where you have the ability to influence.

00:34:38 Speaker 2

That's why I'm wondering why so many VCs are going into that defense tech right now, to be honest.

00:34:43 Speaker 2

I think it's actually quite a horrible market, super constrained on the sales side.

00:34:50 Speaker 2

You're selling to governments only, which is the worst customer, large degree of corruption as well in these markets.

00:34:58 Speaker 2

Huge incumbents with...

00:35:02 Speaker 2

almost century-long ties to the government.

00:35:06 Speaker 2

I think it's a very, very bad market to be in as a startup.

00:35:12 Speaker 2

It's a forest market.

00:35:15 Speaker 1

Yeah, it's like maybe they're following, I don't know, indicators about media and what is like kind of hype right now.

00:35:23 Speaker 2

Of course, there's some hype and some of the companies have been doing great evaluations, but I'm worried about a lot of these companies, to be honest as well.

00:35:30 Speaker 2

I think they will also be outsmarted by some super cheap solutions from Ukraine and Russia and other places, China and so on.

00:35:39 Speaker 2

These German startups doing a lot of drones, quantum systems, and Helsing and so on and so forth.

00:35:47 Speaker 2

A lot of hype.

00:35:49 Speaker 2

But in the end of the day, they also have no experience.

00:35:51 Speaker 2

They have no battlefield experience.

00:35:53 Speaker 2

And they're having, they're flying their drones in a nice Bavarian backyard or something.

00:36:00 Speaker 2

But the Ukrainians are testing this every day in the field.

00:36:03 Speaker 2

And that's a huge advantage.

00:36:05 Speaker 2

And I think actually the 1st results from Helsing and so on that they put into the battlefield in Ukraine was ****.

00:36:10 Speaker 2

They were shot down immediately.

00:36:13 Speaker 1

Interesting.

00:36:13 Speaker 1

OK, interesting.

00:36:17 Speaker 2

So it's.

00:36:18 Speaker 2

I'm not sure if that, in general, when we talk about security, if that high-tech approach actually wins.

00:36:26 Speaker 2

It's often, it's more likely in the new modern warfare to be the low-tech approach.

00:36:30 Speaker 2

But again, I don't care because I'm not investing into the sector anyhow, but I'll be just super cautious in the sector where dynamics are not free market dynamics.

00:36:42 Speaker 1

Right, understandable.

00:36:44 Speaker 1

So what factors, from your experience, what factors do entrepreneurs consider

00:36:48 Speaker 1

when entering a new market.

00:36:49 Speaker 2

Yeah, exactly that.

00:36:50 Speaker 2

Is it actually a market where I have control, where I have freedom to operate, which can potentially scale globally?

00:36:59 Speaker 2

Do I step on anybody's toes by rolling out my technology globally?

00:37:04 Speaker 2

I mean, of course, you might, but I mean, that's the, and again, just look at the US hyperscalers, that's how you do it, yeah?

00:37:14 Speaker 2

That's a great...

00:37:16 Speaker 2

I mean, now we start to talk about digital sovereignty and so on as well, but it hasn't been a topic, to be honest, before.

00:37:23 Speaker 2

But now it's starting to become a topic because we also see that security is not only in the physical world, but also the digital world, obviously.

00:37:34 Speaker 2

But you look at how easy it is to roll out a Google globally or meta platforms or whatever.

00:37:42 Speaker 2

These are very attractive markers with little boundaries, very easy to adapt and processes to many, many different regulations.

00:37:52 Speaker 2

Or look at SpaceX and...

00:38:01 Speaker 1

OK, Starlink.

00:38:02 Speaker 2

Starlink and now Blue Origin putting the similar thing out.

00:38:05 Speaker 2

These are very basically no regulation space.

00:38:09 Speaker 2

You can do whatever you want.

00:38:10 Speaker 2

You know, it's not a regulated space.

00:38:11 Speaker 2

You can not a regulated space.

00:38:13 Speaker 2

Yeah.

00:38:15 Speaker 2

And you can easily, of course, without much complications on it from a national government level, sell a service through a

00:38:28 Speaker 2

whatever registered company on a global scale.

00:38:32 Speaker 1

Yeah.

00:38:32 Speaker 1

Okay.

00:38:33 Speaker 2

That's, that's a, that these are beautiful that here I see beauty in the cases.

00:38:37 Speaker 1

Yeah.

00:38:37 Speaker 1

Okay.

00:38:38 Speaker 1

So then do you, do you see like, so you mentioned freedom to operate and that you can have an impact in the market.

00:38:43 Speaker 1

So it, do you think the, like, for example, in the case of solar PV, that the amount of previous installations is kind of a sufficient indicator that like, like previously installed capacity is a,

00:38:57 Speaker 1

a good indicator of, market opportunity.

00:39:01 Speaker 2

Yeah.

00:39:03 Speaker 2

Play a role, but that's for later entrant role.

00:39:06 Speaker 2

I mean, the real early entrants, they don't give a damn, right?

00:39:09 Speaker 2

I mean, Elon doesn't give a damn if there was electric cars before, or if there was anybody doing rockets before, or international sports and so on.

00:39:15 Speaker 2

Yeah, he never gave a damn.

00:39:17 Speaker 1

Yeah, right, OK.

00:39:19 Speaker 2

So, well, maybe, yeah, maybe we're not thinking about the players, but yeah, the real pioneers, the real category definers,

00:39:27 Speaker 2

They create the category themselves.

00:39:30 Speaker 2

And of course, Elon is the absolute outlier.

00:39:31 Speaker 2

He's the most crazy category to find out there.

00:39:37 Speaker 2

But so many others have also, I mean, even weird stuff like who would have thought that you like to write your messages with 140 characters only, right?

00:39:49 Speaker 2

And he also created that category out of

00:39:53 Speaker 2

out of something which would sound very unlikely.

00:39:56 Speaker 2

If you would have looked at the first pitch deck of Twitter, it's online, you can look at it.

00:40:01 Speaker 2

It's very unusual that somebody backs this.

00:40:04 Speaker 2

Who did they back, by the way?

00:40:06 Speaker 2

They backed Jack Dorsey back then, right?

00:40:08 Speaker 2

Excellent guy, he knows what he's doing.

00:40:10 Speaker 1

Yeah, the entrepreneur.

00:40:11 Speaker 2

Exactly.

00:40:13 Speaker 2

And that entrepreneur was really, really good and able to define this category.

00:40:18 Speaker 2

Something that you would have never thought people would want to do.

00:40:21 Speaker 1

Right, Do you think the policies play, like for, let's say for the general market, do policies, do you think they play a big role in?

00:40:30 Speaker 2

Of course, they often open opportunities or close opportunities, yeah, often.

00:40:34 Speaker 2

Of course, the tax we talked about earlier in Germany opened up a lot of opportunities in the renewable energies market, right?

00:40:41 Speaker 2

The fact that there was a law that said, okay, we will invest certain amounts into the deployment of renewables, of course, that opens a huge amount of opportunity.

00:40:50 Speaker 2

So it is regulation can be a huge enabler or again, technological shifts.

00:40:54 Speaker 2

We're going to see this non-robotics game.

00:40:55 Speaker 2

We're going to see existing industries.

00:40:58 Speaker 2

I mean, there's just so many sectors that will be completely disrupted due to the advent of robotics where all of a sudden certain tasks like, I don't know, cleaning or something will become so much cheaper than they were before.

00:41:16 Speaker 2

So technology obviously

00:41:18 Speaker 2

has the same effect and can have the same effect as regulation really open up markets.

00:41:22 Speaker 1

Right.

00:41:22 Speaker 1

Okay.

00:41:23 Speaker 1

And what would you say are the main drivers of venture capital availability in a market such as renewables?

00:41:31 Speaker 2

I mean, first of all, that's a big question.

00:41:35 Speaker 2

Big question.

00:41:36 Speaker 2

That's a lot of things.

00:41:39 Speaker 2

Because first of all, you need to have, if venture capital really exists, you need to have a solid base layer of institutional capital that can diversify and invest into venture capital.

00:41:47 Speaker 2

You mean you need a healthy pension fund system, you need a healthy insurance system, you need a healthy corporate system and some private money.

00:41:54 Speaker 2

But private money doesn't play much of a role, really.

00:41:58 Speaker 2

And if those things come together and they all have a certain allocation, it needs to be these huge capital pools.

00:42:03 Speaker 2

It doesn't come from anywhere, to be honest.

00:42:05 Speaker 2

And you could say maybe

00:42:07 Speaker 2

National Promotion Institutes, like whatever, the cyber wealth, like Tisi in Finland, right?

00:42:16 Speaker 2

Those type of pools can also play a certain role.

00:42:21 Speaker 2

So that's, I would say, the general lay of the land.

00:42:28 Speaker 2

You have these things in place and all of them bound by certain rules, the National Promotion Institute less, they can do whatever they want because they're just wasting taxpayer money.

00:42:37 Speaker 2

But specifically the large pools of pension and insurance are the two largest pools by far.

00:42:44 Speaker 2

They are regulated typically in what they can invest, solvency tool rules in Europe, something else in prudent investment standards in the US and so on.

00:42:51 Speaker 2

But if that's set up in the right way, that would bring money into the system.

00:42:56 Speaker 2

In many cases in Europe, it's not set up in the right way, by the way.

00:42:59 Speaker 2

We don't have a lot of pension funds that invest money.

00:43:01 Speaker 2

We have a lot of areas where pension does not invest any sense into venture because they don't invest at all.

00:43:06 Speaker 2

Like Germany, for example, our pension system is a so-called pillar one or pay-as-you-go system, which means every month I pay something to somebody, to some state authority, and it pays out the same month, the same day, basically.

00:43:21 Speaker 2

They pay out to the pensioners.

00:43:22 Speaker 2

It's not reinvested.

00:43:23 Speaker 2

There's no

00:43:25 Speaker 2

It's not based on any kind of capital structure.

00:43:30 Speaker 2

Unlike the Nordics, you guys pay in and it gets reinvested and grows and then it gets paid out.

00:43:37 Speaker 2

But of course, to do that, you need to start somewhere.

00:43:40 Speaker 2

You need to start with a certain base, which some countries started from the get-go like this.

00:43:47 Speaker 2

They put some money back in there and started, but this was many, many, many years ago, often over 100 years ago, like the Netherlands.

00:43:55 Speaker 2

And some switched, like Sweden switched in the 70s from one system to another.

00:43:59 Speaker 2

It's expensive and it also required people to work longer because you cannot keep on paying out and less and less people are paying in.

00:44:07 Speaker 2

But that's the first foundation of financing any innovative ventures, that you need to have proper pools of capital in place and it needs to be several different pools.

00:44:18 Speaker 2

those who are the ones who are going to be investing into real estate, into whatever, infrastructure and so on and so forth, but also a certain amount of portion will go to financing innovation, which turns out is strategically extremely important because technological leadership is critical for any nation's future growth and prosperity and security and sovereignty and everything actually for the living of the nation that actually has a right to exist.

00:44:44 Speaker 2

So this is

00:44:45 Speaker 2

this foundation is mission critical.

00:44:48 Speaker 2

And actually the missing bucket in Europe for most of the part is pension funds.

00:44:52 Speaker 2

We invest way too little of pension money to the point where pension funds hold in Europe about 10 or 12% of GDP in their assets.

00:45:07 Speaker 2

In the US it's 150% of GDP in sitting in pension funds.

00:45:12 Speaker 2

Changes everything.

00:45:13 Speaker 2

So to the point where

00:45:15 Speaker 2

In Europe, we invest 0.07% of our potential pension money into venture.

00:45:21 Speaker 1

Yeah.

00:45:22 Speaker 2

The US is 2.5%, depending on how you measure, 2, 3%, whatever, somewhere around there.

00:45:27 Speaker 2

Yeah.

00:45:27 Speaker 2

And that's a structural disadvantage, which is second.

00:45:32 Speaker 1

Yeah.

00:45:33 Speaker 1

Second.

00:45:33 Speaker 1

Yeah.

00:45:35 Speaker 1

It acts as kind of a constraint.

00:45:37 Speaker 1

Like you cannot, if you don't have those pools of money, then you cannot have

00:45:41 Speaker 1

so many funding, so many funds, and then you can't have so many successful startups.

00:45:46 Speaker 2

That's a very, very basic level already now.

00:45:51 Speaker 2

And if you fail at that, so, and then of course, you need to, this means that not enough managers will come into creation that will back more and more innovative startups.

00:46:02 Speaker 2

So we don't have, like in the US, we have hundreds of venture capital funds.

00:46:06 Speaker 2

In Europe, we have a few.

00:46:07 Speaker 2

It's been growing, it's getting better.

00:46:09 Speaker 2

So I think actually Europe has

00:46:11 Speaker 2

has understood that message and is also starting to take the right steps in the right direction.

00:46:16 Speaker 2

But historically, we've fallen behind.

00:46:18 Speaker 2

And again, Europe is not Europe.

00:46:20 Speaker 2

It's very different from one country to another.

00:46:22 Speaker 2

It's like the Nordics are a bit better.

00:46:23 Speaker 2

The Netherlands is very good.

00:46:25 Speaker 2

UK has also changed their pension scheme some time ago.

00:46:28 Speaker 2

It's also a bit better with these several pools.

00:46:31 Speaker 2

So there are some nations which are doing better than others.

00:46:37 Speaker 1

Okay.

00:46:37 Speaker 1

And then after that first layer,

00:46:41 Speaker 1

There's probably a lot of things that drive, VCs into a specific market.

00:46:48 Speaker 1

In this model, I mean, I made a...

00:46:50 Speaker 2

Then it's about opportunity, of course.

00:46:51 Speaker 2

And then, yeah, but that's so broad as well, of course.

00:46:56 Speaker 2

Typically, you have some type of team which has some sort of know some type of sector or comes from a certain sector, understands a bit of a some type of industry better than others and sees opportunity.

00:47:08 Speaker 2

I see a lot of teams right now raising with very technical backgrounds on robotics that are raising funds right now saying, hey, we know how to invest into robotics.

00:47:15 Speaker 2

We've seen a lot of companies on the energy space over the last couple of years, but of course also in the whole sort of software SaaS, B2B SaaS game and so on.

00:47:24 Speaker 2

So yes, quite a few different alleys, but all of them need capital to deploy.

00:47:37 Speaker 1

Right.

00:47:37 Speaker 1

Right.

00:47:38 Speaker 1

Okay.

00:47:38 Speaker 1

You mentioned teams a few times.

00:47:39 Speaker 1

So I think is that like a critical factor?

00:47:45 Speaker 1

I mean, I see that.

00:47:46 Speaker 2

For starting out for sure, you need a team that has the track record, that has a certain industry expertise that can make people believe that they're going to take good care of their money.

00:47:55 Speaker 2

Yeah.

00:47:56 Speaker 1

Do they come internally from the same market?

00:48:00 Speaker 2

Yeah, not always in the same market, also be from the other diverse markets.

00:48:03 Speaker 2

When you look at the teams in venture capital now, it's very diverse backgrounds, to be honest.

00:48:08 Speaker 2

Some are a bit more concentrated, but actually good teams are typically quite diverse.

00:48:13 Speaker 1

Right, for VC.

00:48:14 Speaker 1

Okay, got it.

00:48:17 Speaker 1

What are the main drivers of successful exits?

00:48:20 Speaker 1

So success rates via, so for IPOs and for M&As, so to get past, you know, you've gotten past the valley of death, you're kind of in a after series B stage.

00:48:30 Speaker 1

What are the main drivers for?

00:48:34 Speaker 2

I think you need to stop here on time.

00:48:36 Speaker 1

OK, that's fine.

00:48:38 Speaker 1

Yeah, we'll stop.

00:48:39 Speaker 1

We'll stop.

00:48:40 Speaker 2

I have to stop at 11.

00:48:42 Speaker 2

It's also, I mean, again, market design, how easy it is to have specifically IPOs in certain market.

00:48:50 Speaker 2

Take Sweden very easily to list.

00:48:53 Speaker 2

Sweden had 800 APOs IPOs for the last 10 years.

00:48:58 Speaker 2

Germany 80, that's 10 times economy.

00:49:02 Speaker 2

So obviously there's a better liquidity possibility and more retail investors willing to invest as well.

00:49:07 Speaker 2

It has to do with a lot of tax incentive schemes as well, how much taxation is in capital gains and so on.

00:49:12 Speaker 2

It's complex, the answer.

00:49:14 Speaker 2

But I think for Europe, the simple answer would be savings and investment union to create a large, large single financial market in Europe now, which has been discussed for a long time, that would do wonders to increase the exit markets in Europe.

00:49:29 Speaker 2

And of course, you could also work on improving secondaries through private or alternative assets.

00:49:35 Speaker 2

It's also something that's been discussion, improve that market could also be huge, huge, hugely beneficial.

00:49:41 Speaker 2

Again, initiatives have been discussed there.

00:49:44 Speaker 2

Don't know exactly where they stand, but the idea is out there to create basically a highly liquid or better liquidity market for private assets, be it a fund or a single asset.

00:49:58 Speaker 1

Okay, awesome.

Interview 1: Fraunhofer ISE, Personal Communication, 2026

Speaker 1: Representative at Fraunhofer ISE

Speaker 2: Author

Transcript

00:00:04 Speaker 1

Okay.

00:00:05 Speaker 2

Yeah, it should be going.

00:00:06 Speaker 2

Okay.

00:00:06 Speaker 2

So I think we can start off by presenting the causal loop diagram, and you can feel free to ask any questions throughout.

00:00:19 Speaker 2

Did you have any questions already based on what I sent you?

00:00:24 Speaker 2

Or should we just run?

00:00:25 Speaker 1

I only had time to look at the questions, so I didn't take a look at the presentation or anything.

00:00:33 Speaker 2

Okay, excellent.

00:00:34 Speaker 2

So this is a causal loop diagram.

00:00:38 Speaker 2

Not sure how familiar you are with the symbols and indications and things like that.

00:00:43 Speaker 2

Okay.

00:00:44 Speaker 2

So system dynamics is a modeling methodology where we take into account all the systemic effects

00:00:55 Speaker 2

which is different to linear regression modeling in that there is feedback and delays and these kinds of aspects of the system are taken into account.

00:01:10 Speaker 2

So the systems that we work with are usually interconnected.

00:01:13 Speaker 2

So as you can see here, we have a

00:01:18 Speaker 2

installation of roof soft solar PV, and then we have this social contagion area, and then we also have a industry section.

00:01:26 Speaker 2

So there's multiple interconnected complex systems.

00:01:32 Speaker 2

You can think about it as kind of in an Excel sheet.

00:01:38 Speaker 2

You can do all of this in an Excel sheet.

00:01:39 Speaker 2

It will just be very complicated.

00:01:41 Speaker 2

So when you look at an Excel sheet cell,

00:01:45 Speaker 2

you see just a number, but behind that number is an equation.

00:01:49 Speaker 2

And these all represent kind of equations.

00:01:53 Speaker 2

So installation rate increases installed rooftop solar PV at the simplest form.

00:01:58 Speaker 2

And these are accumulations of stocks.

00:02:01 Speaker 2

So things that you can measure.

00:02:03 Speaker 2

So if you take a snapshot at any point in time, you can, you have a measured amount of installed rooftop solar PV, but installation rate is something that's changing over time.

00:02:13 Speaker 2

So it's a, it's per year.

00:02:15 Speaker 2

And then startups also snapshot, you can take a picture of it, mature firms, snapshot, patent snapshot.

00:02:21 Speaker 2

And then here we have a willingness to consider.

00:02:24 Speaker 2

It's like a soft variable, kind of like, you know, how, how willing are potential adopters to

00:02:31 Speaker 2

consider installing rooftop solar PD.

00:02:34 Speaker 2

Okay, then these linkages are kind of, if there's a positive plus sign, it might be too small to see.

00:02:41 Speaker 2

It means that it's, they're positively correlated or caught causally linked.

00:02:48 Speaker 2

So if installed rooftop solar PD increases, the, so through the economies of scale, the utility will improve.

00:02:59 Speaker 2

Right?

00:02:59 Speaker 2

The same here.

00:03:00 Speaker 2

Like if you have more installed rooftop solar PV, then the social exposure increases.

00:03:05 Speaker 2

More people are being exposed to the platform.

00:03:07 Speaker 2

If it's negative, it goes the opposite direction.

00:03:10 Speaker 2

And then a loop basically creates this kind of exponential pattern.

00:03:16 Speaker 2

So as installed rooftop solar PV increases, social exposure increases.

00:03:21 Speaker 2

As you have more non-adopters, potential adopters coming into contact with adopters,

00:03:28 Speaker 2

There is this social exposure, and this has been shown in literature as well, that you kind of create these clusters that if in an area there is more installations, then it's more likely that closer to that region, there are more installations.

00:03:48 Speaker 2

And then you have more willingness to consider, and then the perceived utility goes up.

00:03:52 Speaker 2

So you have this utility function is a function of

00:03:57 Speaker 2

willingness to consider and the kind of actual utility.

00:04:02 Speaker 2

So if you're not being exposed to the platform through this marketing or through being in contact with adopters, then you don't even consider the platform.

00:04:15 Speaker 2

And as the perceived utility goes up, installations increase, you get more installed solar PV and more social exposure.

00:04:22 Speaker 2

So you start to see this exponential reinforcing pattern.

00:04:27 Speaker 2

Then, so that is the R1 social contagion loop.

00:04:30 Speaker 2

And this has been seen with many, many technological innovations, not just obviously rooftop solar.

00:04:41 Speaker 2

The other thing to notice, yeah, we're speaking specifically about, or I've modeled specifically rooftop solar PV and not, you know, ground mounted utilities or commercial installations.

00:04:53 Speaker 2

for the purpose of the modeling.

00:04:55 Speaker 2

So we can keep it really focused because a lot of the mechanisms, a lot of the feedback would be very different with utility scale.

00:05:06 Speaker 2

So as installed rooftop solar PV increases, as I mentioned, you have the factories producing the modules have more capacity and there's production learning.

00:05:20 Speaker 2

And this ultimately

00:05:22 Speaker 2

decreases the cost of production through economies of scale, and which ultimately reduces the price for the consumer and the utility thus increases.

00:05:32 Speaker 2

So this is the economy of scale reinforcing loop, R2.

00:05:37 Speaker 2

Then you have the R3 loop, which is learning by doing.

00:05:40 Speaker 2

So another common phenomenon with technological innovations that adds you, that the industry improves and you get more business model innovation and complementary products.

00:05:50 Speaker 2

So as installed rooftop increases, the perceived market opportunity increases for entrepreneurs to enter.

00:05:57 Speaker 2

You have more startups coming in to the market.

00:06:01 Speaker 2

And as you have more startups and more firms, they come up with new business models, new complementary products.

00:06:11 Speaker 2

You can think about battery storage or smart metering or something like this.

00:06:16 Speaker 2

And this, again, decreases the price for the consumer.

00:06:20 Speaker 2

Ultimately, which increases the utility, again, you get more installations.

00:06:24 Speaker 2

So there's another reinforcing loop learning by doing.

00:06:27 Speaker 2

Then increased R&D is another reinforcing loop.

00:06:31 Speaker 2

So solar industry revenue is a function of the amount of installations.

00:06:39 Speaker 2

So there is a CapEx and then OpEx for operating a solar PV system.

00:06:49 Speaker 2

This increases, this all ultimately goes to the industry revenue and the industry spends some amount of their revenue on R&D, on research and development, which increases patents.

00:07:05 Speaker 2

So patent filings, essentially.

00:07:08 Speaker 2

And another thing here to note is this R&D policy.

00:07:14 Speaker 2

So this is essentially the amount of

00:07:17 Speaker 2

funding that the government that the German government spends on R&D in the solar industry.

00:07:24 Speaker 2

This also increases the amount of the amount of patents and technological innovations.

00:07:31 Speaker 2

And as you have more patents, you know, roughly, of course, it it's not like if you have a patent, you have a consistent amount of utility improvement.

00:07:40 Speaker 2

But after some amount of patents, you do have some technological innovations that that improve the

00:07:48 Speaker 2

either the cost or the performance of solar PV modules to the point that the price, again, and the utility decreases for consumers.

00:08:04 Speaker 2

And then again, you have the perceived utility is improving and you have more installations.

00:08:08 Speaker 2

So again, a reinforcing loop.

00:08:12 Speaker 2

Another reinforcing loop is

00:08:16 Speaker 2

within the industry sector itself.

00:08:18 Speaker 2

So as you have more startups coming into the market, some percentage of them will mature and become success cases.

00:08:27 Speaker 2

You can think about Solar World, for example, in Germany.

00:08:30 Speaker 2

And these success cases, these kind of like role model companies also increase the perceived market opportunity for potential entrepreneurs that they

00:08:43 Speaker 2

that they perceive that, hey, this is a market we want to, that we can enter, where we can be successful, and that it has matured to a point that there are successful companies, successful exits here.

00:08:54 Speaker 2

So that's another reinforcing feedback loop.

00:08:59 Speaker 2

Then R6, this marketing effect.

00:09:01 Speaker 2

So similarly to the R&D, as industry revenue increases for more installations,

00:09:09 Speaker 2

A certain percentage of this is spent on marketing efforts of the platform.

00:09:15 Speaker 2

Also, it can partly happen residually as in the form of newspaper articles or magazines, just it being in the public discourse.

00:09:28 Speaker 2

And also some amount, direct advertisements through whichever marketing channels they use.

00:09:36 Speaker 2

And this also increases the

00:09:40 Speaker 2

Social exposure.

00:09:42 Speaker 2

So again, you can your social, the social exposure can increase through meeting, you know, your neighbor has a installed roof of solar PV or someone in the neighborhood, but also through direct sort of marketing that you hear about it through other means.

00:09:56 Speaker 2

And this increases the social exposure, willingness to consider perceived utility again.

00:10:02 Speaker 2

So you can kind of see that this marketing effect is also

00:10:09 Speaker 2

strengthening the social contagion.

00:10:10 Speaker 2

So you have more and more, yeah, exposure to the platform.

00:10:17 Speaker 2

Another thing that can increase the marketing is kind of this political discourse.

00:10:24 Speaker 2

So if the government makes an initiative, for example, in Germany with the EEG Act or these kinds of initiatives that we want to

00:10:38 Speaker 2

we want to boost or strengthen the solar PV sector or have more solar PV energy, then this is another sort of marketing effect.

00:10:53 Speaker 2

Then our setting, the reinforcing loop of funding availability.

00:10:59 Speaker 2

So as installed reflush solar PV increases, it becomes a market

00:11:05 Speaker 2

that's interesting for venture capital investors to enter.

00:11:09 Speaker 2

And this valley of death, I'm not sure how familiar you are with the term.

00:11:14 Speaker 2

So essentially, it's the term that, so 90% of startups fall into this valley of death.

00:11:21 Speaker 2

So this is the early stages of a company trying to mature.

00:11:25 Speaker 2

And the principal reason for failure in the valley of death is a lack of financing.

00:11:31 Speaker 2

So essentially, a company runs out of money.

00:11:34 Speaker 2

Technology companies, traditionally, in most cases, they depend on venture capital funding.

00:11:42 Speaker 2

So if there's more venture capital funding in the market, then less companies will fail in the valley of death.

00:11:47 Speaker 2

They will cross this valley of death.

00:11:49 Speaker 2

They will go from mature firm, from startups, sorry, into mature firms.

00:11:54 Speaker 2

And then we get all these learning by doing effects, for example, increasing and successful exits are five.

00:12:03 Speaker 2

effects are happening.

00:12:04 Speaker 2

But if they're all or many are falling into the valley of death, then we don't have the same amount of exits.

00:12:11 Speaker 2

So that all sounds extremely rosy, a rosy picture that everything just reinforces itself and we have unlimited installations.

00:12:20 Speaker 2

But of course, there's balancing effects in the market as well.

00:12:23 Speaker 2

So B1 is a balancing loop.

00:12:28 Speaker 2

So essentially,

00:12:32 Speaker 2

If there's too many firms entering this market, that this entrance rate is too high, there's too many firms, then the average revenue per firm is lower.

00:12:44 Speaker 2

So the total market share is divided by too many companies and more of them will thus fit.

00:12:53 Speaker 2

Yeah, so less will essentially exit if we have the average revenue per firm going down.

00:13:00 Speaker 2

And that means that they're staying here as startups and failing more in the valley depth.

00:13:08 Speaker 2

Then the crowding effect.

00:13:10 Speaker 2

So this is a balancing crowding effect.

00:13:16 Speaker 2

As I mentioned earlier, that as installed rooftop solar PV increases, the perceived market opportunity also increases.

00:13:24 Speaker 2

However, at some point, the market becomes saturated.

00:13:27 Speaker 2

So

00:13:29 Speaker 2

it's no longer as interesting for entrepreneurs to enter a market that is so saturated where there's so many sort of incumbents already, and there's a market crowding effect.

00:13:43 Speaker 2

So the new entrance rate is again decreased.

00:13:46 Speaker 2

Then there's the counter lobby effect.

00:13:53 Speaker 2

So this is another balancing loop.

00:13:56 Speaker 2

As we know, in this industry, there are incumbent regimes, which include traditional utilities and coal industry, chemical industries, which resist the transition to renewables.

00:14:14 Speaker 2

So as we have more solar industry revenue, that revenue is essentially decreasing the revenue from the incumbent industry.

00:14:25 Speaker 2

And as that revenue goes down, they engage in counter lobby efforts, which affects the marketing.

00:14:37 Speaker 1

What's incumbent industry?

00:14:39 Speaker 1

I don't know the English word.

00:14:42 Speaker 2

Yeah, so it's essentially traditional utilities.

00:14:47 Speaker 1

Okay.

00:14:48 Speaker 2

Yeah, coal plants, chemical industry that traditionally have been

00:14:56 Speaker 2

in the literature or in Germany, we have experience that they have, they have engaged in some counter lobby ethics.

00:15:03 Speaker 2

So it's a kind of aggregation of incumbents.

00:15:08 Speaker 1

And why does it grow when solar industry revenue grows?

00:15:14 Speaker 2

Yeah, so I just, I just realized that this, I just made this mistake.

00:15:19 Speaker 2

So this should be a minus sign.

00:15:20 Speaker 1

Okay.

00:15:21 Speaker 2

Yeah, but it's about, but it's a balancing feedback.

00:15:24 Speaker 2

That's a

00:15:26 Speaker 2

Good that you that you caught that as well.

00:15:27 Speaker 2

So as solar industry revenue increases, the revenue of income industry should be decreasing.

00:15:34 Speaker 2

So that should be a minus sign.

00:15:36 Speaker 2

And then the counter lobby efforts are increasing.

00:15:39 Speaker 2

And then this affects the marketing.

00:15:41 Speaker 2

Yes.

00:15:42 Speaker 1

Okay.

00:15:45 Speaker 2

Yes.

00:15:45 Speaker 2

So okay.

00:15:48 Speaker 2

And then two more policies that I didn't point out.

00:15:52 Speaker 2

So in red.

00:15:55 Speaker 2

So there's the, essentially the feed-in tariff decreases the price for the consumer to some extent.

00:16:04 Speaker 2

So that's what, and this is a simplified model.

00:16:07 Speaker 2

In the actual model, I have a, you know, there's a mathematical formula behind this of how much it decreases based on the historical and future feed-in tariff.

00:16:20 Speaker 2

And then, however, the feed-in tariff also

00:16:24 Speaker 2

directly impacts the perceived market opportunity.

00:16:29 Speaker 2

So regulation is regulations have been seen to be a important part of startups willingness to enter a market.

00:16:39 Speaker 2

Yeah.

00:16:42 Speaker 2

And again, here.

00:16:45 Speaker 2

So here you see incumbent again.

00:16:47 Speaker 2

So this utility of solar PV is always kind of compared to

00:16:51 Speaker 2

the utility of the fossil fuel component.

00:16:53 Speaker 2

So if it's more, if it's, let's say, cheaper and more convenient to buy directly from utilities rather than installing your own solar PV, then you will continue to use the traditional utilities rather than installing your own PV module.

00:17:15 Speaker 2

So that's essentially the, that's the narrative.

00:17:20 Speaker 2

If you have any questions, feel free to shoot or else we can go to the questions.

00:17:33 Speaker 1

Yeah, I guess it's basically all covered of what effects we see here in Germany.

00:17:39 Speaker 1

That's just thinking about capacity of a number of installers.

00:17:50 Speaker 1

But I guess it's covered with a number of total firms, I guess.

00:17:56 Speaker 1

Because what we had in some years and there were less installations, so the firms basically closed, many firms closed.

00:18:08 Speaker 1

And then when the

00:18:12 Speaker 1

when people wanted to have PV systems again, then there weren't enough installers, so they had to wait for a long time until the firms grew up again.

00:18:22 Speaker 1

But I guess, yeah, I guess it's covered in the number of firms, right?

00:18:27 Speaker 2

Yes.

00:18:28 Speaker 2

So the total firms is, that's an aggregation of companies that are in this market, essentially.

00:18:36 Speaker 2

So it can be installers, it can be new startups, you know,

00:18:41 Speaker 2

developing, you know, smart metering tools, data analytics, things like that.

00:18:49 Speaker 2

So it's an aggregation.

00:18:52 Speaker 2

But that's a really good point.

00:18:53 Speaker 2

So I think one question that I would follow up on that point that you have is, you know, where do the people come from into the industry?

00:19:05 Speaker 2

So if you have less, I imagine the installers need to have

00:19:11 Speaker 2

some education.

00:19:15 Speaker 2

So does it take some time for them to, you know, get re-educated?

00:19:21 Speaker 2

Why was there such a delay that you experienced at one point?

00:19:26 Speaker 1

Again, 2003, I think we had so many, so many people asking for a PV system that you had to wait.

00:19:36 Speaker 1

a year, for example, until you get your PV system because the firms just didn't have the capacity to install so many or to realize so many projects.

00:19:49 Speaker 1

And then also one effect was that they were able to pick the project that they could install.

00:19:56 Speaker 1

So if you wanted a small PV system, it was not easy to get in that year.

00:20:02 Speaker 2

Right.

00:20:03 Speaker 2

Yeah.

00:20:03 Speaker 2

So they

00:20:04 Speaker 2

essentially prioritized larger installations where they could, which were more profitable for them.

00:20:10 Speaker 1

Yes.

00:20:11 Speaker 2

Okay.

00:20:12 Speaker 1

And I mean, it was just, how do you say, supply and demand thing that the demand was much higher than the supply in that year because it grew so rapidly after energy crisis in 2022?

00:20:35 Speaker 2

Okay.

00:20:36 Speaker 2

Interesting.

00:20:37 Speaker 2

Yeah, that's something to note.

00:20:45 Speaker 2

Anything else that pops up or is unclear or.

00:20:50 Speaker 1

No, I think it's very comprehensive model.

00:20:53 Speaker 1

Yeah.

00:20:54 Speaker 2

Okay.

00:20:54 Speaker 1

Looks good.

00:20:57 Speaker 2

Awesome.

00:20:57 Speaker 2

So we can jump forward to the questions.

00:21:04 Speaker 2

and also the simulation graph.

00:21:05 Speaker 2

So did you have a time?

00:21:06 Speaker 2

You didn't have a chance to look at this one either.

00:21:08 Speaker 2

Only the questions.

00:21:08 Speaker 1

No, not yet.

00:21:09 Speaker 1

Okay.

00:21:09 Speaker 2

So we can have a we can have a look through the simulation results.

00:21:13 Speaker 2

So.

00:21:16 Speaker 2

So again, the yeah, so we have graphs.

00:21:20 Speaker 2

So they installed rooftop Pv.

00:21:22 Speaker 2

I can try to zoom it a bit even more.

00:21:27 Speaker 2

Right.

00:21:27 Speaker 2

Oh, oops.

00:21:28 Speaker 1

This is Germany or yes, Europe or

00:21:33 Speaker 1

Germany.

00:21:33 Speaker 2

This is Germany, yeah.

00:21:35 Speaker 2

And again, so you have, okay, installed rooftop solar PV for residential 10 kilowatt and lower.

00:21:44 Speaker 2

The reason for that is because the data that I find online generally has this as a, you know, a residential bar.

00:21:54 Speaker 2

If it goes above 10 kilowatt peak installations, it might be a commercial

00:22:02 Speaker 2

installation, but 10 kilowatt peak installation, then we can say, okay, this is probably a residential.

00:22:11 Speaker 1

Okay, yeah, we usually work with 30 kilowatt peak as the border here.

00:22:18 Speaker 1

But assuming that there are some commercial installations included in that, so I guess if you go down to 10, then it's sure that there's almost no commercial installations.

00:22:31 Speaker 2

Okay,

00:22:35 Speaker 2

Right.

00:22:37 Speaker 2

So the gigawatts on the left side, year on the bottom axis, and we chose the time horizon from 2000 to 2050.

00:22:51 Speaker 2

It's a nice time horizon to choose, but also in 2000 is when the EEG Act came into effect with the feed-in tariff, and then 2050

00:23:02 Speaker 2

50 years, it allows us a large enough time horizon to examine as well.

00:23:08 Speaker 2

Germany has some goals of reaching to, I think it was 25% of total energy supply coming from solar energy in 2040.

00:23:20 Speaker 2

I think it was 300, yeah, I don't remember the exact numbers right now of the amount of gigawatt installations, but there are some targets.

00:23:35 Speaker 2

So, yeah, in the red dashed lines, we see the real data moving here all the way until 2025.

00:23:47 Speaker 2

I think it's around, yeah, 17 gigawatts in this below

00:24:01 Speaker 2

below 10 kilowatt peak.

00:24:02 Speaker 2

So it produces the historical behavior quite well.

00:24:07 Speaker 2

And then here's kind of a linear forecast of a desired scenario.

00:24:13 Speaker 1

And does this relate to the climate goals, the desired scenario?

00:24:18 Speaker 1

And how did you break it down to 10 kilowatt peak systems?

00:24:24 Speaker 2

Yes, so, okay, now I think so.

00:24:29 Speaker 2

So how, so how I came up with it was there's a 25%, the goal is 25% electricity generation share from solar energy in total by 2025.

00:24:49 Speaker 2

Then I examined the from Fraunhofer's data of the technical potential of

00:24:59 Speaker 2

residential installations in this kind of criteria, so below 10 kilowatt peak.

00:25:10 Speaker 2

And that came out to roughly 70 as a technical maximum that you can get of residential 10 kilowatt peak.

00:25:24 Speaker 2

So if you're thinking, okay, the technical maximum

00:25:28 Speaker 2

No, sorry, if 25% share translates to the total amount of generation that you need, it was something like 400 gigawatts total of solar energy.

00:25:43 Speaker 2

So only 70 gigawatts can be of residentials below 10 kilowatt, if that makes sense.

00:25:51 Speaker 2

I hope I explained it sufficiently well.

00:25:55 Speaker 2

So that's how I

00:25:57 Speaker 2

created this kind of forecast as it's moving now.

00:26:02 Speaker 1

400 gigawatts is for all PV installations, and then-- Yes.

00:26:09 Speaker 1

70 is for 10, based on which data?

00:26:14 Speaker 2

It was the technical potential of the rooftop potential based on how many roofs there are, based on what direction they're facing.

00:26:28 Speaker 1

But if you take the whole rooftop potential, then it would be more than 10 kilowatt peak systems, right?

00:26:35 Speaker 2

Yes, exactly.

00:26:36 Speaker 2

So then it would be more, and then it would be more than 70 gigawatts as well, if you're counting, for example, commercial rooftops or rooftops above 20, 30 kilowatts, yeah.

00:26:47 Speaker 1

Okay, so you have, and how do you then break it down to the 10 kilowatt peak systems from all the rooftop systems?

00:26:55 Speaker 2

Yes, there was a,

00:26:58 Speaker 2

It was based on the data that I found.

00:27:02 Speaker 2

So Fraunhofer has crunched these numbers.

00:27:12 Speaker 1

Okay.

00:27:12 Speaker 1

I don't know the publication.

00:27:18 Speaker 1

Do you have it by hand, where it's from?

00:27:23 Speaker 2

Yeah.

00:27:48 Speaker 2

Just a second, I didn't have it handy.

00:28:20 Speaker 2

So, so it's the integrated photovoltaics, uh, report.

00:28:49 Speaker 2

I don't have for ISC.

00:29:03 Speaker 1

Photovoltaics report.

00:29:05 Speaker 2

Um, no, it was not, not in the, not in the, um, recent facts about photovoltaics report.

00:29:12 Speaker 2

It's the integrated photovoltaics.

00:29:17 Speaker 1

Integrated, but not roof integrated.

00:29:43 Speaker 1

Yeah.

00:29:43 Speaker 1

Okay.

00:29:43 Speaker 2

Here's another article from the PV magazine.

00:29:53 Speaker 2

There is a bit.

00:29:56 Speaker 2

And then it was, this is the,

00:30:07 Speaker 2

It was in one of the reports of it was solar power plants and integrated photovoltaics.

00:30:20 Speaker 2

They calculated the technical potential.

00:30:25 Speaker 1

Okay.

00:30:34 Speaker 1

No, I can only see the

00:30:41 Speaker 1

I can only see the landing page.

00:30:43 Speaker 1

It's not a study.

00:30:46 Speaker 2

This, okay, yeah, here I have the...

00:30:50 Speaker 2

Can you see this study?

00:30:55 Speaker 1

But this is not rooftop, right?

00:31:00 Speaker 2

This is...

00:31:02 Speaker 1

It's building integrated, road integrated.

00:31:12 Speaker 1

Yeah, maybe you can check it because I don't, I wouldn't know which number would be right there for an upper bound.

00:31:20 Speaker 2

Okay, I need to check the upper bounds.

00:31:22 Speaker 1

You can, I wouldn't know if it's right or wrong now.

00:31:25 Speaker 1

That's why I'm asking where we have the data from.

00:31:28 Speaker 1

So I guess it's fine.

00:31:31 Speaker 1

And another question, we sometimes we differentiate between

00:31:38 Speaker 1

what's it called, balcony solar systems, because we have so many here in Germany that we cut off the systems below 2 kilowatt peak because they have this different mechanism.

00:31:52 Speaker 1

They don't get the EEG levy and the EEG, what's it called, the price per kilowatt hour.

00:32:03 Speaker 1

they don't get it and a lot of people install it.

00:32:07 Speaker 1

And if you model up to 10 kilowatt peak, you might have these in also, but with a different mechanism because I guess it's different from people buying these have different motives than if it's a system above 2 kilowatt peak.

00:32:30 Speaker 1

Or are you including these or have you thought about this group of PV systems?

00:32:38 Speaker 2

So I didn't differentiate them.

00:32:41 Speaker 2

I read about balcony, but I thought they would be sort of like, for example, the data that I've seen doesn't, I think, calculate like in recent facts about photovoltaics and the photovoltaics report.

00:32:56 Speaker 2

It doesn't differentiate between balcony and residential solar modules.

00:33:01 Speaker 2

So I haven't taken that into account.

00:33:06 Speaker 1

You can have a look at our recent study we did for a German electricity supplier supplying renewable energies.

00:33:22 Speaker 1

So we have about 1% of these balcony PV systems, 1% of the installed capacity.

00:33:42 Speaker 1

Okay, in this study, we don't differentiate how much of the energy they provide, but

00:33:49 Speaker 1

Yeah, I can send you the link of the study and then you can consider if you need to differentiate between those and the others or not.

00:34:00 Speaker 2

Okay.

00:34:00 Speaker 2

Yeah, definitely need to mention it at least.

00:34:03 Speaker 1

It's in German, but I guess you can find some translation possibility.

00:34:10 Speaker 2

Okay.

00:34:14 Speaker 2

Great.

00:34:14 Speaker 2

So imagining that the

00:34:19 Speaker 2

upper bound is correct or incorrect.

00:34:23 Speaker 2

The behavior is kind of the shape of the graph is what we're most interested in for the validation.

00:34:35 Speaker 2

But I do need to check the actual numbers.

00:34:39 Speaker 2

And then we have the undesired situation.

00:34:43 Speaker 2

So the difference between these two graphs here is, oh, thanks for sending that.

00:34:48 Speaker 2

The difference between these two graphs here is the strength of the policy.

00:34:51 Speaker 2

So in the desired scenario, the policy has been continuing, you know, throughout the simulation.

00:35:01 Speaker 2

And then in the undesired scenario, the policy is redacted in 2016.

00:35:07 Speaker 2

So this is a hypothetical because we're trying to learn more about the tipping point phenomenon and, you know,

00:35:17 Speaker 2

What, because, and we chose installed, so sorry, we...

00:35:22 Speaker 2

chose solar PV in Germany because it's been one of the most successful low carbon adoption, low carbon technology adoption case studies that we have so far.

00:35:36 Speaker 2

And it could have been different, let's say, if some of the policies were reduced.

00:35:41 Speaker 2

And it definitely has impacted.

00:35:44 Speaker 2

So based on the model, thus, it's if you extend the

00:35:51 Speaker 2

the policy to, let's say, 2020, we would see a similar curve for installations.

00:36:03 Speaker 2

So you can kind of say that, okay, a positive tipping point has been crossed.

00:36:09 Speaker 1

Do you include that some systems are taken out of order after 20 years or 30 years?

00:36:16 Speaker 2

Yes.

00:36:17 Speaker 1

Because it's going down.

00:36:20 Speaker 2

Yes.

00:36:20 Speaker 2

So degradation rate is degradation rate is taken into account.

00:36:26 Speaker 2

So I put a 30 year module lifetime.

00:36:30 Speaker 1

Okay.

00:36:30 Speaker 1

But when why is it then going up again?

00:36:33 Speaker 1

Like in 2040, 2050.

00:36:36 Speaker 2

Yeah.

00:36:36 Speaker 2

So essentially you do get some some improvements in the technology still.

00:36:46 Speaker 2

but it's not enough to spur all those reinforcing feedback loops that we explained before.

00:36:54 Speaker 2

So it goes up to some extent, but not much.

00:36:58 Speaker 2

And if you were to extend the time horizon to 2020, it doesn't repeat the pattern.

00:37:04 Speaker 2

It stays low.

00:37:10 Speaker 1

And why does it not go down all the way?

00:37:13 Speaker 1

Like saying, okay, there's no...

00:37:17 Speaker 1

No market anymore.

00:37:21 Speaker 2

So there will still be some some people that keep their their that that do install the rooftop solar.

00:37:34 Speaker 2

So and and eventually eventually the price and performance can can improve to a point that

00:37:47 Speaker 2

it's still, it's the utility of the product or the platform can be good, but there's not enough social contagion or social exposure to consider the platform.

00:38:01 Speaker 1

And what does the undesired scenario represent?

00:38:06 Speaker 1

Is it a world without feed-in tariff or.

00:38:10 Speaker 2

Yes.

00:38:11 Speaker 1

How do you define it?

00:38:12 Speaker 2

World within feed-in tariff after

00:38:15 Speaker 2

2016 when it's removed.

00:38:16 Speaker 1

Yeah.

00:38:21 Speaker 2

Yeah.

00:38:21 Speaker 2

So that's for that's for the installed rooftop.

00:38:24 Speaker 2

This is for the installation rate.

00:38:27 Speaker 2

So the real data obviously is, you know, more choppy than than a than a modeled modeled scenario.

00:38:40 Speaker 2

At the peak it's about 8 gigawatts per year.

00:38:46 Speaker 2

of the installations.

00:38:51 Speaker 1

Why does it drop again so heavily?

00:38:56 Speaker 2

Because of the balancing, because it has a maximum, maximum bound.

00:39:04 Speaker 2

So you kind of reach the peak installations per year and then it becomes more difficult to

00:39:14 Speaker 2

install further.

00:39:19 Speaker 2

It's a function of the potential adoption.

00:39:24 Speaker 1

But then the market is decreased by two thirds within a few years only.

00:39:31 Speaker 1

Is that correct?

00:39:33 Speaker 2

Yeah, this is the gigawatts per year, but the installation, but the installed capacity is still high.

00:39:41 Speaker 2

So this is the function that creates this behavior.

00:39:49 Speaker 2

So you have the S-shaped curve here at the inflection point where it's growing the fastest corresponds with this installation rate.

00:40:09 Speaker 2

And then after that, it's still, you see, it's still increasing.

00:40:12 Speaker 2

However, it's increasing slower until it reaches the maximum amount.

00:40:18 Speaker 1

But would that be desired?

00:40:19 Speaker 1

Because, I mean, for the market, it's not a good situation.

00:40:22 Speaker 1

So many installations in the year 20, I don't know, 2030.

00:40:29 Speaker 1

And then afterwards, there's a

00:40:32 Speaker 1

huge breakdown.

00:40:33 Speaker 1

I mean, you have the curve here in 2011 or something where we had a big crisis in the German market.

00:40:40 Speaker 1

But if you compare it then to the bigger crisis, it would be crazy.

00:40:46 Speaker 2

Yeah, it's a good point.

00:40:46 Speaker 2

I mean, so this is, again, I didn't model the installers, for example, as you mentioned.

00:40:54 Speaker 2

This could be not such a desired scenario.

00:40:57 Speaker 2

This could be a situation that, oh, we don't have enough.

00:41:01 Speaker 2

people to install these, like kind of you mentioned, I think it was, was it 2023 or 2003 when you didn't have enough installers, right?

00:41:10 Speaker 2

So you could face a similar situation at this peak.

00:41:18 Speaker 2

Yeah.

00:41:20 Speaker 2

So that constraint is not modeled.

00:41:24 Speaker 2

But if, yeah, if everything

00:41:31 Speaker 2

were rosy and you had enough installers, it could look like this.

00:41:35 Speaker 1

And is the forecast based on achieving the climate goals?

00:41:43 Speaker 1

Yes.

00:41:45 Speaker 1

Why not?

00:41:46 Speaker 2

Yes.

00:41:46 Speaker 2

So I should have marked it here.

00:41:50 Speaker 2

I should have marked it here explicitly.

00:41:51 Speaker 2

So there's a there's a goal for, yeah, 2030 and 2040.

00:41:57 Speaker 1

OK.

00:41:58 Speaker 2

And they are.

00:42:01 Speaker 2

And that's what the forecast is based on.

00:42:03 Speaker 1

And why does it go up and down in the yearly installation so much?

00:42:10 Speaker 1

2025, I guess you included already where the number of installations already went down, right?

00:42:16 Speaker 2

Yeah, I essentially chose numbers that would create the pattern that would reach the

00:42:32 Speaker 2

desired scenarios.

00:42:36 Speaker 2

So would reach the climate goals.

00:42:41 Speaker 2

But I could probably do a linear forecast that would be smoother.

00:42:47 Speaker 2

I probably should.

00:42:49 Speaker 1

Yeah, at least.

00:42:51 Speaker 1

Yeah, this up and down seems like a forecast which will not be hit maybe.

00:42:59 Speaker 1

But if you have it linear, then maybe in some it might be more correct.

00:43:04 Speaker 2

Yeah, it should be.

00:43:04 Speaker 1

Or not linear, but like smoother.

00:43:07 Speaker 2

It should be smoother, yeah.

00:43:09 Speaker 2

Agreed.

00:43:11 Speaker 2

So that's the installation rate.

00:43:13 Speaker 2

Then here's the levelized cost of electricity.

00:43:18 Speaker 2

So for the consumer, yeah.

00:43:20 Speaker 1

Okay.

00:43:21 Speaker 2

So this is, so, and we don't have,

00:43:27 Speaker 2

The data before, I think it was 2010 about the LCOE.

00:43:34 Speaker 2

But from then on, this has been the behavior.

00:43:38 Speaker 2

And we're reaching the minimum, which is with the technical feasible minimum of LCOE, which I believe was 2.027 euros, so 2.7 cents.

00:43:55 Speaker 2

It's reaching that point.

00:43:57 Speaker 1

Did you see we have the study on the LCOE every several years?

00:44:03 Speaker 1

And there's also a forecast on the in that one.

00:44:09 Speaker 1

Do you know the study?

00:44:09 Speaker 2

Okay, a specific study on that.

00:44:11 Speaker 1

And yes, I can send you the link.

00:44:14 Speaker 2

I may have missed it, yeah.

00:44:18 Speaker 1

I don't have the numbers on the top of my head for this.

00:44:23 Speaker 1

Yeah, the values.

00:44:24 Speaker 1

But you can double check with the values there.

00:44:28 Speaker 2

That would be great.

00:44:29 Speaker 2

Thank you.

00:44:36 Speaker 1

The last one is from 2024.

00:44:42 Speaker 1

But yeah, there's a forecast up to 2050, I think, in the end.

00:44:49 Speaker 1

or I can maybe just quickly check if I find the numbers right away in the study.

00:45:00 Speaker 1

it goes from, it's up to 2040 and it goes from 2 to 7, but this is for all PV systems.

00:45:17 Speaker 1

So we would be rather in the range of, I don't know, maybe 3 to 7 or 4 to 7 for the rooftop, small rooftop systems, because they're always the most expensive ones.

00:45:30 Speaker 1

And you, yeah, it seems like your your curve is going down more quickly than in our prognosis.

00:45:38 Speaker 1

Ours is also based on learning rates.

00:45:43 Speaker 2

Yes.

00:45:44 Speaker 2

yes.

00:45:45 Speaker 2

So yeah, this is based on learning rates, which I tried to recreate.

00:45:51 Speaker 2

This is kind of the date.

00:45:53 Speaker 2

Well, up until 2025, it should be essentially the same, no?

00:45:57 Speaker 1

I guess so.

00:45:59 Speaker 1

Which value do you have in 2025?

00:46:01 Speaker 2

I'm just going to...

00:46:21 Speaker 2

I'll look up the exact number.

00:46:26 Speaker 2

So in my simulation, it's 25 cents.

00:46:33 Speaker 2

Wait, hold on, is that the...

00:46:37 Speaker 2

Oh, this is the undesired snare.

00:46:46 Speaker 2

This would be roughly

00:46:51 Speaker 2

10 cents.

00:46:55 Speaker 1

Okay, we have six to 11.

00:46:57 Speaker 2

Yeah, roughly 10 cents in the simulation.

00:47:02 Speaker 2

And then in the data we have, I think it's five or so.

00:47:11 Speaker 2

Yeah, less than five, maybe four.

00:47:14 Speaker 2

I have the Lcoe data, and then the forecasted low that I have for Lcoe.

00:47:22 Speaker 2

Yeah, for data.

00:47:23 Speaker 2

I have 4 cents for 2024.

00:47:26 Speaker 2

Yeah.

00:47:28 Speaker 2

that's what this this red line is.

00:47:30 Speaker 2

And then the low is 2.7 cents technically, technically feasible low.

00:47:36 Speaker 1

On which year.

00:47:38 Speaker 1

2014.

00:47:41 Speaker 2

Yeah, that it would reach that around

00:47:43 Speaker 2

2040, 2050.

00:47:46 Speaker 1

Okay, you can compare it to our study.

00:47:49 Speaker 1

We also have a prognosis on the cumulative installed capacity in the study.

00:47:54 Speaker 2

Okay.

00:47:55 Speaker 1

And based on that, the prognosis for the LCOE.

00:48:00 Speaker 2

Okay, excellent.

00:48:02 Speaker 1

But why does the desired LCOE start much higher than the actual?

00:48:09 Speaker 1

Is that modeling?

00:48:10 Speaker 2

Yeah.

00:48:11 Speaker 2

So it's it's the fact that we don't have a reliable data for what was happening before 2010.

00:48:19 Speaker 2

So the it essentially just takes the number from 2010, and and every every year before that is is there.

00:48:29 Speaker 2

But due to the learning.

00:48:31 Speaker 2

Yeah.

00:48:31 Speaker 2

So due to the learning rates.

00:48:33 Speaker 2

it would.

00:48:34 Speaker 2

It would probably look more like like this.

00:48:38 Speaker 1

Okay.

00:48:39 Speaker 2

So

00:48:40 Speaker 2

We can say that it follows the behavior pattern to some extent, but I think the more problematic area is here that it doesn't continue to accelerate at the same speed.

00:48:53 Speaker 2

It's kind of it's not following learning rates at this point, I have to admit.

00:48:59 Speaker 2

But around the beginning here, I think it's following the learning rates of 25% decrease in LCOE per doubling.

00:49:11 Speaker 1

Okay.

00:49:14 Speaker 1

I just checked our first study was 2012.

00:49:20 Speaker 1

And we had PV LCOE at 15 cent per kilowatt hour.

00:49:34 Speaker 1

So you may be a bit too high with the 40.

00:49:38 Speaker 2

Okay, so in 20, okay, I have for 2012, I have 26 cents.

00:49:43 Speaker 2

So yeah, I need to look at your data.

00:49:45 Speaker 2

I think the data that I used was from and potentially another source, our world in data potentially.

00:49:53 Speaker 1

In the link that I sent you, there's all studies starting in 2012 and then 2016, 18, 21, 24.

00:50:03 Speaker 1

So you can always get the recent numbers then.

00:50:06 Speaker 2

Okay, thank you.

00:50:08 Speaker 2

Okay, so I have one general question.

00:50:11 Speaker 2

Like, how do you, do you, what does the term positive tipping point mean?

00:50:19 Speaker 2

You know, anything to you?

00:50:20 Speaker 2

Do you, or how do you understand the term?

00:50:28 Speaker 1

Positive tipping point means that

00:50:35 Speaker 1

the installations will grow even though, even if there is no support anymore, I would guess.

00:50:42 Speaker 2

Okay.

00:50:43 Speaker 1

Would that be correct?

00:50:45 Speaker 2

Yeah, it's, I mean, it's a term that's up for interpretation, but that's also how I interpret it in this case.

00:50:53 Speaker 2

So if all external policy support was removed, would it continue?

00:50:59 Speaker 2

So do you agree that solar PV adoption in Germany has crossed the positive tipping point?

00:51:06 Speaker 1

No, not if you look at the section for up to 10 kilowatt peak because it still relies on the feed-in tariff.

00:51:13 Speaker 1

So I don't know if you've followed the discussion in the German politics at the moment where they discuss about abolishing the feed-in tariff for up to 10 kilowatt peak.

00:51:25 Speaker 1

Yeah, this is why we did this study for the electricity provider.

00:51:34 Speaker 1

EVS, because when you don't have the feed-in tariff anymore, you need to go into direct marketing.

00:51:44 Speaker 1

And direct marketing is established for larger PV systems, but for the small systems, it's, yeah, even the people who do it, they say it's still too much work for the

00:52:01 Speaker 1

low amount of revenues you get from that.

00:52:06 Speaker 1

So we say that if the feed-in tariff is stopped now, then the rooftop or private rooftop will not grow anymore.

00:52:20 Speaker 1

It will go down, definitely, because then it's too complicated for the people and to

00:52:29 Speaker 1

insecure about the revenues they will get if they install a PV system.

00:52:35 Speaker 1

So if you take that away, we'll have a breakdown of that market again.

00:52:43 Speaker 2

So yeah, okay, that answers sufficiently.

00:52:48 Speaker 2

What about the causal loop diagram?

00:52:51 Speaker 2

So does it accurately, in your view, represent solar PV consumer behavior and

00:52:59 Speaker 2

industry activity.

00:53:00 Speaker 1

Yes, I think so.

00:53:01 Speaker 1

I'm not very much familiar with that type of model, but as you explained it, I couldn't find anything that would be missing.

00:53:11 Speaker 1

So, yeah.

00:53:12 Speaker 2

Okay.

00:53:13 Speaker 2

And would you say that, I mean, you just alluded to it in a way, but would you say that potential adopters of residential solar PV are more sensitive to price, price of the module and system, the performance or the convenience?

00:53:30 Speaker 2

That's.

00:53:34 Speaker 1

A good question.

00:53:42 Speaker 1

From what I said before, I should say they're more sensitive to the price, actually.

00:53:52 Speaker 1

Because I think if the revenues are not high enough,

00:53:58 Speaker 1

There will still be some people who do it because many people do it because they're convinced that it's good for the environment and for their taking part in the energy transition.

00:54:11 Speaker 1

But I think the highest number of people is still the ones who invest because it's because they get money out of it.

00:54:23 Speaker 1

So if they don't get money out of it anymore, then they won't.

00:54:27 Speaker 1

do it.

00:54:29 Speaker 1

And of course, how did you call it the convenience?

00:54:40 Speaker 1

If that is too high, then of course people, yeah, are not, they have more problems in setting up the program.

00:54:53 Speaker 1

And I think this is also part of it.

00:54:57 Speaker 1

But maybe the problem is that with the feed-in tariff, now you have assured revenue and it's easy.

00:55:06 Speaker 1

And if the feed-in tariff is abolished, then both is gone.

00:55:14 Speaker 1

You could say the economics are not good enough.

00:55:19 Speaker 1

And also it's not convenient anymore because you need to find someone who

00:55:26 Speaker 1

markets your your energy.

00:55:30 Speaker 2

Right.

00:55:31 Speaker 1

So it's not easy to separate the both the 2 things from each other.

00:55:38 Speaker 2

Yeah.

00:55:38 Speaker 2

Do you need to?

00:55:42 Speaker 1

Yeah.

00:55:42 Speaker 2

Do you need to?

00:55:43 Speaker 2

Do you have a hard hard stop now at 11?

00:55:46 Speaker 2

And we end it.

00:55:47 Speaker 1

No, we can take some more minutes.

00:55:50 Speaker 2

A few minutes.

00:55:50 Speaker 2

Okay.

00:55:51 Speaker 2

that's great.

00:55:53 Speaker 2

Yeah.

00:55:54 Speaker 2

Okay.

00:55:54 Speaker 2

So

00:55:56 Speaker 2

That's quite clear.

00:55:57 Speaker 2

Many adopters looking at it kind of as an investment in a way that they should earn something from it.

00:56:05 Speaker 1

Yeah, I guess that's the majority.

00:56:09 Speaker 1

I've, yeah, when I talk to other people, some people say, yeah, people just want to have their own energy and they are willing to install crazy things.

00:56:16 Speaker 1

We know

00:56:18 Speaker 1

people who have a 20 kilowatt hour battery storage or just for fun or 100 kilowatt hours even just for fun.

00:56:28 Speaker 1

But I think that's still the minority because if you look at the number of installations, they have some correlation with the economic viability in the last years.

00:56:41 Speaker 1

So if that is not there anymore, then the numbers will go down, I'm very sure.

00:56:47 Speaker 2

Okay.

00:56:48 Speaker 2

And how have, you know, the entrepreneurial activity in the sector, you know, contributed to the adoption of solar Pv?

00:57:00 Speaker 1

And that's the part where I'm not so firm.

00:57:03 Speaker 1

I don't know.

00:57:05 Speaker 1

Maybe you can go more into detail with a question.

00:57:09 Speaker 1

What what could be a question there?

00:57:11 Speaker 2

Right?

00:57:11 Speaker 2

So.

00:57:18 Speaker 1

The number of firms.

00:57:19 Speaker 2

Yeah, so how about the innovations in the sector?

00:57:24 Speaker 2

So have you observed that some innovative activities in the sector have played a part in increasing the adoption and to what extent?

00:57:40 Speaker 2

Or is it more

00:57:43 Speaker 2

that these innovations are, you know, marginal effect and it's more down to availability of panels, availability of installation, of installers, sorry.

00:58:00 Speaker 2

Or do these kinds of, you know, innovations like smart metering, business model innovations like, you know, energy as a service, pay as you go,

00:58:13 Speaker 2

kind of models have any impact?

00:58:17 Speaker 1

I guess from how I observe it, there's no real innovation that has led to more installations.

00:58:27 Speaker 1

I guess it's mainly really the price and the feed-in tariff.

00:58:31 Speaker 1

So if the price goes down, feed-in tariff is high enough, then people install it.

00:58:37 Speaker 1

If not, then not.

00:58:38 Speaker 1

And the innovations

00:58:39 Speaker 1

Of course, there's innovations in the efficiency, which is always good, but in effect, this reduces the price.

00:58:48 Speaker 1

Smart meter rollout goes really slow in Germany, and it's rather a negative factor on anything in Germany.

00:59:03 Speaker 1

It's rather that business models are waiting for

00:59:07 Speaker 1

number of smart meters to be installed, for example, in the multifamily houses, we need the smart meters to have good business models there and it doesn't work.

00:59:19 Speaker 1

Or if you look at dynamic tariffs, they're waiting for smart meters also.

00:59:24 Speaker 1

So I guess more people would be willing to have a dynamic electricity tariff, but it takes a long time to get a smart meter.

00:59:33 Speaker 1

So yeah, I would say no, there's not really no special innovations which have brought the market forward.

00:59:42 Speaker 2

How about these big financial innovations, like covering the upfront cost?

00:59:51 Speaker 1

That may be, yeah.

00:59:54 Speaker 1

There's some companies who do this kind of contracting models, and I think people are interested.

01:00:01 Speaker 1

I wouldn't

01:00:02 Speaker 1

Yeah, I wouldn't know how many, like I haven't seen any study on how many people do that in comparison to investing themselves.

01:00:13 Speaker 1

But they're there, they're often offering their services and people are using it apparently.

01:00:20 Speaker 1

So that could be a good positive factor.

01:00:25 Speaker 2

Okay.

01:00:27 Speaker 2

And then back to the

01:00:33 Speaker 2

Simulation.

01:00:34 Speaker 2

So does the behavior, you know, seem plausible for you?

01:00:40 Speaker 2

Assuming that this upper bound is that the upper bound is correct, assuming that that it's somewhere somewhere between 70 and let's say, or 50 and 90, let's say.

01:00:52 Speaker 1

Yeah, I think after looking at the yearly installations in the next graph, I think that maybe that increase is too steep in these years and then falling down again.

01:01:07 Speaker 1

So, I mean, desired would be that it doesn't go up, that it goes up steadily so people can install, capacities can grow along.

01:01:21 Speaker 2

Right.

01:01:21 Speaker 2

And I think we experienced something like this in Germany as well, that the installations were growing so fast that they had to start producing the tariff and put a cap on the amount of installations that you could have in a year.

01:01:40 Speaker 1

You mean in 2011, 2012?

01:01:43 Speaker 2

Yes.

01:01:44 Speaker 1

Yeah.

01:01:44 Speaker 1

And then it was a really breakdown of the market.

01:01:48 Speaker 1

It doesn't look so bad in that graph, actually, but for Germany, it was bad.

01:01:52 Speaker 1

Many firms closed down and many people lost their jobs.

01:01:57 Speaker 1

And then it took a long time until that was built up again.

01:02:01 Speaker 1

So it was really not favorable for the market.

01:02:06 Speaker 1

So if you painted a picture of what is desired, then you should

01:02:13 Speaker 1

always have it going up then more slowly and steadily.

01:02:17 Speaker 1

Even the fast growth rates are not so desired also because I heard then there's many cheap modules installed or installations not done very nicely and then people are not satisfied or the systems break down early or...

01:02:37 Speaker 2

Right, Yeah, so it would be more favorable if it's...

01:02:43 Speaker 2

Yeah, understandable.

01:02:45 Speaker 2

Because here, this is a situation where many would lose their jobs as well.

01:02:50 Speaker 2

But I mean, this collapse here in 2010, 2011 is quite dramatic.

01:02:59 Speaker 2

I think if we

01:03:00 Speaker 2

If we were to zoom in on this.

01:03:01 Speaker 1

All right.

01:03:03 Speaker 2

It would be quite dramatic.

01:03:05 Speaker 1

Yeah, I see.

01:03:05 Speaker 1

I looked at the blue instead of the red one.

01:03:08 Speaker 1

Of course, the red one goes down, right?

01:03:10 Speaker 2

It would be relatively dramatic.

01:03:12 Speaker 2

And then and then we see that between 2013 and 20, maybe 18, this is it takes a while, as you said, to again, speed up.

01:03:22 Speaker 2

So yeah, okay, that's fair.

01:03:26 Speaker 1

And why does the

01:03:29 Speaker 1

Shouldn't you start with the scenarios from 2025?

01:03:34 Speaker 1

Or is it because of modeling that you have the whole picture of desired and undesired?

01:03:40 Speaker 2

Yes, so it's for modeling purposes.

01:03:48 Speaker 2

The model, in order to be conceptually valid, it needs to be able to recreate to some

01:03:56 Speaker 2

you know, to as good as it can, the past behavior as well as the future behavior.

01:04:04 Speaker 1

Okay.

01:04:04 Speaker 2

So if we only modeled, if we only modeled from 2025, then it's hard to say that it's conceptually valid because it's the same system that produces the behavior from in the past and in the future.

01:04:19 Speaker 1

Okay.

01:04:19 Speaker 1

Now I understand.

01:04:20 Speaker 1

Okay.

01:04:21 Speaker 2

Yeah.

01:04:22 Speaker 2

Okay.

01:04:23 Speaker 2

Excellent.

01:04:24 Speaker 2

Thanks for that.

01:04:27 Speaker 2

Then I can stop.

01:04:31 Speaker 2

Well, okay, I'll just keep these up.

01:04:32 Speaker 2

So would you expect Germany to reach the future desired targets?

01:04:40 Speaker 2

I think it was 25% was the desired in 2030 and 400 gigawatts of total solar energy by 2040.

01:04:53 Speaker 1

I don't know.

01:04:55 Speaker 1

Good question.

01:04:57 Speaker 1

Well, we had this change in the government and now we are very skeptical.

01:05:08 Speaker 1

But the government says they want to reach the climate goals and we'll see.

01:05:13 Speaker 1

At the moment, what they haven't really changed things yet, but what they announced was already

01:05:21 Speaker 1

affecting the market.

01:05:22 Speaker 1

So the installations in 2025 not growing so fast is probably one part of the announcements about abolishing the feed-in tariffs, other stuff.

01:05:37 Speaker 1

So yeah, we don't know.

01:05:44 Speaker 2

And what do you see as the worst case and best case scenarios?

01:05:50 Speaker 2

for the future of rooftop solar PV.

01:05:54 Speaker 1

In terms of number of installations or?

01:05:58 Speaker 2

Yeah, yeah, that the, let's say the behavior of the graph, what would be, you know, worst case than best case?

01:06:11 Speaker 1

Okay, well, the best case, of course, would be in reaching the climate goals or even beyond.

01:06:17 Speaker 1

maybe a little bit beyond, because we have some problems in the other sectors.

01:06:21 Speaker 1

For example.

01:06:24 Speaker 1

building sector.

01:06:26 Speaker 1

or also the what's it called the transport sector.

01:06:33 Speaker 1

We have problems in reaching the climate goals, and there it's much more difficult than installing more Pv systems.

01:06:41 Speaker 1

So we should be a bit better than

01:06:45 Speaker 1

the goals actually in the electricity sector to reach the overall climate goals.

01:06:52 Speaker 1

And then the worst case, yeah, I guess as you said, I would agree only a few systems installed because some people are so interested in the technology or have a very high own consumption.

01:07:08 Speaker 1

I mean, if you have a very high own consumption, you can still

01:07:12 Speaker 1

have a profitable PV system, even if you have no feed-in tariff.

01:07:18 Speaker 1

That's for sure.

01:07:19 Speaker 1

I mean, if you have a new building with a heat pump and an electric car and a battery, and then you can, and then you don't build the PV system too big, but maybe 10 kilowatt peak, we calculated this one example in the first study that I sent you.

01:07:42 Speaker 1

then you can have such a high own consumption that it doesn't matter so much if you don't get much for the PV electricity you feed into the grid.

01:07:51 Speaker 1

And then you could still install it.

01:07:54 Speaker 1

So I guess that would be the minimum that these people still install PV systems and some were interested to just spend the money.

01:08:04 Speaker 2

Okay, okay.

01:08:05 Speaker 2

And what do you, what would be the critical reason

01:08:09 Speaker 2

you know, behind these scenarios.

01:08:10 Speaker 2

So if the best case happens, what do you think is the going to be the critical reasons that it happens?

01:08:18 Speaker 1

Well, politics and then the feed-in tariff, which provides reliable income and easy to calculate revenues for the PV system.

01:08:28 Speaker 1

I guess this is the very key in that case.

01:08:32 Speaker 2

Okay.

01:08:32 Speaker 2

Okay.

01:08:33 Speaker 2

And in the worst, yeah, I guess in the worst case then, this feed-in tariff is abolished.

01:08:39 Speaker 2

That would be the difference in your opinion.

01:08:42 Speaker 1

Yeah, worst case would be feed-in tariff abolished and no chance of direct marketing of the PV electricity.

01:08:52 Speaker 1

So if the, which is not very realistic because there are companies who do direct marketing of these small PV systems.

01:09:06 Speaker 1

I guess you would have to take that into account that this will also happen.

01:09:10 Speaker 1

But if, yes, for some reason, direct marketing wouldn't work or companies would stop doing this, then it would be worse because then you have no income at all for the PV electricity feed in.

01:09:24 Speaker 2

Right.

01:09:25 Speaker 2

So if companies, can you expand on that?

01:09:28 Speaker 2

So if companies stopped.

01:09:31 Speaker 1

Doing direct marketing.

01:09:33 Speaker 1

So there's very few companies who do direct marketing for PV systems below 100 kilowatt peak today.

01:09:41 Speaker 1

Right, And we talked to them in the course of that study and they said it's very difficult and it's not really profitable and it's so few, so little electricity and it's so much, you have to, you have.

01:09:58 Speaker 1

to have so many people talking to the electricity providers.

01:10:02 Speaker 1

And that's just a lot of work to do the direct marketing for these small systems, that it's actually not profitable.

01:10:11 Speaker 1

And they do it because they want to be the first ones, if that's coming.

01:10:18 Speaker 1

But it's very questionable if it's really worth it to do the direct marketing for these small systems.

01:10:25 Speaker 2

Okay.

01:10:25 Speaker 2

That makes sense.

01:10:28 Speaker 2

All right.

01:10:29 Speaker 2

I think that's the end of the interview.

01:10:33 Speaker 2

Thanks a lot.

01:10:34 Speaker 2

Thanks a lot also for going over time.

01:10:36 Speaker 2

I really appreciate it.

01:10:38 Speaker 1

Yeah, thank you.

01:10:39 Speaker 1

It's an interesting topic, I think.

01:10:44 Speaker 2

Yeah.