Supplementary material

Table S1. Tableau of the six selected scenarios and their combinations of descriptor variants (the definitions of all descriptors and their variants can be found in detail in https://elib.uni-stuttgart.de/handle/11682/5710?locale=en)

Target - centralized	Target	Market	Value Change	Coping with pressure	Inertia
global development in general: market forces			global development in general: policy reform	global development in general: market forces	global development in general: fortress world
global fossil price pathway: medium (166 $/b in 2050)			global fossil price pathway: low (100 $/b in 2050)	global fossil price pathway: high (210 $/b in 2050)	
global interest rate trend: moderate recovery of interest rates (2.5%)					
EU integration: EU Renaissance		EU integration: nobody cares	EU integration: EU Renaissance	EU integration: EU under threat	
population in 2050: strongly decreasing (67.4 m)			population in 2050: relatively high population (78.7 m)	population in 2050: strongly decreasing (67.4 m)	
GDP growth: moderate (1.2 %/a)		GDP growth: strong (1.8 %/a)		GDP growth: moderate (1.2 %/a)	GDP growth: weak (0.6 %/a)
employment market development: employment market bifurcation		employment market development: low unemployment / strong transition to flexible working hours			employment market development: employment market bifurcation
tertiarisation of the economy: strong (80 %)					
innovative ability of the economy: stable			innovative ability of the economy: increasing	innovative ability of the economy: stable	innovative ability of the economy: decreasing
transnational flows of trade: European Germany - focus on services		transnational flows of trade: global Germany	transnational flows of trade: European Germany - focus on services		
international integration of electricity grids: stronger European transmission network with European self-reliance				international integration of electricity grids: trend towards national self-reliance (regarding capacities)	
development of infrastructures in the power transmission and distribution grids: delayed			development of infrastructures in the power transmission and distribution grids: undelayed		development of infrastructures in the power transmission and distribution strongly delayed
expansion of renewable energies in the electricity sector (electricity produced in 2050): moderate (450 TWh/yr)			expansion of renewable energies in the electricity sector (electricity produced in 2050): strong (700 TWh/yr)		expansion of renewable energies in the electricity sector (electricity produced in 2050): weak (300 TWh/yr)
trends central/decentralised electricity generation and storage: trend towards integrating decentralised units into a centralised system	trends central/decentralised electricity generation and storage: trend towards mixed structures		trends central/decentralised electricity generation and storage: trend towards the transition to a decentralised system		trends central/decentralised electricity generation and storage: trend towards integrating decentralised units into a centralised system
regulation electricity market: modifications of existing markets (security of supply via market)				regulation electricity market: introduction of new markets (security of supply via state)	
policy stability in the energy field: constant			policy stability in the energy field: increasing		policy stability in the energy field: decreasing
governance in the energy field: preference for non-technology-specific economic instruments				governance in the energy field: preference for technology-specific economic instruments	governance in the energy field: preference for administrative regulations
governance of infrastructure expansion: trend towards non-coordinated expansion			governance of infrastructure expansion: trend towards coordinated expansion		governance of infrastructure expansion: trend towards non-coordinated
planning legislation/public infrastructure planning: compromise			planning legislation/public infrastructure focus on legitimation and acceptance	planning legislation/public compromise	planning legislation/public infrastructure focus on legitimation and acceptance
political guidelines: more focus on market mechanism			political guidelines: more focus on public participation and transparency	political guidelines: more focus on state/public governance	
welfare state development: more emphasis on liberal welfare elements			welfare state development: more emphasis on corporatist-statist welfare elements	welfare state development: more emphasis on liberal welfare elements	
income distribution: increasing inequality and increasing average income			income distribution: constant or decreasing inequality and increasing average income	income distribution: increasing inequality and increasing average income	income distribution: increasing inequality / continuing weak or no growth of average income
technology acceptance (energy technologies): decreasing	technology acceptance (energy technologies): slightly increasing				technology acceptance (energy technologies): decreasing
individual energy consuming behaviour: trend towards non-involvement			individual energy consuming behaviour: trend towards technophily	individual energy consuming trend towards sufficiency	individual energy consuming behaviour: trend towards non-involvement
educational development: strong focus on MINT/strong limitation on access			educational development: strong focus on MINT/slight limitation on	educational development: strong focus on MINT/strong limitation on access	
public attitude towards the energy trend towards negative attitude	public attitude towards the energy transition / NIMBY: no trend visible		public attitude towards the energy transition / NIMBY: trend towards positive attitude		public attitude towards the energy trend towards negative attitude
value orientation and objectives in economic development: trend towards materialism and performance			value orientation and objectives in trend towards post-materialism	value orientation and objectives in economic development: trend towards materialism and performance	
media discourse: slight plurality of opinion/ strong trend for tabloidization		media discourse: high plurality of opinion/ strong trend for tabloidization	media discourse: high plurality of opinion/ weak trend for tabloidization	media discourse: slight plurality of opinion/ strong trend for tabloidization	media discourse: high plurality of opinion/ strong trend for tabloidization
reduction energy demand - household appliances: weak (0.6 % per year)					reduction energy demand - household strong (1.3 % per year)
reduction energy demand - PC electric weak (0.8 % per year)	reduction energy demand - PC electric vehicles: moderate (1.7 % per year)			reduction energy demand - PC strong (2.1 % per year)	reduction energy demand - PC electric weak (0.8 % per year)
reduction energy demand - PC strong (1.55 % per year)	reduction energy demand - PC weak (0.8 % per year)	reduction energy demand - PC engines (% per year): strong (1.55 % per year)		reduction energy demand - PC engines (% per year): weak (0.8 % per year)	
renovation rate / depth - buildings (private): strong (2 %/yr - 70 %)				renovation rate / depth - buildings weak (1 %/yr - 30 %)	renovation rate / depth - buildings strong (2 %/yr - 70 %)
reduction energy demand - industry: strong (2.3 % per year)					reduction energy demand - industry: weak (1 % per year)
reduction energy demand - commercial sector: strong (3.4 % per year)					
expansion district heating: strong expansion					expansion district heating: no change
investments new vehicle concepts and small (20% of vehicle market)	investments new vehicle concepts high (~100% of vehicle market)	investments new vehicle concepts moderate (50% of vehicle market)	investments new vehicle concepts and infrastructures: high (~100% of vehicle market)		investments new vehicle concepts and small (20% of vehicle market)
living trends: strong increase (60 qm space per head)			living trends: slight increase (50 qm space per head)		living trends: strong increase (60 qm space per head)
expansion of renewable energies for heating: strong (400 THw per year)			expansion of renewable energies for heating: very strong (500 THw per year)		expansion of renewable energies for weak (250 THw per year)
rebound effects individual energy demand: moderate					

Details on assessment methods for model-based indicators and overview over indicator targets

The development of the energy demand is to a wide extent constrained by the context scenario (assessment method "CS" in Table S2) and requires only little extra assumptions and modelling. This is in particular true for the final energy productivity of the German economy, the German industry, and small enterprises. In other cases, indicators are pre-constrained by the context scenario. However, a number of other indicators are also rather directly determined by the context, but require extra energy system modelling ("ESM" in Table S2) and/or extra

modelers' assumptions ("MAS") to a larger extent. This includes, e.g., the final energy consumption for space heat of private households, where a simple building stock model is used to translate the context factors "renovation rate of buildings", "renovation depth" of buildings, population development, and development of the average floor space into the energy demand for heating. In the case of the indicator "final energy consumption of the transport sector", the assessment requires modelers' assumptions on, e.g., the split between BEVs/PHEVs on one hand and FCEVs on the other hand. Quantitative values for a last group of indicators cannot easily be traced back to a small number of context descriptors. They are thus regarded as a result of the complex interactions of the energy system model (thus assessment method "ESM" in Table S2).

The different assessment methods in Table S2 cannot always be clearly distinguished—their boundaries are fluid. However, it illustrates well that some sustainability indicators are more directly constrained by the context scenario than other indicators, which require more modelling and/or other input from the modelers' side.

Table S2. Details of assessment methods and target values for the 16 model-based indicators.

Indicator	Assessment Method	Target Value 2050
Energy-related emissions of particulate matter (TSP)	EF	45.6 kt
Energy-related emissions of Cadmium	EF	2.0 t
Energy-related greenhouse gas emissions	EF	207 Mt CO_2eq
Energy-related emissions of acid forming gases	EF	690 kt SO_2eq
Final energy productivity of the German economy (GDP per FEC)	CS	743 €/GJ
Final energy productivity of the German industry (GVA per FEC)	CS	621 €/GJ
Final energy productivity of small enterprises (GHD) (GVA per FEC)	CS	3251 €/GJ
Final energy consumption in the transport sector	CS+MAS	1521 PJ
Final energy consumption of private households per capita	CS+ESS	17.6 GJ/cap
Installed capacity of renewable energy power plants	CS+MAS+ESM	169 GW
Number of electric vehicles	CS+MAS+ESM	22 Mio
Share of imported energy to primary energy consumption	ESM	43%
Share of renewable energy on gross final energy consumption	ESM	60%
Area under cultivation of energy crops	ESM	1.6 Mio h
Use of primary energy	ESM	7190 PJ
Modal split in the transport sector	MAS	20%

Results (frequency distribution) of non-model-based indicators for all consistent scenarios as a data basis for the definition of targets for those indicators

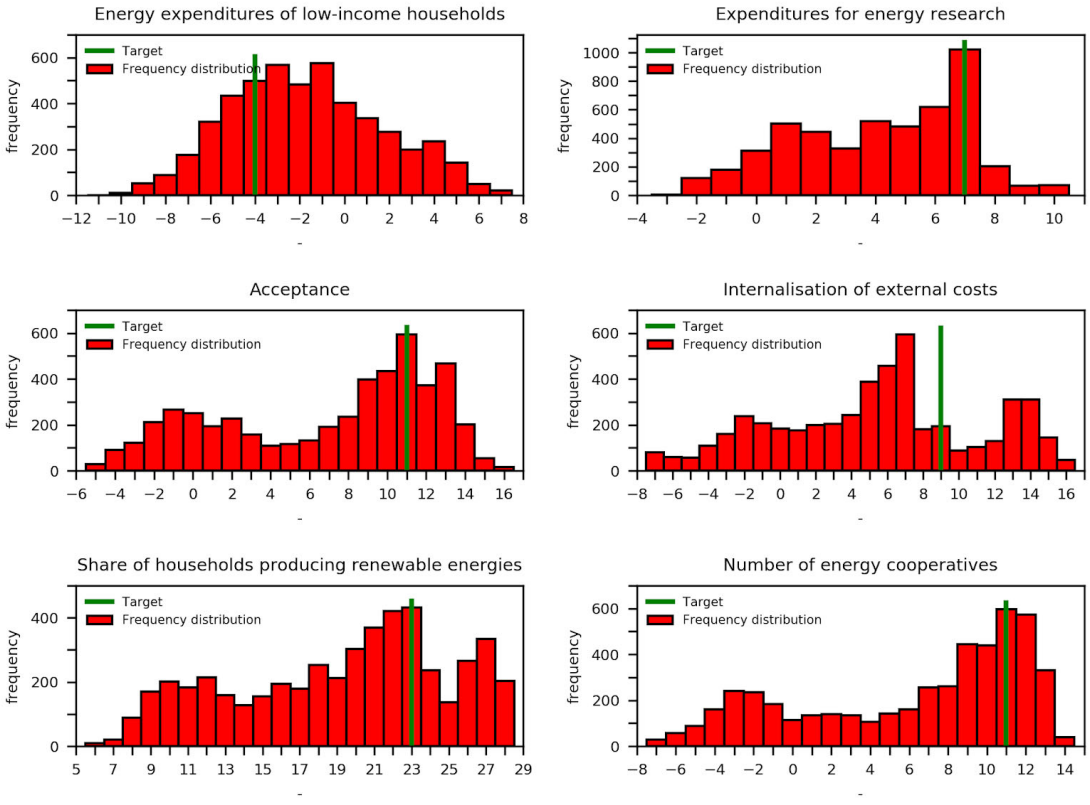

Figure S1. Frequency distribution of the values of all six non-model-based indicators among all consistent scenarios.

Figure S1 shows the frequency distribution of the results for the non-model-based indicators for all consistent scenarios. The green line indicates the target value defined as the 25% or 75% percentile, respectively (see Section 2.5 and Table S3). As explained in the main text, for each non-model-based indicator, a target value was chosen corresponding to the 25% percentile for those indicators where a decrease in the absolute indicator value is desired, and to the 75% percentile for those indicators where an increase in the indicator value is desired. Table S3 gives an overview over non-model-based indicators and the resulting target values.

Table S3. Definition of target-values for non-model-based indicators.

Indicator	Target Percentile	Target Value
Monthly energy expenditures of households with a monthly net income < 1300€	25%	-4
Federal expenditures for energy research	75%	7
Acceptance of renewable energies in the neighbourhood	75%	11
Degree of internalization of energy-related external costs	75%	9
Share of households producing renewable electricity	75%	23
Number of energy cooperatives engaged in renewable energy plants	75%	11

Additional results for model-based indicators

Table S4. Overview of model-based indicator results: Absolute values (top) and normalized values (bottom). A green color in the bottom table indicates normalized indicator values > 1 (scenario exceeds target), orange cells indicate that the indicator development 2015-2050 is going in the desired direction, but the target is not reached. The red cells indicate where the development between 2015 and 2050 is going in the opposite direction (relative to the target).

Model-based indicators	unit	Target	Inertia	Market	Value Change	NH3	NH8
model results (absolute values)							
Energy-related emissions of particulate matter (TSP)	kt	29,6	45,7	39,6	34,8	35,0	29,0
Energy-related emissions of cadmium	t	0,77	1,88	1,14	1,03	0,99	1,14
Share of imported energy to primary energy use	%	48%	79%	59%	43%	39%	55%
Final energy consumption of private households per capita	GJ/cap/a	17,6	16,0	17,4	16,1	26,9	17,6
Share of renewable energy on gross final energy consumption	%	65%	33%	51%	74%	80%	56%
Area under cultivation of energy crops	Mio. ha	3,7	3,1	2,2	2,1	2,1	1,9
Use of primary energy	PJ/a	7.274	11.057	8.498	9.078	8.502	7.876
Specific Final Energy Consumption for Space Heat of Households (Temperature Adjusted)	MJ/m2	145	146	146	144	362	146
Final energy consumption in the transport sector	PJ/a	1.411	2.039	1.962	1.565	1.268	1.901
Modal split in the transport sector (share of milage by public transport - trains, trams, busses)	%	23%	21%	21%	26%	24%	21%
Number of electric vehicles	Mio	53,1	11,7	30,9	47,2	52,1	11,7
Final energy productivity of the German economy (GDP per FEC)	€/GJ	851	630	853	891	770	776
Final energy productivity of the German industry (GVA per FEC)	€/GJ	598	344	589	582	591	603
Final energy productivity of small enterprises (GHD) (GVA per FEC)	€/GJ	4.705	5.435	4.554	4.465	4.599	4.742
Energy-related greenhouse gas emissions	Mt CO2eq/a	160	582	243	166	141	227
Energy-related emissions of acid forming gases	kt SO2eq	414	952	726	449	395	683
Installed capacity of renewable energy power plants (w/o import, w/o biogenic waste)	GW	187	118	170	346	318	175
normalised values							
Energy-related emissions of particulate matter (TSP)	%	201%	103%	140%	169%	168%	205%
Energy-related emissions of cadmium	%	161%	90%	138%	145%	147%	137%
Share of imported energy to primary energy use	%	83%	-28%	44%	102%	118%	58%
Final energy consumption of private households per capita	%	107%	122%	109%	121%	21%	107%
Share of renewable energy on gross final energy consumption	%	91%	31%	65%	110%	121%	75%
Area under cultivation of energy crops	%	-254%	-142%	6%	11%	19%	56%
Use of primary energy	%	95%	32%	75%	65%	75%	85%
Specific Final Energy Consumption for Space Heat of Households (Temperature Adjusted)	%	130%	129%	129%	130%	42%	129%
Final energy consumption in the transport sector	%	109%	51%	58%	95%	122%	64%
Number of electric vehicles	%	352%	77%	205%	313%	346%	77%
Final energy productivity of the German economy (GDP per FEC)	%	124%	73%	124%	133%	105%	106%
Final energy productivity of the German industry (GVA per FEC)	%	84%	18%	82%	80%	83%	86%
Final energy productivity of small enterprises (GHD) (GVA per FEC)	%	156%	190%	149%	145%	151%	158%
Energy-related greenhouse gas emissions	%	107%	26%	91%	106%	110%	94%
Energy-related emissions of acid forming gases	%	217%	60%	126%	207%	223%	139%
Installed capacity of renewable energy power plants (w/o import, w/o biogenic waste)	%	125%	29%	102%	351%	311%	109%

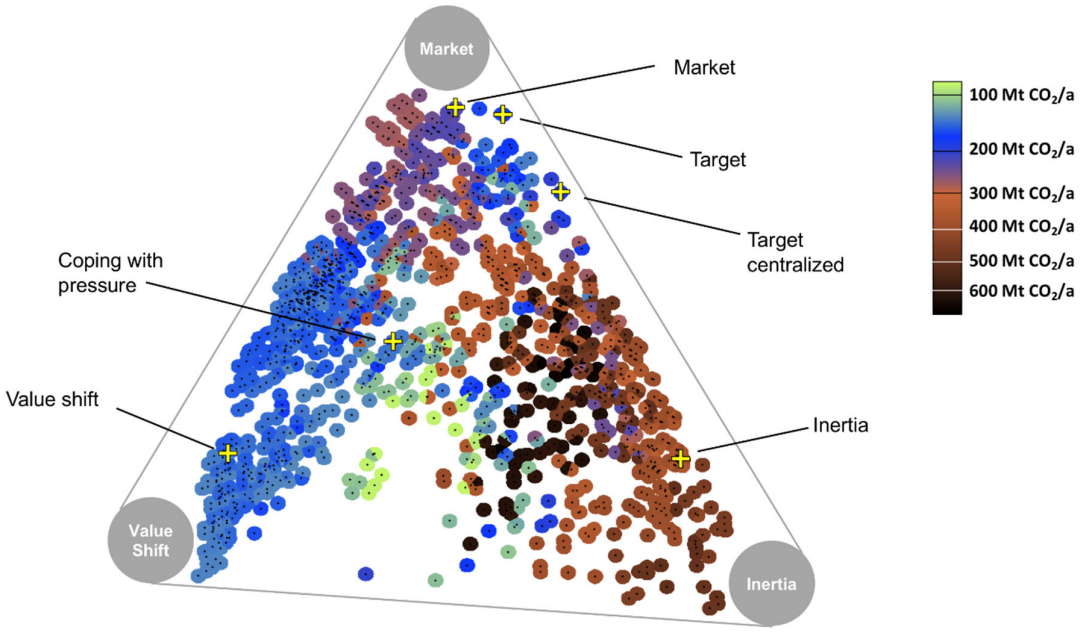

Figure S2. Localizations of the selected scenarios on Pregger et al.'s "landscape of societies".

Impact assessments for indicator "Acceptance of Renewable Energies in the Neighborhood"

This table shows the impacts of all descriptor variants (2 to 4 per descriptor) on the indicator "Acceptance of Renewable Energies in the Neighborhood". The impacts were rated by the expert panel using an integer scale -3 (strongly restricting) to +3 (strongly promoting).

Table S5. Descriptor impacts on the indicator "Acceptance of Renewable Energies in the neighborhood" for different variants of the descriptors used in the scenarios.

Acceptance of Renewable Energies in the Neighborhood				
Global development General	Market Forces	Policy Reform	Fortress World	Eco-Communalism
	0	1	2	2
Global development Price for fossil fuels	Low prices	Moderate growth of prices	Strong growth of prices	
	0	1	2	
EU integration	EU Renaissance	Nobody Cares	EU under threat	
	0	0	0	
Population development	Strongly decreasing	Moderately decreasing	Relatively high population	
	0	0	0	
GDP growth	Weak development	Moderate development	Strong development	
	0	0	0	
Labour market development	Low unemployment / pro-worker flexibility	High unemployment / pro-employer flexibility	Division of labour market	
	0	0	0	
Tertiarisation of the economy	Weak tertiarisation	Strong tertiarisation		
	0	0		
Innovation capabilities	Decreasing	Constant	Increasing	
	0	0	1	
Transnational trade flows	European Germany	European Germany - focus on services	Global Germany	Renationalization
	0	0	0	0
International power line integration	Trend national capacity autarky	Trend European power grid / European autarky	Trend trans-European optimization	
	1	0	0	

Infrastructure expansion of power lines	Appropriate expansion	Delayed expansion	Strongly delayed expansion	
	0	0	0	
Renewable electricity expansion	Weak expansion	Moderate expansion	Strong expansion	
	0	0	1	
Centralized/decentralized power generation and -storage	Integration of dec. units into the central system	Hybrid structure	Conversion to decentralized system architecture	
	0	0	1	
Electricity market regulations	Market in charge of security of supply	Providers in charge of security of supply	State in charge of security of supply	
	0	0	0	
Energy policy stability	Decreasing policy stability	Constant policy stability	Increasing policy stability	
	-1	0	1	
Energy policy instruments	Regulatory instruments	Technology-specific economic instruments	Technology-unspecific economic instruments	
	0	0	0	
Governance in the field of infrastructure expansion	Coordinated expansion	Uncoordinated expansion		
	0	0	x	
Planning law / public infrastructure planning	Focus acceleration	Focus legitimacy and acceptance	Dominance of group interests	Compromise
	0	0	0	0
Political design model	State control	Citizen's participation and transparency	Market mechanisms	No significant shift
	-1	1	-1	0
Social welfare state design	Liberal welfare state	Conservative-corporatist welfare state	Social democratic welfare state	
	0	0	0	
Private income development	Increasing inequality / low income growth	Const.- decr. inequality / low income growth	Increasing inequality / high income growth	Const.- decr. inequality / high income growth
	0	0	0	0
Acceptance of energy technologies	Decreasing	Constant	Slightly increasing	Strongly increasing
	-2	0	1	3
Energy consumption behaviour (individual)	Trend towards being unconcerned	Trend towards being economical	Trend towards being technology-focused	Trend towards sustainability
	0	0	0	0
Education development	Focus MINT / low access barriers	Focus MINT / strong access barriers	Focus general education / low access barriers	
	1	0	-1	