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Evaluating energy systems through a well-being lens

COLLECTION: MONITORING AND EVALUATION

PEER-REVIEWED PAPER

JOHANNES THEMA
SINA DIERSCH
HANS HAAKE
JULIA SWAGEMAKERS
SHIMA SASANPOUR

*Author affiliations can be found in the back matter of this article

ABSTRACT

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Monitoring and evaluation of any measures – regarding the economy, the energy system or energy efficiency – requires to comprehensively capture as many impacts as possible, going beyond solely monetary and energy impacts. One plausible end point for these multiple impacts is human well-being, understood as a multifaceted construct including e.g. material security, health, social connections or environmental quality. A growing body of scholarship and practical experimentation has created lists of necessary dimensions and potential indicators for countries and regions, often based on the work of Amartya Sen and others. The well-being literature is often situated in a beyond-GDP debate, with GDP being criticized for its use as a measure of progress. In complementing GDP, these indicator sets often are challenged with the question of how to weigh their many dimensions. In our paper we aim to apply well-being approaches to the energy system by developing an indicator set that may later help to compare and assess different configurations of the energy system. The goal is to go beyond standard model-based assessment of energy systems which is primarily based on costs and GHG emissions. Based on a full well-being framework, we develop a manageable list of indicators with plausible data availability to be included in energy system models. To this end, we combine a large collection of well-being indicator sets and single indicators, a summary of the relevant frameworks and an interdisciplinary review process to arrive at a first list. We then conduct a representative survey in Germany (n = 1019) to derive indicator weights, allowing for later multi-criterial optimisation within energy models. Where possible, we collect existing data for how energy system technologies impact indicators. Where not possible, we use the survey for collecting data on the public perception of how energy system technologies impact a number of well-being indicators. This paper presents the indicator list and findings from the survey on indicator weighting.

CORRESPONDING AUTHOR:
Johannes Thema
Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany
johannes.thema@wupperinst.org

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INTRODUCTION: CONCEPTUAL BACKGROUND AND GENESIS OF THE INDICATOR SET

The paradigmatic approach to evaluating energy systems are system costs. Supply-side energy system models are therefore typically techno-economic optimisation models that follow a cost-minimization approach. Modern models do include climate emissions, so mostly CO_2, to arrive at Climate Neutrality at the lowest price point. There have been some recent efforts to add additional elements of sustainability, such as ecosystem quality, health or employment in energy system models (Naegler et al., 2021), as well as adding social/socioeconomic Indicators to technology assessments next to more established environmental assessments such as LCA (Abu-Rayash & Dincer, 2019; Eschmann et al., n.d.).

Within the ENERGOOD research project, an enhanced multi-criterial optimization approach is developed that aims to optimise not only costs, but a wider concept of societal well-being, closely connected to sustainability but using a different conceptual basis. To this end, we develop a set of indicators that can be operationalised, quantitatively attached to supply-side technologies in the energy system optimisation model that we later apply (REMix), and which need to be weighed against each other as to their well-being contribution.

The project builds on the concept of societal well-being as a multidimensional framework for assessing societal welfare beyond economic performance only. In response to longstanding critique of gross domestic product as a proxy for societal progress (Daly & Cobb, 1989; Jackson, 2009), well-being frameworks have gained prominence in economics, social sciences, and sustainability research (OECD, 2011; Sen, 2001; Stiglitz et al., 2009). These approaches argue that societal progress should be assessed in terms of people's actual living conditions and capabilities rather than economic output alone.

Within these frameworks, societal well-being is commonly understood as a multidimensional construct encompassing material living standards, health, environmental quality, social relations, security, civic participation, and subjective life evaluations (OECD, 2013). Importantly, well-being is not conceived solely as an individual attribute, but as an outcome of collectively produced and distributed societal conditions. It therefore captures both current well-being and its sustainability over time, explicitly acknowledging intergenerational dimensions and trade-offs between different well-being components (OECD, 2013).

Conceptually, societal well-being overlaps with related notions such as quality of life, social sustainability, and social justice, while maintaining a distinct analytical focus on outcomes rather than inputs, processes, or procedural aspects. In contrast to narrower concepts, societal well-being encompasses a broader range of material, environmental, and social effects. Similarly, while the concept of a Just Transition emphasises fairness and distributional justice in socio-technical transformations (Heffron & McCauley, 2018; Newell & Mulvaney, 2013) a well-being perspective provides a more comprehensive evaluative framework that includes, but is not limited to, distributive concerns.

Energy systems are a fundamental determinant of societal well-being, as they constitute a core infrastructure underpinning economic activity, social participation, and everyday life. Energy production, conversion, transport, and use affect societal well-being directly through factors such as energy affordability, security of supply, environmental pollution, land use, and local impacts of energy infrastructure (Hillerbrand & Goldammer, 2018; Ulgiati et al., 2019). Indirectly, energy systems shape well-being through their contribution to climate change mitigation, public health, employment, and regional development (e.g. Seddighi et al., 2023). Consequently, transformations of energy systems entail far-reaching implications for societal well-being, including synergies and trade-offs across different well-being dimensions.

Despite these strong conceptual links, energy system modelling has traditionally focused on techno-economic objectives, such as cost minimisation, system efficiency, and emission reductions (Pfenninger et al., 2014). While indispensable, these criteria capture only a limited subset of the societal consequences of energy system development. As a result, model-based analyses may overlook important social and societal trade-offs or implicitly assume that improvements in techno-economic performance translate directly into societal benefits. Integrating societal well-being indicators into energy system modelling therefore represents an attempt to broaden the evaluative space of model-based analyses and to cover the

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societal trade-offs associated with decarbonisation pathways. The fundamental motivation for including well-being indicators is to enable a more comprehensive and socially informed assessment of energy system configurations beyond cost and emissions alone.

Against this theoretical background, the indicator set developed in this study is derived from established well-being frameworks and tailored to the context of energy system development and modelling. The focus lies on identifying those dimensions of societal well-being that are plausibly influenced by energy transition technologies and that can be translated into indicators suitable for quantitative modelling. Abstract well-being dimensions are thus operationalised into concrete, technology-related indicators reflecting impacts, interactions, and externalities of energy systems.

Building on this theoretical grounding, the following section describes the systematic procedure used to select, refine, and validate the indicators included in the analysis.

METHODS AND MATERIAL

INDICATOR SELECTION

The selection of indicators followed a multi-step, iterative procedure combining desk-based research with expert-based validation.

First, a structured review of existing well-being frameworks, sustainability indicator sets, and studies on societal (including environmental) impacts of energy systems was conducted. The OECD Well-Being Framework was identified as the conceptual foundation due to its theoretical robustness and multidimensional structure. Although originally developed for national-level assessment, it was adapted here to evaluate the impacts of specific energy technologies. Based on the literature review, a comprehensive long list of potential indicators was compiled, covering societal effects of energy production, conversion, transport, and storage. Particular attention was given to indicators previously applied in modelling or assessment contexts.

In a second step, the long list was systematically screened against a set of selection criteria: Indicators were retained if they (i) exhibit a plausible link to energy system development, (ii) can plausibly be influenced by energy technologies and (iii) allow for technology-specific operationalisation. The latter was a strict requirement, as all indicators are implemented at the technology level within the energy system model. Indicators that could not be disaggregated accordingly were excluded.

In a third step, the preliminary indicator set was refined through internal discussions within the interdisciplinary project team and validated externally in a workshop with the ENERGOOD project's advisory board. The purpose of this step was to assess the conceptual validity, completeness (with its limitations, see below), and practical applicability of the indicators, and to evaluate potential trade-offs between conceptual breadth and model tractability. Where necessary, indicators were reformulated or specified more narrowly to ensure consistent technology-level attribution and quantitative operability. Iterative feedback rounds within the project team further ensured that all indicators could be clearly assigned to individual technologies, that overlaps were minimised, and that the set remained aligned with the underlying well-being framework while being suitable for subsequent weighting and integration into the model-based optimisation. The final set thus reflects both theoretical grounding and practical feasibility for energy system modelling applications.

In a fourth step, we collected data from literature, existing modelling approaches and our own calculations on how specific technologies – typically applied in modelling decarbonised energy systems – affect each indicator. For some indicators, no such data was available.

Finally, for a subset of indicators lacking technology-specific data and reflecting subjective or perception-based dimensions of societal well-being, empirical data from a German-wide representative survey was used. These indicators were selected because they capture aspects of societal well-being that cannot be adequately derived from technical or secondary data alone.

The last two steps with technology-specific quantifications for each indicator are not within the scope of this paper. Instead, we focus on the overall indicator list and their relative weights.

INDICATOR WEIGHTING

For a later model-based optimisation of a decarbonised energy system including the indicators, it is necessary to weigh indicators. We derive weights from a German-wide representative survey. Data was collected by Forsa in its online panel *forsa.omninet* from 1,019 respondents above age 18, with a quota-based random sampling, from 25 September to 5 October 2025. The dataset is published as an SPSS file (.sav), together with the codebook and a synthesis report (German) open access at Zenodo (Thema et al., 2026).

The survey includes a question on the importance of indicators on a Likert scale from 1 (not important at all) to 5 (very important). We use this variable as primary input for constructing indicator weights. For weight generation, we present two options: First, the simple mean of responses per indicator item. Second, we aim to penalise the weight if respondents are discordant, i.e. the variance of responses is high. We thus calculate a weight alternative of mean/standard deviation (mean/sd).

Our standard weights are based on the full sample. In addition, we test potentially diverging weights that may result from subsamples. The motivation for this was to investigate how indicator prioritisation may diverge for subgroups e.g. being supportive of the energy transition, having own experience with electricity generation, or by socioeconomics (income classes, age groups). Consequently, we calculate both indicator options (mean, mean/sd) also for respective subsamples.

RESULTS

RESULTS OF THE INDICATOR SELECTION

Structure of the final indicator set

The indicator selection process resulted in a set of five core well-being dimensions comprising eleven indicators. These dimensions do not replicate the original dimensional structure of the OECD Well-Being Framework. Rather, they represent a context-specific adaptation derived from it and tailored to the requirements of technology-specific energy system modelling (Table 1).

While the OECD framework served as the conceptual foundation, its original national-level dimensions were selectively reinterpreted and reorganised. Only those aspects that can be plausibly influenced by energy technologies and operationalised at the technology level were retained. Consequently, the resulting dimensions reflect an analytically condensed and model-compatible structure rather than a direct transfer of the OECD taxonomy.

Table 1 Technology-specific operationalisation of well-being indicators for energy system modelling.

WELL-BEING DIMENSION	OPERATIONALISED INDICATOR	DATA SOURCE	CONCEPTUAL BACKGROUND
Income and Wealth	Levelised cost of electricity per kWh by technology (€/kWh)	Secondary data sources (literature and existing databases)	Energy costs are a direct impact on disposable income, with limited options to reduce them for households. Income is a component of well-being in any market economy.
Employment	Full-time equivalents (FTE) per unit of energy or installed capacity by technology	Secondary data sources (literature and existing databases)	Energy production creates jobs, in many cases relatively well-paid jobs. Employment is highly relevant for well-being, both for income and for various psychological benefits.
Environmental Quality (objective)	Technology-specific CO_2 emissions per kWh (t CO_2/kWh)	Secondary data sources (literature and existing databases)	Emissions endanger the stability of the climate system and thereby the quality of the natural environment as a direct element of well-being. They also endanger future well-being.
	Land use intensity per kWh by technology (m^2/kWh)	Secondary data sources (literature and existing databases)	Land use by energy technologies directly degrades natural spaces that are relevant to well-being, they can also lose some of their ability to provide ecosystem services.

(contd.)

WELL-BEING DIMENSION	OPERATIONALISED INDICATOR	DATA SOURCE	CONCEPTUAL BACKGROUND
Environmental Quality (subjective)	Perceived landscape impact of the respective technology (Likert scale 1–5)	Primary survey data	Parallel with objective indicators (see above), the perceived impact on landscape quality can directly influence well-being.
	Level of concern regarding potential environmental impacts of technology expansion (Likert scale 1–5)	Primary survey data	Various elements of environmental quality influence well-being, e.g. air quality, water quality, noise. These can all be impacted by energy technologies.
Personal Security	Import dependency of critical raw materials by technology (share of imported inputs, %)	Secondary data sources (literature and existing databases)	Security in different forms is relevant to well-being, here it is in the form of a reliable energy supply being secure or not, with security dropping if supply chains are easily disrupted.
Civic Engagement and Governance	Minimum required financial investment for participation in the technology (ordinal scale)	Secondary data sources (literature and existing databases)	Being able to partake in decision-making at various societal levels is a direct contributor to well-being. If more people can directly decide on the use of a technology by simply deploying it, it should be beneficial for well-being.
	Degree of decentralised ownership or installation structure (scale value)	Secondary data sources (literature and existing databases)	As above, if more people are able to participate in a more decentralized system, it will optimize well-being.
	Perceived societal connectedness or trust in the technology (Likert scale 1–5)	Primary survey data	With more connectedness and trust in the technology a higher level of civic engagement is possible, leading to well-being gains.
	Perceived contribution of the technology to the energy transition (Likert scale 1–5)	Primary survey data	This indicator more broadly captures the multi-dimensional benefits of the energy transition, overlapping with some to the indicators above.

All indicators are either expressed in quantitative, technology-specific metrics (e.g., emissions per unit of energy, land use intensity, employment coefficients) or derived from survey-based measures that can be consistently attributed to individual technologies.

Limitations and excluded dimensions and indicators

As was to be expected, there are some limitations in the entire chain from conceptual foundation to our concrete indicator set. With the given constraints resulting from the need to integrate these indicators into an energy model, some aspects could not be covered. In some areas such as housing or work-life balance the relevance is probably smaller, however the effects of different energy technologies on knowledge and skills could be highly relevant. Within the chosen dimensions there were also many trade-offs to be made, some of which are detailed below.

Within the domain of employment, education, and skills, the indicator quality of work was excluded because its operationalisation would require normative evaluation standards (e.g., job satisfaction, working conditions) that cannot be consistently attributed to specific energy technologies within a modelling framework. Similarly, formal education levels were not included. While different technologies demand distinct qualification profiles, no analytically neutral basis exists for evaluating one skill composition as inherently welfare-enhancing relative to another. “Energy-related civic competencies” were not operationalised separately, as they are conceptually embedded within the governance and participation indicators already included in the set.

Within the environmental quality dimension, additional indicators such as air pollution were excluded because the project’s conceptual framework assumes a CO_2-neutral, renewable-

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based energy system, substantially reducing variation in conventional pollutant emissions across technologies. The indicator biodiversity impacts were considered but not retained due to pronounced site- and technology-specific heterogeneity and the absence of a sufficiently standardised and comparable data basis for technology-level modelling.

Indicators related to personal safety, such as crime rates, were not included due to the lack of a direct or plausible causal linkage to specific energy technologies. The OECD dimension of social connections was likewise not directly operationalised, as robust and measurable technology-specific causal mechanisms remain limited. However, potential indirect effects – such as strengthened local networks through community-based energy initiatives – are partially reflected in the participation and governance indicators.

RESULTS OF INDICATOR WEIGHTING

The weight of indicators is derived from responses to the following survey question:

> In discussions about which technologies should be used and to what extent for the energy transition, the focus is often primarily on their costs. However, other factors can also play an important role. How important or unimportant are the following aspects to you personally regarding the future design of the energy supply?

For each indicator, one corresponding item was included in the question battery and rated on a 1 (not important)–5 (very important) Likert scale, with an additional non-response option. Likert-scale responses are treated as approximately interval-scaled, allowing the calculation of arithmetic means. Non-responses were excluded from the calculation of indicator weights.

Table 2 shows the results for all respondents. As a baseline specification, we use the mean importance rating per item as the respective indicator weight. The mean value ranges from 3.18 to 4.43 (Figure 1, dark green bars). Indicators such as trust in technologies, low energy costs, low environmental impacts, and low raw material import dependency receive the highest average valuations. Lower average ratings are observed for land consumption, minimal visual impact and the diversity and participation of actors.

Table 2 Descriptive statistics on indicator importance (1–5 Likert scale).

ITEM	MEAN	STANDARD DEVIATION (SD)	MEAN/SD
f3_1: Low energy costs for the population	4.34	0.88	4.95
f3_2: Job creation	3.91	1.01	3.87
f3_3: Reduction of CO_2 emissions	4.03	1.15	3.51
f3_4: Low land use/Minimal land consumption	3.55	1.12	3.16
f3_5: Low impact on environment and nature (e.g., biodiversity, soil, water balance)	4.25	0.93	4.55
f3_6: Minimal visual impact on the surroundings or landscape	3.18	1.26	2.52
f3_7: Easy financial participation for citizens through low entry-level contributions	3.75	1.13	3.32
f3_8: Diverse actors involved in energy supply (e.g., private individuals, cooperatives, municipalities, not just large corporations)	3.62	1.14	3.17
f3_9: Use of technologies that can be trusted	4.43	0.83	5.35
f3_10: Low dependence on raw material imports	4.24	0.96	4.40
f3_11: Positive impact on energy transition (climate protection, sustainability, energy independence)	4.14	1.08	3.85

Importance ratings vary not only in their mean values but also in their dispersion, with standard deviations ranging from 0.83 to 1.26 (Table 2). Conceptually, one may argue that indicators characterised by strong disagreement (high variance), could be weighted lower, whereas indicators evaluated more uniformly across respondents could be weighed higher. To explore this idea, we calculated a second weighting option dividing the mean by the standard deviation (mean/sd, see Table 2 and Figure 1).

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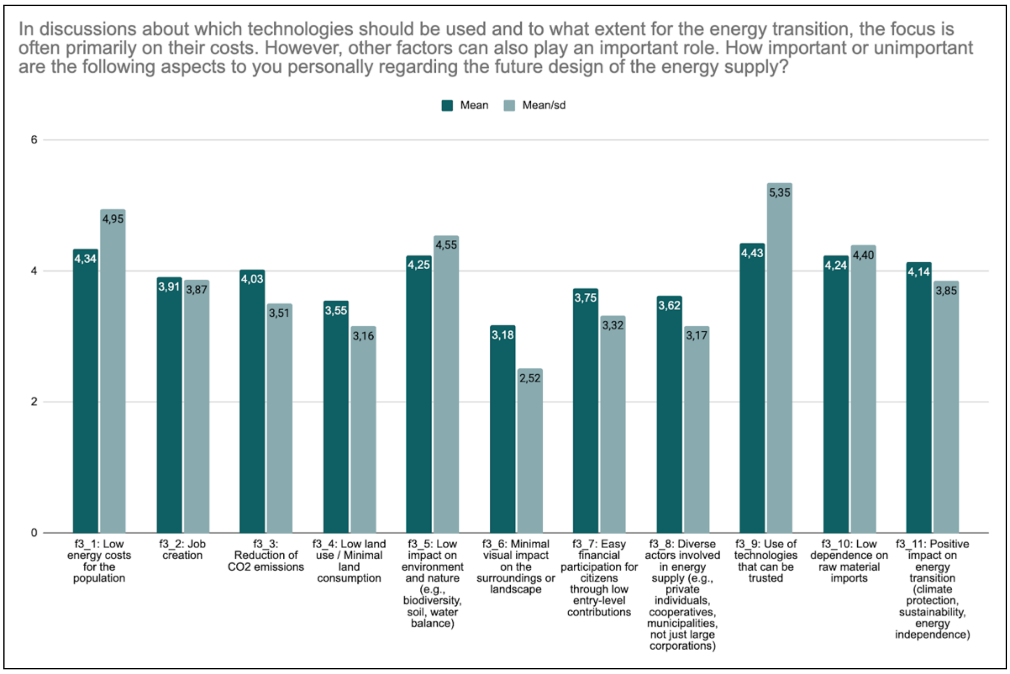

Figure 1 Results for indicator weights based on responses on importance (1–5 scale): simple mean and mean/sd (full sample).

Interestingly, most indicators with high average values have relatively low response variation, whereas lower mean values are apparently the result of a larger share of responses with low valuation, and another part with higher valuation. These heterogeneous responses yield higher variance. As a consequence, weights calculated from the formula mean/sd increase the differences in weights between indicators, boosting higher values and decreasing lower values (Figure 1, light green bars).

While this approach initially appeared conceptually appealing, its application to subsamples reveals important limitations (see below). In particular, very low variance within a subgroup can lead to disproportionately high weights, irrespective of the absolute importance level of the indicator. This results in an artificial dominance of specific indicators within the weighting structure. For this reason, the mean/sd specification is not pursued further, and the simple mean is retained as the preferred and methodologically more robust weighting approach.

Results by sub-samples

In the following, we present average indicator valuations for selected sub-samples, disaggregated by:

- Attitude towards the energy transition (positive vs. negative),
- Income classes,
- Age groups,
- Ownership of rooftop or “balcony” PV systems.

Results may be of interest for scientific reasons, to inform policymakers, but also for a potential variation of the indicator weights in a follow-up multicriterial energy system optimisation, if a plausible argument is made why a certain subsample (subgroup) was more suitable to define the weights for the different well-being indicators, than the entire population.

Attitude towards the energy transition

Disaggregation of average indicator values by attitude towards the energy transition (very positive/positive vs. very negative/negative) shows a significant variance between the two groups (see Figure 2): respondents with a positive attitude generally assign higher importance to environmental and governance-related indicators, including emission reduction, contribution to the energy transition, actor diversity, and import dependency. In contrast, respondents with a negative attitude prioritise low energy costs, land consumption, and minimal visual impact. As expected, GHG emission and contribution to the energy transition receive markedly lower ratings among the latter group.

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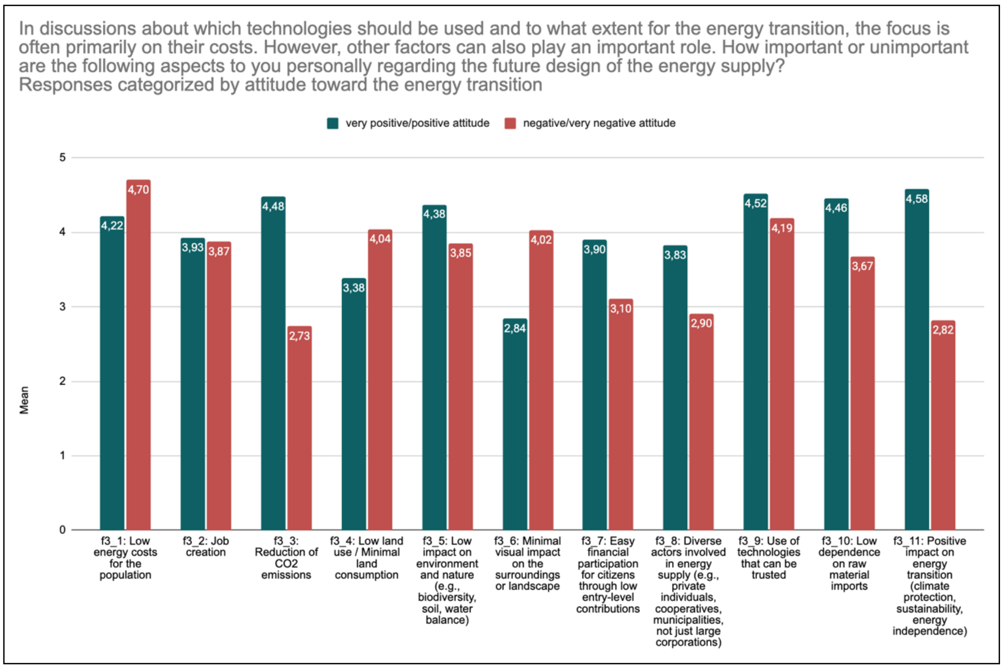

Figure 2 Results for indicator weights based on responses on importance (1–5 scale): mean by positive (n = 540) and negative (n = 183) attitude towards energy transition.

These differences reflect distinct normative orientations regarding the objectives of the energy transition, with one group emphasising environmental and systemic transformation goals, and the other prioritising cost containment and local impacts.

In addition to the average results, we tested the option dividing mean indicator values by the standard deviation. For the subgroup with a positive attitude, respondents are of a very similar opinion regarding the visual impact (low valuation) and financial participation (high valuation). As the variance on these two items/indicators is very low for this subgroup, the alternative weighting approach of mean/sd shows an extreme boost for these to indicator weights (see Figure 3).

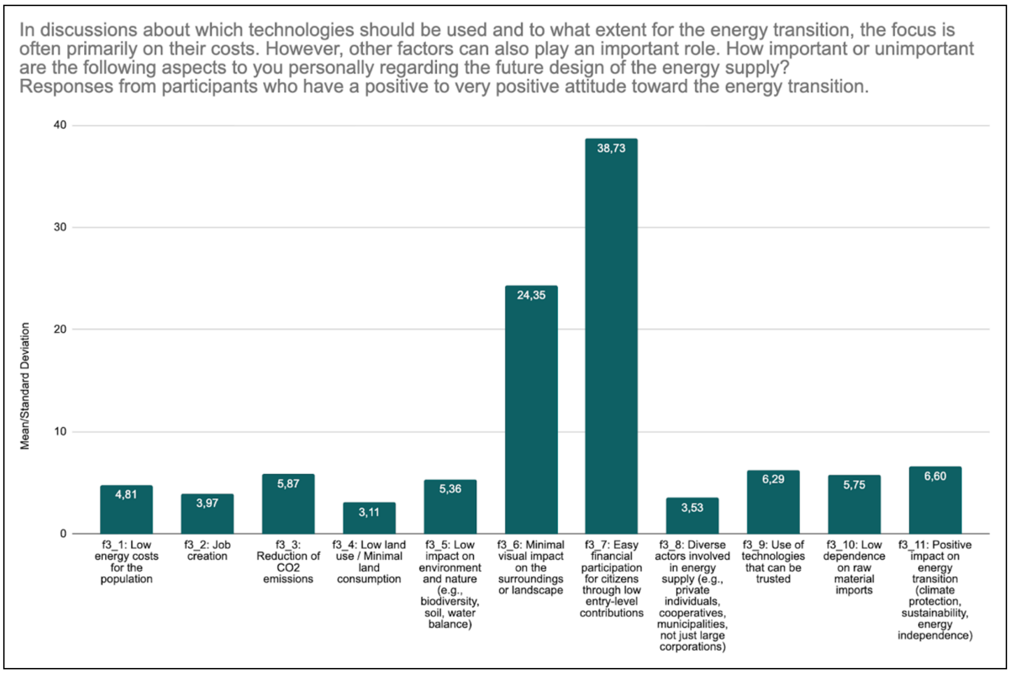

Figure 3 Results for indicator weights based on responses on importance (1–5 scale): mean/sd for sub-sample on positive attitude towards energy transition (n = 540).

While conceptually, the idea was to penalise indicator weights with a high variance, for this subsample instead results a boost for indicators with very low variation. Two indicators would largely dominate the well-being framework, only due to very similar valuation – and irrespective of the value itself: one of them is valued low, the other high. This result indicates that the approach is conceptually not sensible and thus should be discarded.

Income classes

Disaggregation by income classes (in €1,000 increments from below €2,000 to above €6,000) (see Figure 4) shows that respondents with lower incomes tend to assign higher importance to most indicators, particularly energy costs, job creation, land consumption, visual impact and the diversity of involved actors.

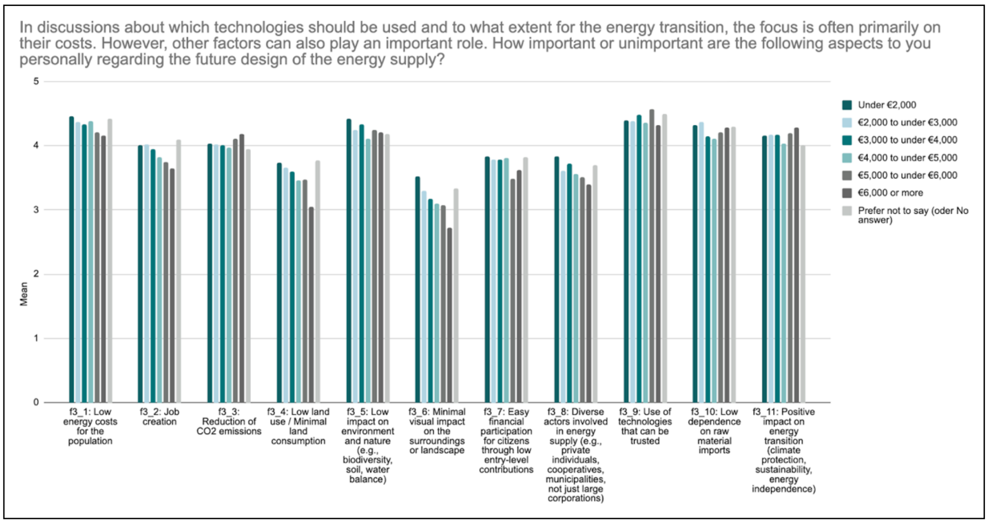

Figure 4 Results for indicator weights based on responses on importance (1–5 scale): mean by income classes (total n = 1019, income classes n = [112,193]).

In contrast, trust in technologies, raw material import-dependency and contribution to the energy transition (consequently also CO_2 emissions) show relatively stable or slightly increasing importance levels with higher income.

Age groups

The disaggregation by age groups (see Figure 5) shows that importance ratings increase with age for most indicators. Respondents aged above 60 consistently report the highest valuations for most indicators. Interestingly, in many cases, the youngest group (18–24 years) assign higher importance to most indicators than the following age cohorts (25–34 years and 35–44 years). This is true for costs, jobs, land use, financial participation, actor diversity and import dependency.

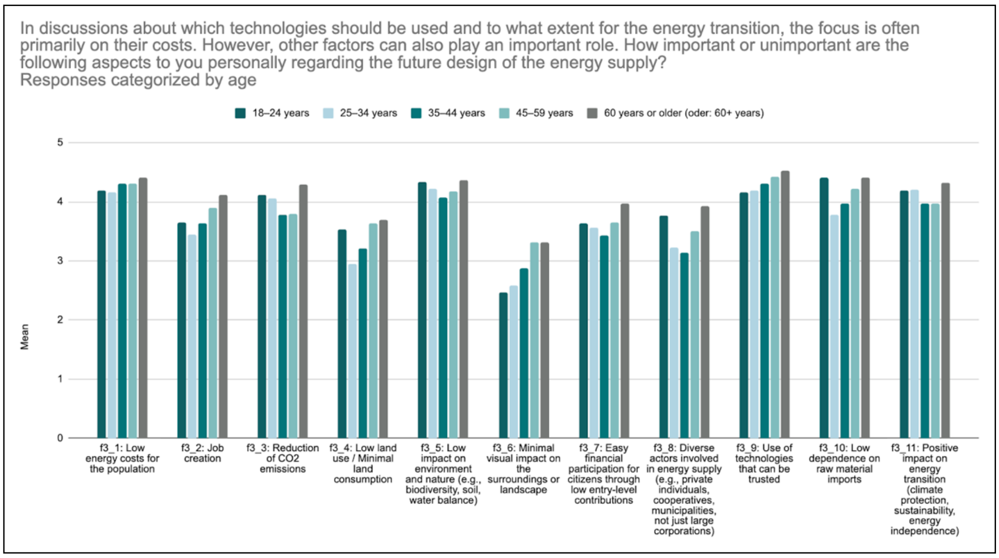

Figure 5 Results for indicator weights based on responses on importance (1–5 scale): mean by age groups (total n = 1019, n_{18-24} = 91, n_{25-34} = 153, n_{35-44} = 163, n_{45-59} = 254, n_{60+} = 367).

Ownership of rooftop or balcony PV systems

Finally, we analyse the sub-sample of the respondents who own a rooftop PV or "balcony PV" system. This group has at least a certain technical understanding of one energy transition technology, and potentially also some understanding of generation and consumption patterns and may thus also have a certain knowledge and interest in energy systems. As PV systems are

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expanding in household coverage, this subgroup might represent valuations by indicators as they might be in the future, when PV systems may be available to a wide majority of households.

For the subgroup of PV system owners, we find only limited deviations from the full-sample averages (see Figure 6). Most indicators receive marginally higher importance ratings, particularly emission reduction/energy transition contribution and the indicators relating to the implementation of technology (financial participation and trustworthiness). Visual impact is rated slightly lower.

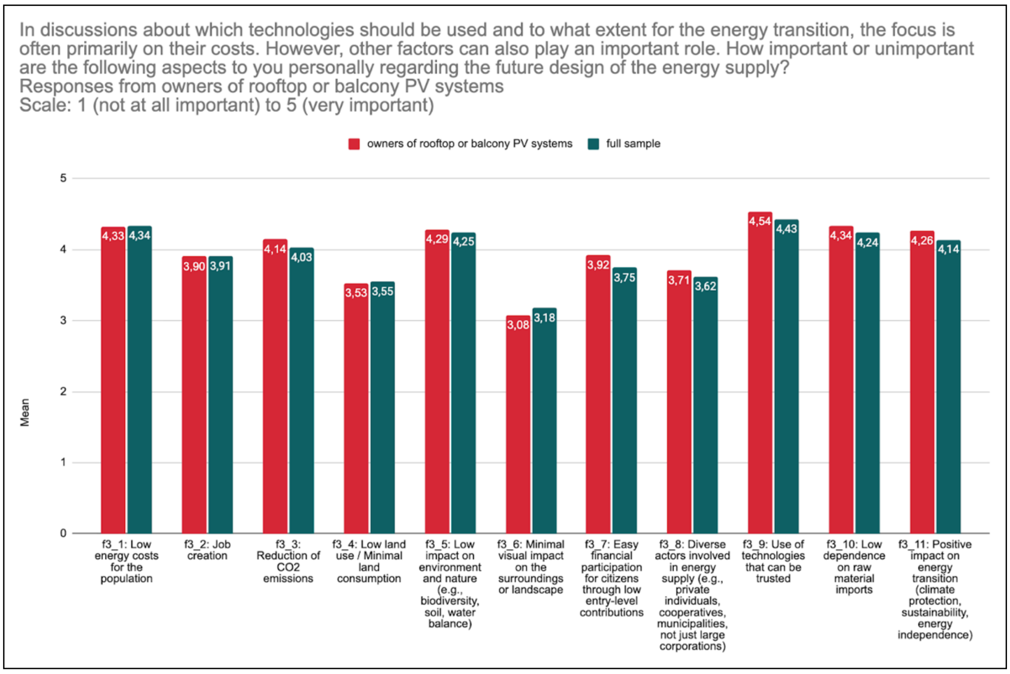

Figure 6 Results for indicator weights based on responses on importance (1–5 scale): mean for full sample and sub-sample of PV system owners (total n = 1019, $n_{PV\text{-}owner}$ = 306).

DISCUSSION AND CONCLUSIONS

Our paper presents the first steps and results of a multi-year project on integrating well-being into energy system models. The two steps described here are first the identification of a suitable set of indicators that captures a significant part of the well-being effects of energy technologies, and second the generation of weights for those indicators based on empirical survey data. We focus on the second step in describing our methodological approach and detailed results.

Regarding step 1 – the general possibility of including well-being in energy system modelling – we show that it is possible to arrive at a plausible set of indicators. While not without limitations, this captures a relevant part of the well-being effects of energy technologies that go beyond a standard analysis of costs. It remains to be analysed how the integration of these indicators will influence the results of energy system models, but preliminary test runs already show promising bases for further discussion. There are many paths forward in further refining or expanding this indicator set, based on known limitations or expanding data availability. The more well-being indicators are adopted at different societal levels, the easier it will be to also use them on the energy system.

Regarding step 2 – the derivation of indicator weights from survey data – we present first results, both on the full sample and disaggregated by sub-samples of potential interest. Importance is rated on a 1–5 Likert scale from not important to very important. The main general finding is that respondents do value the different indicators with varying importance: mean values range from 3.18 to 4.43. On average, the visual impact on the landscape and land consumption are rated of least importance, while costs, impact on environment, trustworthiness of technologies and raw material import dependency are rated highest.

We initially considered a weight generation option that penalizes high variation in responses, operationalised as the division of the mean by the standard deviation (mean/sd). While this seemed initially sensible, for respondent subsamples (specifically: the subsample with positive attitude towards the energy transition) we observed a very low variance for some indicators. This consequently leads to a boost in weights calculated on this basis (mean/sd) for only these specific indicators, which demonstrates the concept as not sensible. We thus discard this option.

The analysis of responses by selected subsamples shows an interesting divergence of indicator valuations which may inform how cleavages regarding a well-being orientation of the energy transition may run through society. For respondents with a positive attitude towards the energy transition, indicators on the environment and society score higher. For those with a negative energy transition vision, costs, land consumption, visual impact are more important. Apparently, the stated attitude towards the energy transition correlates with a higher weighting of environmental and social-related indicators, while sceptics highlight costs and a perceived negative visual impact on the landscape.

We find that people with lower incomes rate jobs, costs, land consumption and visual impact on the landscape higher, while higher-income segments rate energy transition-related indicators and emissions higher. This may reflect financial difficulties in lower income classes and thus a higher importance of financial implications and job opportunities – and potentially a positive correlation with scepticism towards the transition and respectively higher weights of visual impact. Higher income groups allegedly can afford to weigh environmental concerns higher, have a more positive attitude towards the energy transition and consider visual landscape impact and costs less important.

Most ratings generally rise with age, but the youngest group (age < 25 years) rates indicators higher than the following age group. This surprising result might be explained with generally more environmental consciousness rising with age (also in correlation with income), but also a young generation (aged < 25y) which is especially concerned about the environment.

Respondents with own experience with PV technology (rooftop or balcony) show marginally higher ratings (especially of energy transition-related indicators) than the overall sample, and slightly lower ratings for visual impact on the landscape. This suggests that direct technological experience does not fundamentally alter well-being priorities but may modestly strengthen transition-related valuations.

Overall, differences between subgroups are not very large – except for the groups supportive of or opposing the energy transition. Not surprisingly, differences there are especially large for the indicators connected to the energy transition contribution and GHG emission reduction (higher for supportive group), but also regarding visual impact (higher for opposing group).

We conclude that the well-being orientation measured by the weighted indicators does vary to a certain extent by individuals and also by subgroups. If such indicator sets are used for multi-criterial modelling of well-being-optimised energy systems, the weights based on the full population sample seems to be the best option. Alternative weight sets based on sub-samples could yield interesting sensitivity results. From our findings with sub-samples, the option of including the variance to the weights (mean/sd) seems not recommendable. The mean by indicator is likely the best option to be used as indicator weight.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **PowerPoint Slides.** PowerPoint Slides relating to this article. URI: https://eceeeproceedings.org/articles/73/files/6a58b203bc488.pdf

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHORS CONTRIBUTIONS

Johannes Thema is lead author for the final draft, coordinating the writing process and the design, implementation and analysis of indicator survey data collection. To the manuscript, he contributed text drafts on survey methodology and results, review of the entire manuscript, finalisation and publication handling.

Sina Diersch contributed a majority of the text on indicator selection and multiple elements of the text on indicator weights, as well as many of the elements in the discussion.

Hans Haake coordinated the abstract and contributed text to the introduction and the section of the paper on indicator selection, especially tying back into the broader well-being literature.

Julia Swagemakers supported the survey design and led on data management and analysis, creating most of the graphs displayed in the paper.

Shima Sasanpour reviewed the draft paper with a modelling perspective and added qualifications, after being a key part in all discussions on the feasibility of quantifying different dimensions of well-being.

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AUTHOR AFFILIATIONS

Johannes Thema orcid.org/0000-0002-7039-483X
Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany

Sina Diersch
Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany

Hans Haake
Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany

Julia Swagemakers
Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany

Shima Sasanpour orcid.org/0000-0002-7502-6841
German Aerospace Center (DLR), Curiestraße 4, 70563 Stuttgart, Germany

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