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Original research article

Rarely pure and never simple: Exploring perceptions of truth and objectivity in energy modelling and scenarios

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ABSTRACT

Model-based scenarios are widely used to guide energy planning and climate policy decisions. While the mathematical and physical foundations of many techno-economic models assume universal truth and objectivity, their application to explore a yet unwritten future demands a more nuanced understanding of these concepts. Although modellers' beliefs about the certainty and universality of knowledge may influence how they present their findings to decision-makers, the matter has received little empirical attention to date. Here, we address this gap and investigate modellers' epistemic beliefs concerning energy modelling and scenarios, as well as their perspectives on the communication of model outputs and expert authority. To that end, we conducted a survey with over 160 experts from a broad range of geographical regions and disciplines. Our results show significant polarisation in the participants' beliefs, revealing the two stylised profiles of a *Positivist* and a *Postpositivist Modeller*. While there are few differences in the respondents' attitudes based on educational level and background or model usage, we find significant variation particularly based on geographic location. In an effort to overcome this polarisation, we consider our study a call for diversity in modelling teams and argue for fostering the discussion of epistemic beliefs within the broader modelling community. Finally, we recommend incorporating key topics beyond technical aspects into the training and education of future modellers.

1. Introduction

With the adoption of two landmark frameworks, the year 2015 marks a milestone for global sustainability efforts: the United Nations' 2030 Agenda and its 17 Sustainable Development Goals (SDGs), defining an international vision for sustainable development [1], and the Paris Agreement on climate change, committing to keep global warming below 2 °C while making efforts to limit the temperature increase to 1.5 °C [2]. The societal challenges underlying both frameworks constitute *wicked problems* of worldwide proportions – unique challenges without one definitive solution and characterised by uncertainty and conflicting values [3–5]. Not only does addressing these touch on a multitude of sectors, actors, and institutions, but it also requires radical change towards novel socio-technological systems, a fundamental metamorphosis referred to as *sustainability transitions* [6,7]. Sustainability transitions are defined by multiple interdependent developments that involve a range of actors with potentially conflicting values and interests; they span in a non-linear fashion over an often decade-long timeframe and therefore bear substantial uncertainties; and they thus require a co-evolution in economic, cultural, and institutional as well as in technological and ecological spheres [6–9].

While the ambitious normative goals are set globally, it is up to decision-makers at the regional, national, and local levels to operationalise the 2030 Agenda and the Paris Agreement and set priorities in implementation strategies [10,11]. Here, the key role of scientists is evolving under both frameworks from one of analysing problems to that of generating solutions [12–14]. This concerns not least academic and other researchers in the energy sector, which is at the core of both frameworks, accounting for three-quarters of total greenhouse gas emissions [15] and maintaining a key role in human development. Long-term energy planning – the drafting of long-term strategies to foster the development, operation, and management of energy systems – offers a forward-looking approach to identifying solutions in the face of complexity [16]. In particular, the use of computer-based models has become an established practice [17].

By definition, any model represents a simplification of reality [18]. Typically, computer models prioritise techno-economic considerations, being blind to hard-to-capture contextual factors, among them cultural

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discourses, institutions, and power structures [19]. In recent years, however, the representation of social aspects has received more attention [20–22]. Accordingly, translating a wicked sustainability and energy transition problem into a mathematical problem that can be analysed using a computer model requires value-based, normative decisions which prioritise certain perspectives and objectives over others [23]. As Sgouridis et al. argue, “all models are subjective, but few acknowledge it” [24] – and, considering that “there are no statistics for the future”, one’s own assessment sometimes is the only way to deal with the uncertainty [25]. Yet, modelling outcomes are frequently presented as neutral scientific findings and tools for making decisions [26,27]. Models may thus offer a false sense of reliability where none exists, establishing a “veneer of scientific legitimacy” to bolster a particular political position [28].

This is a risk not only in work with a local or national focus but, all the more, in complex collaborations at a global scale. Historically, mathematical modelling has been shaped and advanced predominantly in Western, industrialised, and highly educated contexts [29]. Indeed, the vast majority of computer models employed to understand climate implications and map energy transition pathways were developed in Western institutions. Ringkjøb et al. review 75 energy and electricity system models and list the institutions responsible for their development – none of which are in the Global South [30]. And, as Gusheva et al. show, they often have great impact: research based on integrated assessment models (IAMs) features prominently across all IPCC reporting cycles, is given above-average attention in the summaries for policymakers, and originates largely from the work of a group of male scientists representing Western institutions [31].

The scope of domestic energy planning is seldom limited to the national sphere, and the development of the energy sector and infrastructure financing in many Global South countries is supported and shaped by international actors. OECD Development Assistance Committee (DAC) countries and multilateral agencies have supported energy policymaking and planning interventions as well as capacity development programmes (CRS code 23110[1]) with an average of USD 1.41 billion annually between 2002 and 2022, and with around USD 2.89 billion in 2021 alone [33]. Increasingly, capacity development in the field of long-term energy planning employs mathematical models [34–37]. Optimisation techniques, e.g., today are a dominant approach to energy system modelling [17,30,38]. At the same time, the concept of optimisation is not value-free but rather situated in legacies of colonialism, capitalism, and power, with the crucial question of “for whom and under what conditions” something is deemed optimal often overlooked [39,40]. While this realisation leads to concerns regarding the applicability of such modelling approaches in the Global South, the discussion and development of alternative approaches to creating future visions has yet to gain momentum [41,42].

Someone must make the subjective and value-laden choices that inevitably make up models and scenarios. This task lies primarily with the modellers – those technical experts in research institutes, public agencies, or the private sector who develop and run models. They set assumptions, typically already involving narrative characteristics, and generate scenarios that tell stories about the hypothetical model world – which, in turn, allow us to draw conclusions on parts of the real world [43–45]. Modellers often operate within the institutional and technical constraints of their organisations, which can at times expose them to pressure from policymakers to use specific data sources and assumptions or to focus on particular outcome spaces [46,47]. Yet, they have considerable freedom in shaping model assumptions and translating stakeholder inputs into model parameters [46]. Notwithstanding these influences, modellers – as well as users of scenarios – are sometimes perceived as following a positivist stance that emphasises objectivity and neutrality [27,48,49]. Despite its importance, this charged hypothesis has received little empirical attention.

Convictions about objectivity and truth are captured by *epistemic beliefs* – one’s beliefs about the nature of knowledge and of knowing [50,51]. A central element of the concept are perceptions regarding the certainty of knowledge. While current debates even question the certainty of mathematical knowledge itself [52], the quantitative nature of model-based scenarios continues to convey the appearance of scientific accuracy. When investigating how studies applying models of socio-environmental systems deal with the (un)certainty of their results, Puy et al. discovered that knowledge claims based on work linking social dynamics and natural sciences – particularly water modelling and integrated assessment modelling – are presented with a level of confidence comparable to the physical fields, and they conclude that this overuse of numbers and unwarranted assertiveness may be a cause of concern when informing high-stakes policy decisions [53]. Assuming that the authors behind such studies are as convinced of their outcomes as their framing suggests, it is evident how influential modellers’ epistemic beliefs are in science communication and advising decision-makers.

In this study, we approach the matter by considering the following question: *what are modellers’ epistemic beliefs concerning energy modelling and scenarios, and what are the implications for model-informed decision-making?* In an attempt to finding an answer, we conducted a survey with modellers who work on energy planning and climate policymaking, focusing on their epistemic beliefs regarding the certainty, source, and justification of knowledge. When exploring these, we must acknowledge that modelling in the energy and climate domain sits at the intersection of evidence-based science and Futures Studies – two fields that differ in their assumptions about what constitutes valid, reliable, and objective knowledge. Accordingly, Section 2 reviews the epistemic foundations of scientific work in general and modelling in particular, before reflecting on the complexity of modelling in practice. We then explain our approach in Section 3. In Section 4, we present and analyse the survey results, and in Section 5, we discuss these and their implications before drawing final conclusions.

2. Background

Modelling to support long-term decisions in energy planning and climate policy lies at the intersection of several disciplines and thus partially contradictory scientific traditions and schools of thought. Below, we discuss the differences between these fields, and what this implies for the use of models and scenarios in practice. While the mathematical and physical foundations of models assume universal truth and objectivity, Section 2.1 illustrates that their application to explore a yet unwritten future follows different rules. In consequence, modelling linking complex natural, technical, and socio-economic systems is an inherently transdisciplinary endeavour – regardless of the academic background of the researchers involved, highlighting the weight of their personal epistemic beliefs. In Section 2.2, we further discuss the complex institutional and organisational conditions under which modellers operate, and we point out that aside from the modeller’s own epistemic beliefs, those of involved partners and commissioners may also play a role.

2.1. Modelling and scenarios across disciplines and epistemologies

In long-term energy planning and sustainability transitions, many types of models take a technology-focused bottom-up stance, e.g., energy system or capacity expansion models that cost-optimise technology deployment over time [54], energy demand models that simulate future consumption patterns [55], and geospatial electrification models that support the planning of electricity access, especially in the Global South

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[1] Activities under CRS code 23110 are defined as “Energy sector policy, planning; aid to energy ministries and other governmental or nongovernmental institutions for activities related to the SDG7; institution capacity building and advice; tariffs, market building, unspecified energy activities; energy activities for which a more specific code cannot be assigned.” [32].

[56]. Often, these perspectives are complemented by an economic top-down approach based on econometric or computable general equilibrium (CGE) models [57–59]. Finally, IAMs link the socioeconomic and natural systems and are used to inform climate policymaking [11].

Typically, energy system models [60,61], IAMs [45,62], and other economic models [63], for instance, are underpinned by a positivist philosophical stance. Positivism, often associated with quantitative scientific methods, assumes that reality is independent, objective, and empirically measurable [64]. Under this notion, scientific research aims to discover universal conclusions that are not only falsifiable in the Popperian sense but also have predictive power [65,66]. Knowledge is neutral, free of personal opinions, beliefs, or emotions, and thus truth: it is certain, accurate, and reflective of reality [67,68]. In a positivist understanding, models are thus used to develop scenarios that explain observed or predict yet unknown data, or to understand a theory better [49]. In doing so, uncertainty is minimised to better assess the probability of future developments [69]. As a result, modellers, focusing on technical aspects, are seen as objective and “honest brokers” of science [49].

However, the creation of forward-looking scenarios to support decision-making goes beyond the boundaries of the technical and quantitative disciplines, and questions of objectivity and truth are approached differently in the field of Futures Studies. The use of the term “scenario” for the systematic exploration of uncertain future developments emerged in the middle of the 20th century, first to inform military strategies and later corporate decision-making [70,71]. A scenario, a possible and internally plausible narrative or story, refers to the future and how different factors might shape it, often in a set with alternative distinct scenarios [72]. The analysis of quantitative, model-based scenarios is complemented by a tradition of qualitative scenario analysis that offers advantages in addressing hard-to-quantify factors such as values, culture, and institutions [71]. This entails that the development of scenarios naturally builds on interpretative judgement and is not an exact science.

To organise this spectrum of possibilities, various attempts were made to create a typology, for example, proposing a breakdown into predictive, explorative, and normative scenarios [73]. This typology alone suggests that the ontological and epistemological foundations of Futures Studies stretch beyond those assumed in positivism. Futures scholars are sometimes categorised into two schools of thought – positivists who attempt to predict the future, and practitioners who embrace inherent uncertainty and appreciate engaging in the multiple perspectives of different plausible futures [69,74,75]. This begs the question of how concepts of truth and objectivity can be conceptualised under the latter notion. As not only energy scenarios but also a significant part of the input data they build on are statements about the future, they fall outside the criteria of scientific validation and, by nature, cannot have a truth value [76,77]. Of course, this does not imply that the creators of future statements cannot make more or less definitive truth claims, irrespective of whether they explain their dependence on one or several causal mechanisms, as Bergman et al. explore [78]. Yet, we cannot know whether any specific scenario will come to be, as Baard argues, which bears the challenge of defining a different way of assessing the quality of scenarios [77]. When it comes to truth in models themselves, Mäki suggests a pragmatic understanding that interprets the concept as usefulness for a given purpose and persuasiveness relating to a specific audience [79]. As models do not represent the full complexity of the real world but instead focus on selected causal elements, Silvast et al. conclude from Grüne-Yanoff and Weirich that their truth value depends on how well these isolated factors are represented [80,81]. Gramelsberger et al., finally, describe that a model can only ever increase detail and approach reality, but it cannot achieve completion [82]. Modelling is thus “knowledge in the making”, and learning from differences between models and results may prove more beneficial than the pursuit of “truth” [82].

Positivism assumes that scientific knowledge is objective and unbiased by human influence: meaning is inherent to an object of study and can thus only be discovered, not ascribed [67]. Although philosophers of science debate the precise meaning of objectivity, most agree it can refer either to the nature of knowledge claims themselves or to the methods and practices used to generate them [83]. As we do not know today how the future will unfold, the objectivity of energy scenarios cannot be judged on whether they actually materialise, but by the reasoning behind them today [84]. Reference scenarios – used as counterfactuals for analytical purposes – can be considered objective in the sense that they are treated as existing independently of human influence [85]. Alternative futures, by contrast, are shaped by human decisions and therefore do not exist independently, but they are still considered objective insofar as they serve as real objects of study [85]. According to Lloyd and Schweizer, the scenario development process can, depending on the chosen approach, be characterised as objective in three ways: (1) publicly accessible, (2) impartial and free from vested interests, and (3) free from systematic bias [85]. In addition, they identify two social dimensions of objectivity: procedural objectivity, which refers to processes designed to lead to the same results regardless of who conducts them, thus reinforcing method-based notions of detached and unbiased objectivity (2 and 3); and interactive or structural objectivity, which reflects the kind of agreement achieved through debate within the scientific community [85]. The concept of interactive or structural objectivity is closely related to what Sandra Harding terms “strong objectivity” – a more socially grounded form of objectivity that arises when questions are approached through collaboration among diverse participant groups that together contribute a wide range of perspectives [29,77,83,86]. With that in mind, some epistemologists argue that diversity and objectivity reinforce each other [77]. At the same time, assembling a diverse group does not in itself ensure an objective scenario development process, as group dynamics and collective biases can still influence outcomes [85].

Formalising and linking an increasing number of technical, economic, and even socio-political and environmental assumptions in mathematical terms, state-of-the-art models applied for energy system analysis are becoming increasingly complex and challenging to handle [87–90]. It is thus unsurprising that highly educated experts with a background in technical and quantitative disciplines dominate the field [31,91,92]. While their academic training may be rooted in the idea of absolute truth and objectivity, applying quantitative tools to analyse the future clearly asks for a more nuanced understanding of these concepts – prompting the question of which definitions modellers adopt for their work.

2.2. *The complexity of modelling in the real world*

Energy systems are complex socio-technical systems connecting actors with technologies and other material artefacts, knowledge, and institutions, including social values, behaviours, and relationships [7]. Energy systems are thus embedded in today’s socio-political and economic structures in both visible and more subtle ways, and vice versa [93]. The field of Science and Technology Studies (STS) explores how not only technological systems but also scientific knowledge are inherently integrated in and co-produced with social structures and practices; and, as Jasanoff states, how “[s]cience and technology operate, in short, as political agents” [94,95]. While public discourses often present technological solutions as value-free and neutral science, STS emphasises that these in fact reflect partial or political interpretations of knowledge, shaped by dominant interests [96].

In this sense, models are not simply representations of real systems; they embody socially constructed ideas and shared worldviews that are internalised by the modeller and reflected in their choices about which parameters and structures to prioritise and implement [62]. This, in turn, implies that model-based energy futures are also socially constructed – shaped by human decisions and assembled from diverse forms of knowledge, assumptions, and values [84]. Many climate and energy models rely on value-laden assumptions with normative, ethical implications, without making them explicit [23]. While some consider these to be arbitrary choices [28], Ellenbeck and Lilliestam argue that they are the socially constructed product of ongoing discourses [27]. This implies that it is not only the modeller's own epistemic beliefs and worldview that matter, but that those of other actors may also have an influence. Indeed, beyond being guided by their own worldviews, modellers thus also make assumptions informed by their interactions with policymakers and other stakeholders [47,97,98]. Studies have shown that subjective decisions in the modelling process can be shaped by input from external actors, but are particularly influenced by the modeller's academic network and may even become habitual over time [99,100]. Better understanding such decisions and making them explicit in model documentation and reporting of outcomes is crucial given the potentially far-reaching consequences, e.g., the justice implications in a given decarbonisation pathway [101–103].

In practice, modelling efforts often occur within a research institute and a project context [84], and the development of many scenarios is commissioned by an organisation with specific objectives and interests [104]. This implies that decision-making along the modelling process – stretching from the research design and definition of assumptions and data, over the model run and discussion of results, their communication and evaluation [46,105] – takes place within specific social constellations and may be *intentionally* influenced by different actors at different stages. The use of scenarios to guide political decision-making constitutes a specific instance of the science-policy interface – a dynamic space where scientists and policymakers collaborate to exchange ideas and create shared knowledge for decision-making [106–108]. Computer models can thus be viewed as *boundary objects*, political and scientific at the same time, brokering between science, policy, and the public sphere by connecting and meeting the needs of several communities simultaneously [60,109,110]. In consequence, the meaning and purpose attributed to a model thus also depend on who is engaging with it, challenging the notion of universal truth and objectivity.

Science often reinforces dominant perspectives through mechanisms like peer review, journal self-selection, and appointment systems that favour conformity with prevailing paradigms, while established lobby groups help maintain the energy system's status quo by influencing modelling through selective funding, editorial control, and researcher self-censorship [24]. The influence of important organisations and their complex models can extend so far that professional networks between universities, industry, and government form a “cognitive monopoly”, holding a shared view of the energy system and shaping the course of debates [111,112]. While modellers have considerable flexibility in the design of model structure and assumptions at first glance, in practice, they are therefore often caught between the requirements and worldviews of the involved project partners and decision-makers and the path dependencies resulting from modelling decisions in earlier projects.

3. Methods

Below, we outline our approach to explore how modellers think about the presented concepts. To collect a large number of perspectives that represent different parts of the institutionally diverse modelling community worldwide, we conducted a survey based on a structured questionnaire. The section begins by stating our own positionality as researchers (Section 3.1). We then clarify how we operationalised epistemic beliefs in this study (Section 3.2), before presenting our questionnaire design (Section 3.3) and the data collection process (Section 3.4). Finally, we explain the statistical analysis methods we used in Section 3.5.

3.1. *Researcher positionality*

In this paper, we study how modellers perceive the truth in and objectivity of their models and outputs, linking the results to their background. In particular, as our findings indicate variation between different world regions in our sample, we believe that it is important to be open about our own background and perspectives.

This work was conducted by two white researchers from Western Europe. Researcher 1 has a background in economics and several years of experience in international cooperation, advising policymakers in the Global South on the use of models for decision-making. While she is not a modeller, her role involved facilitating dialogue between modellers and policymakers. In her view, knowledge is understood both through personal experiences and analysing evidence. Researcher 2 is an experienced energy system modeller with a background in environmental science. He is one of the developers of an energy system modelling framework and permanently employed at a research university. Both researchers recognise that objectivity has limits and that truth is complex, shaped by power dynamics and other contextual factors.

3.2. *Epistemic beliefs*

To understand how modellers think about objectivity and truth, we draw on the concept of *epistemic beliefs*. Educational psychologists understand epistemic (or epistemological) beliefs as beliefs about the nature of knowledge [113]. These may include, e.g., convictions about the certainty, source, justification, acquisition, and structure of knowledge [113]. In the context of climate and energy modelling, we consider the following concepts to be of particular importance [114–116]:

- *Certainty and construction of knowledge*: Does absolute knowledge exist and will ultimately be known? Is objective truth attainable? Is knowledge certain, and is it time-consistent?
- *Simplicity of knowledge*: Is knowledge a collection of straightforward, isolated facts? Do individuals tend to look for single, clear-cut answers, or do they aim to integrate multiple viewpoints or sources of information?
- *Omniscient authority*: Is knowledge seen as something that resides with experts or institutions believed to have privileged access to truth?

The empirical study of epistemic beliefs poses a challenge as these are often implicit and elusive, in part because questions about knowledge are rarely discussed in everyday life or in formal education [117]. Most studies on personal epistemology treat beliefs about knowledge as general in nature, and although research into domain-specific differences increases, it is challenging due to the diverse knowledge structures and epistemological assumptions across academic fields [118]. A variety of different instruments for measuring epistemic beliefs have been developed and applied, criticised and further refined [119–121].

We used these psychological studies to inform and guide our approach. However, we do not precisely measure epistemic beliefs in our study but rather approximate them by mapping the range of viewpoints within the modelling community.

3.3. *Survey questionnaire*

We created a questionnaire specifically for this study. It comprises structured questions to enable statistical analysis of the responses, and open-ended questions that allowed participants to contribute with their own feedback and thoughts. Respondents were asked to take the field of mathematical modelling and scenario development to guide long-term energy planning and climate policy decisions as the relevant context when completing the survey. Beyond the content-related sections, we gathered details on the demographic background of the participants.

Participants were invited to evaluate their attitudes and epistemic beliefs regarding models and scenarios in 18 individual statements across 9 themes on a five-level Likert scale (see Table 1). Each theme was represented by two statements with opposing framings, such that a consistent opinion would lead participants to agree with one and

Table 1
Overview of the Likert statements.

	Theme	Code	Statement
A	Truth in mathematical modelling	L.1	There is no way to determine whether someone has the right answer in this field.
		L.2	In this field, modellers can come to the correct answer.
B	Influence of a modeller's personal background	L.3	In this field, it is important to question the subjective choices a modeller makes in the light of their origin and worldview.
		L.4	The individual background and belief system of a modeller are not relevant to their model and scenario design.
C	Objectivity in mathematical modelling	L.5	In this field, true answers are more of an opinion than a fact.
		L.6	In their work, modellers can ultimately get to the objective truth.
D	Time consistency of approaches	L.7	Truth in this field keeps changing.
		L.8	Common principles applied in this field are consistent over time.
E	Common understanding of applied approaches	L.9	Modellers typically understand the field and its approaches in the same way.
		L.10	The practice of modelling is more of a subjective art than a hard science.
F	Universal applicability of models across diff. contexts	L.11	Due to their scientific basis, the same modelling tools consistently yield precise results in diverse situations and contexts.
		L.12	Modelling tools contain value-laden assumptions that must be tailored to a specific situation and context.
G	Information needs for scenario judgement	L.13	Model-based analyses should be easy to interpret even without knowing the model, assumptions, or data used.
		L.14	Model-based scenarios cannot be read appropriately without information on the used model, assumptions, and data.
H	Communicating modelling outputs for decision-making	L.15	Modellers should recommend precise actions rather than solely analysing possible choices.
		L.16	Modellers should outline pros and cons of decision options instead of offering direct recommendations.
I	Expert authority of modellers	L.17	One should rely on the assessments and recommendations of renowned modellers without question.
		L.18	Even recognised modellers are biased so that their analyses and recommendations should be scrutinised.

disagree with the other item. These pairs are related, but not designed to reflect a single latent construct, and internal consistency measures such as Cronbach's alpha were therefore not applied. Statements L.1–L.12 focus on the respondents' epistemic beliefs, and statements L.13–L.18 relate to the participants' opinions on scenario presentation and expert authority. The questionnaire is available on Zenodo [122].

Most Likert statements were inspired in particular by the *Epistemological Questionnaire* ('Certain knowledge', themes A, C, D, and E; 'Simple knowledge', theme H; 'Omniscient authority', theme I) [114], the *Epistemic Beliefs Inventory* ('Certain knowledge', themes A, C, D, and E; 'Simple knowledge', theme H; 'Omniscient authority', theme I) [115], and the *Epistemological Beliefs Survey* ('Attainability of objective truth', themes A and C; 'Knowledge construction and modification', themes D, F, and I; 'Structure of knowledge', themes G and H) [116].

Consistent with prior studies on epistemic beliefs, we did not provide definitions for most key terms and concepts to the survey respondents. Building on the positivist foundation of many models discussed above, as well as the often-made claim that modellers and scientific policy-advice more broadly follow value-free, objective ideals [27,97,123–125], we assume an understanding of *objectivity* or *objective* as free of personal bias, values, and perspectives; and *truth* or *true* as universal, accurate, and reflecting reality. Taking the diversity of everyday language expressions into account, we further employ the phrases *right answer* or *correct answer*, which we interpret in line with the positivist notion of "true". The term *subjectivity* or *subjective*, in turn, refers to the influence of personal bias, values, or perspectives on knowledge or judgement. That in mind, we define *value-ladenness* or *value-laden* as something being shaped or influenced by personal, cultural, or political values, e.g., accepting possibly controversial ethical implications [23]. Finally, we consider *worldview* or *belief system* as a set of underlying perspectives, assumptions, and values through which individuals interpret knowledge and their experience, shaped by factors such as cultural background, education, socio-economic status, and generational context.

We used a broad set of demographic variables to capture diversity in the modelling roles, disciplinary backgrounds, and regional contexts of our respondents. This approach reflects the exploratory nature of the study, which aims to identify patterns across a wide range of perspectives rather than test predefined assumptions.

Before being published, the questionnaire was pretested internally with 7 colleagues to improve comprehensibility and user-friendliness. Minor wording and structural revisions were made based on their feedback.

3.4. Data collection

Given the global dimension of climate change and the energy transition, modellers who support decision-making work across research, governmental, and consulting institutions, often in transnational and interdisciplinary teams. This community, both heterogeneous and widely scattered across countries and industries, is thus not easily accessible through a formal sampling frame. In consequence, we made an open call for survey participation in a convenience sampling approach [126], addressing all modellers and model users who work on topics related to energy planning and climate policymaking. Our objective was not to obtain a representative sample, but instead to get a first impression of epistemic beliefs across the broader modelling community.

The survey was published online and widely advertised on platforms such as LinkedIn, thematic mailing lists, and discussion boards, allowing us to reach relevant participants from a wide range of different backgrounds. Hosted on Qualtrics, the survey remained open for four weeks, from 23 November until 20 December 2023. The anonymised survey data and relevant associated materials have been deposited on Zenodo [122].

3.5. Analysis

As this is an exploratory study, our analysis aims to discover patterns in our data rather than test predefined hypotheses. To this end, we proceeded in several steps. First, we summarised the responses to each Likert item. Second, we explored the internal relationships between items using Spearman's rank correlation. Third, building on the found relationships, we looked for distinct profiles among our respondents based on k-means clustering. Finally, to explore significant differences in the rating of individual Likert items among different groups, we used the Kruskal-Wallis test.

First, we grouped the participants' responses to each Likert item into categories of *agreement*, *disagreement*, and *neutrality* based on their original selections. Responses of "Strongly agree" and "Somewhat agree" were counted as agreement, while "Strongly disagree" and "Somewhat disagree" were counted as disagreement. "Neither agree nor disagree" was treated as neutral. We define *consensus* as a shared agreement or disagreement of 70 % or more. Accordingly, we refer to a shared agreement or disagreement of $<$70 % as *dissensus*. If the absolute difference between agreement and disagreement is within ±10 %, we consider this to be *polarisation*. To statement L.11, for instance, 67 respondents agreed and 75 disagreed. As the difference ratio $\frac{[agreement-disagreement]}{[agreement+disagreement]} = \frac{67-75}{67+75} = -5.63\%$ falls within the ±10 % range, we label the respondents' assessment of L.11 as polarised.

We then explored the correlation between the respondents' attitudes to different Likert statements. The Shapiro-Wilk test revealed that the data do not follow a normal distribution. Accordingly, we used Spearman's rank correlation coefficient, a non-parametric method well fit for analysing ordinal data. Fig. 3 visualises the statistically significant correlations ($p \leq 0.05$) in hierarchical clustering order, showing those statements which were rated similarly by the participants close to each other. It reveals one main cluster and two smaller ones. The main cluster, Cluster A, shows weak to moderate positive correlations among items spanning eight of the nine examined themes (L.2, L.4, L.6, L.8, L.9, L.11, L.15, L.17).

A k-means clustering analysis then allowed us to investigate patterns in the respondents' epistemic beliefs. We selected the eight correlated Likert items included in Cluster A as the base for this step, and the Likert responses were coded from 1 = "Strongly disagree" to 5 = "Strongly agree". We opted for a two-cluster solution in order to identify broader structures without risking the interpretability of the results. Table 2 provides an overview of the outcome. To better understand the characteristics of each cluster, we then explored differences across our demographic and professional variables based on descriptive statistics and Chi-squared tests.

Further, we investigated whether different demographic groups also have different attitudes towards the individual Likert statements. To that end, we applied the Kruskal-Wallis rank sum test, a non-parametric technique suitable for comparing more than two independent groups when the data are not normally distributed. Where the Kruskal-Wallis indicated significant differences, we additionally used Dunn's multiple comparison test to identify the specific groups in question. Here, to control for false positives in the process, we followed the Benjamini-Hochberg p-value adjustment procedure. The full results are summarised in Appendix Tables 1 and 2 in the supplementary material.

To better understand the link between modelling experience and continent of origin as well as continent of residence and workplace, we finally conducted a Chi-squared test of independence.

4. Results

4.1. Respondent demographics

A total of 166 survey responses are included in the analysis. Incomplete responses were counted if participants answered at least six individual sub-questions (equivalent to, e.g., rating six Likert statements). The survey was at least 93 % completed by 149 respondents (89.8 % of counted responses). The below percentages refer to the total number of provided responses to a given question, with the corresponding n in brackets.

Coming from 58 countries and speaking 43 native languages, survey participants represent diverse backgrounds. With 78.4 %, the majority are male ($n = 139$). Most respondents (82.2 %) are between 25 and 44 years old ($n = 146$). About 41.4 % are originally from Europe, 32.9 % from Africa, and less than 10 %, respectively, from one of the remaining world regions ($n = 140$). At the time of answering the survey, 67.9 % were living in their home country ($n = 131$), and 80.7 % on the same continent on which they grew up (n = 140). The high technical requirements and academic focus of modelling work are reflected in the participants' education: while over half (57.8 %) have a background in engineering, followed by 10.9 % of respondents who studied economics ($n = 147$), a total of 61.7 % are either currently enrolled in a doctoral programme or have already obtained a PhD degree or equivalent ($n = 149$).

Overall, more than half of the participants (62.2 %) work in academia ($n = 143$).

Fig. 1 illustrates that the participants' most widely applied type of tool is energy or electricity system models, used by 77.6 % of respondents across all different work environments ($n = 147$). Although the exact distribution between different model types varies, no clear trends stand out with regard to the use of specific model types in a particular kind of workplace (see Fig. 1).

Further background information on the respondents' model utilisation patterns and modelling frameworks can be found in the supplementary material.

4.2. Attitudes towards models and scenarios

4.2.1. Some consensus, but much polarisation

Fig. 2 illustrates how the survey respondents rated the 18 statements presented to them on a Likert scale. While the results indicate consensus among the participants on seven statements, their viewpoints differ widely concerning the remaining two-thirds. Regarding four of the statements, we observe distinct polarisation among the respondents.

Overall, there is considerably greater consensus with regard to the presentation of scenarios and expert authority (L.13–L.18) than in relation to the participants' epistemic beliefs (L.1–L.12). The respondents displayed strong consensus on two themes, expressing their general understanding that the individual background of a modeller is not without consequences (L.3, L.4) and that even insights offered by esteemed experts warrant careful examination and reflection (L.17, L.18). In stark contrast, the results reveal dissensus across four themes, and the participants are divided on whether there is any truth (L.1, L.2) or objectivity (L.5, L.6) in mathematical modelling, as well as on the time consistency (L.7, L.8) and a common understanding (L.9, L.10) of the applied approaches in the field.

On the remaining three themes, the picture is more mixed, with

Table 2

Summary statistics for identified respondent clusters.

Likert statement		Respondent Cluster 1 (n = 107, 64.5 % of sample): Postpositivist tendencies			Respondent Cluster 2 (n = 59, 35.5 % of sample): Positivist tendencies		
		Mean[a]	SD[a]	Median[a]	Mean[a]	SD[a]	Median[a]
L.2	In this field, modellers can come to the correct answer.	3.12	1.07	3	4.1	0.74	4
L.4	The individual background and belief system of a modeller are not relevant to their model and scenario design.	1.97	1.02	2	2.85	1.27	3
L.6	In their work, modellers can ultimately get to the objective truth.	2.37	1.18	2	4.12	0.91	4
L.8	Common principles applied in this field are consistent over time.	2.94	1.12	3	3.98	0.75	4
L.9	Modellers typically understand the field and its approaches in the same way.	2.35	0.94	2	3.83	0.79	4
L.11	Due to their scientific basis, the same modelling tools consistently yield precise results in diverse situations and contexts.	2.42	1.08	2	3.9	1.09	4
L.15	Modellers should recommend precise actions rather than solely analysing possible choices.	2.61	1.29	2	3.52	1.28	4
L.17	One should rely on the assessments and recommendations of renowned modellers without question.	1.25	0.52	1	2.29	1.25	2

[a] Likert responses were coded from 1 = "Strongly disagree" to 5 = "Strongly agree".

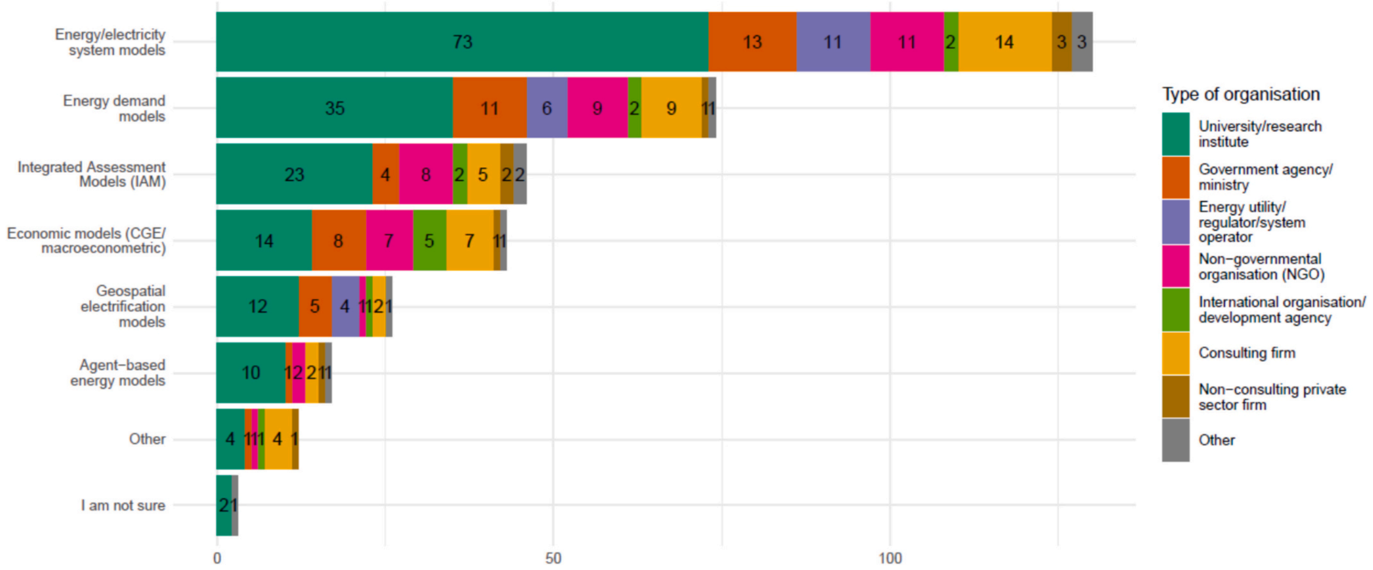

Fig. 1. Overview of model types, sorted by number of mentions, grouped by type of organisation they are applied in. Participants (n = 147) were allowed to select several multiple-choice options both for model type and for type of organisation.

consensus on one statement and dissensus on the other. Participants are divided regarding the consistency of modelling outcomes when a modelling tool is applied across diverse contexts (L.11) but agree that all tools need contextual customisation (L.12). Further, we found contradictory views on what information is essential for judging scenarios and how best to communicate modelling results for decision-makers: although respondents agree that clarity on model and data details is essential for scenario interpretation (L.14), 55 % are convinced that model-based analyses should be understandable without such background information (L.13). 50.3 % of participants agree or disagree with both statements respectively, revealing significant inconsistency in their viewpoints. Similarly, there is broad agreement with the notion that modellers should highlight decision pros and cons instead of advising directly (L.16), while, at the same time, 42 % would argue that modellers should give precise recommendations instead of merely analysing choices (L.15). Again, 39.0 % of participants agree or disagree with both statements respectively.

4.2.2. *Two stylised modeller profiles emerge*

Fig. 3 illustrates the associations between individual Likert statements based on the survey responses.

One large and two smaller clusters emerge, indicating that the participants' agreement with certain notions tends to move in the same direction. At the heart of this is Cluster A in the top left-hand corner of Fig. 3, highlighting a weak to moderate positive link between statements across eight of the nine evaluated themes. Since each theme includes two statements with opposing epistemic orientations, consistent views would typically produce correlation within only one statement per theme. The fact that Cluster A spans nearly all themes suggests thus a high degree of internal coherence. The result is a juxtaposition of two stylised modeller profiles. The *Positivist Modeller* agrees with the statements in Cluster A (L.2, L.4, L.6, L.8, L.9, L.11, L.15, L.17) and maintains that in mathematical modelling, personal backgrounds are irrelevant. They strive for correct answers and objective truth by applying universally accepted and time-consistent approaches which lead to reliable recommendations and actionable results across different situations and contexts. To contrast this profile, we use the term *postpositivism* or *postpositivist* as a pragmatic label to describe more context-sensitive and reflexive epistemic beliefs, which acknowledge the influence of values, perspectives, and uncertainty in the production and interpretation of knowledge. Accordingly, the *Postpositivist Modeller* disagrees with the listed statements and asserts that personal backgrounds significantly influence models and modelling results which are built on ever-changing and diversely understood principles. Accordingly, they argue against the idea of achieving objective truth and, instead, advocate for a diversity of perspectives in modelling outcomes. The only one of the nine themes for which there is no clear tendency included in Cluster A is the question of what information is required to assess a scenario (L.13, L.14).

To examine to what extent the participants in our survey are reflected in the stylised model profiles, we conducted a k-means clustering analysis. Table 2 provides an overview of the results.

Our analysis builds on the Likert items included in correlation Cluster A above. Here, in Table 2, low values stand for disagreement with the Likert statements and point to postpositivist attitudes, while high values imply agreement with the statements and, accordingly, indicate positivist tendencies. With median values of 2 or 3, Respondent Cluster 1 shows more neutral or disagreeing responses, indicating a more sceptical or postpositivist-leaning profile. On the other hand, the participants in Respondent Cluster 2, which is only about half the size, show consistently higher agreement with the statements and emphasise the importance of objectivity, thus displaying a more positivist orientation. At the same time, internal consistency in Respondent Cluster 2 appears high, in particular regarding the ideal of objective truth in modelling (L.2, SD = 0.74; L.6, SD = 0.91).

4.2.3. *Location and gender matter, education and work environment not so much*

When comparing the characteristics of our two Respondent Clusters, we cannot detect statistically significant differences relating to most of the demographic variables, and we find none at all based on how the respondents use models. However, a Chi-square test showed a highly significant association between the participants' geographic location and cluster membership, indicating that epistemic profiles varied systematically across different regions ($p < 0.001$; both for continent of origin and for continent of current residence and workplace). Members of Respondent Cluster 1 are predominantly based in Europe (55.1 %) and North America (9.3 %), while Respondent Cluster 2 has a higher share of respondents currently based in Africa (45.8 %). A similar pattern appears when looking at the continent of origin. These differences suggest that both the current geographic context and background may play a role in shaping the respondents' epistemic beliefs.

Additionally, we investigated the variations in attitudes to individual

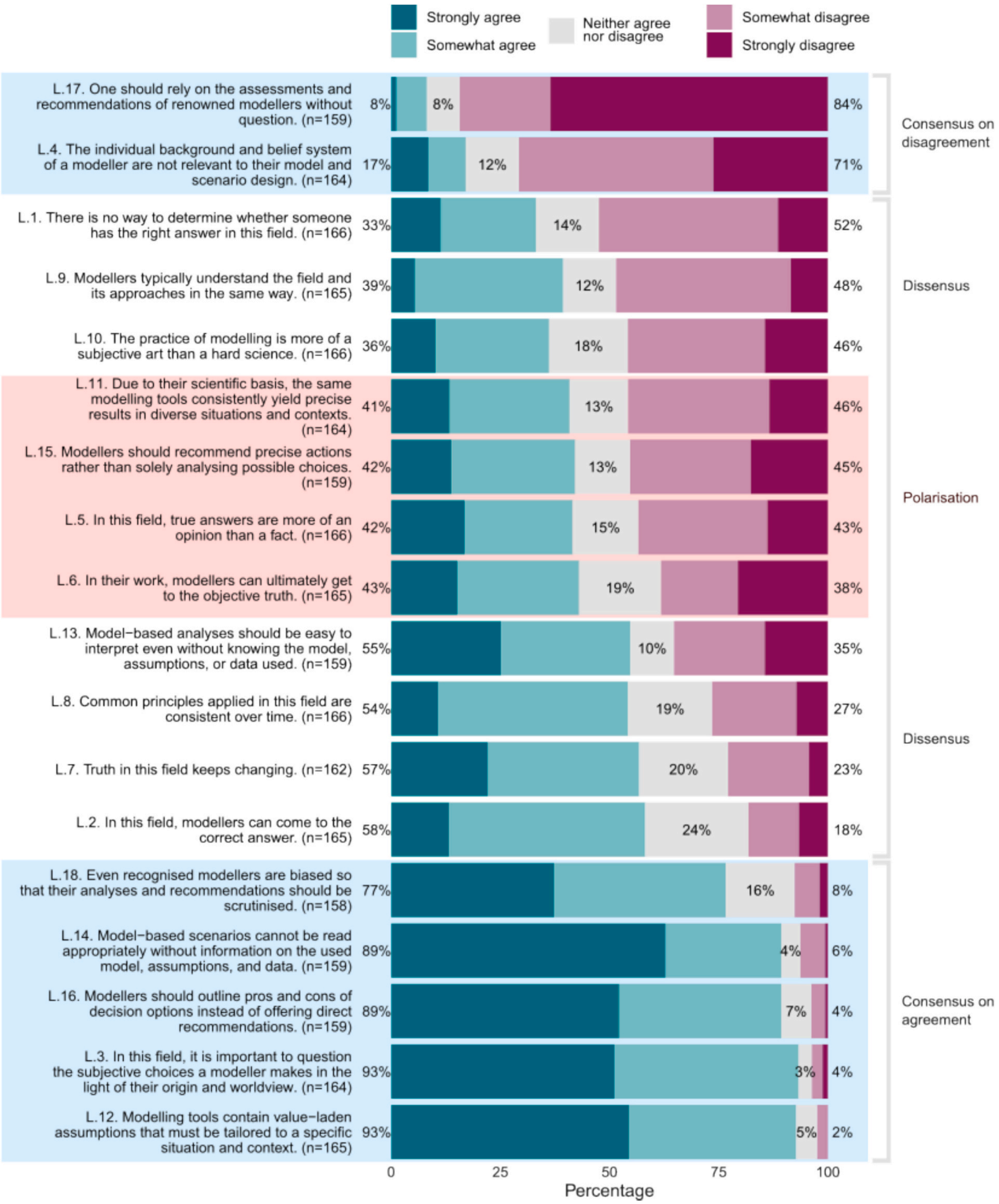

Fig. 2. Survey participants' ratings of the presented Likert items. Items reflect two broadly opposing epistemic orientations; consistent views would typically result in a mix of agreement and disagreement rather than uniformly high or low ratings.

Likert items between demographic groups. In the supplementary material, Appendix Table 1 presents the overview of statistical differences associated with the respondents' demographic information and Appendix Table 2 illustrates the differences relating to their use of models.

Participants of varying ages, educational levels, and backgrounds exhibit systematically divergent perspectives on only a few aspects, if any. In contrast, there is a relationship to the gender of the respondents in four Likert statements with moderate significance ($p \leq 0.05$). These statements (L.1, L.5, L.6, L.10) collectively highlight the tension between subjective viewpoints and the pursuit of objective truth in modelling, reflecting the essence of a field that walks the line between art and science and demands of its practitioners in equal parts creativity and scientific rigour. Overall, our female respondents appear more open to the notion that truth is subjective and context-dependent than their male counterparts. For instance, half of the women (48 %) but less than a third of the men (28 %) agree that there is no way to determine whether

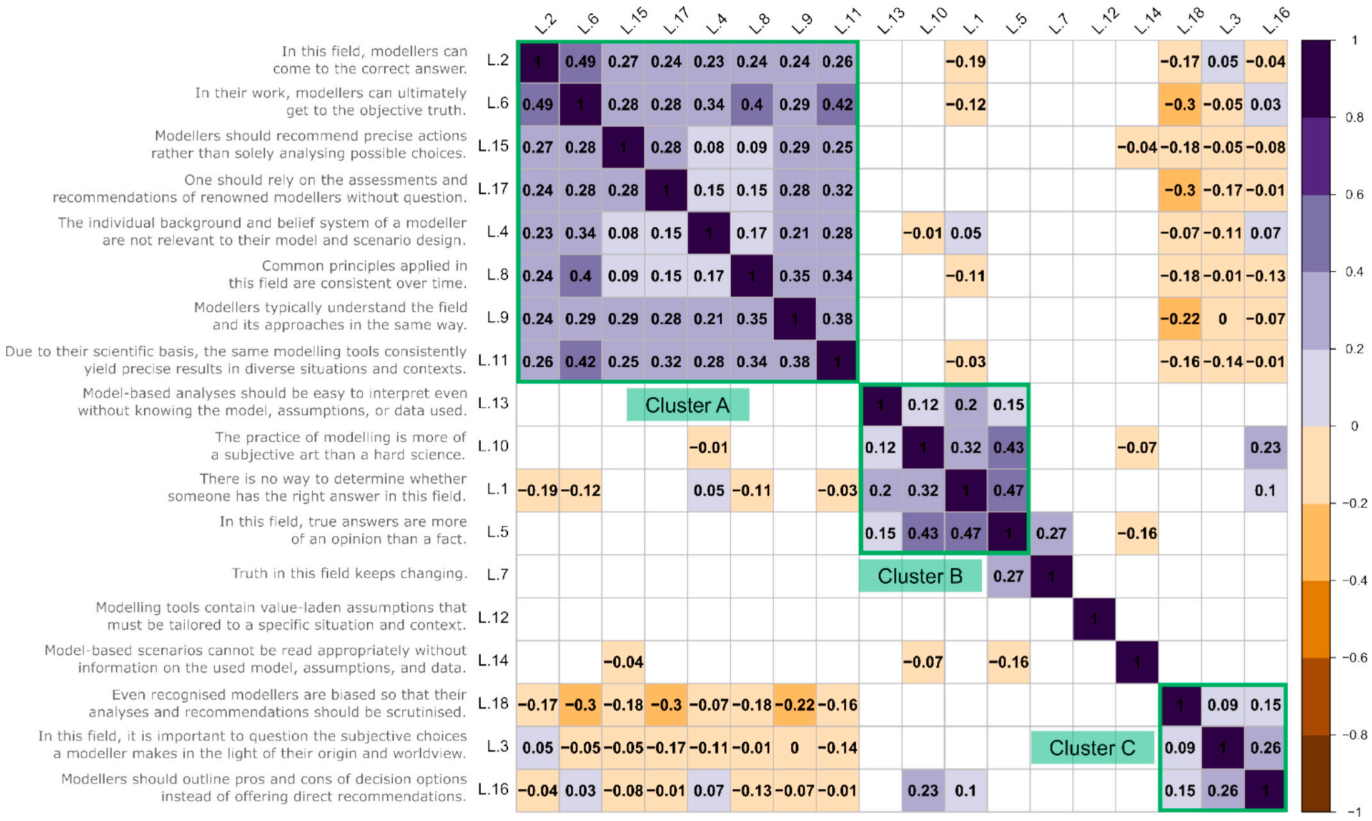

Fig. 3. Exploring Likert statement associations using Spearman's coefficient. Statistically insignificant connections ($p > 0.05$) are not included. The Likert items reflect two broadly opposing orientations. In a fully consistent response pattern, we would thus expect two clusters with minimal correlation between them.

someone has the right answer in modelling to guide energy planning and policymaking (L.1), and, again, half of the women (52 %) but just one-third of the men (32 %) consider the practice of modelling to be more of a subjective art than a hard science (L.10). The upper chart in Fig. 4, capturing the attitudes towards L.5 grouped by gender, provides a similar impression, with significant differences specifically in the perspectives of women and men.

Again, particularly numerous and distinct differences can be observed in our sample between the perceptions of groups in different regions of the world. We found statistically significant heterogeneity in the attitudes towards 8 out of 18 statements between participants who come from different continents, and in views concerning 10 out of 18 statements between participants who currently live on different continents. The findings of the Dunn test show, above all, diverging attitudes

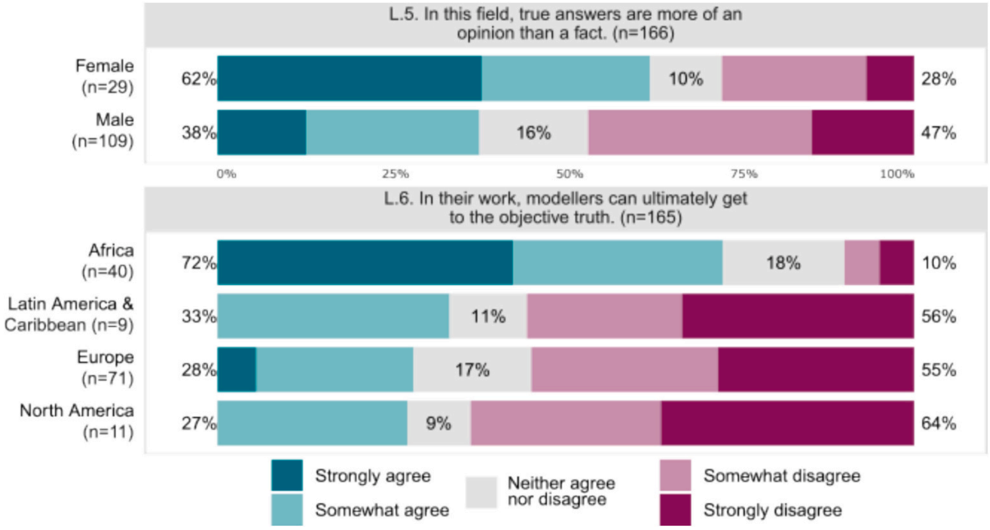

Fig. 4. Attitudes towards L.5, grouped by the respondents' gender, and towards L.6, grouped by the respondents' continent of residence and workplace. L.6 is the statement where the differences show the highest statistical significance for location, L.5 is the second highest for gender (after L.6). Only groups for which the Dunn's test indicated a statistical difference are included (see Appendix Table 1).

between participants associated with African countries and those linked to other regions of the world – primarily in Europe, but also in North America as well as in Latin America & the Caribbean.

As is evident from the lower chart in Fig. 4, participants residing in Africa are, for instance, with high statistical significance more positive about uncovering objective truth through modelling efforts than those based in North America, Europe, or Latin America & the Caribbean. Likewise, they are more confident that the same modelling tools deliver accurate results across diverse settings (62.5 % agree, 30.0 % disagree) than their colleagues in Europe (30.0 % agree, 60.0 % disagree) (L.11). Further, when it comes to providing advice to decision-makers, respondents based on the African continent value a modeller's precise recommendations for action more so (65.0 % agree, 30.0 % disagree) than experts active in Europe do (34.7 % agree, 54.2 % disagree) (L.15). On closer inspection, it becomes clear that the assessment of all statements contained in Cluster A (see Fig. 3) also displays regional variation. This is in line with the results of the k-means clustering analysis, which identified a comparatively higher share of respondents in and from Africa in Respondent Cluster 2 with positivist tendencies.

Compared with demographic characteristics, there are few significant differences between the groups in terms of their use of models (see Appendix Table 2). Experience in working with models emerges as the most important factor, with statistically significant differences recognisable in the opinions on three Likert statements. On closer inspection, however, the data reveal that participants of different experience levels are geographically not evenly distributed. While a Chi-squared test did not result in sound evidence of a relationship between modelling experience and current location in our sample ($p = 0.06$), we did discover a statistically significant link between modelling experience and place of origin ($p = 0.03$). Considering the respondents who provided information on their background ($n = 140$), over half (53.8 %) of those with no or up to two years of experience are from an African country, and more than half (56.4 %) of participants with six years of experience or more come from Europe (see Fig. 5). It is thus not surprising that two of the three Likert statements for which there are differences between the groups with regard to modelling experience (L.4, L.15) also show differences with regard to place of origin.

In contrast, however, there are significant differences only in terms of modelling experience, not related to place of origin or residence, when it comes to the statement that models include value-based assumptions requiring fit-for-context tailoring (L.12). These indicate a striking trend: although overall support for the proposition is very high, agreement in our sample drops with increasing modelling experience. Compared to 80.0 % of respondents with no and 64.3 % of those with up to 2 years of modelling experience who strongly agree, this proportion falls to just one-third for participants with >10 years of experience – while, at the same time, 8.3 % of this group even somewhat disagree with the notion. In other words, the more experienced the respondent is, the less likely they are to think that value-laden assumptions must be tailored to a specific context.

5. Discussion and conclusion

The use of models to support decision-making in sustainability transitions bridges the traditional evidence-based sciences and Futures Studies, two areas with differing expectations around truth and objectivity. With an exploratory approach, our study offers an initial empirical contribution to understanding the epistemic principles and aspirations that guide energy and climate modellers in their work.

Our survey results indicate that there is significant heterogeneity in how modellers working on energy planning and climate policymaking perceive the truth, universality, and explanatory power related to models and scenarios. A weak to moderate correlation in the survey participants' agreement to statements across eight of nine themes emerges, revealing the stylised profiles of a *Positivist Modeller* and a *Postpositivist Modeller*. Further, a clustering analysis identifies one respondent group with more neutral or sceptical viewpoints, suggesting the tendency of a postpositivist orientation, while the opinions of the other, smaller group show signs of a more positivist worldview. Although there are few observable differences in the respondents' attitudes based on educational level and background or manner of using models, the significance of attributes such as gender and geographic affiliation raises questions.

In the following, we discuss the implications of three central themes. First, we address the need to make a distinction between the real world and the mathematical world of the model (Section 5.1). Second, we explore the disparity between modelling ideals and lived reality (Section 5.2), and third, we consider the implications of differences in attitudes between demographic groups (Section 5.3). We end by addressing limitations as well as opportunities for future work and drawing final conclusions.

5.1. Translating between the real world and mathematics

Past studies with questionnaires on epistemic beliefs, which included statements such as "Scientists can ultimately get to the truth" [116] or "It is possible to discover what is true in scientific fields" [127], do not report that participants were provided with definitions of underlying concepts. In line with this, our participants were not given definitions of concepts such as "correct answer" or "objective truth". This lack of definition was taken up by some of the respondents. Three pointed out that they were unsure about the definition of certain terms, or they offered a clarification following their own understanding. The design of the questionnaire led to frustration for at least one participant, who

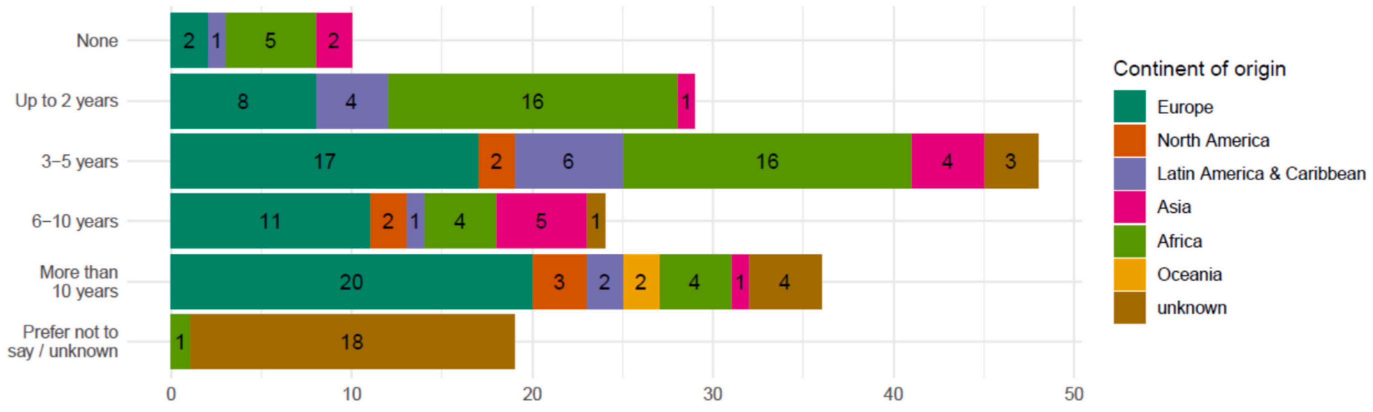

Fig. 5. Overview of respondents' modelling experience, grouped by continent of origin ($n = 166$).

perceived the Likert statements to be “suggestive”, “unscientific”, and even “emotionally laden”. Another respondent views mathematics as the hidden language of nature, serving as a tool for unveiling the deeper structures of the environmental and human spheres. This suggests that they consider the mathematical “truths” of the model as the origin and benchmark, not as their application to our real world.

These comments point to one core issue with modelling: the distinction between the self-contained mathematical nature of the model and the real world. Thompson [29] calls the former *Model Land* – a place where the mathematical assumptions are literally true – and points out that there is no system governing how we translate from the real world into Model Land and back. Oreskes et al. [128] illustrate that numerical models in the earth sciences are no closed systems, which would be the prerequisite for verification, i.e., an establishment of truth. Similarly, and although validation does not imply truth, energy system models cannot be empirically validated in their entirety due to their open-bounded nature [89,128]. Instead of looking for truth in mathematical models of techno-socioeconomic systems, scholars have suggested viewing them as metaphors [129], as thought experiments [27], or as caricatures which highlight the relevance of some characteristics while overlooking others entirely [29]. The findings of our sample imply that not all parts of the modelling community are united on whether we are doing hard science, or whether we are, in fact, using mathematical methods to enter the more speculative realm of futures research – a question that deserves more attention.

Views within our sample vary greatly regarding the truthfulness and explanatory power of models, and the stylised profiles of the *Positivist* and the *Postpositivist Modeller* reveal a link between these and the respondents’ preferences for communicating modelling results and their implications. Accordingly, these attitudes likely have implications for how scenarios are interpreted and used. Encouraging deeper discussion within the modelling community, both at team and project levels, can help raise awareness for the matter.

5.2. Supply and demand for understandability and for normative recommendations

It is striking that respondents are polarised in terms of their beliefs on the more abstract concepts related to modelling, while there is a clear consensus that the *individual* modeller is not infallible: respondents largely agree that every expert is influenced by their personal background, and that their work should be read with care. This contrast between the theoretical ideals in modelling and the lived practice where modellers occasionally err may also be the key to understanding the apparent inconsistency of views on the presentation of scenarios. While the respondents agree that model-based scenarios cannot be interpreted responsibly without knowledge of the model, assumptions, and data, some participants believe that they *should* be understandable on their own. Similarly, there is consensus that modellers should prioritise the analysis of different courses of action instead of making normative recommendations. Yet, almost half of the respondents believe that the modeller *should* make suggestions for actions.

Such a simplified representation may be desired by both the modellers on the supply side and the decision-makers on the demand side, one struggling to translate the complexity and the other without the time to dive deep into the technical details. The topic of policy recommendations specifically is yet to be scientifically examined in depth, and it is not as black-and-white as the survey might suggest [130]. Instead of providing single unconditional recommendations, researchers can also make a series of carefully crafted conditional recommendations that identify suitable levers for different policy goals and preferences [130,131]. This leaves value-based decisions on priorities and ambitions to the policymaker.

5.3. Practical implications of the differences between demographic groups

While modellers’ epistemic beliefs in reality are much more nuanced and flexible than our stylised profiles suggest, of course, the residents of the African continent in our sample do have a higher tendency to agree with positivistic statements than those living in other regions. Indeed, differences in epistemic beliefs between groups of different origins have been observed [127,132,133]. Past work suggested that these differences can be related to aspects such as religious beliefs or authority [134]. Exploring these cultural factors in depth goes far beyond the scope of this work – especially as our data are aggregated at the continental level and cannot be linked to any one culture. Similarly, research results on the link between gender and epistemic beliefs are overall mixed [135–137], and we cannot offer a straightforward explanation for the differences we discovered in our sample. However, we can discuss possible practical implications.

The ecosystems for energy modelling and planning are still at an early stage of maturity in many countries in the Global South [138]. In Africa, efforts in this field are still dominated by non-African actors and experts, and purposeful development and expansion of local expertise are urgently called for [139–142]. Such capacity development measures are often implemented by international organisations within the framework of international cooperation programmes [34–37]. Although we did not ask participants where they acquired their modelling skills and have no access to the curricula of training programmes, we know that the survey invitation was circulated among alumni of such programmes. As a result, we recognise that at least some of the responses collected may have been submitted by graduates of short-term training and that our data are biased accordingly.

On average, participants of African origin have less modelling experience than those from other continents in our sample; we thus cannot be sure whether factors related to the regional context actually play a causal role, or whether, for example, the type of modelling training is much more important. Follow-up research could examine training programmes and whether they focus on the technical aspects of the modelling process, or if the importance of epistemic beliefs and the translation between the real world and the mathematical model world are also covered. Beyond epistemic beliefs, we suggest that modelling training should include, for instance, how to carry out a political economy analysis as part of the study [143], or the ethically responsible use of mathematics, and instead of wholesale adoption of Western curricula, targeted to the specific local context [133].

With this in mind, we acknowledge that other aspects, some of which are difficult to capture, could also have an influence on epistemic beliefs that our study does not cover. These could include, for instance, the organisational culture of our participants’ employers, the regional culture in academia and education, or linguistic nuances that are lost in the completion of an English-language survey by non-native speakers.

5.4. Limitations and future work

Among the limitations of our work is the reliance on the predefined answer choices of the questionnaire. Future research might follow a more open approach, for example, with semi-structured interviews or other qualitative methods, enabling respondents to share perspectives that allow more nuance than stylised profiles like *Positivist Modeller* and *Postpositivist Modeller*. While this binary framing offers a useful conceptual starting point, we further acknowledge that it risks oversimplifying the complex epistemic beliefs and opinions of the respondents and should thus be interpreted with caution. We further acknowledge that the variation in terminology and lack of definitions in the questionnaire may have introduced ambiguity or inconsistency in the interpretation of the survey items. As a result, some responses may reflect not only the participants’ beliefs but also differences in wording, adding unintended noise to our data.

The sampling was based on reaching modellers whose networks were accessible to us. That means that experts from certain regions of the world, users of certain methods, and certain professional settings are comparatively more strongly reflected in the results. As discussed above, for respondents in the Global South, our sample may be skewed towards modellers with strong connections to researchers from the Global North, including alumni of short-term training courses in particular. Accordingly, we cannot assume and do not claim that the observed epistemic beliefs and attitudes are representative of the entire modelling community, and we do not claim the generalisability of our findings. This limitation is further reinforced by the fact that the questionnaire was only available in English. Further work could re-examine some of the more surprising findings in light of larger respondent samples – such as that more experienced respondents are less likely to think that value-laden assumptions must be tailored to a specific context. Additionally, further studies might use a multivariate design or apply a more targeted sampling strategy to address confounding effects more systematically.

Beyond tackling these limitations of sampling and questionnaire methods, future research could survey the demand side and analyse the epistemic beliefs of decision-makers and scenario users. Moreover, it is worth considering the comparison between the self-reported attitudes of the modellers as outlined here and the lived practice, i.e., the way in which model-based scenarios are produced and presented – for instance, in terms of language or normative recommendations.

5.5. Conclusion

We know that scenarios often influence the future rather than predict it [111]. Not only do our findings suggest that views on the truth, objectivity, and explanatory power attached to models and scenarios vary widely in the modelling community, but we hence must further expect that they impact how outcomes are presented to and perceived by the audience. A perspective that sees models and scenarios as tentative and subject to revision highlights that the future is not set in stone and may empower actors to make informed decisions. A focus on objectivity and truth, in contrast, may negatively impact the perceived scope of action and effectively delegate decision-making power to the model.

To bridge the perspectives between different groups of modellers, we consider our findings to be a call for diversity in modelling teams as well as for increased awareness of and discussion about the importance of epistemic beliefs within the modelling community. In addition to diversity of backgrounds and perspectives, this also involves the question of what kinds of expertise and experience are required in modelling projects beyond the actual work with code and data. While transdisciplinary collaboration is frequently called for, in practice, there is often a strong reliance on experience in the technical and quantitative domains. Yet greater involvement of social science experts, in particular, could help bring a breath of fresh air into ongoing debates about within the modelling community – and not least with regard to the nature of truth and objectivity.

CRediT authorship contribution statement

Franziska Bock: Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **Stefan Pfenninger-Lee:** Writing – review & editing, Supervision, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2025.104229.

Data availability

Data will be made available on request.

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