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Ecologies of integrated modeling: configuring policy-relevance in Swedish climate governance

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Due to the long timescales and deep uncertainties involved, comprehensive model-building has played a pivotal role in creating shared expectations about future trajectories for addressing climate change processes, mobilizing a network of knowledge-based experts who assist in defining common problems, identifying policy solutions, and assessing the policy outcomes. At the intersection between climate change science and climate governance, where wholly empirical methods are infeasible, numerical simulations have become the central practice for evaluating truth claims, and the key medium for the transport and translation of data, methods, and guiding principles among the actors involved. What makes integrated assessment unique as a comprehensive modeling-effort is that it is explicitly policy-oriented, justified by its policy-relevance. Although recognized by the Intergovernmental Panel on Climate Change as invaluable to their review assessments, the role of integrated modeling in implementations of the Paris Agreement, such as in impact assessments of climate legislation on the national level, is far less known. Taking as its starting-point the boundary-work carried out in public administration, this paper examines how foresight knowledge produced with the help of model-based scenario analysis has been made relevant in Swedish climate policymaking, focusing on the processes by which key indicators for political action become institutionalized through the choice and use of model parameters. It concludes by arguing for an expanded understanding of policy-relevance, beyond institutional approaches and toward a process-based point of view, treating relevance as something in-the-making.

KEYWORDS
climate mitigation, integrated assessment, model-based forecast, scenario analysis, science-policy interface, policy-relevance

1. Introduction: model-based forecasts of climate change mitigation pathways

When it comes to the role of scientific research in informing public policy about wicked problems, like that of climate change, integrated assessment processes with the aim of organizing, evaluating, and presenting the latest scientific findings to inform political decision-making have become increasingly important (Funtowicz and Ravetz, 1993). Climate change mitigation, for instance, involves the simultaneous transition of industry, transport, agriculture, and energy systems on national, regional, as well as international levels, comprising a wide range of stakeholders. Such problems are wicked because they affect multiple temporal and spatial scales at the same time; they are also transboundary, as they stretch across several governance levels, involving many different policy fields, and requiring expert input from a plethora of disciplines (Ravetz, 1987). Since the anticipation of climate impacts is neither routine nor short-term, with a scarcity of objective data, these are problems that involve scientific knowledge and its present limits, encouraging assessments that are built on highly uncertain findings of the best available research "[...] at a particular time, given the information currently available, even if those judgments involve a considerable degree of subjectivity" (Moss and Schneider, 2000, p. 36).

Because of the transboundary nature of the problem, coordinated responses to climate change have relied upon unusually sophisticated information systems. It has spurred the development of new institutions and organizations for compiling a whole swath of individual measurements across the globe into a coherent assortment of commensurable and in effect useful numbers. First, by recording the variables measured, then by connecting the data within any one system, as well as between systems, before linking and sharing it across various scales to enable the production of synoptical forecasts through computer simulation (Miller and Edwards, 2001; Edwards, 2010). Due to the long timescales and deep uncertainties involved, numerical simulation modeling has played a pivotal role in creating shared expectations about future trajectories for addressing climate change processes, mobilizing a network of knowledge-based experts who assist in defining common problems, identifying policy solutions, and assessing the policy outcomes (Borie et al., 2021). At the intersection between climate change science and climate governance, where wholly empirical methods are infeasible, numerical simulations have become the central practice for evaluating truth claims (Edwards, 1996), and the key medium for the transport and translation of data, methods, and guiding principles among the actors involved (Shackley and Wynne, 1995a).

The Intergovernmental Panel on Climate Change's (IPCC) exploration of climate change mitigation pathways compatible with the temperature goals of the Paris Agreement is a case in point (Intergovernmental Panel on Climate Change, 2014). Some of the most prominent and influential tools to help us explore low-carbon futures are integrated assessment models (IAMs), which is a family of numerical simulation models that seek to capture the societal dynamics between energy use choices, land use changes, and its consequences for various sectors of the economy. Unlike modeling the convection of heat through the atmosphere, or the way it absorbs solar radiation, however, the same regularities of nature do not apply to the economic demand and supply of different fuels or the behavioral relationships between income, diets, and transport use (Dessai and Hulme, 2004). Relying for the natural-systems side on outputs from other efforts based primarily in the climate sciences (Edwards, 1996, p. 51), model-building for the sake of integrated assessments puts its focus on the economic, technological, and political elements of anthropogenic forcing, with ambitions much more modest than prediction at statistically significant levels (Ackerman et al., 2009).

Instead of predicting the future then, exploratory techniques of model-based forecast are employed as a means of providing policymakers with a map to navigate the trade-offs and consequences of various so-called emissions scenarios. Simulating scenarios of interacting environmental, financial, and technological change (Intergovernmental Panel on Climate Change, 2000), mitigation pathways are mapped out by combining and mutually revising scientific evidence in concert with various policy means, objectives, and value judgments into potential policy solutions. Once policies are implemented, their consequences can be carefully monitored, and the cartography of pathways reapplied, based on the analysis of those consequences (Edenhofer and Kowarsch, 2015, p. 60–63). By identifying poorly understood or previously unanticipated consequences, such as co-benefits, policy synergies, and cascading effects, model-based scenario analysis has been widely adopted as a strategy for deciding what mitigation policies to implement and when.

What makes integrated assessment unique as a comprehensive modeling-effort is that it is explicitly policy-oriented, justified by its policy-relevance (Cointe et al., 2019). Although recognized by the Intergovernmental Panel on Climate Change (2014, p. 51) as invaluable to their review assessments, the role of integrated modeling in implementations of the Paris Agreement, such as in impact assessments of climate legislation on the national level, is far less known. This is no trivial oversight, because the incentives that influence policymakers most in political decision-making tend to reward projects that are nicely bounded, enjoy a tangible and easily perceived connection between action and outcome, and can produce a steady series of short-term payoffs (Brunner, 1996, p. 129–130, 142–144; Edwards, 1996, p. 156). Yet, scenario analyzes would at best be able to assign highly subjective estimates to the costs and benefits associated with various mitigation pathways [Intergovernmental Panel on Climate Change, 2014, p. 40], whose outcomes would take decades to materialize, with few milestones to mark the path of progress.

In such cases, when "[...] uncertainty is high, and actors, unsure of what outcomes are possible, are unable to specify reliably their own interest, nor understand with precision the interests of others" (Sabel and Victor, 2017, p. 16), integrated bargaining around top-down treaties become very demanding and other strategies may have to be more widely employed as a fallback position. With the adoption of the Paris Agreement, scholars have identified a general shift away from the top-down model of the Kyoto Protocol and toward a bottom-up policy regime with voluntary pledges in its place (Falkner, 2016; Guillemot, 2017; Jordan et al., 2018). Often described in terms of a transition toward a solution-oriented mode (Jabbour and Flachsland, 2017), this change in the structure of the international climate policy regime has reinforced the importance of scenarios to serve as a basis also for the efforts undertaken by each country to reduce national emissions (Hermansen et al., 2021; Hermansen and Sundqvist, 2022).

However, given the centrality of their role in the implementation of the Paris Agreement, the scenario analyzes carried out in the administrative branch of governments have been poorly documented, and their influence on mitigation policy remains ill-understood. In the wake of the bottom-up structure of the Paris Agreement, as Hermansen et al. (2021, p. 3) point out, there is thus a need for empirical studies examining how the foresight knowledge produced with the help of model-based scenario analysis is made relevant at the national just as much as at global level, including the significance of actors other than modelers in contributing to these assessment processes.[1] By looking at the case of the Swedish climate policy framework in particular, the aim of the present study is to contribute to addressing this gap in the existing research literature.

2. Conceptual framework: emissions scenarios at the science-policy interface of integrated assessment

In a global world of complex interactions, there is a rising demand for accessible and comparable knowledge. Since numbers are said to possess many features that cater to this demand, quantification has been recognized as a pervasive feature of contemporary governance (Rottenburg et al., 2015). Politics in the 20th century created a whole array of indicators, such as gross domestic product (GDP), that became crucial for the structure of entire policy fields. Politics in the 21st century, inspired by New Public Management (NPM) discourse, deepened this trend both by developing more indicators (Bartl et al., 2019, p. 8) and by connecting the development and use of indicators to techniques of model-based forecast.

Indicators are a special form of quantification in that they emphasize the intentional use of numbers for the sake of political action (Espeland, 2015). They can be described as numbers that use a limited set of measurable parameters to make phenomena visible that cannot be observed directly (Porter, 2015). The otherwise intangible consequences of a changing climate can for instance be forecasted by simulating a number of interacting systems, under a given set of conditions, to explore the linkages and trade-offs between different policy options. An often-cited definition states that "[…] desirable indicators are those that summarize or otherwise simplify relevant information, make visible or perceptible phenomena of interest, and quantify, measure, and communicate relevant information" (Gallopín, 1996, p. 108). While this definition might not be entirely uncontroversial, it nevertheless highlights four key features that are typically associated with indicators of importance to processes of integrated assessment. First, as already mentioned, indicators are a form of quantification; second, the knowledge produced is the result of a reduction in complexity; third, indicators make phenomena visible that might not otherwise be directly observable; and fourth, since indicators are based on indirect measurement rather than direct observation, questions of validity become especially salient, and the relevance to policy of the knowledge produced tends to be a burning issue (Bartl et al., 2019, p. 9–13).

Since indicators simplify complex phenomena, their interpretation depends on mediums, such as numerical simulation models, that ensure their communicability (Lehtonen, 2015). Mediums aid interpretation by relating the phenomena of interest to a chosen measure. However, these mediums implicitly contain causal attributions and, hence, suggest scripts for political action. Whereas the specific conditions of a medium may be obvious in expert circles, this is not necessarily the case when they are transferred into the political sphere (Bartl et al., 2019). During the last two decades, research on the science-policy interface of integrated assessment has for instance concerned itself with questions of transparency and participation (Schneider, 1997; Van Der Sluijs, 2002). It has focused on efforts by modelers to make explicit the specifications underlying various emissions scenarios, and to facilitate policymakers with a better grasp of how to interpret the foresight knowledge produced (Kriegler et al., 2015; Harmsen et al., 2021). When it comes to fostering policy-relevant science, emphasis has been on how to improve the quality of communication between modelers and policymakers (Dilling and Lemos, 2011; Lemos et al., 2012; Kirchhoff et al., 2013). Combating the opaqueness of models has been recognized as one of the most decisive aspects of such an undertaking (Robertson, 2020). Without a sense of the uncertainties pertaining to model parameters and structure, scholars have cautioned that the numbers and figures produced may end up providing a distorted picture of the stakes involved in following specific mitigation pathways (Stirling, 2010; Rosen, 2015; Krey et al., 2019).

There has been a general concern that, due to the growing role of large-scale information systems in anticipating climate impacts, the technical performativity of valuation in integrated assessments of climate change has delegated the definition and measure of value to models (e.g., Scheinke et al., 2011; Frisch, 2013; Beck and Mahony, 2018; Hollneicher, 2022). Unsurprisingly so, because the power of indicators lies in their ability to reduce a plurality of meanings and valuations to a single number, and thereby to function successfully as objects of compromise between actors (Boltanski and Thévenot, 2006): it is precisely the polysemy of language that can be overcome by quantification. The relevance to policy of foresight knowledge emphasized by certain indicators, then, is not invariable. Rather, it may become relevant if indicators are used collectively, if they are attributed a relatively consensual meaning, and if their production, publication, and use have significant consequences for the constitution, reproduction, or transformation of a particular field of policymaking (Bartl et al., 2019, p. 13); or vice versa, to become irrelevant if their indicators fail to have these consequences.

This means that there is an inherently political dimension even to methodological issues in the quantification process (Saltelli et al., 2016, 2020; Havstad and Brown, 2017, p. 110–115).[2] As noted by Winsberg (2012, p. 130), "[…] climate

1 I borrow the term "foresight knowledge" from Von Schomberg et al. (2006, p. 149–151), for whom it denotes an action-oriented form of strategic knowledge used for agenda setting and problem-solving related to the anticipation of future threats, challenges, or opportunities, and whose quality, insofar as it is characterized by relatively high degrees of uncertainty, has to be evaluated on grounds of its plausibility rather than in terms how accurate it is in predicting events.

2 A much-debated indicator in integrated assessments of climate change is the social discount rate applied to climate impacts. Although some modelers stress that a concern for intergenerational justice must lie at its heart, others advocate the use of observed market interest rates to inform this choice. But even if we adopt a descriptive as opposed to a prescriptive approach to the choice of discount rate, it is unavoidably the product of a value judgment, namely, that governments ought to "[…] consider individuals' everyday decision-making to determine what consideration future generations receive

modeling involves literally thousands of unforced methodological choices," a result of the fact that such models are highly idealized representations of incredibly complex target systems, and doubly so when we consider that integrated assessments include energy, transport, and agricultural factors too. Such choices include decisions about possible parameterizations and model structures; parameter values; choices between different approximation methods; decisions about which climate forcings to include in the model, exclude as insignificant, or approximate with a simple parameter; choices of higher or lower model resolution; decisions about aggregating ensembles of models, and so on Beck and Krueger (2016). To the extent that such choices become embedded within models, the design of emissions scenarios allow for integrated assessments to rely on the quantification of numerical data, building expectations about the future to make plans and collectively binding decisions (Shackley and Wynne, 1995b; Turnhout, 2009). As Klenk and Meehan (2015, p. 162) have argued:

> In the context of climate change and transdisciplinary science, [...] we should understand integration as an exclusionary practice, which establishes boundaries between what knowledge claims are internalized from what knowledge claims are externalized. Differentiated matters of concern become factual claims deliberately and carefully composed through practices of production, reduction, negotiation, translation, amplification, [and] circulation[.]

Boundary judgments involved in the design of scenarios thus influence the scope of future potential reflected in scenario outcomes, which is to say that the analytical distinction between value-neutral modeling and value-laden policymaking is unhelpful in the context of integrated assessments (Edenhofer and Kowarsch, 2015, p. 59; Kowarsch, 2016, p. 101–132), and that sociological attention ought to be paid to the processes by which key indicators for political action become institutionalized through the seemingly technical choice and use of model parameters and numerical inputs (Saltelli et al., 2020). If not, burying parameters within the structure of black-boxed models risks making modelers into technocrats that both identify and formulate the relevant problems, identify the relevant goals, and prescribe the means, all the while policymakers, at the end of the process, simply implement the recommended policies.[3]

In mapping out mitigation pathways then, assessments of scientific findings are in many ways entangled with the valuation of climate impacts (Stanton et al., 2009, p. 179; Pfenninger, 2017; Doukas et al., 2018, p. 4–6). Making use of scenarios to mobilize, shape, and hold together matters of political concern (Lidskog, 2014), integrated assessments involve a constant interaction between scientific and political processes. In situations like these, where weighing the social consequences of climate change is inseparable from evaluating the characterization of ambiguous data, the standards of evidence, or the adequacy of the chosen conceptual frameworks, integrated assessment processes "[...] determine which knowledge is relevant while at the same time being co-constituted by the same knowledge" (Hermansen et al., 2021, p. 5), establishing climate change as simultaneously knowable and governable (Miller, 2004). In this paper, integrated assessments will be examined as sites for the co-production of science and social order (Jasanoff, 2004; Lövbrand, 2011; Mahony, 2013). Such a co-productionist approach focuses on how the use of scientific instruments—such as parameters in numerical simulations models—bind our collective performance of matters of political concern—mitigating climate change—through the production of knowledge; and conversely, how the production of knowledge—in this case, about the feasibility of mitigation pathways—is shaped by the indicators that mediums like models give expression to (e.g., Sundberg, 2007).

Model-based scenario analysis thus makes for a paradigmatic focal point to understand how problems that have long-term but uncertain implications, and that must be addressed in a coordinated manner, are worked out. In such cases, where the linear model of interfacing science and policy—wherein science is understood to inform policy by producing objective, valid, and reliable knowledge, such that to develop a policy is seen as a matter of scientists delivering the facts and then, in a second step, policymakers sorting out diverse values and preferences (Funtowicz, 2006, p. 139)—fails to capture the nature of policy-relevance in post-normal science (Van Der Sluijs, 2010; Beck, 2011), it becomes necessary to study relevance in-the-making. As opposed to ex post evaluations of the foresight knowledge produced, policy-relevance within processes of integrated assessment is herein approached as relational achievements that are assembled in the boundary-work of delegation, argumentation, negotiation, and conclusion, and in effect something to be studied as provisional accomplishments (Sundqvist et al., 2015). Boundary-work is necessary to create common understanding, to ensure reliability across domains, and to gather information that can retain integrity across time, space, and local contingencies. It does not, however, presuppose consensus. Taking inspiration from Jasanoff (1987; 1990, p. 234–236), who uses "boundary-work" to denote "[...] contestations over scientific knowledge and its appropriate relationship to policy that reflect and reinforce different conceptions of social order" (Low and Schäfer, 2020, p. 2), this paper homes in on model-based scenario analysis as a set of practices for the configuration of policy-relevance, where such configurations can either be contested or entrenched.

Consequently, the conceptual framework of this paper qualifies the above-mentioned aim: to examine how the foresight knowledge produced with the help of model-based scenario analysis has been made relevant in Swedish climate policymaking, focusing on the processes by which key indicators for political action become institutionalized through the choice and use of model parameters.

in climate policymaking" (Beck and Krueger, 2016, p. 636. See also Broome, 2010).

3 It is worth pointing out that for some assumptions central to integrated assessments of climate change, the exercise of valuation tied to them have been widely recognized and explicitly addressed. Two examples well worth mentioning are the rate of pure time preference and the rate of risk aversion (Stern, 2007, p. 25–45).

3. Methodology: boundary-work in impact assessments of national climate legislation

Turning its attention to the administrative agencies of government, the analysis revolves around the boundary-work carried out by administrators assessing Swedish climate policy. Administrative agencies are government bodies that are authorized to manage aspects of law and regulation, and to develop more precise and technical rules than is possible in a legislative setting. Though a long-standing feature of governance arrangements, administrative agencies have come to prominence in the last three decades as a key part of neoliberal inspired NPM-reforms in the Anglosphere, across Europe, and beyond. These agencies typically have a restricted technocratic or advisory mission that is intentionally disconnected from partisan preferences or public opinion, with their operations detached from short-term political concerns and instead focused on rational execution of policy (Roberts, 2010, p. 6–13). The focus on administrative agencies and the relevance-making that emerges in and around their work is therefore instructive, because these bodies would seem to epitomize the technocratic nature of contemporary policymaking. However, they also embody informal webs of relationships within which administrators work to adapt to, make sense of, and enact new sociotechnical arrangements in practice. Administrative agencies do not just compile scientific evidence; they actively construct expertise, respond to it, interpret it within their context, incorporate it into their own models and reports (Bocking, 2004, p. 42), and fit all this together with their own bureaucratic cultures and agendas (Süsser et al., 2021; Hermansen and Sundqvist, 2022). In assessments of national climate legislation, understanding the dynamics between scenario analyzes of climate impacts on the one hand, and domestic climate policymaking on the other, requires treating policy-relevance itself as an active effort, pursued not just by modelers and policymakers, but at least as much by the administrators that mediate between the two.

In order to give empirical weight to this approach, the analysis is based on two main sources of data. First, a survey of white papers and reports produced as part of Sweden's climate policy framework. While white papers are produced by the government, setting out their proposals for future legislation, the reports are usually commissioned by ministries, sometimes with affiliated experts from academia and interest groups, though most often authored by administrators in various agencies of the executive branch. Secondly, textual analysis has been pursued in conjunction with semi-structured, in-depth interviews with informants working directly with policy assessment, specifically as it relates to climate mitigation. Conducted over the past 12 months with 12 informants working at the science-policy interface of the Swedish government, the interviews ranged from half an hour to 45 min in length. At the time of the interviews, the informants were affiliated with either the Swedish Environmental Protection Agency, the Swedish Energy Agency, the Swedish Climate Policy Council, or the Swedish Governments Offices Office for Administrative Affairs, serving as investigators coordinating and conducting the Swedish government's action on climate mitigation, expert advisors to the government on the progress of its climate goals, or specialists in public agency initiatives to strengthen the scientific basis of Swedish climate policy.

The use of interviews to study scientific practice has been criticized. According to the actor-network approach (e.g., Latour and Woolgar, 1986; Latour, 1987), actors' accounts should not be used as sources of information about what they are doing, only about how they do it. From this perspective, interviews are less suitable than observations, which are free from the actors' subjective understanding and interpretations of activities and events. Interviews are also at odds with the anthropological approach to science, in which aspects of scientific activity readily taken for granted should be apprehended as strange (Latour and Woolgar, 1986, p. 29). However, from a social constructivist approach concerned primarily with "how"-questions, interviews are less problematic, or even preferable (Sundberg, 2005, p. 51–54), especially so in this case, since they capture the hermeneutic dimension that is so central to the use of model-based scenario analysis in the production of foresight knowledge (Von Schomberg et al., 2006, p. 150).[4] Providing orientation in an otherwise uncharted territory (Edenhofer and Kowarsch, 2015), scenarios reflect different interpretations of the risks and uncertainties involved in traversing mitigation pathways. Selective compromises must therefore be made, making the translation of qualitative conceptions about net-zero transitions into quantifiable scenarios a fruitful site for the study of intersubjectivity. Considering the tension between the usefulness of scenarios in projecting the future and the significant uncertainties under which climate policymaking must be carried out, the central theme in the analysis is how relevance is configured through the reduction of complexity. An important element of this theme is the construction of a shared sense of plausibility when it comes to descriptions of how the future may develop. It is this intersubjective side to the boundary-work performed through model-based scenario analysis that the chosen methods seek to investigate. Relying on textual analysis and interviews, the methodological gambit of this paper is that sociological questions, theories, and approaches may recover features that are not acknowledged in the same way from the practitioners' own perspectives (cf. Lynch, 1985, p. 19).

4. Background: the Swedish climate policy framework

The Swedish government is beholden to the European Union's (EU) determined contribution under the Paris Agreement for a greenhouse gas (GHG) reduction of 40% by the year 2030. Just a few months before the meeting in Paris in 2015, however, the government began working on a national climate plan, setting down a goal in the statement of government policy that Sweden should become the world's first fossil-free welfare country [Swedish

4 Furthermore, all scientific practices are not equally suitable for observations. For instance, the practical work on the shop floor in an experimental laboratory is accessible in an entirely different manner than the model-based scenario analyzes of administrative agencies, whose structure of organization is dispersed between numerous sites and whose work is not so easily studied as an observer in a physical space (Sundberg, 2005, p. 53).

Government Bill (Prop.), 2017, p. 7–9]. Two years later, it decided on a climate policy framework [Swedish Government Bill (Prop.), 2017, p. 146], including climate goals and a climate act. The government's aim is to achieve net-zero emissions by 2045, which means an 85% reduction compared to the year 1990. The remaining part required to reach zero emissions is expected to take place through increased carbon dioxide absorption, bioenergy with carbon capture and storage (BECCS), and investments in emission-reducing measures outside of Sweden's borders [Swedish Government Bill (Prop.), 2017, p. 37; Swedish Government Official Report (SOU), 2021, p. 160–166].

In regard to climate policy impact assessment, the climate act [Swedish Laws and Regulations (SFS), 2017, p. 720] binds future governments to its targets through a requirement to present annual reports on measures decided and planned, to indicate the effects these have had and are expected to have on GHG emissions, and to indicate further measures required to reach the intended targets [Swedish Environmental Protection Agency, 2012, p. 40; Swedish Government Official Report (SOU), 2016, p. 76–77; Swedish Environmental Protection Agency, 2019a, p. 30–35]. In order to facilitate the impact assessment, long-term scenarios are updated every 2 years with recently passed policy measures and with new estimations by the Swedish Environmental Protection Agency (2021, p. 6) on the price development of coal, oil, natural gas, emission permits, and annual GDP growth. Reference scenarios about expected emissions until 2045 are developed and used as baselines against which alternative scenarios can be compared and the effects of policy options estimated (Swedish Environmental Protection Agency, 2012, p. 20–21). Once scenarios have been simulated, the results are used to describe indicative target paths from the actual emission level in 2015, over the milestones in 2030 and 2040, to net-zero emissions by the year 2045 [Swedish Government Bill (Prop.), 2017, p. 31–42].

Reporting takes place in connection with the submission of the budget bill, with the additional proviso that the government must put forward an updated action plan every 4 years. Additionally, the climate framework includes a Climate Policy Council, which is an independent body of expert advisors whose task it is to evaluate the government's climate report annually and its action plan quadrennially, and whose feedback must then be taken into consideration by the government in the following year's report. In this sense, the Swedish climate policy framework is similar to the Paris Agreement in that clear and ambitious goals are formulated—the most ambitious in the world—and that a continuous assessment is in place.

5. Analysis: navigating an information ecology of models

Outlining a national roadmap toward low-carbon futures, the chief indicators employed in Sweden's assessment work are those putting a monetary cost on the policy measures adopted to reach specified emissions targets. At the heart of the Swedish integrated modeling-effort is thus the ambition to estimate the socioeconomic consequences of various climate policy options, using emissions scenarios to explore how the transition toward net-zero can be achieved in the most cost-effective manner. Although administrators acknowledge that it is in principle impossible to predict in advance which mitigation pathways are most cost-effective in the long term,[5] scenarios analysis is nevertheless hailed as paramount to manage issues of uncertainty, scale, and delay between action and response, with an action plan that continually evolves as new forks in the road, alternative destinations, pitfalls, and uncharted territories turn up [Swedish Environmental Protection Agency, 2012, p. 32; Swedish Government Official Report (SOU), 2016, p. 38–39].

One of the most important instruments in the climate policy impact assessment is the computable general equilibrium (GCE) model used by the Swedish National Institute of Economic Research, called EMEC. CGE-models are a family of economic models used to estimate how an economy might react to changes in, for instance, policy. Production and utility functions are specified based on model assumptions about functional form and elasticities. It is then calibrated to be consistent with the Swedish Central Bureau of Statistics' national and environmental accounts for a chosen base year, which serves as a reference scenario. In the development of the reference scenario, account is taken, among other things, of current raw material price forecasts and existing and decided policy measures. Since EMEC is a so-called recursive-dynamic model, the economy can be projected into the future between equilibrium positions. At each point in time, the modeled actors choose optimal levels of production and consumption based on the given conditions. Economic growth in the model is driven by the growth of the labor force and of labor productivity. As the economy grows, investments in physical capital also increase, causing the capital stock to grow, which feeds positively back into economic growth again. When exogenous shocks, such as changes in world market prices, or various policy measures, like tax increases, are entered into the model, new equilibria are calculated, and the results are compared to the reference scenario. Just like other country-specific CGE-models, EMEC can primarily be used to assess the effects of non-marginal policy or environmental impacts. This model type is particularly useful for analysis of policy measures that can be expected to affect or have repercussions in large parts of the economy. It is thus employed to compare and rank different policy options on the basis of, for instance, the lowest overall welfare cost to reach an emissions target (Swedish Environmental Protection Agency, 2012, p. 34–35).

In order to estimate the impact of policy options aimed at specific markets or sectors of society, whose repercussions in the rest of the economy is likely negligible, the Swedish government complements their use of EMEC with partial equilibrium (PE) and sector specific models. Of particular importance to its climate policy impact assessment is the energy system model TIMES-Nordic, which, in contrast to the highly aggregated design of a CGE-model, can represent the technical details of energy production. Following the optimization criteria dictated by EMEC, TIMES-Nordic is used to calculate the combination of existing and

5 Echoing Working Group III of the Intergovernmental Panel on Climate Change (2014, p. 58), the Swedish Energy Agency (2021, p. 6) has been keen to emphasize that their scenario analyzes are not meant to be predictive, but that their simulations are dependent on the conditions that have been assumed for each scenario and thus rather explorative in nature.

new facilities and energy flows that meet the specified energy needs at the lowest possible discounted cost to 2050, estimating the price and available supply of different types of energy. It is a bottom-up model that contains detailed descriptions of facilities and flows in the energy system, such as different types of power plants and fuels. Being so detailed, however, the model requires a lot of input data on, among other things, energy prices, energy needs, fuel quantities, and investment costs (Swedish Energy Agency, 2021). Since the resulting GHG emissions depend on the types of energy that cover the energy needs at the lowest cost, model results are highly contingent on assumed future energy costs.

Indeed, many inputs—like the expected rate of electrification in society, the impact of stricter requirements in the GHG reduction mandate, technology diffusion rates in the transport sector, and changed production costs for wind power—relate to situations far into the future and are subject to significant uncertainty. Prices of energy types are good examples of parameters that are given as inputs in TIMES-Nordic yet whose uncertainty greatly affects the model result. In fact, as administrators are keen to emphasize, the real challenge consists in including as many conceivable energy types and facilities as possible since they could unexpectedly become part of the optimal pathway. If, for instance, some unconventional policy measure was to be proposed by policymakers, or if, say, there would be falling investment costs due to disruptive innovation, this could result in sudden changes in energy prices. Some of the most important parameters, such as the costs of renewable electricity production technologies, are therefore also some of the most uncertain ones. Being a sector specific model though, TIMES-Nordic does not consider any economic effects outside the energy system, which means that the data must be fed back into a CGE-model in order to estimate the impacts on the domestic economy as a whole—and this is where the epistemic uncertainties in the Swedish government's integrated modeling-effort start to have a significant impact on the model results.

In order to make their scenario analyzes more relevant to climate policy impact assessment, administrators overwhelmingly agree that there is a need for increased integration and interpretation of model results. As they reiterate, it is not enough that the models and their basic functioning and frameworks are transparent to the user, as in the case of EMEC and TIMES-Nordic, whose detailed model descriptions are openly available. On the contrary, administrators would like to see more resources being put into improving the agencies own experiences in developing or at least professionally using numerical simulation models, not the least so that they can have a more sophisticated understanding of the inferential risks of the model choices, so as to make them more qualified to interpret the data. One such suggestion, with reference to the British government's strategy, is to support greater capabilities for in-house modeling. In contrast to their British counterparts, the Swedish administrative agencies outsource most of the modeling to consulting companies. As a result, there are no established forms for ongoing collaboration and cooperation between the agencies regarding the actual modeling. Furthermore, since consultants take care of the modeling, the models are at best weakly coupled, and so assessments from each of the agencies are relatively compartmentalized, without a clear working method or framework for how to weigh together results that have been calculated in different types of models and for different sectors of society. The Swedish Environmental Protection Agency (2022b, p. 3), for instance, emphasizes that:

> [...] more comprehensive work is needed with both quantitative and qualitative analyzes in collaboration between the relevant authorities[.] [...] The authorities should contribute their competences with the aim of achieving a long-term and deeper collaboration that results in more useful analyzes and data. The objective [...] should be to develop joint scenario methods to produce data and assessments of socioeconomic consequences that are requested by the government. [My translation].

Although the use of emissions scenarios in Sweden's action plan is governed by the European Parliament (2013) regulation on a common mechanism for monitoring and reporting GHG emissions, the Swedish Climate Policy Council (2020, p. 7, 19) similarly criticizes its government for the lack of a national coordination of the impact assessment process. Estimated impacts of policy measures on future emissions have not only been processed through a variety of distinct models but also presented in different units and formats, which, as the Climate Policy Council points out, makes it difficult to compare and assess the results.[6] Similarly, the Swedish National Audit Office (2019) recently recommended that the government clarify which areas of responsibility for scenarios that the various agencies have, including how scenarios for economy, traffic, and energy should inform each other.

Whilst several widely shared scenario assumptions regarding energy prices, carbon prices, GDP growth, population forecasts, and technological development have been applied to the overall assessment work, scenario analyzes of how net-zero emissions can be reached in different sectors have involved a plethora of agencies acting individually [Swedish Government Official Report (SOU), 2016, p. 168], each with their own informal rules for doing things. The Swedish Environmental Protection Agency, the Swedish Energy Agency, the Swedish National Institute of Economic Research, the Swedish Transport Administration, and the Swedish Board of Agriculture all develop target scenarios for different sectors, each with their own brand of model, ranging from the EMEC CGE-model and the TIMES-Nordic energy systems model to other sector specific ones like the agricultural SASM model, the HBEFA road transport emissions model, and the Heureka RegWise forest management model (Swedish Environmental Protection Agency, 2022b, p. 10–21). In this sense, the Swedish case of climate policy impact assessment matches the observations made by Braunreiter et al. (2023) in their study of model-based scenario analysis in the Swiss energy industry, in which they note that scenario use is rarely part of a formalized process. Navigating the myriad areas of expertise that are involved in drafting,

6 Echoing WG3 of the Intergovernmental Panel on Climate Change (2014, p. 58), the Swedish Energy Agency (2021, p. 6) has been keen to emphasize that their scenario analyzes are not meant to be predictive, but that their simulations are dependent on the conditions that have been assumed for each scenario and thus rather explorative in nature.

reviewing, and assessing Sweden's action plan, these processes of relevance-making are better described as distributed and emergent across information systems than in any sense centralized and premeditated. Since the integrated modeling-effort of the Swedish climate policy framework is compartmentalized in an informal network of sociotechnical connections, the relationships between these agencies are at least as important for configuring relevance as the models themselves. For instance, at the request of the Environmental Protection Agency, TIMES-Nordic is employed to calculate prices for electricity, district heating, and solid biofuels, which is then used by the National Institute for Economic Research in EMEC. Based on the result of EMEC, the Energy Agency then receives data from the National Institute for Economic Research on the value added for various industries. This information provides a basis for the Energy Agency's assessment of how much energy will be demanded by various industrial sectors and by the vehicle fleet. The Energy Agency also takes part in the Transport Administration's scenarios but makes its own assessments of the energy needs of the transport system. These numbers are then delivered back to the Environmental Protection Agency, where it is compiled and reported to policymakers.

Regarding the way in which data is processed in the computer-based simulations of low-carbon futures employed by these administrative agencies, one could do worse than to paraphrase the famous expression about regress and note, as Oreskes (2011, p. 103) does, "[...] that it is models all the way down." What Oreskes' (2011, p. 105) expression aptly captures is how the data employed in assessing the Swedish action plan is not simply collected; it is checked, filtered, and interpreted by numerical simulation models. The growth in GDP and the added value of various industrial branches that the EMEC puts out are for instance used as input to assess the energy demands of the Swedish industry and transport sector, which means that it feeds into, and significantly affects, the results from TIMES-Nordic and HBEFA. Since assessments of future energy demands are highly contingent upon the numerical input, this introduces uncertainties in the calculation of the models further down the line, which can lead to incorrect estimates of future GHG emissions in the final report. While it is commonly understood that net-zero transitions involve complex relationships playing out over long terms, which obviously makes them difficult to assess, the Swedish Scientific Council for Sustainable Development (2018) warns that the current, sociotechnical organization of Sweden's climate policy impact assessment makes them even more so. In other words, the manner in which the Swedish government's integrated modeling-effort is organized—or, rather, its lack of organization—is believed by these experts to amplify epistemic uncertainties.

5.1. Between robust policy options...

On the one hand then, to produce foresight knowledge of relevance to the action plan, agencies must make their models communicate with each other in such a way that they may collectively contribute to manage all this uncertainty. At the information systems-level of Swedish climate policy impact assessment, where emissions scenarios are simulated, this is less of an intentional and pre-planned activity than one of navigating an information ecology, working within the already existing conditions without thereby being completely determined by them. The dominant criterion for relevance can of course shift: it is only as permanent as the sociotechnical network of administrators and experts involved in climate policy impact assessment agree about its undisputed status. But no single actor can accomplish such a herculean task all alone. In order to participate in the process by which climate mitigation is shaped into a shared matter of political concern, these actors have to adapt to the wider information ecology of the impact assessment process.

The current conditions enacting a selective pressure on the way in which these administrators pursue model-based scenario analysis is by encouraging the production of foresight knowledge that can be used not only to estimate the costs of mitigation pathways, but even more importantly, to indicate the risks that the outcome of a policy option will differ from what is expected. Since they are based on different assumptions regarding future development within various sectors of the economy, emissions scenarios can at best indicate probable socioeconomic consequences of policy options. But such model results need to be interpreted, contextualized, and made subject to sensitivity analysis and plausibility assessment, and should not, therefore, be treated as forecasts. Rather, model results can contribute information about the order of magnitude and direction of relationships between various factors, as well as assist with analytical perspectives regarding dynamic effects and connections in the domestic economy. Model results can thus add valuable insights into the complexity of the structure that policymakers seek to manage, but they are not intended or suitable to be used directly as a basis for policy design.

In many ways, this reasoning resembles Dryzek (1983, p. 360–361) recommended replacement of optimization as the primary criterion for the design of policies with a stronger focus on "robustness," since "[...] a robust policy alternative is one expected to perform tolerably well across the whole range of scenarios given any one of the pertinent theoretical perspectives. [...] Its main virtue is its invulnerability to the weaknesses in our understanding, and to unexpected changes in the environment of policy" (see also Lempert and Schlesinger, 2000; Hallegatte, 2009, p. 241–243). If a steadfast course toward low-carbon futures is to be kept, the action plan needs to be somewhat predictable in function while at the same time mitigating as much as possible against known unknowns. In the Swedish case, the importance attributed to the sensitivity of energy price parameters has gone hand in hand with the relevance ascribed to indications of how robust the performance of various policy options is to quantifiable risks. Swedish administrators consistently stress the importance of designing an action plan that can maintain a stable and predictable level of performance even in face of the many challenges to anticipation that a long-term, nation-wide transition involves. Since changing environmental, social, technological, and economic conditions may suddenly alter the costs associated with emission reductions, and thereby the incentives that may need to be implemented and maintained, it is crucial to reduce the price risk of decarbonization. Designing for the ability of Sweden's net-zero transition to remain on course in a world that is rapidly changing, administrators are working within information ecosystems where they are encouraged to assist in identifying policy options whose performance is maximally robust to price risks.

Because of increased climate ambitions at the EU-level, however, administrators believe that the demand for sector-wide analyzes, with high levels of detail, will only grow. In the EU's new "Fit for 55"-package, land use in agriculture and forestry are important areas for domestic policy measures (Swedish Environmental Protection Agency, 2021). Due to the aggregated design of EMEC, price changes within these sectors are difficult to assess in a robust fashion. An acknowledgment of this can be found in the Swedish National Institute of Economic Research's (2021, p. 65) latest environmental economic report, where the authors note that:

> EMEC captures flows of forest biomass used in energy production, and the biogenic carbon dioxide emissions resulting from biomass combustion. Other than that, the carbon balances in the LULUCF-sector are not represented. Land is not represented as a finite resource in the model, and uptake and storage of carbon in living biomass is not accounted for. [...] It means that there is a strong limitation on the types of questions that can be answered by the model, which is especially problematic with regard to the need for assessments of how Sweden can fulfill its obligation in the LULUCF-sector. [My translation].

Increased integration, primarily by stronger model coupling, is thus identified by administrators as paramount to ensure that the foresight knowledge produced by these models is relevant to climate policymaking.

5.2 ...And resilient policy design

On the other hand, a much too uniform and homogenous information ecology is undesirable as it makes the integrated assessment process rigid, leaving it unable to deal with changes to values as opposed to changes to knowledge. Pressures toward robustness may for instance entrench the longevity and continuance of policies that favor incremental processes at the expense of large-scale changes. Although the above-mentioned efforts at improving robustness ensure that the action plan and the policies it embodies remain adapted to anticipatable risks, such an action plan may quickly become obsolete if it proves unable to respond to events that cannot so easily be anticipated by extrapolating from existing data. In its scrutiny of the government's first action plan from 2019, the Swedish Climate Policy Council (2020, p. 35–36, 46) identified the lack of an explicitly normative vision about how to become the world's first fossil-free welfare country as one of its most serious deficiencies, especially in light of Sweden's so-called generation goal, which has been formulated with the intent of providing "[...] guidance regarding the values that are to be protected and the changes in society that are needed if the desired quality of the environment is to be achieved" [Swedish Environmental Protection Agency, 2022a, p. 5]. Summarizing this as a disregard for the social drivers of net-zero transitions, the Swedish Climate Policy Council (2020, p. 30–31, 60) warned that the action plan relied much too one-sidedly on robust price estimations, to the detriment of changes to social values. Although estimating and reporting the economic costs of emissions was acknowledged to be a necessary condition for successful climate policy, the Swedish Climate Policy Council (2020, p. 48–49, 78) argued that it was not sufficient. Instead, it called for supplementary indicators to assess net-zero transitions as processes of parallel and interconnected changes to not only business models and technologies but behaviors and norms too (Lidskog and Sundqvist, 2022, p. 9–10).

A similar concern about the failure of imagination in Sweden's action plan, demonstrated by its negligence in addressing the social drivers of net-zero transitions, is expressed in Swedish Environmental Protection Agency (2019b) review of the National Institute for Economic Research's scenario analyzes of the transport sector. The Environmental Protection Agency points out that results from EMEC will be skewed by the model's inability to take disruptive innovation and changes in cultural norms and attitudes into account, which, the agency argues, risks severely limiting the government's vision on how Sweden's net-zero transition could take place. In fact, this concern even found its way into a government investigation under the Ministry of Climate and Enterprise [Swedish Government Official Report (SOU), 2016, p. 166], where the administrators noted that most of the Swedish emissions scenarios assume that today's economic and political relationships and trends will persist well into the future, and that the populace's values and behaviors will remain unchanged, with the exception that new technology is assumed to automatically gain acceptance and taken up without much further ado. A prominent attitude among administrators is thus that the social drivers of net-zero transitions need to be given, if not as much attention as economic and technological drivers, then at least more than is now the case.

Claims like these are made primarily from an output-oriented point of view, namely, that model parameterizations relying on excessively narrow definitions of feasibility simplify the complexities of net-zero transitions to an unhelpful degree and, as Riahi et al. (2015, p. 19) have warned, may thereby end up producing false expectations and sub-optimal results. As an example, modeling the Swedish energy system, TIMES-Nordic is more suited to reflect certain types of policy measures than others, and the impact of some options is therefore poorly represented—or, in some cases, not represented at all—when the Energy Agency's scenarios for energy supply and emissions are developed. If policy options that are poorly represented in models should turn out to be decisive for the Swedish net-zero transition, such oversights will introduce additional uncertainties into the model results. As investments into for instance wind power—which has variable electricity production, energy storage, and demand flexibility—become more pressing in the near term, it becomes increasingly important to also employ energy models with a more detailed time-division than TIMES-Nordic.

The problem, as Bankes (1993, p. 437) famously put it, is that there is "[...] a strong tendency to model in detail phenomena for which good models can be constructed and to ignore phenomena that are difficult to model, producing a systematic bias in the results [by] [...] emphasiz[ing] the aspects of a problem that can be best simulated." Since Sweden's climate policy design and assessment process is to a significant degree informed precisely by model-based scenario analysis, it is particularly sensitive to dominant assumptions about the feasibility of mitigation pathways that figure in the development of emissions scenarios, including the choice of parameters when formalizing assessments of feasibility into functionable models amenable to computer-based simulation (Low and Schäfer, 2020). Consumption, lifestyle changes, alternative growth paradigms, food and water security, and impacts on biodiversity are examples of parameters that have been reported by experts as at best severely underrepresented, and at worst absent, because of formal abstractions in modeling (Pedersen et al., 2022, p. 8). To ensure that models do not systematically underestimate facets of feasibility that are difficult to resolve within cost-optimization equations, or for which there is a lack input data to reliably do so (Tavoni and Valente, 2022), it is important that agencies actively reflect upon the inferential risks in encoding qualitative conceptions about net-zero transitions into quantifiable scenarios—which, at least in the Swedish case, they in fact do.

As a result, some administrators make the same claim but for reasons of input legitimacy, emphasizing how inclusive deliberations about feasibility are decisive for recognizing a diversity of values and enrolling stakeholders in such a way that they can articulate them in all their plurality. In 2016, the Swedish National Audit Office commissioned a report on the integrated model-efforts of Swedish climate policy impact assessment (Copenhagen Economics, 2016). Estimates of the economic consequences of climate goals, the National Audit Office noted, vary greatly between different scenarios; the projected cost of reducing emissions is highly dependent on scenario assumptions; narrow choices around the parameters to include in the models limit the measures available to reduce emissions; and the rate at which the measures can be implemented is sensitive to the values of those parameters. In fact, the Swedish National Audit Office (2013) had reviewed the use of scenarios in climate policy impact assessment three years prior and pointed out that, while EMEC is an important tool for producing foresight knowledge, this model alone, even if run in tandem with PE and sector specific models, cannot give sufficient clarity to the kind of questions that need to be explored in the event of major climate impacts. Instead, the National Audit Office recommended that results from EMEC regularly be supplemented with more detailed sociotechnical transition analyzes of the energy and transport sector, with expert elicitations about what measurements are needed to fulfill long-term climate goals at a reasonable cost, as well as with stakeholder participation in articulating Sweden's generation goal. In other words, since the choice of model specifications has consequences for policy, the sheer underrepresentation of social drivers in models will indirectly sideline policy options addressing aspects like consumer behavior and norms. It is the way in which the simulation of emissions scenarios shapes social expectations in real time that some sociologists have sought to highlight by attending to the performative dimension of modeling: model specifications frame the way in which policy is led to intervene into the modeled system by orienting users toward an actionable future (Beck and Mahony, 2018; Beck and Oomen, 2021).

To make the identification of robust policy options into the sole criterion of relevance would thus constitute a significant shortcoming in the Swedish climate policy impact assessment. Relying on models calibrated to measure outcome may overlook other values tied to the impact assessment process, such as how the cultivation of value disagreement with the help of sociotechnical transition analysis or expert elicitation may improve policymakers' insights about possible blind spots in the action plan, and in effect the agility of the action plan to adapt if foundational assumptions should turn out to have been implausible. Prominent economists such as Stern (2008, p. 11) have for instance warned about an overestimation of the role of abatement cost curves in policymaking concerning "[...] major strategic decisions for the world as a whole, with huge dynamic uncertainties and feedbacks." While risk assessments are an improvement upon cost-optimization methods, the foresight knowledge foregrounded by such indicators is still insufficient when we are faced with the wickedness of a changing climate, where the conditions for which these probabilities have been calculated may suddenly no longer apply (Weitzman, 2009; Pindyck, 2013).

Hence, if robustness denotes an insensitivity to quantifiable risks, then some administrators have put this measure of relevance into question by contrasting it with so-called resilient policy design, which refers rather to a preparedness for sudden punctuations that the quantification of risk, extrapolating from historical trends of incremental change, cannot aid in mapping out. The Swedish Environmental Protection Agency (2022b, p. 45) is explicit about this challenge:

> Existing models (both in Sweden and in other countries) in many cases lack the ability to analyze challenges and opportunities for a large-scale societal transformation, that is, analyzes of major shifts in, for instance, technology, norms, and behavior, as well as changes in how society is organized. Such transformative change stands in contrast to the linear, incremental, and stepwise change that proceeds from the prevailing social structures, which existing models have been developed to assess. We are aware that it will be very difficult—perhaps impossible—to describe and analyze transformative change through numerical simulation modeling. In many cases, these are changes that have not yet been observed, cannot be extrapolated from past conditions, and are insufficiently explored to be quantified in a way that can be used in models. [My translation].

A point of contention in the Swedish case is thus whether indicators ought to estimate future risks from trends, which requires the use of a consistent set of parameters with data rich enough to assess likelihoods, or whether they ought rather to diversify the parameters used, explicitly aiming to account for the contingency of the future.

6. Conclusions and discussion: sociotechnical information systems as sites for reciprocal capture

In the case of the Swedish climate policy framework, robustness has inspired administrators and seems to have become a guiding criterion for governing the complexity associated with climate change, directly factoring into impact assessment. Due to the ill-defined solution space that encompasses the collective action of climate change mitigation, administrators are faced with the challenge of uncertain linkages between policy measures and outcomes. This interest in robustness derives from an experience of increasing complexity, and from a growing recognition of the importance of measures that can mitigate against quantifiable risk. For administrators, this criterion is also consistent with those commonly used to manage other situations that cannot be forecast with certainty and have already been applied in many long-term planning contexts, such as that of water management (e.g., Dessai and Hulme, 2007; Groves and Lempert, 2007).

As we have seen, the models at administrators' disposal are incredibly powerful in shaping their collective matter of political concern into that of economic growth and efficiency. But while performance indicators, concerned with output legitimacy and to demonstrate the cost-effectiveness of policies (Scharpf, 1999, p. 16–28), have enacted key functions in Swedish climate policy impact assessment, their power has not gone unchallenged. While scenarios make available certain affordances at the expense of others (Beck and Oomen, 2021), the translation of qualitative conceptions about feasible mitigation pathways into a set of quantitative parameters and numerical model inputs is never indisputable (Alcamo, 2008, p. 143). Even though they provide the scientific basis for impact assessment, these measured quantities do not speak for themselves. Some administrators, including experts in the Swedish Climate Policy Council, have challenged the authority of robustness, emphasizing instead the value of resilient policy design as a potentially conflicting criterion for producing foresight knowledge of relevance to climate policymaking. What we know about climate change, these administrators and experts agree, is alarming enough, but what we do not know about the extreme risks could be far worse. As the burning of fossil fuels fills the carbon stock of the climate system to points of possible tipping, what we face is climate instability and disruption of everyday life. In other words, there is no means, no average, no return to normal—it is a one-way traffic into the unknown. While economic parameters that measure incremental changes to fuel prices and GDP feed perfectly into indicators like emissions abatement costs and policy measures such as carbon pricing, it risks institutionalizing a gradualism in responding to climate change that is entirely out of touch with the severity of the situation.

When it comes to relevance-making in Swedish impact assessment, the dialectical relationship between data and models thus highlights the need for attending to the sociotechnical systems through which the production of foresight knowledge takes place (Zimmerman, 2008). When enrolled in exploring, supporting, and legitimizing mitigation pathways, emissions scenarios are held in place by matrixes of administrative concerns, managerial boundary judgments, and technical practices, with the involved data being the result of constant interpretation. It means foregrounding the often-invisible practices of information system management, "[…] from sampling design choices to data collection methodologies, from calibration issues to quality assessments, from analysis algorithms to data presentations, from conceptual mappings to knowledge synthesis. From the diverse flows of information, forms of knowledge, and interrelationships between them, the view of an information ecology as an open system arises" (Baker and Bowker, 2007, p. 141). As foresight knowledge is produced through practices of numerical simulation modeling, its relevance is given meaning through the context and framing provided by these simulations, as well as through the way in which the flow of data through models makes agencies link up with each other in sociotechnical networks.

Such sociotechnical dynamics are expressed in ongoing boundary-work (Baker and Bowker, 2007, p. 137–138). As the case of Swedish climate policymaking demonstrates, the relevance of the foresight knowledge produced reflects the joint ability of models to give expression to a common set of indicators. Since it creates an exploitable space for differing interpretations in the quantification process, conceptual ambivalence within models can therefore be a threat to indicator validity. Indeed, the power of an indicator to overcome the polysemy of language is only ever as lasting as the network of actors engaged in the quantification process is held together by a consensus about its validity. In fact, the output of a model may very well be reliable, yet its policy-relevance contended on grounds that it has failed to evaluate the feasibility of net-zero transitions in a valid manner. To use Klenk and Meehan (2015) words, the "integration imperative" in Swedish climate policy impact assessment will not necessarily lead to a widened perspective for policymakers on the feasibility of mitigation pathways. Different indicators can be bound up with competing configurations of policy-relevance, and thereby also be contingent upon incompatible forms for sociotechnically organizing the government's integrated modeling-effort. Increased integration through stronger model coupling may for instance be a sound strategy for improving the robustness of policy options to quantifiable risks, useful for estimating the sensitivity of various sectors of the economy to price risks on fuels (Swedish Energy Agency, 2014; Swedish Environmental Protection Agency, 2015). However, such a strategy may not only be less useful but even outright detrimental to the ability of the Swedish action plan to address transformative change to cultural norms and behavior, simply because criteria for policy-relevance are configured by the organizational shape of the entire network of agencies. Even though indicator validity may be a question of potential controversy, there is an inertia to the network in the sense that the struggle between competing configurations of policy-relevance is as much of a social and technical as it is of a conceptual nature. These boundaries are not so easily drawn by any one agency, and they are not drawn exclusively in the heads of humans, but at least as much in technical inscriptions like parameters and model inputs, inscriptions that together constitute the information ecology within which these agencies can act.

Contrast this to the literature on the science-policy interface of integrated assessment, where dominant understandings of policy-relevance have tended to rely on an overly mechanistic notion of how scientific knowledge is organized and evaluated, one that assumes that all significant value judgments can be deferred to policymakers until after a select amount of feasible mitigation pathways has already been mapped out. Most proposals on the table for reforming integrated assessments of climate change draw inspiration from, and usually try to emulate, the ideal conditions of a deliberative model of scientific expertise. They involve changing formal rules and procedures to promote capacity building regarding devices, methods, and skills for integration and synthesis, or by coupling institutions to each other, such as by facilitating direct interaction between modelers and policymakers (Hulme et al., 2010; Edenhofer and Kowarsch, 2015; Kowarsch et al., 2017). While institutional rules and procedures can shape prospects for configuring policy-relevance, deliberative forums are ill-equipped to address how key indicators for political action are institutionalized through the choice and use of model parameters (Havstad and Brown, 2017, p. 108–115). Looking at the complexities of integrated modeling-efforts, and the ways in which these complexities interact with issues of outcome and assessment demarcation, it seems highly unlikely that the proper dimension on which to represent the feasibility of mitigation pathways can be determined without a thoroughly pragmatist interrogation of not only the "ends-in-view" (Kowarsch and Edenhofer, 2016, p. 302) but also the interdependency of means with these ends.

There is thus a need for an expanded understanding of policy-relevance, beyond institutional approaches and toward a process-based point of view, treating relevance as something in-the-making, whereby ongoing assessment demarcation on an information systems-level is at least as fundamental as the map of mitigation pathways that serves as the end-product of the assessment process (Aitsi-Selmi et al., 2016, p. 5–6). Emissions scenarios are important objects in this boundary-work. In the scenario analyzes of Swedish administrative agencies, there is a lack of agreed-upon standards for climate policy impact assessment (Swedish Climate Policy Council, 2020, p. 42–43), forcing these agencies to improvise.[7] By homing in on this balance between order and disorder, making the emergence of standardized forms of evaluation through scenario analysis into an object of study, we must consider how dilemmas of complexity and ambiguity in modeled representations of low-carbon futures are handled at the science-policy interface, such as the narrowing down of feasibility that indicators implicitly perform in assessing pathways toward net-zero emissions, or how the availability of the means to model certain dimensions of feasibility shapes the possible problem-solving conditions and determinants of success, such as through the choice and use of model parameters.

Such a change of perspective alters how sociotechnical interfaces in processes of integrated assessments are approached, treating model-based scenario analysis neither as the production of facts that can then inform value-based deliberations, as if scenarios merely communicate expertise about the means required to achieve a given set of ends, nor as an ideologically supported exercise of power on an unreliable basis of legitimation,[8] as if scenarios function exclusively as inscriptions of non-epistemic values, but rather as sociotechnical practices through which facts and values are simultaneously negotiated by administrators through the pragmatic navigation of their information ecology. Borrowing an expression from Stengers (2010, p. 42), these practices, from a process-based perspective on relevance-making, are better understood as giving rise to events of "reciprocal capture." To recognize sociotechnical information systems as sites for reciprocal capture is to assert that the configuration of policy-relevance that takes place at an information systems-level cannot be addressed by means of novel deliberative designs alone. On the contrary, a reciprocal capture emerges through a process of mutual interaction and is not engineered by one individual or group. Unlike institutional reform, information system-based boundary-work around processes for producing foresight knowledge involves diverse activities whose criteria for relevance emerge in the midst of those same activities. Rather than assume that scenario analysis can provide a range of different mitigation pathways given certain objectives and values, and then simply defer the decision between them to policymakers, this case study supports viewing the sociotechnical information systems that undergird the integrated assessment processes of Swedish climate policymaking through an ecological lens. Doing so points to the limitations of treating policy-relevance as the outcome of a sequential procedure, emphasizing instead the nonlinear and emergent nature of relevance-making.

7 In fact, historians of technology, such as Hughes (1989), have argued that a significant degree of flexibility is a necessary condition for the smooth function of large technical systems (LTS), whose development and maintenance over time requires the crisscrossing and renegotiation of boundaries.

8 What Pielke (2007, p. 3 *et passim*) refers to as "stealth issue advocacy."

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans, because the information collected is not considered sensitive. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

JDA conceptualized and designed the study, collected the empirics, performed the subsequent analysis, wrote all of the sections of the manuscript, and also took care of manuscript revision, read, and approved the submitted version.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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