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Getting models (and modellers) to inform long-term mitigation strategies

Abstract:

An increasing number of jurisdictions have issued long-term mitigation plans. Though the formats of these plans differ, they typically include one or several numerical scenarios. The present paper investigates what numerical model(s) are called upon to produce these scenarios, how they are used, and how models, modellers and, in some cases, other stakeholders contribute to the overall production of these Deep Decarbonization Strategies (DDS). Case studies in France, Brazil, the United States, Sweden show that for technical and institutional reasons large assemblages of models are typically used. The setting up of these assemblages requires significant work, especially when they are not (partly) inherited from past processes. The objective and configurations of these modelling assemblages can be very different, and the design of DDS is perceived to be successful when the political context and the objective of the process are aligned. Finally, there is always a tension between the granularity of the models – underpinning stakeholders' possibility to recognize their expertise in the modelling results – and the comprehensiveness of the model coverage – underpinning the planners' ability to get a systemic view of the proposed mitigation pathway(s). The paper concludes with tracks for further research on the issues raised by multi-model assemblages, which have not been considered by the academic literature.

Key policy insights

- DDS raises unique challenges for policy making (e.g. long term horizon, integrating sectors beyond energy, evaluating economic impacts).
- The setting up of these assemblages of models to evaluate DDS require time, resources, expecially when they are not (partly) inherited from past processes.
- Policy makers should support the creation of 'hybrid' modelling collectives bringing together, over a long period of time, modellers and experts by major sectors.
- Economic evaluations should be more at the heart of the process and consistent with sectorial analysis.
- More effort should be conducted to address the tension between granularity of the models and policy makers' expectations.

Key words: Mitigation pathway, mid-century strategy, NDC, modelling assemblage, public policy

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Introduction

In addition to their Nationally Determined Contributions (NDCs) to the Paris Agreement, which outline mitigation objectives for 2025 or 2030, a growing number of countries and regional institutions such as the EU are committing to deep decarbonisation objectives by mid-century, with such targets as "factor four" (a division by four of greenhouse gases emissions related to a base year) or, increasingly, 'carbon neutrality' (a balancing of remaining emissions by sources and removals by sinks).[1] These long-term objectives and the steps to achieve them are typically described in a national deep decarbonisation strategy document (hereafter DDS), the format and legal status of which depends on the context. Where they exist, DDS inform national submissions to the UN Framework Convention on Climate Change: NDCs and long-term mitigation strategies.[2] As such, they constitute innovative policy instruments that give an operational content to political and environmental objectives. They carry political weight because they are supposed to orient policies and shape expectations about future policy choices, thereby contributing to structure a 'green governmentality' or 'eco-governmentality' (Lövbrand and Stripple, 2014; Rutherford, 2007).

Compared with traditional policy-making, the production of DDS raises unique challenges. First, the long-term horizons of DDS extend much beyond the horizon of typical policy-making, resulting in high uncertainties and the impossibility for all the actors involved, including the government, to make actual commitments over such distant future. In fact, DDS often spell out broad orientations (e.g., penetration of renewables, reinforcing building retrofits, etc.) rather than detailed policies and measures. Yet their credibility depends on them influencing actual policies and measures, even though DDS are typically not legally binding. Second, meeting DDS ambitious decarbonisation objectives requires significant mitigation efforts in many sectors, much beyond energy. This adds one layer of complexity, all the more so that mitigation at such scale has potentially broad, economy-wide implications.

Governments preparing DDS have typically responded to the challenges outlined above by doing two things. First, they have involved a broad range of parties in the preparation of the DDS. This includes a large range of departments and administrations, as well as, in most cases, major non-public stakeholders such as business groups, unions, and NGOs. Second, they have mobilized numerical models from academia and/or public administrations to help them grasp the consequences of a wide range of mitigation actions in a wide range of sectors, and, ultimately, to lend some credence to the notion that the policy orientations spelled out in the DDS are in fact compatible with the deep mitigation objective stated in the DDS.

Though the role of numerical models in providing quantified forms of knowledge to help justify policy decisions in a (seemingly) objective way has been explored for a long time (Porter, 1995), this paper explores an under-researched issue in the literature, namely *how* models and modellers are embedded into these multi-stakeholder DDS processes. Specifically, we ask: *what types of models are used* in the process of developing DDS? And *how are they used*? This in turn allows us to tentatively draw some normative insights on

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[1] Art 2 states that global temperature to well below 2°C and pursue efforts to limit warming to 1.5°C. In accordance with Article 4, para 19, all Parties are called ('should strive') to formulate and communicate long-term low greenhouse gas emission development strategies. For an overview: https://unfccc.int/process/the-paris-agreement/long-term-strategies, last access on 26 November 2020).

[2] DDS are part of a growing number of strategies that national governments have been adopting since they started to implement sustainable development objectives (Rumpala, 2017).

how models should be used in such processes. As the case studies will show, there is indeed evidence that modelling practices polished in academic, single-model foresight exercises do not fully apply to rushed, multi-stakeholder, multi-model processes such as DDS elaboration. To do so, we draw both from critical social sciences approaches to the use of models in public policymaking, and from the more normative, 'best practice' thinking that modellers, engineers and economists rely on when they develop and use models. Our goal in crossing disciplines[3] is to capture both modellers' know-how and the fact that DDS processes bring this know-how to work in multi-model assemblages and in complex relational settings, acknowledging the fact that DDS modelling assemblages are both tools and relations, which jointly produce quantitative data and new collectives, shared visions, if not coalitions.

Our exploration relies on the observation of four DDS production processes: The second French National Low Carbon Strategy (2050 NLCS2), the Brazilian Intended Nationally Determined Contribution (2030 BINDC), the US Mid-Century Strategy (2050 MCS), and the Swedish Zero Net Emission Strategy (2045 ZNES). The paper is structured in three sections. The first introduces method and material. The second develops the four cases. The third discusses the use of models in these four processes and draws some lessons on how the specifics of DDS production processes questions modellers' tools and practices. Finally, the conclusion points out the limits of the paper and outlines lines for further research about DDS processes.

1. Method and material

Recent and under-analysed processes

Relatively few academic publications have addressed DDS processes in a non-exclusively technical perspective. Interestingly, they have focused on ways of bringing multiple calculations and visions into dialogue, thanks to the use of "dashboards". Such a practice has circulated quite widely, in different contexts, in the run up to the Paris Conference in 2015. Nadai and Aykut (2019) have developed a STS perspective (Science and Technology Studies) on the French National Debate about Energy Transition (DNTE, 2012-2013), showing how the recourse to different types of modelling and calculation practices, and the opening of the process to new 'collective of actors', helped bring to light new energy choices, especially 100% Renewables (REN). Importantly, this process relied on scenarios and visions devised by actors, which were brought into comparison and discussion through a simple spreadsheet-based dashboard template. Other authors have focused on a similar practice in participative research processes, yet involving one model (Mathy et al., 2016; Mathy, Fink, and Bibas, 2015). The systemic practice of dashboard drew from the Deep Decarbonization Pathway Project (DDPP) (2012-2015)[4], a research project aimed at building national capacities in scenario-making to support the elaboration of INDC. Bataille et al. (2016) had already put forward the relevance of structuring

[3] The authors of this paper are, respectively: economist and modeller, sociologist, and political scientist.
[4] The DDPP framework has been developed and utilized by a consortium of energy research teams led by The Institute for Sustainable Development and International Relations (IDDRI) and the Sustainable Development Solutions Network (SDSN) to to construct practical pathways to deeply reducing greenhouse gas emissions in 15 countries (http://deepdecarbonization.org/about/) (last access 27/04/2020). IDDRI has also been in charge, as a separate and distinct mission, of coordinating the French DNTE process.

stakeholders' dialogue around a 'dashboard' featuring the different visions of a country specific decarbonization challenge. This approach had been shared with South countries - Chile, Brazil, Columbia, Peru and South Africa - through the Climate Change Mitigation Action, Plans and Scenarios (MAPs) South-South project (2010-2015) (La Rovere et al., 2015). According to Kane and Boule (2018, p4) this action-oriented facilitated co-production of low carbon pathways in South countries, thereby creating 'communities of practice and a culture of knowledge sharing' and challenging a Northern de-contextualized climate change mitigation-development planning approach[5].

Although scenarios used in the devising of DDS are not published in academic journals, detailed material can be found in grey literature. Official national strategies reports provide useful insights, in spite of the language barrier (see the material mentioned in the case studies below). The implementation of the Paris Agreement has also raised awareness for DDS within international organizations and transnational initiatives[6], as illustrated by the recent WRI report (Ross and Fransen, 2017). Albeit an invaluable insight about DDS content and elaboration process - it highlights differentiated priorities and 'tones' in six countries (Benin, Canada, France, Germany, Mexico, and the US) – this report does not address the ways in which models have interacted during these processes.

Importantly, while the processes for devising DDS involve multiple models, the academic literature mostly address assemblages of no more than 2 models. As a result, there is no ready-made analytical framework to address the way in which DDS devising processes actually work or could better work. This is in sharp contrast with the abundance of academic literature since the 1970s, describing the results of quantitative foresight exercises, at different scales (global, national, local) and with different framing (economy, energy, sustainable development goals [SGDs] …) (Clark et al. 2016 for a recent review). This gap might be explained either by the cost of implementing such clusters of models or by the challenge of describing them within the framework of academic publication.

Country	Publication year	DDS name	Goals	Models involved	Legal status
France	2019	Low Carbon National Strategy (LCNS 2)	Carbon neutrality by 2050	Menfis (residential), Modev (transport), model of automobile park, agriculture and forest models, Prometheus (services), Imaclim-Fr and Threeme (macroeconomic)	Mandatory only for the State
Brazil	2015	Brazilian INDC (Intended National Determined Contribution)	37% GHG emissions below 2005 in 2025, 43% below 2005 in 2030	Imaclim-BR (macroeconomic), Message (energy), Matriz (forest), Leap (technology optimization), Blum (Land use), Waste simulation model	Based on existing mandatory policies
USA	2016	United States Mid-century Strategy for Deep Decarbonization	80 % GHG emissions or more below 2005 levels by 2050	GCAM (macroeconomic) (NEMS), EPA Global Timber model, USDA Forest Assessment System Service Model	Not legally binding
Sweden	2017	Zero Net Emission Strategy	Carbon neutrality by 2050	Sectoral models (land use, energy, industry), TIMES-Sweden (technico-economic), EMEC (macroeconomic)	Legally binding

Table 1: Main features of the four DDS analyzed (Source: CIRED)

[5] https://mapsprogramme.org/ (last access 11/12/2020)
[6] This is for instance the explicit mandate of the 2050 pathway platform https://www.2050pathways.org/about/ (last access 11/12/2020)

Tools and relations, figures and visions

In order to analyse how these combinations of multiple models work and/or should be made to work, we adopt an interdisciplinary approach, drawing from social sciences and modelling. The idea is that any combination of models is made up of modelling tools and relations, and it produces both relations and figures. Relations result in collectives of actors working with or around a modelling tool or a scenario, as well as in visions about the future(s) that are shared by these collectives. Shared visions are a key outcome since they mean that protagonists such as heterogeneous stakeholders and modellers, who do not necessarily share the same interests, come to share an understanding of what our common future can be. Figures are quantitative data describing what these futures can be. Additionally, in these processes, the possibility of and performance in producing figures is intimately articulated to the way in which the relations between tools and people are set. Studying DDS processes in a complete way will be conducted by crossing social sciences which allow us to acknowledge the relational dimension of these processes and modelling (as a discipline) to address the organisation of calculating operations.

Modelling assemblages

Since DDS involve several models, we can call them modelling 'assemblages'. The notion of assemblage is well known in Science and Technology Studies (STS) (Callon, 1986; Latour, 1993; Walker and Day, 2012). It has even been used in order to describe settings for scenario making ('predictive policy assemblage'; Aykut, 2019). The notion is interesting because it brings emphasis on the relational dimension of DDS processes. Indeed, as *several* models are involved in producing a DDS, these processes rely on webs of relations between models, modellers and non-modellers. The way in which these relations are organised is key for the way in which models and protagonists perform. Importantly, sociology and political sciences have developed a critical perspective on the use of models in policy making processes, stating that models are part of the emergence of an anticipatory (and more reflexive) State (Guston, 2014). They then warn that models could act as black boxes enforcing technocratic values and ways of knowing (Wynne, 1984; Jasanoff, 2010) and address the multiple roles models can play. Models can serve as mediators in the sense that they do not only translate theories, they have certain autonomy in representing the realm and help us learn about it (Morgan and Morrisson, 1999). They can also contribute to legitimate policies and certain views by producing quantitative data (Desrosières, 1999; 2000; Porter, 1995). Models can thus be used to convey and enforce values, either as instruments of government (Rose, 1991) or as instruments of activism (Bruno et al., 2015).

(Good) modelling practices

Designing clusters of models raises issues that are addressed through mundane modelling practices. This include for instance: setting up the order in which different models should process data; writing taxonomies that bridge the categories of one model with that of another one; explicating the assumptions underlying the production of data so as to make it transparent to collaborators, stakeholders or the larger public.

There is an abundance of methodological literature about the structure of quantitative forecasting models, such as about: the tension between the so-called Bottom-Up approaches ('engineer's' models, with a high technical content) and Top-Down approaches ('economist's' models, with a high macroeconomic content) (Weyant, 2017; Hourcade et al., 2006), the interpretation of the notion of cost (Hourcade et al., 1996) or the transparency of models (Pindyck, 2017). The 'art' of constructing models (degree of precision, choice of objectives) was also the subject of specific analysis (Merrick and Weyant, 2019).

There is however little work on how swarms of different models can be exploited. One exception is the literature about how to link Bottom-Up and Top-Down modelling approaches, one strand of which is devoted to coupling techniques (Börhinger and Rutherford, 2008; Lefèvre, 2016). The other dimensions of the articulation between models (e.g. steps to be followed in the interactions between modellers, better ways of exchanging data between models etc.) are absent from the literature, whether academic or 'grey'. Importantly, there is no formal corpus of 'best practices' about these issues, which could, for example, have been formalized by institutions such as the Integrated Assessment Modelling Consortium (IAMC). Alike, with regard to interactions between modellers and stakeholders in participatory scenario building, the literature is quite extended for single-model based processes, especially in the backcasting literature (Robinson, 2003; Robinson et al., 2011), but limited to our knowledge when it comes to considering assemblages of models.

At least, the choice of scenarios for exploring variants is addressed in the more general methodological literature on foresight (for example, Swart et al., 2004). This choice depends in particular on the approach adopted, either normative and based on a given future ('backcasting') (Robinson et al., 2011), or exploring a full range of possible pathways to reach the objective (Lempert et al. 2006). While there are no explicit or written 'good practices' about how to explore variants, modellers do agree on right ways of doing so, using methodologies such as scenarios axes (van't Klooster et van Asselt, 2006) or '*story-and-simulation*' (Alcamo, 2008a, 2008b), Monte Carlo analysis or robust decision making (Lempert et al., 2003). Such 'good' ways of practicing do not however necessarily fit processes that rely on multiple models because of the relational and technical complexities involved in these processes. In what follows, we will take this specific issue as an example and a pretext to reflect on how to approach the good use of models in DDS devising.

Five case studies

The material on which we rely is a census of DDS processes, identified through a survey of academic and grey literature. While this survey was quite extensive and strongly equipped (Lepault and Lecocq, 2020), the lack of academic publication about DDS processes only allowed pointing out few cases of DDS processes (Table 2). These four processes cover a range of configurations in terms of intensity of modelling (use of variants), articulation between models/ modellers, and between modellers and other actors (concertation).

	France	Brazil	United States	Sweden
Articulation between modellers and stakeholders	X	X		X
Articulation between modellers	X	X	X	
Use of variants	X		X	X

Table 2: *Relevance of selected cases (source: CIRED)*

The US Mid-Century Strategy (2050 MCS) strongly relies on integrated modelling and a close articulation between academic modellers and the federal administration. The French Low Carbon National Strategy (2050 NLCS2), the Brazilian Intended Nationally Determined Contribution (2030 INDC) and the Swedish Zero Net Emission Strategy (2045 ZNES), combine a different range of modelling competences with stakeholders' concertation, while varying as to the type of modelling involved (resp. energy, multi-sectorial, multi sectorial and economic) and the organisation of concertation.

While the Brazilian, Swedish and US processes have mostly been informed on the basis of the available literature and archives, completed with a semi-directive interview with one key player in the process, the French process was subjected to a deeper inquiry, based on more extensive written information and more interviews [13 interviews: public administration 4, academic researcher 2, public agencies 4, energy consultancy 1, energy expert 2]. This allowed us to derive insight from this process, about the issues that multi-model assemblages may raise in DDP design processes, insight that was used in order to develop our inquiry about the other three DDP processes. Thus, these other processes have mostly value as counterpoints to the insight derive from the French process.

2. DDS case studies

2.1 The second French Low Carbon National Strategy: a long-term modelling assemblage in the making (2050 LCNS2)

The French DDS (LCNS) is embedded into law since 2015. Its elaboration runs every five years, parallel to a short-term (2030) energy policy planning (PPE). The former is run under the heading of the environment branch of the climate-environment department (DGEC) of the French ministry of environment, whereas the latter is supervised by its energy branch.

PPE is short term and submitted to institutionalised public debate. It is closely watched after by stakeholders from the energy sector, because it impacts their current activity. The French DDS, on the contrary, is not endowed with a legal status making it mandatory to actors other than the State itself. Yet, its mere existence sets it as a counterpoint to short-term energy policy planning, and forces PPE to explain the coherence of its objective with long term Net Zero Emissions targets.

The scenario production for the first version of French DDS (LCSN 1) in 2015 was basically commissioned by DGEC to a private consultancy. By contrast, for the second version (2050 LCSN 2), issued in 2019, a wide array of models has been mobilized, controlled by several public agencies and loosely coupled together. They produced, in a condensed timeframe (Spring 2016 – Autumn 2018), one unique long-term scenario, which is the backbone of the LCSN 2 strategy.

This change in setting was impulsed by DGEC, because of limited funding, and because commissioning did not allow it to 'capitalise'[7] expertise and run the devising with sufficient agility when it came to interact, internally, with the political level (ministry cabinet). The intended setting (figure 1) was to use 'macro' models to simulate the 2050 'net zero' horizon and guide the work of sectorial technico-economic models, which outcomes (2030, 2050) would then be aggregated thanks to an aggregative model (MEDPRO) and translated into emissions to adjust to neutrality. Last, a macroeconomic evaluation of DDS would be run to inform recommendations. 2030 outcomes would be based on the full implementation of existing (but not necessarily yet implemented) policy measures (EPM); 2050 would include supplementary policy measures (SPM), not yet adopted but deemed necessary to meet carbon neutrality by 2050.

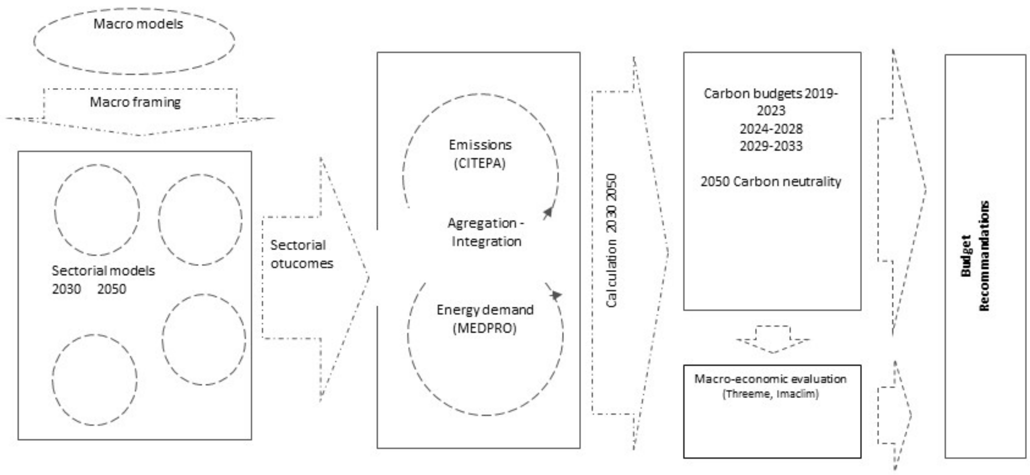

Figure 1: Modelling assemblage in SNBC 2 (intended setting) (Source: CIRED)

The extreme results obtained by macro-models (sky-rocketing energy prices, de-structured industries, etc.), however, proved these to be brought beyond their range of validity by the 'net zero' objective. The DGEC had thus to adapt and decided to proceed through 'backcasting'[8] in three steps: first constructing an image of 'carbon neutral' France by 2050 and the associated sectorial targets (based on available scenarios and expert judgement; designing first 2030 EPM then 2050 SPM) (September 2017-April 2018), then adjusting the trajectory for achieving it in a confrontation with PPE (May-June 2018), finally calculating and aggregating the emissions budget corresponding to this trajectory (Summer-Autumn 2018).

[7] Public administration, interview of the authors
[8] Public administration, interview of the authors

The exercise proved challenging in several ways. The DGEC clearly had had very few time to anticipate the organisation of the process and, above all, needed to change method given the limitations of macro models. This resulted in the DGEC not having the time to properly structure the sectorial working groups, and thus becoming the point of 'passage' and coordination for virtually all relations between modellers and experts at all steps. The centralised organisation of the process put modellers in a situation where they could neither grasp the meaning of their contribution to the process nor make sense of the trials and errors at work.

The now limited commissioning of the aggregation work also constrained the DGEC to wait the ultimate step in the process to delegate the final aggregation of the results. Most of the intermediary aggregations and the runs to answer political demands had to be undertaken with an ad hoc spreadsheet-based dashboard. This became utterly challenging when it came to aggregate not only end points but trajectories (2030 and 2050). This was particularly acute, at the end of the process, when the confrontation between PPE (2030) and LCNS (2050) showed a discrepancy at the 2030 points, PPE emissions being higher than SBNC ones: the negotiation imposed SNBC 2030 point to align with PPE 2030 one. Importantly, as the modelling assemblage developed, the communication between the technical and political branches in the Ministry became also challenging: it was increasingly hard to translate the complex web of proxies - political measures have to be translated into proxies in the model - and technicalities into simple political terms. In the end, capitalising on both errors and innovations met transparency issues because technical adjustments, deemed worth to be memorised for the continuity of the modelling assemblage and the SNBC 3, had for some of them endorsed a political meaning that made them difficult to be publicised on the spot.

The French DDS process sheds light on some potentially important dimensions of DDS processes. First, articulating models together and with stakeholders' consultation, produces both quantitative figures and collectives (working groups, coalitions) that share visions of the future. Both outcomes should be recognised as decisive to sustain the emergence of shared long term policy objective. The French DDS has an original political framing in which long term devising ends up interacting with short-term energy policy planning. While this raises tensions, it can be regarded as productive in making the LT objective of the strategy ('net zero') palatable to most and forcing explicit negotiation at crossroads.

Second, it shows that introducing DDS objectives - such as net zero emissions - in modelling exercises may bring models at the limit of their range of validity, witnessing of their embedding into ongoing political objectives and calling for an updating of these implicit political norms. This means that DDS have a role that goes beyond the mere devising of scenarios and partake into to a political updating of policy assemblages.

Third, DDS devising, because it relies on linking multiple-models to stakeholder consultation, requires resources and time, so to coordinate the adequate phasing and distribution of roles across actors and tools. Capitalisation and continuity in time seems highly desirable.

Last but not least, on a technical level, the process witnesses a tension between the granularity of the modelling assemblage – representing the different sectors, translating policy measures into proxies – and the capacity to share and circulate a simple appraisal of its technical and political meaning.

2.2 The Brazilian 2030 Intended Nationally Determined Contribution: inheriting and integrating short term modelling and participation assemblage under political support (2030 INDC)

In December 2009, under Lula's government, the Brazilian climate policy was adopted with the objective to reduce GHG emissions from -36,1% to -38,9% by 2020 (incl. LULUCF) which then fed the Brazilian Copenhagen pledges (Brazil, 2009; Viola, 2009, 2013; Da Silva and Visentini, 2010). Three years later, Brazil launched a process in order to prepare the devising of the GHG commitments to be included in its intended Nationally Determined Contribution (INDC) at the Paris conference. The two year IES-Brazil participative research project (2013-2015) was part of this process; it was aimed at developing 2050 scenarios with stakeholders and at assessing their socio-economic implications. The Brazilian Forum on Climate Change (FBMC), gathering the main political stakeholders, ensured the overall supervision of INDC devising. A Scenario Building Team (SBT) was established. It brought together around 100 stakeholders from industry, government, NGOs and trade unions, spread into six sectorial working groups (agriculture, industry, transport, energy, housing, economy), which met five times.

The process leaned on a modelling assemblage gathering sectorial models, which assumptions and outcomes were made consistent and aggregated through the IMACLIM-Br macroeconomic model. IMACLIM-Br was in charge of sending macroeconomic and technological information to the sectorial models, which in turn modelled the energy supply (quantities, investments) and the related emissions (Lefevre, 2016; la Rovere et al., 2018) (figure 2).

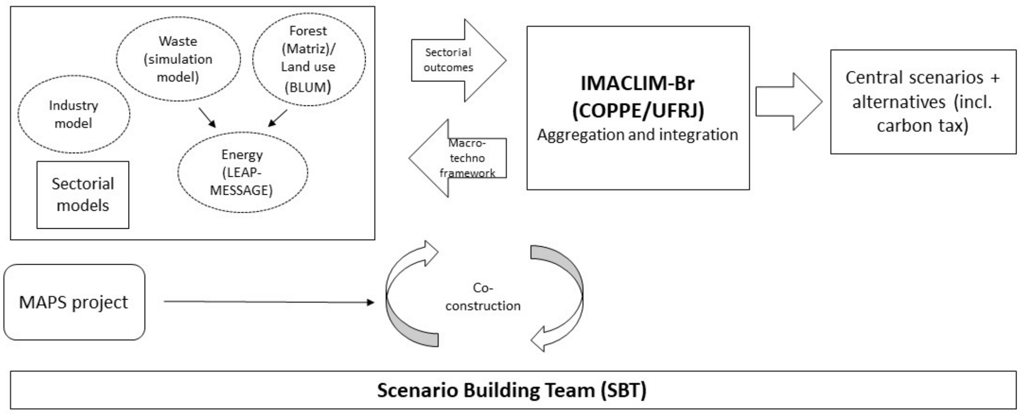

Figure 2: Modelling assemblage in the IES process (source: CIRED based on Pereira et al., 2014)

The technical coordination of the SBT was ensured by Centro Clima/COPPE (UFRJ), an academic department, which had been part of a longstanding network between academic research and ministries, and benefited from close connections with the Ministry of Environment. The process also benefited from COPPE parallel involvement in the South-South countries MAPS project, in which a participatory scenario-building methodology, first implemented in South Africa in 2005, was used[9]. When IES-Br started, the methodology

[9] The MAPS project was coordinated by the University of Cape Town. At its origin is the South African Long Term Mitigation Scenarios project (LTMS) sponsored by the South African government (2005-2008). Low-carbon energy transition scenarios were developed with a range of stakeholders, using techno-economic models as a tool for dialogue. These scenarios fed into South Africa's position in Copenhagen and contributed to the development of its national energy and climate policies.

was thus already operational. This and the time offered by IES-Br upstream from scenario making, allowed the researchers to visit all the partners (sectorial modellers, stakeholders) and prepare the collective work. This eased learning and in-depth stakeholders' involvement, in a context of coupling of a wide array of models.

Compared to Brazilian past modelling exercises, which had mostly been techno-sectorial, a key innovation was the introduction of a macroeconomic dimension in the process, through Imaclim-Br. This made it possible, among other things, to reflect on a set of dimensions that some stakeholders (e.g. business sectors) felt decisive in order to legitimize the feasibility and relevance of climate policies. These dimensions were for instance: the design of climate policies (e.g. assessing different options of recycling tax), their level of ambition, the short-term and long-term articulation, the impacts in terms of international competitiveness and redistributive effects.

Three scenarios were elaborated. The reference scenario - called 'Government Plan Scenario' (GPS) - was based on current set of measures. The two alternative scenarios of the Brazilian energy and low-carbon transition in 2030, included additional mitigation measures in the transport and residential sector (Additional Mitigation 1 - AM1), with early implementation in one of them (Additional Mitigation 2-AM2). Both alternative also included a tax-neutral carbon tax – resp. US$ 20/tCO2 for AM1 and US$ 100/tCO_2 for AM2 – recycled on labour taxes. The overall conclusion of the study was that ambitious climate objective accompanied with adequate supportive policies (e.g., AM2) had a very limited impact on business competitiveness and economic growth. The Brazilian INDC was designed as a middle pathway between the two alternative scenarios.

The IES-Br process has therefore benefited from a political momentum, anticipation for its setting up, and inherited relationships between research and the government. This allowed the participatory process between modellers and stakeholders to fully develop, within the hybrid collectives, as 'a participatory scenario building project, not just a participatory modelling exercise'[10]. This resulted in a genuinely collective learning process and laid the ground for an epistemic community[11] (bringing together members of the administration, sectorial experts, etc.) capable of influencing decision-making, as initially aimed by the MAPs project.

The modelling process in itself has also been intense and integrated. The IMACLIM-Br model was used as a tool for mediation with groups of experts and has contributed to a real acculturation effect. The existence of an ecosystem of models, most of which located at the Centro Clima /COPPE, also eased modelling interactions and helped making the overall exercise more reactive and flexible.

2.1. The US Mid-Century Strategy: an administrative-academic long term modelling assemblage to showcase official commitment to mitigation (2050 MCS)

Under the Obama administration, the DDS exercise (henceforth called the mid-century strategy) was primarily aimed at convincing the rest of the world (and partly US stakeholders and institutions) that such a strategy was feasible by mid-century in the

[10] Academic, interview of the authors.
[11] We use that term according to the meaning given by Haas (1992).

country. The 2050 MCS was elaborated in a very short timeframe (11 months); the strategy was officially submitted to the UNFCCC on 16 November 2016.

The preparation of the 2050 MCS built on an extensive modelling work, largely based on the Global Change Assessment Model (GCAM), an integrated assessment model (IAM) jointly developed since the 1990s by the Department of Energy's Pacific Northwest National Laboratory (PNNL) and the University of Maryland. The preparation work focused on the role of agriculture and forestry in achieving emission reduction targets (-80% in 2050 compared to 2010). It consisted in making main GCAM assumptions (e.g. biomass carbon sequestration, costs and evolution of energy technologies) consistent (without real integration)[12] with other forestry and energy models (see Figure 3). Finally, a model of marginal abatement costs in non-CO2 sectors developed by the U.S. Environment Agency (EPA), was used downstream to assess mitigation potential in these sectors (integrating the carbon price generated by GCAM).

The MCS was piloted directly from the White House by a team led by Rick Duke, President Obama's Special Assistant for Climate Change. This team mobilized a network of experts, from the EPA and the Department of Energy and Agriculture (DEA), who had already worked together, notably on two occasions: the preparation of the joint declaration between the US and China on climate change and clean energy (2014), and the second biannual review of US emission reduction efforts submitted to the UNFCCC in January 2016 (Duke and Hansel, 2018). Within this inherited network, GCAM and other modellers were set in close cooperation with the federal administration, without much participation from the outside. Though leatening workshops were organized by the White House with stakeholders, NGOs and private sector representative, very few mentions of them are in the official documents, revealing for the study coordinators, Duke and Hansel, one of the main limitations of the process.

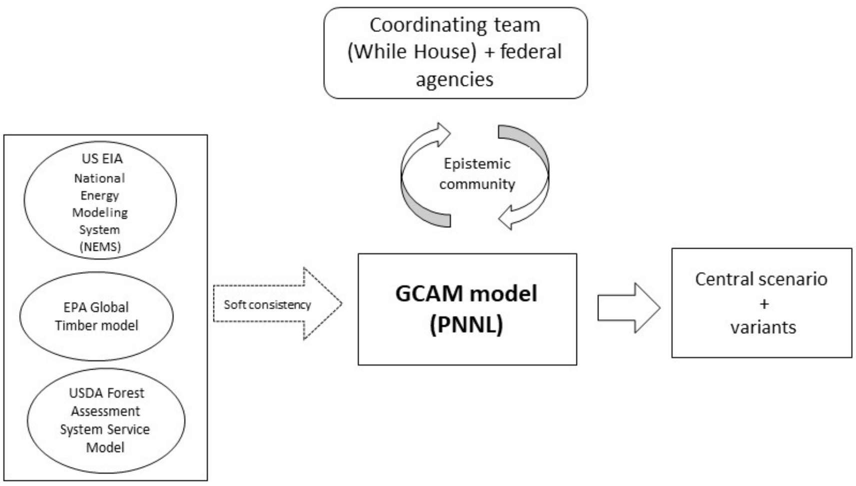

Figure 3: Modelling assemblage in US MCS (source: CIRED)

Sensitivity analysis was central. Seven variants of the central scenario were produced to demonstrate that the -80% objective was robust to changes in assumptions about the technology (Duke and Hansel, 2018), especially regarding potential for carbon sinks, and carbon capture, use and storage (CCS).

[12] Academic, interview of the authors

Two of these scenarios illustrated the somewhat alternative strategy: a 'Beyond 80' scenario based on a globally ambitious effort, and a 'smart growth' scenario with a strong focus on energy efficiency. The 2050 MCS strategy eventually relied on these two variants to demonstrate that the main pillars of decarbonization (e.g. electrification, decarbonized electricity, energy efficiency, soil and biomass sinks, CCS) were robust to uncertainty.

Different from the French DDS, the 2050 MCS was a 'one shot' political attempt to position into an international process without looking for a national consensus (Duke and Hansel, 2018). The efficiency of the process depended upon a pre-existing shared culture of modelling / scenario making between a highly recognized modeling institution (PNNL) and parts of the federal administration. Such an inherited integration and political framing allowed for a fairly straightforward and technical foresight exercise.

2.2. The Swedish Zero Net Emission Strategy: a modelling assemblage embedded in an integrated and participatory institutionalized process (2045 ZNES)

The Swedish DDS (henceforth called Zero Net Emission Strategy (2045 ZNES)) is embedded into law since 2017, when a new climate policy framework was adopted (Table 1). It consists of a Climate Act, climate targets and a climate policy council (Swedish Ministry of the Environment and Energy, 2017).

It results from a two-stage political and expert process. In 2011, the EPA was commissioned by the Swedish government - public agencies are regularly asked to update GHG baselines to be reported to the UNFCCC and EU - to prepare a 2050 carbon neutral roadmap (Sweden Environmental Agency, 2012). The EPA coordinated a set of public agencies, research institutes and a private company, so to bring together sectorial expertise (modelled or not), and feed them into scenarios (figure 4). For each sector, explorative scenarios were developed using a backcasting approach. The relatively short time frame of the study (July 2011- December 2012) did not allow for strong interactions with stakeholders. In particular, representatives from the steel industry, which felt 'skeptical'[13] about carbon neutrality, conditioned their participation on the harmonisation of CO_2 prices on a global scale, as well as on the adoption of an international carbon permit system to allow for flexibility.

Three scenarios were produced, each articulating a set of sectorial outcomes. The baseline scenario (- 25% in emissions compared to 1990) included measures and instruments adopted until 2011. The two carbon neutral scenarios were respectively based on high energy efficiency gains in the transport, household and agricultural sectors, and on large scale electrification (with heavy reliance on hydrogen) in the transport and industry sectors.

[13] Member of the Swedish EPA, interview of the authors

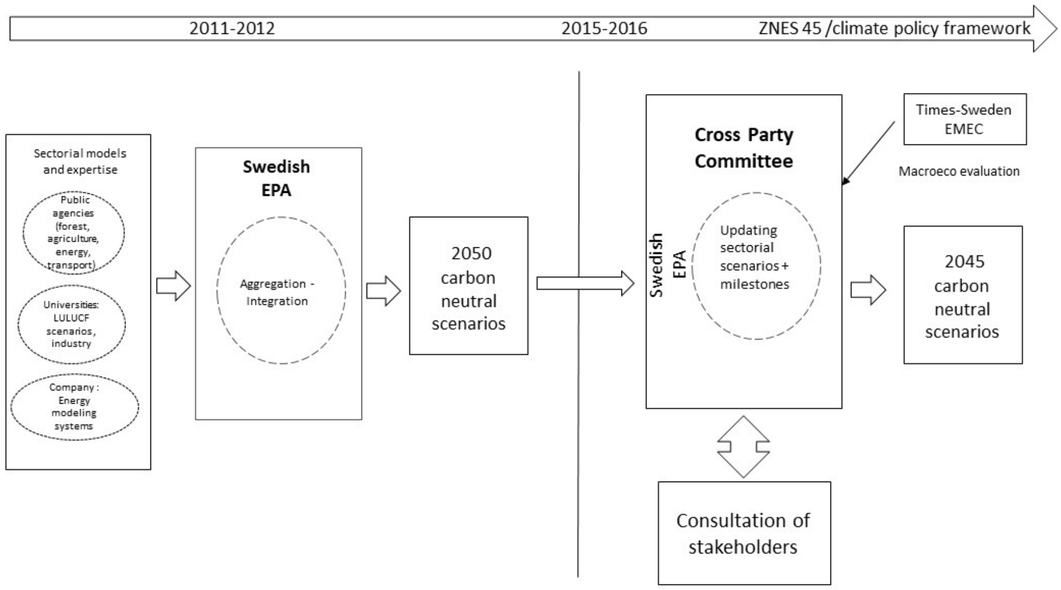

Figure 4: modelling assemblage in the ZNES 45 (source: CIRED)

Then, in 2012, the Green Party (formally allied with the Social Democrats) introduced the idea of a Climate Policy Framework. In 2014, a Cross-Party Committee was set up with the aim of advising the government and develop proposals in cooperation with public research agencies, about how to achieve decarbonisation targets (incl. milestones, targets and other public policy instruments).

The committee brought together 8 representatives from all parties (except the far right) and consulted with experts from business, civil society, and other government bodies. Its chair, Anders Wijkman, was a leading figure in environmental activism in Sweden. The secretariat was entrusted to the Swedish EPA. The work lasted one year (2015-2016). It reported twice to the Government in June 2016, first on 2045 carbon neutral scenarios, and secondly on the air quality co-benefits of decarbonisation policies, providing important basis for devising the Climate Policy Framework.

One basis of the work of the cross-party committee was the 2012 EPA study. Some members considered its outcome as to conservative and pushed for more disruptive assumptions in the field of lifestyles changes[14], especially in the wake of the adoption of the Paris agreement. Polices and measures for each sector were revised with a particular focus on domestic emission reduction efforts. The time horizon was reduced from 2050 to 2045 and milestones included in 2030 and 2040 (for non ETS sectors) and beyond (net-negative emissions). TIMES-Sweden (Luleå University of Technology) and EMEC (National Institute of Economic Research) models were mobilized to define this emission trajectory and evaluate their technico-economic implications (SOU 2016:21; SOU 2016:47) (figure 4). In contrast with 2012 EPA study, stakeholders consultation was key and 'reassured' the committee members on the feasibility of the neutrality objectives (e.g. CCS and H2 reduction in the industry sector)[15].

[14] Member of the Swedish EPA, interview of the authors
[15] Member of the Swedish EPA, Interview of the authors

The Swedish 2045 ZNES has therefore benefited from a research and institutional ecosystem centred around government agencies. The Swedish EPA was key in the two-stage political and expert process that began in 2011. Building upon the EPA work, the Cross-Party Committee stresses the decisive role of politics in the devising of DDS.

3. Lessons learned

We draw six main insights from the case studies analysed above.

First, DDS are developed under very different political framings depending on country circumstances. In some, they are part of the devising process of climate and/or energy policy and endowed with legal / mandatory status (e.g., France, Sweden). In others, they are developed in parallel with these policies, which they help steer. In the latter, they play a key role in articulating short- and long-term climate objectives without being endowed with any clear legal status (e.g., Brazil). Last but not least, they can be developed as separate and independent exercises, for example to serve a strategic positioning in international climate processes (e.g., US), without any formal articulation to domestic energy or climate policy. Experiences are perceived as successful when the political context and the objectives of the process are aligned.

Second, all DDS surveyed are built using arrays of loosely connected models. This is because no single model can encapsulate all the relevant expertise (on the energy sector, the various demand-side sectors, non-CO2 gases or LULUCF). This is also the result of the strategy of different agencies (e.g., France, U.S., Sweden) or of different stakeholders (Brazil), which insist on bringing in the models they master and trust. Plurality of expertise is also viewed as relevant in such complex matters, as shown by the IES-Br parallel process and the recent Quinet Commission in France (Quinet, 2018).

Third, linking modelling to stakeholder consultation is possible, but requires preparation and resources. It has been done successfully in Brazil and in Sweden, but neither in the U.S. (where stakeholders consultation was not part of the political framing of DDS) nor in France (where the two processes have remained mostly separated). The US case, however, draws attention to the links between the administration which supervises the process, stakeholders and modellers. Longstanding modelling assets and assemblages (experience in working together with and around modelling tools) highlights the importance of upstream 'epistemic communities' (Haas, 1992). Creating the conditions for the emergence of 'hybrid communities' of modellers, stakeholders and the administration appears central to create an efficient learning processes. However, the modelling assemblage set up for the French LCNS2 is complex. Whether it can be maintained until LCNS 3 is debatable.

Fourth, in the assemblages of models that we have observed, the emphasis is on checking that the emissions target is met. The costs and economic implications of DDS, on the other hand, are seldom analysed (Brazil being the exception). This is not surprising because the consistency between elements of the strategy and its stated emissions target is the central reason models are convoked in the first place (Brazil being the exception again). In addition, very stringent targets such as carbon neutrality can put economic models beyond their validity range (e.g., France). However, lack of economic analysis is problematic because costs and implications of DDS for other economic objectives such as sustaining economic growth, reducing unemployment or reducing inequality matter critically for the acceptability and ultimately the implementation of the policies. In Brazil, the economic analysis was decisive in order to discuss and negotiate the feasibility and legitimacy of the DDS with the business sector.

Fifth, models 'best' degree of granularity to inform DDS construction processes is debatable. On the one hand, stakeholders need to be able to 'see' their expertise reflected in the categories and the numbers, and thus need some disaggregation. On the other hand, too many variables create black boxes; they make the results less tractable and the discussion with policymakers less transparent (France). Moreover, models typically cannot represent policy measures. They often capture measures by proxy (e.g., manipulating the rate of discount to represent a tax credit), or by assuming the results of measures (e.g., x thousands of thermal renovation of buildings done each year).

Finally, the number of scenarios produced varies considerably across exercises (from 1 in France to 8 in the US). Normally, in a forward-looking exercise of 'prospective', one should explore the future using several variants. Yet, at the end of the day one needs one unique DDS. The content of the variants depends on what issues the exercise puts emphasis on, and on the interactions with stakeholders (e.g., Brazil, US, Sweden). The complexity of the modelling ecosystem can also limit the possibility to develop sensitivity analysis, while this seems less the case for simpler and more integrated (between research and the administration) assemblages (e.g., US).

Conclusion

This paper has analysed in depth how models are conveyed and used to produce scenarios within DDS. Based on four case studies, it has scrutinized some modelling assemblages – defined as assemblages of models, tools and relations between modellers, stakeholders and the administration – that are brought to work in order to design DDS, and how they are or have been brought to work.

Our analysis underlines that DDS are produced by multi-model assemblages. It shows that the corresponding modelling assemblages produce figures, visions and also relations, and that all of these are equally important when it comes to successfully devise DDS. Accordingly, the setting up of these assemblages requires significant work, especially when they are not (partly) inherited from past processes. This in turn points to the importance of institutional, relational and technical heritages in easing this work. The case studies that we have considered also suggest that DDS devising is perceived as successful when the political context and the objective of the process are properly aligned.

DDS devising raises issues related to the right granularity of the models, because this granularity allows stakeholders and planners to gauge the alignment of DDS scenarios with their respective objective. It also raises issues as regards to the proper ways of articulating models – be it soft or hard linking – in an assemblage and the proper ways to develop variants in scenarios and / or sensitivity analyses. While ways of doing such things are known by modellers, this knowledge is mostly shared for single-model assemblages in the literature. As shown by our case studies, the complexities involved in working with multi-model assemblages suggest that there is no evidence that good ways of practising single-model assemblages can straightforwardly apply to multi-model ones, a challenge for further research.

The study proposed in this paper should also be enriched by considering a more important number of case studies, refining or challenging some our lessons and conclusions.

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