This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No *837089*.

Topic: LC-SC3-CC-2-2018 of the Horizon 2020 work program: *Modelling in support to the transition to a Low-Carbon Energy System in Europe*

BUILDING A LOW-CARBON, CLIMATE RESILIENT FUTURE: SECURE, CLEAN AND EFFICIENT ENERGY

Project number: *837089*

Project name: ***Sustainable Energy Transitions Laboratory***

Project acronym: SENTINEL

Start date: 01/06/2019 **Duration: 36 months**

Deliverable reference number and title:
D1.1: The use of energy modelling results for policymaking in the EU
Version: 1

Approved, revised due date of deliverable: 09.2020
Submission date: 18.08.2020

Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	
EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)	
EU-CON	Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)	
EU-SEC	Classified Information: SECRET UE (Commission Decision 2005/444/EC)	

The use of energy modelling results for policymaking in the EU

August 2020

SENTINEL

IASS POTSDAM

Renewables Grid Initiative

TEESlab
University of Piraeus Research Center

SENTINEL

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No *837089*.

Note about contributors:

The deliverable criteria are met by the teams of the Institute for Advanced Sustainability Studies (IASS) Potsdam, the Renewable Grid Initiative (RGI), and the University of Piraeus Research Centre (UPRC).

WP leader responsible for the deliverable:

Johan Lilliestam (IASS)

Contributors:

Diana Süsser (IASS)
Andrzej Ceglarz (RGI)
Hannes Gaschnig (IASS)
Vassilis Stavrakas (UPRC)
George Giannakidis (UPRC)
Alexandros Flamos (UPRC)
Antina Sander (RGI)
Johan Lilliestam (IASS)

SENTINEL Internal Reviewer:

Anthony Patt (ETHZ)

Please cite as:
Süsser, D., Ceglarz, A., Gaschnig, H., Stavrakas, V., Giannakidis, G., Flamos, A., Sander, A., & Lilliestam, J. (2020). The use of energy modelling results for policymaking in the EU. Deliverable 1.1. Sustainable Energy Transitions Laboratory (SENTINEL) project. Potsdam: Institute for Advanced Sustainability Studies (IASS).
DOI: 10.48481/iass.2020.058

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Acronyms

ARE	Energy Market Agency
CAKE	Centre for Climate and Energy Analyses
CO_2	Carbon dioxide
CRES	Centre of Renewable Energy Sources
E^3MLab	Energy-Economy-Environment Modelling Laboratory
EED	Energy Efficiency Directive
EEG	Renewable Energy Sources Act
EEWärmeG	Renewable Heating Act
EU	European Union
GER	Germany
GR	Greece
IRENA	International Renewable Energy Agency
ITRE	Renewable Energy Directive proposal, the Industry, Research and Energy
NECP	National Energy and Climate Plan
NTUA	National Technical University of Athens
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
RED	Renewable Energy Directive
PEP	Energy Policy of Poland until 2040
POL	Poland
SWE	Sweden

Executive summary

Achieving the EU's commitment under the Paris Agreement, the Energy Union Strategy, and the European Green Deal, requires a significant transformation of current energy systems. Renewable energy is a major component of this transition, and thus, policymakers face the challenge of making decisions about new renewables-dominated energy systems. Because real world experimentation is in large scale not possible, models can serve as 'laboratories' by allowing policymakers to explore different decarbonisation options in a virtual world and generate a better understanding of the policy domain.

While many energy policies are backed by computational models, we do not know exactly how and when policymakers use models, and to what extend policymakers influence modelling performed. We take these gaps as a starting point to empirically investigate the twofold processual interaction between computational energy modelling and energy policymaking. In particular we study: (i) how and when models are used in the policymaking process, and (ii) whether and how policymakers influence the design, use and results of energy modelling. Thus, we investigate how energy modelling and energy policymaking affect each other, so as to advance future model development for sounder policymaking. We conducted analyses of modelling and policy documents and performed 32 interviews with four different stakeholder groups in five different jurisdictions within Europe.

First, we show that **models are used and have an impact on policymaking**. Depending on countries context, we reveal that models are used to push ambitious climate and energy policy, while in other cases models are not used at all, or model results are used to justify political inaction. Furthermore, we show that modelling tools function as 'laboratories of sustainable transition' and support decision-making processes along the whole policy-cycle: from target setting, through policy formulation to evaluation. Models are especially useful when they are set up to directly answer specific questions that policymakers might have, i.e. to explore the implications of options that they are considering. In contrast, they are less useful when they tell policymakers what course of action, from the modeller's perspective, would be best. We find, however, that model use is also limited, because of the complexity of modelling processes, as well as the lack of open data and open-source models. In the end, models have to compete with other information sources and concerns.
Second, we also show that **policymakers influence models and modellers**. Especially, 'in-government' and government-commissioned modelling allows policymakers to set the framework conditions of modelling performed. Even a higher level of the policymakers' influence is reflected by deciding over how models and their results are politically used. Overall, the case studies demonstrate, **energy modelling and policymaking can influence each other**

‘for the good and for the bad’: they can foster radical policy changes and ambitious target setting, or they can be instrumentalised to justify inaction and radical no-change, respectively.

Based on our research, we draw **implications** for the development and use of models for and in policymaking: first, models should be improved to be applied as ‘sustainable energy transition laboratories’, not delivering exact numbers, but to be used for exploring questions and policy measures policymakers are having in mind. In this regard, they can be applied within stakeholder processes to catalyse the political and societal debate on what are the pros and cons of different possible energy futures. Second, open-source models and an open modelling platform can foster model understanding, trust and use, as well as deliver comparable and credible results for European and national policymaking. Importantly, all interested stakeholders from the energy sphere should have an equal and understandable access to such tools, even if they are not modelling experts and developers, because it could increase model legitimacy and impact in policymaking. To conclude, computational energy models can assist in exploring different energy futures towards Europe’s climate neutrality, but it requires ambitious modelling in line with the Paris Agreement, the Energy Union’s objectives and the European Green Deal.

1 Introduction

To meet the EU's commitment under the Paris Agreement, the Energy Union Strategy, and the European Green Deal, a significant transformation of current energy systems is pivotal. Renewable energy, as a major component of the transition, brings new dynamics to the current fossil-based energy systems, which makes the decision-making process about the energy future more complex. Policymakers face the challenge of making decisions about new renewables-dominated energy systems, like for example, designing policies supporting the decarbonisation of the energy system (Purkus *et al.*, 2017) or dealing with sector-coupling (Pfenninger *et al.*, 2014), while balancing interests of involved actors at the same time (Stavrakas *et al.*, 2019).

Because real world experimentation is in large scale not possible, models can serve as 'laboratories' by allowing policymakers to explore different decarbonisation options in a virtual world and generate an understanding of the policy domain (Gilbert *et al.*, 2018). Modellers produce results that should be useful for policymakers; however, despite of the growing relevance of models for ambitious climate and energy policymaking (Pfenninger *et al.,* 2014), we do not really know whether, how and when policymakers use models – do they use them as sources of information, experiment incubators, or rather as justification devices for policies they already want to implement. Moreover, we do not know exactly what kind of impact the policymaking sphere has on the energy modelling process. We take these gaps as a starting point to investigate how policymaking and energy modelling influence each other.

1.1 Energy models and their role in European policymaking

Models are purposeful, mathematical simplifications of reality – "smaller, less detailed, less complex, or all together" (Gilbert and Troitzsch, 2005:2), but they are also shaped by, and potentially shaping, the social world in which they are embedded (Van Egmond and Zeiss, 2010). The same holds true for the modellers themselves, who define the model's nature-based theories, empirics, and also their ideas and mental models, respectively (Ellenbeck and Lilliestam, 2019). Thus, computer models and mental models are mutually dependent.

In this regard, models can function as 'discursive spaces' or 'negotiation spaces', bringing together different social worlds – such as represented by scientists and policymakers – and enabling these worlds to create shared understanding, work together, and negotiate knowledge and policy (Star and Griesemer, 1989; Evans, 2000; Van Egmond and Zeiss, 2010). Hence, energy models can support governmental decision-making processes (Lopion *et al.,* 2018); however, they cannot be a "final decision for the policy process to [be] simply implement[ed]" (Gilbert *et al.*, 2018:2).

Pfenninger *et al.* (2014) distinguish between four key groups of energy models relevant for national and international climate policies: energy systems optimisation models, energy systems simulation models, power systems and electricity market models, and qualitative and mixed-methods scenarios. Optimisation and simulation are common underlying methodologies of energy models (cf. Lopion *et al.*, 2018), which provide solutions of lowest economic costs of the energy transition, and represent developments of energy systems based on potentials, costs, policies and constraints, respectively. Those energy system models are often combined or completed with macroeconomic models. Different approaches to modelling are represented by agent-based models, or models based on network and fuzzy theory (e.g., Jebaraj and Iniyan, 2006; Süsser, 2016; Stavrakas *et al*., 2019). Depending on the problem formulation and input data, diverse model types are suitable to be deployed in policymaking in different ways: while some models help to understand long-term developments and answer a wide range of energy policy questions, others answer precise policy questions, relevant to specific sectors or localities (Savvidis *et al.*, 2019).

Energy models have been used for policy advice and in policymaking processes in Europe, such as to explore potential energy futures, or alternative socio-technical pathways and scenarios (Geels *et al.*, 2018). They are contributing to energy policy-making processes indirectly by referring either to model-based studies or to scenarios published in other contexts. Dedicated model runs are conducted for particular policy processes and directly used by official government institutions for policy guidance. In this context, governments seem to have different approaches and practices to modelling. While some of them do model runs internally, other governments commission modelling-based studies. For example, in the UK, the MARKAL model, and subsequently TIMES-UK, have been helping to underpin energy and climate policies for over 35 years (Taylor *et al.*, 2014). Taylor *et al.* (2014:35) noticed a shift from using models "to focus on the relative prospects of specific technologies in order to inform R&D priorities, towards a focus on the costs and possible evolution of the entire energy system to meet carbon targets". Currently, modelling has been embedded and institutionalised in the energy policy community and contributes to target-oriented climate policy in the UK. Another example provides Switzerland, where after the Fukushima nuclear disaster, the government commissioned the consulting company Prognos to carry out a modelling-based study, determining how the Swiss energy system should develop until 2050 (Prognos AG, 2012). Although the feasibility of future energy scenarios drawn in the Swiss Energy Strategy 2050 have been questioned (Piot, 2014) and evaluated with other models (Redondo and Van Vliet, 2015), the policies resulting from the modelling were largely adopted the way Prognos suggested it.

A recent survey by Chang *et al.* (2020) found that among 48 investigated energy system modelling tools, almost two-third had a direct or indirect policy impact. Over a third of the modelling tools did not have any identifiable policy contribution, because they are rather new in-house developments, mainly used within academic research, or because their application had a limited scope (Chang *et al.*, 2020). Thus, many models fall short of their potential in policymaking (McIntosh *et al.*, 2008). Several difficulties along the policy process cause the gap between the design of models in research and their use in policy (McIntosh *et al.*, 2008; Van Ittersum and Sterk, 2015; Capros, 2016; Savvidis *et al.*, 2019; Chang *et al.*, 2020), such as: inability of models to fit to end-user needs (McIntosh *et al.,* 2007), missing transparency of models (Pfenninger *et al.*, 2018) and lack of trust, inability of models to deliver timely support for decision-making, missing capacities in institutions to make use of complex modelling, the diversity of stakeholder involved in the decision-making or changes, and uncertainties inherent in the policy environment (Kolkman *et al.*, 2016).

By engaging policymakers and other stakeholders in the modelling process, this gap can be counteracted and the chance of model use increases (van Daalen et al., 2002; Kolkman *et al.*, 2016; McDowall and Geels, 2017). As a result, various forms of stakeholder-informed modelling have been developed, such as participatory modelling, mediated modelling, companion modelling, group model building, or participatory simulation (for a review see: Voinov and Bousquet, 2010). In this context, policymakers can be engaged at different stages of the model development: from data collection, through model construction and validation, to interpretation of model results and model use (cf. Voinov and Bousquet, 2010).

1.2 Objectives

To unfold the potential of models to support ambitious European Union's (EU) and national climate and energy policies, it is paramount to reflect on and better understand the way models and their results (do not) influence policy decisions (or vice-versa). We conceive energy modelling and policymaking as dynamic processes over time. We define energy models as computational models in the field of energy, which are dealing with multiple dimensions of energy systems, whereas policymaking concerns issues related to rules and procedures on how and to what extent modelling results are integrated into policymaking sphere as well as to who is involved in these processes.

In this deliverable, we empirically investigate the twofold processual interaction between computational energy modelling and energy policymaking. In particular we study: **(i)** whether, how and when models are used in the policymaking process, and **(ii)** whether and how policymakers influence the design, use and results of energy modelling. Thus, we investigate how energy models and energy policy affect each other, so as to advance future model development for a sounder policymaking. We deliver rich empirical findings, which in a comparative way present similarities and differences between processes and mechanisms in different institutional settings. Even though we expect diversity in the interactions between energy models and energy policymaking in different cases, we aim to draw general lessons for the use of energy system models especially in view of the European policy mid-century strategy. Finally, we address implications of energy models future potential role in decision-making, as well as draw implications for the development of an energy modelling platform under the EC-funded Horizon 2020 project SENTINEL[1].

The overall contribution of this deliverable is: **i.** we contribute to the understanding of the use of computer-based support tools in policymaking by investigating diverse model purposes along the policy-cycle, **ii.** we add to the literature on stakeholder-informed modelling by investigating forms of collaboration between modellers and policymakers, **iii.** we contribute to the previously often only indirectly addressed aspects of policymaking's influence on modelling, and **iv.** we provide new perspectives on (open source) modelling to accelerate the potential of modelling towards decarbonised economies and societies.

[1] https://sentinel.energy/

2 Theoretical underpinnings of policy processes

As a theoretical starting point, we apply and complement the classical political research ‘formula’ by (Lasswell, 1958) on "*Politics: Who Gets What, When, How*” to conceptually structure the influence of models in energy policymaking. We consider *who* (which actors) provide *what* (information) to *whom* (policymakers) via *which* channels (personal conversations, emails, …) with *what* effect (impact). While the channels appear to be less relevant for our research, the questions of *why* and *how* are which means of information sources used and *when* in the policy cycle, are highly relevant.

Policy processes are complex and continuous processes, which involve interactions over time between public policies and actors, contexts, events, and outcomes, including different sources of pressures and information (Lasswell, 1958; Shipman, 1959). Some research has put emphasis on the role of different interests groups and coalitions, to highlight various actors influencing the policymaking process (Sabatier, 1988). Since policymakers (*who*) have only limited temporal, organisational and economic resources available to evaluate information *(what)* and to base their decisions on it, they need to prioritise some information over other (Botterill and Hindmoor, 2012). Therefore, information matters (Jones and Baumgartner, 2005), which leads to the consideration of *what*, and *how* different means and carriers of information (like models) are actually used, and *when* in the policy process.

Although being a simplified reflection of the political reality, the policy cycle model reflects the policymaking process quite accurately. The stages of the policy cycle include agenda setting, policy formulation and adoption, policy implementation, and policy evaluation. The cycle then starts again, as new circumstances or needs generate new policy demands (Weible and Sabatier, 2017).

Instead of applying a concrete theoretical framework to each case study, we take an abductive approach (Héritier, 2008), giving us the flexibility to consider appropriate frameworks for studying the most important aspects in a specific political context. We apply Lasswell’s formula and the policy cycle model not to make a deep analysis of processes themselves, but to structure *how* models support political decision-making processes, and at *what* stage of the policy cycle: to set their agenda/target (exploring), develop policies (ex-ante assessment), justify implementation of policies (validating) and/or evaluate targets and specific policies (ex-post assessment) **(Figure 1).**

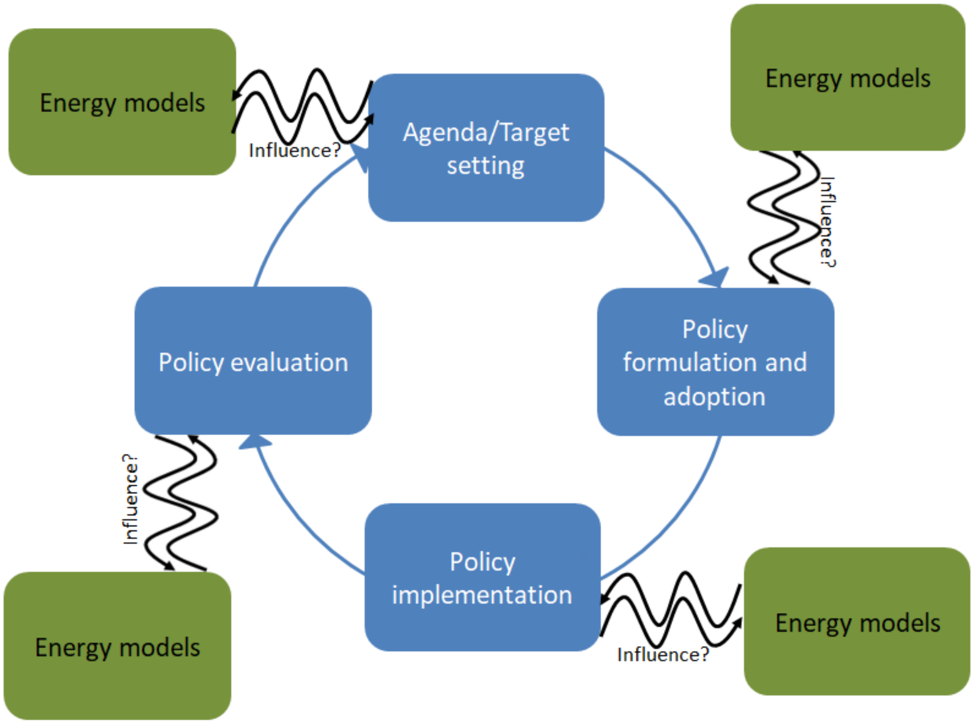

Figure 1: *Simplified policy cycle and potentials for the use of models*

3 Methods and case studies

To empirically study the interaction between energy models and energy policymaking, we applied a triangulation approach (Wolf, 2010), in five case studies, examining events leading up to major policy decisions in the recent past (<10 years).

3.1 Methods

First, we performed a document analysis, based on policy documents, such as legislation, position papers, assessment reports, and (government-commissioned) studies, as well as secondary literature describing policy processes. The document analysis was done to derive key information on policy processes themselves, confirm and redefine respective case studies to be investigated in more depth, gain first insights on model's use in policymaking, and identify relevant stakeholders to be interviewed.

Second, we conducted 32 interviews to fill the knowledge gaps from the document analysis and to get a deeper understanding about the role and the use of models in the policymaking process, as well as the influence of policymakers in model development and improvement. We interviewed four different stakeholder groups: policymakers, working in the governments/European Commission or governmental organisations (abbr. "P"); scientists and analysts, working in academia or consulting (abbr. "S"); energy industry representatives, including transmission and distribution system operators (abbr. "I"); and representatives of civil society organisations (abbr. "C") (**Table 1**). Note, that we do not interview all stakeholder groups for each case study, given their relevance in the case study context. It should be also noted that the classification of stakeholders, which we adopted in our research is quite simplified and it represents a stakeholder group, to which an interviewee belonged at the time of conducting the research. In reality, some interview partners have rich modelling experience, which they have gained in their professional work in differentiated fields, often changing the environment between policymaking, industry and research. The interviews followed a semi-structured guideline, which has been pre-tested and revised project-internally. To reveal how the policy process was influenced by models, we asked about the role of modelling in policymaking generally and in specific policy processes, and how modelling impacted policy decisions. We also asked how the collaboration between policymakers, modellers and other potentially involved actors looked like, whether policymakers influenced modellers and/or modelling exercises performed and about institutional structures determining the involvement of external actors in the energy modelling process (see **Appendix 1**). Interviews were partially conducted in the official language of the case study country and thus, presented quotations have been translated by the authors. Furthermore, more interviews have been requested than finally conducted. Potential reasons for this are the COVID-19 pandemic, which demanded much attention of many countries, and controversial debates surrounding policy decisions and model use to which no information wanted to be provided. The interviews were recorded, transcribed, and analysed (Creswell and Creswell, 2018). The interviews were analysed performing a content analysis and process-tracing (Collier, 2011). Based on the insight of what models were used by which actors and when, we developed a timeline for each case study.

***Table 1:** Stakeholder groups interviewed in the different case studies*

Stakeholder groups interviewed (abbreviation for citation):	Policymakers ("P")	Scientists and consultants (modellers) ("S")	Energy industry ("I")	CSO's ("C")
Country:				
EU	3	1	2	2
GER	2	1	-	-
GR	1	2	1	-
POL[2]	1 (2)	4 (5)	1	3
SWE[3]	4	4	-	-

To synthesise the findings across the cases, we also assessed the relative influence of the interaction between energy modelling and policymaking. For modelling on policymaking, we defined the influence and effect to be s*ignificant,* if modelling results made it into final policy documents, or demonstratively influenced final policy decision; *meaningful,* if modelling results were used within negotiation processes; *moderate*, if modelling results were used at some point of the policy-making process; *and low,* if modelling was conducted but did not have any substantial influence in the policy-making process. For policymaking on modelling, we defined the influence and effect to be *significant*, if policymakers determined modelling process; *meaningful*, if policymakers were closely involved in the modelling process; *moderate*, if policymakers were partially involved in the modelling process; and *low*, if policymakers were not meaningfully involved in the modelling process.

3.2 Case studies

In order to reassure plausible generalisations of our research, we chose five case studies providing sufficient variance in terms of policy scope and focus. We investigated different

[2]Since in two cases the interview was conducted with more than one person, numbers in brackets show a total number of interviewees, which represented the same institution or stakeholder group.
[3]One interviewed scientist was based in Norway, while being interviewed because of its expertise in the context of the Nordic electricity market.

jurisdictions within Europe: the EU as a whole, Germany, Greece, Poland, and Sweden. The case studies have been selected based on their differences in regard to radical change or maintaining non-ambitious *status quo* in the context of decarbonisation policies, with clear and documented references to energy models' use, as well as to their geographical diversity. The time range of analysed cases encompasses mostly recent interactions between modelling and policymaking (up to five years), with some exceptions in the German and Polish cases. For each case study area, model developers and users, as well as model results' users have been identified, and interactions between the two groups investigated. We focused on specific cases of policymaking, which did not allow us to provide a complete picture of the modelling exercises done within a country. In **Box 1**, we briefly present the relevance of each one of the case studies selected.

Box 1: *Case studies investigated*

With its global ambitions to be a climate change mitigation leader (Oberthür, 2011) the **European Union** delivers an overarching framework for the case analysis. For more than a decade it has been strongly influencing national energy policies of Member States (cf. Solorio and Jörgens, 2017). The recent establishment of various policy frameworks, like the Energy Union Strategy, the Clean Energy for all Europeans package and the European Green Deal reinforces its position. While among diversified measures the renewable energy development constitutes a backbone of these endeavours, there have been controversies around the overall EU ambition by 2030 in that matter (Bürgin, 2015), as well as around the modelling accompanying this process (Graf and Buck, 2017).

Germany is not only one of the most influential Member State of the EU, but it also played a pivotal role in pushing the development of renewable energy policies, either at the global or at the European level, harmonised with domestic energy transition, known as the *Energiewende* (Cox and Dekanozishvili, 2015; Steinbacher and Pahle, 2016). The German Renewable Energy Source Act has been the main regulation supporting the ambitious and dynamic renewable energy deployment. Yet, its 2009 amendment and especially the reduction rate of the feed-in tariff of photovoltaics caused a lot of national controversies, which not only involved numerous political actors, but which were also built around modelling results.

Greece is a transcontinental country with a diverse geographical landscape and a large potential in renewable energy (Stavrakas and Flamos, 2020). It presents a very recent case of a radical change in the planning of the energy system development. Although the introduction of renewable energy was actively promoted in the energy policy agenda over the past ten years (Nikas *et al.*, 2019), indigenous lignite continued to play a major part in the electricity generation in all scenario analysis and policies formulated until 2019. However, in the second half of 2019, Greece took the political decision of phasing-out lignite-fired power plants in a short time horizon (by 2028), which called for extensive modelling work to analyse its effect on the further development of the energy system.

Some climate and energy policies' scholars in their analyses characterise **Poland** as an extreme or an exceptional case (e.g.: Kundzewicz et al., 2019; Szulecki, 2020). Here, it represents a case, in which the non-implementation of ambitious decarbonisation policies has roots in a report based on modelling. During the 2008 EU's negotiations over the 2020 climate and energy package, a study conducted by a consultancy company EnergSys (EnergySys, 2008) was a base of Poland's position. It argued that the package's implementation would impact the Polish economy negatively. This statement became one of the strongest arguments in the narrative explaining Poland's reluctance to ambitious climate and energy policies (Karaczun, 2011). More than a decade later, this approach has not changed substantially, as modelling results continue to support little ambitious renewable energy targets (Ministry of State Assets, 2019a).

Sweden has a strong national climate policy and the highest share of renewable energy in its gross final energy consumption (54.6 %) among the EU members (Eurostat, 2020). Thus, it serves as a global model of ambitious climate policy (OECD, 2014). At the same time, Sweden can benefit from being part of the common Nordic energy market system, and its large natural resources, delivering the foundation for the use of hydro energy and biofuels. Furthermore, over the last decade, Sweden has experienced a vast development of wind and solar energy projects, leading to decarbonised electricity and heat sectors. Sweden's ambitious climate policy framework sets the further policy signal towards net zero greenhouse-gas emissions by 2045. Extensive modelling has supported the development of the framework and beyond.

4 Results

Our research reveals the influence between computer-based modelling tools and energy policymaking in both directions: models have an influence on policymaking, and policymakers do influence model developments and improvements. Based on our data, we could identify three main categories underlying the energy modelling-policymaking nexus: (i) *influence sources* – concerning the questions different actors involved (who), and the relevance of models in relations to other sources; (ii) *model purpose* – considering what kind of models have been used and why; and (iii) *model process* – concerning the way models are used when along the policymaking process. **Figure 2-6** provide overviews of the process-tracing for each case study.

4.1 EU Renewable Energy Directive 2018: modelling-backed revision of the renewable energy target

The European energy policy is based on three pillars: security of supply, competitiveness and sustainability. In the course of the last 15 years, the latter − embodied by decarbonisation − became the most important factor guiding the EU's policy actions (EU_I1; EU_P1; EU_C1). As one of the representative of policymaking put it: "*I see the climate policy as number one […] and this is our main paradigm for policy*" (EU_P3). In this context, since early 2000s energy models have played a substantial role in supporting the EU in planning and designing of energy-related policy proposals, mostly by accompanying modelling-based impact assessments. The PRIMES model (E3MLab and ICCS, 2014), a modelling set of tools for energy and CO_2 projections[4], occupies a prominent position in this regard (EU_C1). Started as an EU-financed research programme, it has been utilised mostly by the DG Energy (EU_P1). The PRIMES model, next to macroeconomic models E3ME (Pollitt, 2019) and GEM-E3 (E3MLab and ICCS, 2010), was also applied in the impact assessment of the 2018 Renewable Energy Directive. Impact assessment, focusing on the heating sector only, used: FORECAST, Invert (Kranzl *et al.*, 2006), Green-X (Huber *et al.*, 2004) and Astra-EC models (Breitschopf and Winkler, 2019).

In October 2014, the European Council determined the initial target of 27% of renewables share in the EU's final energy demand until 2030. This decision was not supported by any modelling exercise (EU_P2). In November 2016, the European Commission presented the 'Clean Energy for all Europeans' package – a comprehensive proposal of eight legislative acts, which aimed at shaping the EU energy policies' landscape for the decades to come (Hancher and

[4] For an overview of models used by the EC see: https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en (16.06.2020).

Winters, 2017). One of the new regulations concerned the recast of the Renewable Energy Directive, with the same overall target of 27% of renewables' share **(Figure 2).** The Council meeting in December 2017 confirmed this minimum target. Experts criticised the impact assessment accompanying the Renewable Energy Directive for its conservative and overestimated cost assumptions of renewable energy and CO_2 prices (EU_C2; Graf and Buck, 2017). While the European Commission was aware about these shortcomings, it held to the minimum target of 27%, because of its political mandate coming from the Member States (EU_P3). It was not clear, however, what should be a maximum target, according to which additional modelling exercises were meant to be made (if conducted at all) (EU_P3).

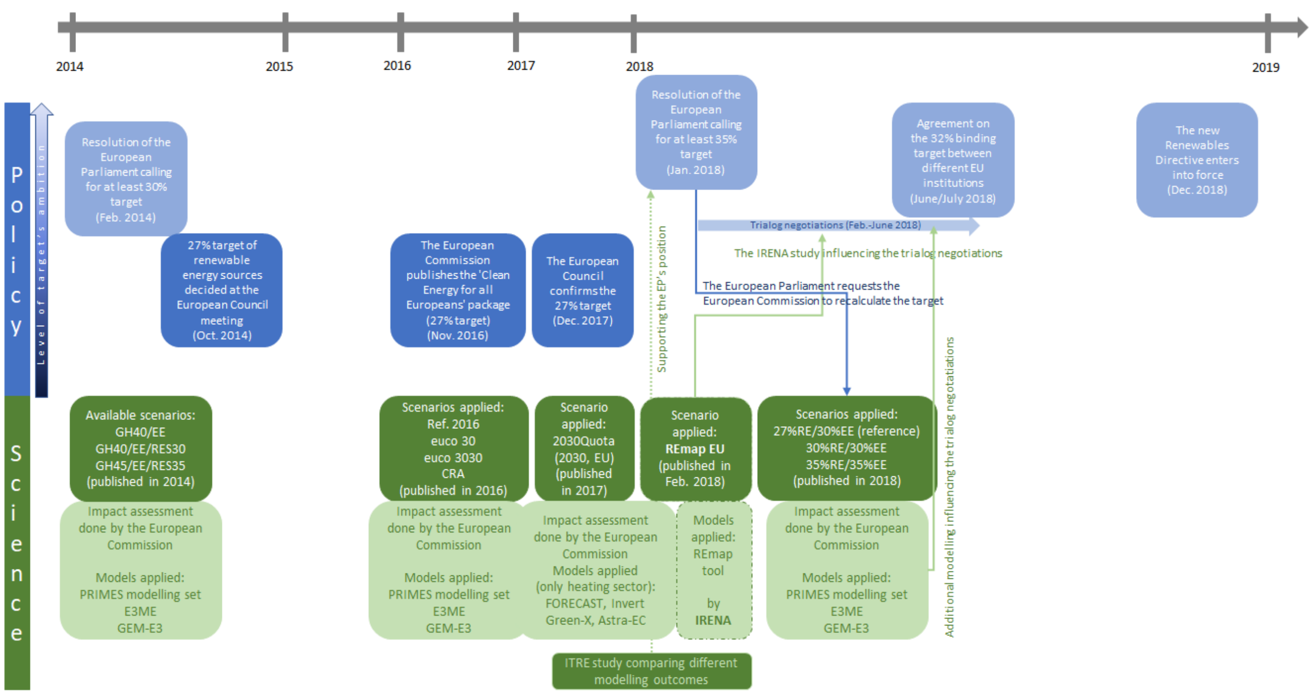

Figure 2: *Timeline presenting the evolution of the European renewable energy target until 2030*

The European Parliament undertook different attempts to re-define and increase the renewable energy target. Already in February 2014 it called for at least 30% of renewables target (Breitschopf and Winkler, 2019). After presentation of the Renewable Energy Directive proposal, the Industry, Research and Energy (ITRE) committee of the European Parliament took over the responsibility for this document. A small, but extremely engaged group, consisting of some parliamentarians and their assistants investigated in detail the impact assessment (EU_S1; EU_P2; EU_C2). They received additional support from an external analysis that compared various model-based studies concerning the feasibility of higher renewable energy targets (Winkler *et al.*, 2018).

Based on that work, in January 2018, the European Parliament voted for a binding 35% renewable energy target and gave a mandate for trilogue negotiations (European Parliament, 2019). At the same time, the Parliament requested the Commission to recalculate its impact assessment, assuming higher renewables numbers (EU_P1; EU_P2). Although this inquiry was reinforced with lobbying attempts of NGOs and different sectoral actors, which prepared their own modelling analyses (EU_I2; EU_P2; EU_C2), it was a modelling study conducted by the International Renewable Energy Agency (IRENA) (Janeiro *et al.*, 2018) that convinced policymakers that a higher renewables target is feasible. This argument was strengthened by IRENA's institutional credibility (EU_S1; EU_P2). Additional impact assessment conducted by the European Commission confirmed this claim.

The trialogue process was dominated by political negotiations between Member States (EU_P1) and a significant role in this process played Italy and Spain, which in the meantime experienced government changes in favour of higher renewable energy targets (EU_S1). Thus, although modelling had a meaningful influence on policymaking beforehand, the final decision about the 32% of renewables target adopted at the end of 2018 was an effect of political negotiations. As some of policymakers involved in the process summarised it: "*In the end, of course, it's always a very political decision*" (EU_P2) and "*this is not the models that fix the target*" (EU_P3). Yet, the role of modelling should not be underestimated: on the one hand it enabled to develop internal capacities of the EU institutions by improving a better understanding of the energy system (EU_P1). On the other hand, it opened up the discussion advocating for higher renewables targets and based on scientific results – as one of interviewees described: "*It doesn't mean, however, that whatever comes from the modelling is automatically endorsed as a proof by policymakers, but that's the ground. That creates […] a battlefield and based on that, different opinions can be exchanged. But everything starts with the modelling*" (EU_P2).

4.2 The German photovoltaic reform in 2009: Model assumptions under fire

The Renewable Energy Sources Act (EEG) is the legal basis for the support scheme of renewable energy diffusion in Germany. In the context of the 2009 Act's revision, a contrary scientific as well as severe political debate took place that lasted almost two years. According to the policy analysis of the Act by Dagger (2009) and confirmed by the interviews (GER_P2), two coalitions dominated the debate as opposing opinion leaders: an environmental-friendly coalition guided by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and an economic coalition guided by the German Federal Ministry for Economic Affairs and Energy. The reduction rate of the photovoltaic feed-in tariff, so-called 'degression factor', was one of the main topics of dissent. Finally, the law change in 2009 substantially increased the factor from 5% to approximately 10% (Dagger, 2009). During the political process two energy models, namely ARES and PowerACE, were of meaningful importance, of which one in particular contributed to the controversy (GER_P2; GER_S1) (**Figure 3**).

Since 2002, the Environment Ministry had been responsible for renewable energy and, consequently, also for the preparation of the Renewable Energy Sources Act amendment (GER_P2). The Ministry commissioned two model-based scientific studies for impact assessment and adjustment recommendations of the Act (Nitsch, 2007; Sensfuß and Ragwitz, 2007). While non-commissioned studies were less noticed by the Environment Ministry (GER_P2), it relied much on the commissioned non-model and model studies in the preparation process: *"We definitely wanted the number [for the photovoltaic feed-in tariff] from them, which we should write into the law"*, stated one policymaker (GER_P2). Therefore, the assignment was clear, while only view instructions regarding the modelling were provided by the Ministry.

Nitsch and his team used their ARES model for a scenario-based economic assessment of renewable energy deployment in Germany (Nitsch, 2007). They showed that the short-term total cost increase in the electricity sector by substantial renewables investments could pay off for German welfare in the long-run. The scenario analysis highlighted that photovoltaic installations would drive the short-term cost peak of additional costs; however, it also showed that after a while the curve of additional costs fell below the costs of the baseline scenario representing a fossil-fuel-based energy system. Thus, the short-term investment in renewable energy, including photovoltaic, would start amortising from a societal perspective in the medium-term (Nitsch, 2007). However, the scenario's assumptions came with uncertainties which were communicated transparently with the Environment Ministry. A modeller of the team expressed it as follows: *"[...] we always emphasised that the model is poor, because [...] we don't have the market dynamics in it [...]"* (GER_S1). Those doubts and other aspects were discussed within the meeting between the Environment Ministry and the modelling teams.

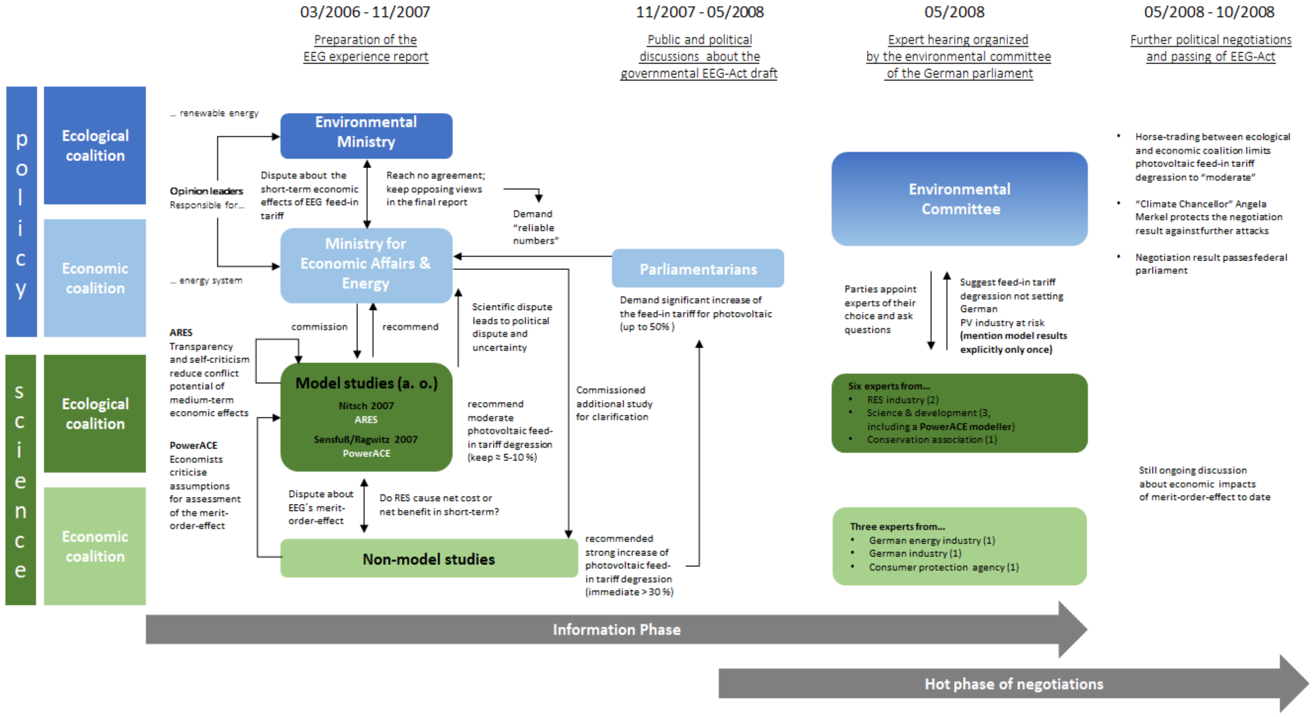

Figure 3: *Timeline of the German Renewable Energy Sources Act 2009 policy cycle with a focus on the role of science and especially energy models*

Sensfuß and Ragwitz used the electricity market simulation model PowerACE and investigated the so-called merit-order-effect (Sensfuß and Ragwitz, 2007). They concluded that in 2006 the prioritised feed-in of renewables by the Renewable Energy Sources Act lowered the prices on the electricity exchange more than they caused total additional expenses for society. As a result, renewables made economic sense not only in the medium or long term. The study was conducted to verify a thought developed in the Environment Ministry (GER_P2), and the findings played into the arguments of the environmental-friendly coalition (Dagger, 2009). However, a study commissioned by the Federal Ministry for Economic Affairs and Energy, and conducted by economists Wissen and Nicolosi (2008) heavily criticised the underlying assumptions of this analysis (Dagger, 2009). Wissen and Nicolosi criticised that the modellers used a static power plant portfolio although the electricity market was in continuous change due to the renewables deployment. A snapshot of the electricity market in the present would, therefore, not be sufficient for conclusions regarding the financial advantage of the society (Wissen and Nicolosi, 2008). In the following months, the Environment Ministry and Ministry for Economic Affairs and Energy were not able to find a common ground regarding the net costs or benefits of the merit-order-effect (Dagger, 2009). Finally, they kept both opposing perspectives in the experience report of the Renewable Energy Sources Act (Federal Environment Ministry, 2007), on which the governmental draft of the Act and the included feed-in tariff was based upon (The Federal Government, 2008). Here, one of the policymakers confirmed: *"[...] the dispute [about the merit-order-effect] has not really been resolved to the present day"* (GER_P2).

After the draft of the Renewable Energy Sources Act was published by the federal government, the conflict between the ministries became especially visible in the political dispute about photovoltaics (GER_P2; Dagger, 2009). Several politicians of the economic coalition heavily criticised the suggested moderate reduction of the photovoltaic feed-in tariff of 7-8% in the draft law, instead demanding 30 up to 50%. Besides, they insisted on reliable data regarding the economic situation of renewables deployment and potential of safe feed-in tariff reduction of the Ministry for Economic Affairs and Energy, as the draft was primarily prepared by the Environment Ministry and based on its commissioned studies (Dagger, 2009). A different, subsequent Ministry for Economic Affairs and Energy-commissioned study, took side of the economic coalition, describing solar energy as expensive, over-subsidised, highly inefficient from a CO_2 abatement point of view, and as a driver of electricity price increases (Stratmann, 2008 cited in: Dagger, 2009).

The environmental committee of the German Parliament, Bundestag, scheduled a hearing of experts to provide further information about the draft of the Renewable Energy Sources Act (Dagger, 2009). Energy models did not play an important role in this hearing (German Bundestag, 2008). Experts representing both coalitions appreciated the Act's draft, and recognised the strategic global role of photovoltaic among renewables as well as supported to not endanger the German solar industry by a radical policy change suggestion (Dagger, 2009).

In the political negotiations after the hearing, scientific results, including energy models, were not of importance anymore. Instead, two high-ranking and prominent politicians from the parties in power made a 'horse-trading' deal for photovoltaic, namely Sigmar Gabriel, as minister and social democrat of the Environment Ministry, and Volker Kauder, head of the Conservative Union fraction, agreeing on an 'only moderate' photovoltaic degression. In return, the federal state of Baden-Wurttemberg, from which Kauder came, was supposed to get some benefits within the amendment of the Renewable Heating Act (EEWärmeG). Despite further attacks from the economic coalition, the deal made it into the final result with the support of 'climate chancellor' Angela Merkel (Dagger, 2009).

As shown above, the model-based studies informed the coalition leaders Environment Ministry and Ministry for Economic Affairs and Energy with scientific suggestions and decision aids (GER_S1; GER_P1; GER_P2; Dagger, 2009). Along the policy process, they (as well as non-model studies) played an important role for the agenda setting and policy formulation of the Renewable Energy Sources Act's amendment and, as confirmed by one policymaker: *"[...] of course, the studies contributed to the dispute*" (GER_P2). However, *"[...] in the last coalition-level negotiations [...] I have no longer any direct connection to scientific models or scientific results. This can then only be used as a helpful argument",* confirmed one interviewee

(GER_P1). One important reason for the minor relevance at the later stages of negotiations may be the complex policymaking process and the involvement of many opposing sides, representing various interests. As the same interviewee put it: *"We are dealing with a legal procedure in the EEG (Renewable Energy Sources Act), in which a ministry first writes a draft, so that the federal government has a government draft, which the cabinet may then decide on, before it officially comes to parliament in the German Bundestag. And here the game starts again"* (GER_P1).

4.3 Phase-out of coal in Greece: Modelling the 'wind of change' towards the 2030 & 2050 targets

Over the past decade, energy modelling was introduced in Greece on a wider scale to support policy decisions in the energy sector. This development was considerably driven by the implementation of the EU law, as the Energy Efficiency Directive (EED-2006/32/EC), resulting in the development of the 1st National Energy Efficiency Action Plan (NEEAP), and the Renewable Energy Directive (RED-2009/28/EC), resulting in the development of the 1st National Renewable Energy Action Plan (NREAP) (Figure 4). One of the reasons why energy models have not been used broadly in policymaking before is that "[o]pen-access to energy models, as well as to their databases and their high-resolution results, have not been often available to policy/decision-makers in Greece. This has caused policymakers to become less familiar with the processes and requirements for using such models", as one interviewee explained (GR_P1). However, the implementation of the EU's Governance Regulation and, in consequence, the compilation of the National Energy and Climate Plan (NECP) (64) induced a very broad application of energy modelling with meaningful to significant impact at all stages of the document's preparation. This trend will be additionally strengthened with the introduction of a set of monitoring and verification procedures, aiming at directing and supporting data collection, continuous monitoring of modelling activities, and periodic verification of modelling outcomes. That was confirmed by the representative of the policymaking sphere, who admitted that: "So far using energy models in Greece has been more of an ad-hoc process. However, this is anticipated to change with the establishment of the NECP, as well as with the development of a national monitoring and verification system" (GR_P1).

As the only indigenous conventional energy source, lignite has been the backbone of the Greek power sector for decades. Despite of that, in September 2019, the new Greek government announced the complete phase-out of coal by 2028, which has corresponded with the reduction of lignite's contribution to power generation, resulting from its low quality combined with increasing environmental restrictions. Actually, the decision about the lignite-phase out could have been taken earlier. This did not happen because of the influence of industrial actors, as expressed by one interviewee "[…] the fossil-fuel lobby has given a more or less successful fight over the last decades to delay decisions on climate change and energy transition, much like the tobacco industry successfully delayed for decades the diffusion of scientific knowledge to the public and the corresponding policies implementation" (GR_I1).

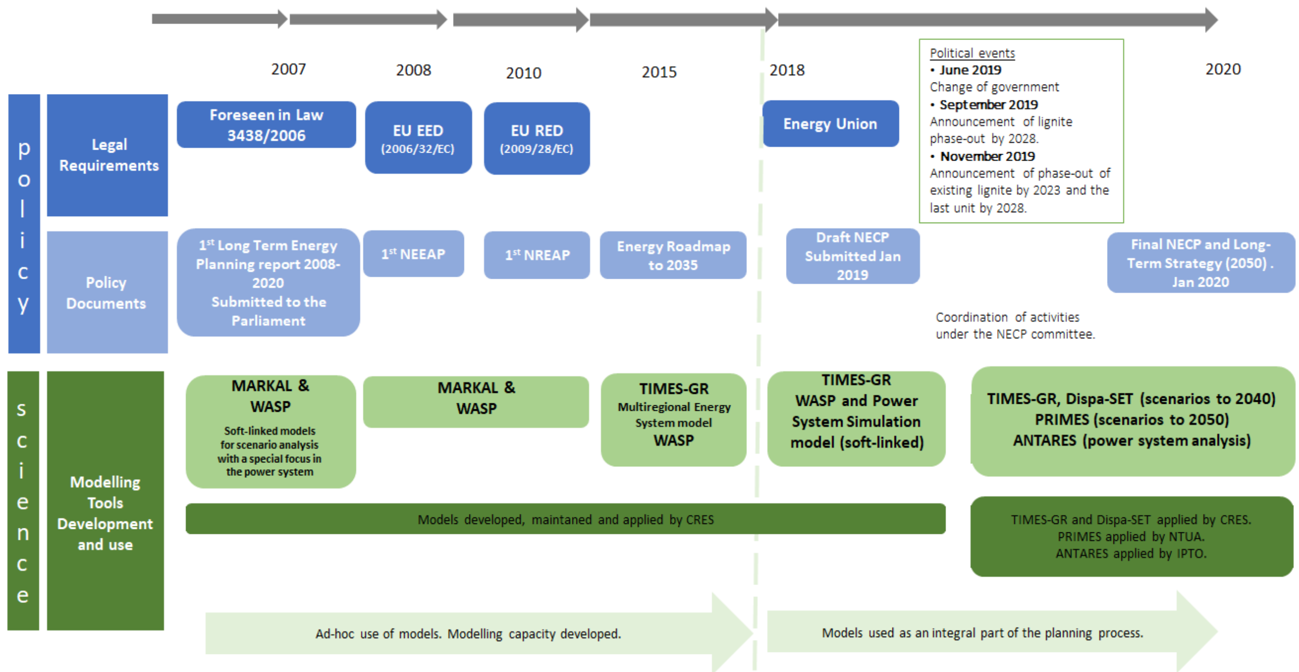

Figure 4: *Timeline of energy model tools development to support policy documents and decisions in Greece over the past decade*

Lignite-fired power plants were still a part of the first draft of the NECP submitted to the European Commission in December 2018, whereas the coal phase-out became a focal point during the revision process of the updated NECP. "The timeline for the lignite phase-out is mainly reflective of an increased ambition, as well as of a strong political will from the government, to support clean energy investments in Greece", stated one policymaker (GR_P1), and it was underpinned with similar declarations of other EU countries, especially Germany. Interestingly, "[…] the political decision for shutting down the lignite-fired power plants was already made before the modelling work took place", as a representative of the industry indicated (GR_I1). While models had no influence on the political decision of the coal phase-out, their results became decisive in providing ex-post evidence of its viability, both from technical and economic point of view.

Several model-based studies were performed, combining various models with different granularity. The Ministry of Energy and Environment commissioned the Centre of Renewable Energy Sources (CRES) to perform a series of scenario analysis using the TIMES-GR energy system model (65) to explore and evaluate how the lignite-phase out could be implemented, and what should be the alternative options to ensure capacity adequacy, including the estimation of investment requirements. Furthermore, CRES used the Dispa-SET model (66) to study the operation of the power system until 2035, and examine potential operational limitations after the decommissioning of the lignite-fired power plants. In parallel, a more detailed analysis of the power system's operation under high renewables penetration was performed by the Greek Independent Power Transmission Operator (IPTO), using the ANTARES model (67). The same model was applied to conduct a study for the transport sector, focusing on the introduction of electric vehicles and possible effects to the power system, as highlighted by a representative of energy industry: "The decisions taken for the renewable energy target in the transport sector were explicitly based on the results of the modelling work done within this study" (GR_I1). Finally, the Energy-Economy-Environment Modelling Laboratory (E3MLab) from the National Technical University of Athens (NTUA) developed the national Long-Term Strategy to 2050, 'Energy Roadmap 2050', using explicitly the PRIMES model to explore the expansion of modelling scenarios towards climate-neutrality pathways of both 2oC and 1.5oC.

The selection of the modelling teams for the NECP and the 'Energy Roadmap 2050' was to a large extent based on credibility and trust, resulting from the high capacities and the experience of all three institutions in the modelling field. In fact, they have been supporting the Ministry for over a decade, and this institutional continuity between policymaking and energy modelling in Greece has been highly appreciated: "[…] it is necessary to engage institutions (i.e., structures with continuity) and not only consultants/personalities" (GR_I1). Coordination and communication were very intense, especially during the initial stages of the process, for the definition of the specific input assumptions and constraints that needed to be considered, and have taken various forms, as described by interviewees: "[c]oordination was almost daily, especially during the initial stages (for the definition of the specific input assumptions and constraints that needed to be considered), and the results preparation phase, and a communication loop was established between modelling teams and representatives from the Ministry" (GR_P1), and: "Collaboration involved different stages of communication such as meetings purely of modelling purposes and data verification, as well as the participation in a wider roundtable with the Greek Ministry and the panel on the Greek NECP. There was also a close coordination between the TIMES and the PRIMES teams to ensure the consistency of data inputs and the continuity/consistency of modelling results" (GR_S2).

Additionally, the Ministry, in a close cooperation with the modelling teams, conducted a set of formalised public consultation meeting, in which opposing views of key stakeholders and civil society representatives have been voiced, with a special focus on socio-economic strategies that must be incorporated into the national energy planning process. As one of the policymakers claimed, the feedback from this process shall be included in the "[…] plan for the transition in the post-lignite era, with a special focus on the regions where the power plants exist. The plan analyses ways of alleviating the effect of the loss of employment and the overall economic consequences of the phase-out on the whole supply chain of the lignite-fired plants" (GR_P1).

All in all, policymakers in the Ministry put a considerable effort to embrace diversity of different models, not only to take better-informed decisions, but also to justify them. While the main results on the feasibility of the lignite phase-out decision were derived from TIMES-GR, two additional models were also used to explore the technical feasibility of the system. Nevertheless, interviews revealed that the broad use of the models in policymaking resulted also from the open-source character of these models, which fostered credibility and trust in modelling outcomes. That was highlighted on many occasions during the interviews, as for example: "Policymakers need to base their policy documents on credible data sources, otherwise the results can be challenged" (GR_P1), or "model transparency is important" (GR_S1). Last, but not least, policymakers acknowledged models' shortcomings, like the fact that there are topics not covered in detail or the role of uncertainties and unforeseen events (GR_P#1). Especially the latter issue was highlighted in the context of the COVID-19 pandemic's impacts, which have not been included in the revision of the NECP. As one of the scientists expressed: "Impacts of the recent pandemic should not be neglected, as this new situation increases uncertainty. For me, a revision of the NECP should definitely take place to take into account potential rebound effects, with the concept of "resilience" being the focal point, considering also that planning for the next decades is a task that by default induces a lot of uncertainty in decision-making" (GR_S1).

4.4 Energy policymaking in Poland for 2030, 2040 and 2050: modelling into or out of the carbon lock-in?

In the last 15 years, the EU has had a tremendous influence on climate and energy policies in Poland (POL_S3; POL_P1; POL_S4). Yet, the relationship between Poland and the EU has been 'uneasy' in this policy field (Ancygier, 2013), what results from the misfit of the overall policy directions. While decisions in Brussels are driven by the decarbonisation paradigm, the Polish energy system relies on domestic coal resources, which assure for energy security (POL_S4; POL_S5). The overall approach to energy policy in Poland is dominated by the energy security aspect (POL_S1; POL_C3; Szulecki, 2020). As one of the employees of the Ministry of Climate noticed: "*energy security […] is a priority for our national actions, and almost in every moment of the energy policymaking, this aspect is taken into account*" (POL_P1).

As a consequence, the EU climate and energy policies have been contested (POL_C#3; Marcinkiewicz and Tosun, 2015; Cianciara, 2017), and the strategic decisions about the energy policy were highly influenced by energy system incumbents, embodied by utilities and the mining sector (POL_C1; POL_C2; POL_S2; POL_S4; Szulecki, 2017). The use and influence of modelling in energy policymaking was limited (POL_S4), most of modelling studies was conducted by state agencies, e.g. the Energy Market Agency (ARE) and they were not publicly available (POL_S1), as for example a draft of Energy Policy of Poland (Ministry of Economy, 2015). Some of them led to governmental inaction and even cemented the Polish carbon lock-in. For example, for more than a decade, the results of the model-based EnergSys' report, utilising the CGE-PL, PROSK-E and EFOM-PL models (EnergySys, 2008), became a reference point for many policymakers, displaying the introduction of ambitious decarbonisation policies as something 'unachievable' (POL_P1) (**Figure 5**).

In the last years this situation has changed – the preparation of three strategic documents: the Energy Policy of Poland until 2040 (PEP), the Polish NECP and the Long-term strategy by 2050 broadly involved energy modelling. Despite different time-spans or legal basis, all three documents and accompanying modelling are complementary, "*because all these documents together must somehow harmonise and fit*" (POL_S3). The modelling tools used were: STEAM_PL, MESSAGE, CGE and models for contaminant levels analysis and health impact assessment[5] (Ministry of State Assets, 2019b) and PRIMES and DCGE PLANE 2.0 (for the Long-term strategy).

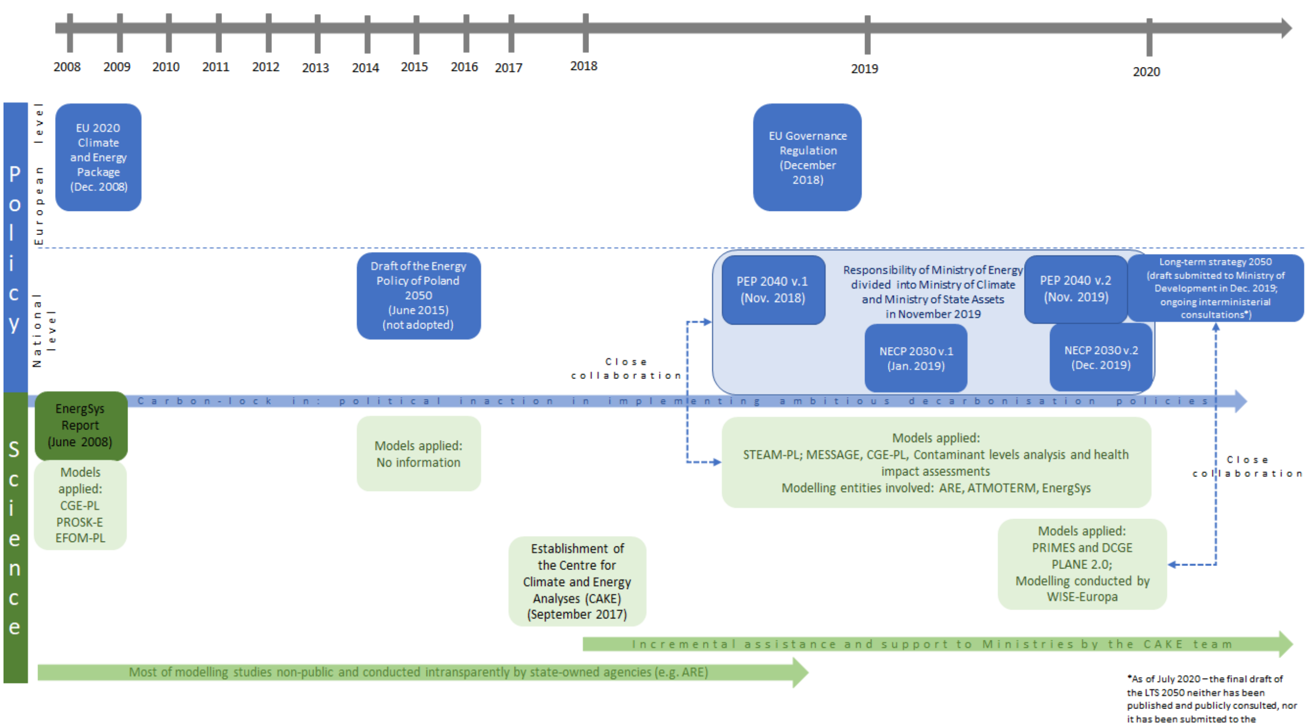

Figure 5: *Timeline presenting incremental use of modelling in the energy policymaking in Poland*

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[5]It should be underlined that only the appendix to the NECP lists these models – they are not mentioned directly in the PEP. Nevertheless, from basing on the interviews, it can be assumed that the same models have been used for preparation of both documents.

The preparation of the strategic documents was complex and iterative process, involving many people (POL_P1). Ministries played a role of coordinators and the modelling has been commissioned via tenders to external entities: ARE, ATMOTERM and EnergSys (in case of NECP and PEP) (Ministry of State Assets, 2019b) and WiseEuropa Institute (for the Long-term strategy by 2050). The team established in the Centre for Climate and Energy Analyses (CAKE), supervised by the Ministry of the Environment, played an important role by supporting the central administration in understanding complex details of modelling on a day-to-day basis (POL_C1; POL_S1; POL_S4). At the same time the CAKE's team designed its own modelling tool, which at the time of the strategic documents' preparation was under development, but after its completion it was supposed to serve Ministries to realise analytical needs (POL_C3; POL_P1). Since the government-owned CAKE's tool was not yet available, the selection of modelling teams for the NECP and Energy Policy of Poland was based on credibility and trust to experienced entities (POL_S1; POL_P1). However, some interviewees questioned the transparency and inclusiveness of this process and perceived it as advantageous towards consultancies, which are not in favour of strong decarbonisation policies (POL_S1; POL_C3; POL_S2).
The processes around preparation of three strategic documents and adequate modelling have, however, not been homogenous. First, interviewees remarked differences in the general approach to modelling of responsible Ministries: while the Ministry of Development (in charge for the Long-term strategy by 2050) was more eager to apply ambitious assumptions leading to a low-carbon transformation for 30 years ahead, the Ministry of Energy (in charge for NECP and PEP[6]) was relatively conservative and under a stronger influence of energy system incumbents (POL_S3). Second, within Ministries there is a disparity between operational levels: the working level is perceived as more open to discussion and external opinions of diversified stakeholders, what does not hold the truth for higher, political level (POL_C1; POL_C2; POL_S1; POL_C3). Such openness was reflected by one of employees of the Ministry of Climate at the expert level: "*We are not closed to these changes. We know that they will happen, they have to happen, but the time frame is completely different than, for example, the comments from other institutions indicate. In fact, this is an increasingly difficult process, even when making these forecasts and consulting their results...*" (POL_P1).

The Ministry of Energy collected the input for the two strategic documents (NECP and PEP) and the feedback on the modelling results via formalised public consultations, the meeting of the Parliamentary Committee (only PEP) and bilateral conversations with representatives of selected industries (POL_C3; POL_S3; POL_P1). It also took final decision on the shape of these two documents, including the modelling assumptions (POL_C2; POL_S3). In context of designing

[6]Initially it was the Ministry of Energy, but after the elections and government change at the end of 2019, the administrative structure has changed and currently leading tasks related to the NECP and PEP are divided between departments based in the Ministry of Climate and the Ministry of State Assets.

of the decarbonisation objectives, the Ministry followed three main principles: energy security, cost optimality and the technical feasibility of the current energy system (POL_P1).

Thus, most of interviewees evaluated the influence of modelling on the creation of the strategic directions of energy policy in Poland as highly questionable (POL_S1; POL_S2; POL_S3; POL_S4). Furthermore, they pointed to politically appointed assumptions and limitations that determine the results of the analyses (POL_S4), by some described as "*wishful thinking*" (POL_C1). As one of the civil society representatives summarised it: "*Of course, here a political decision can be made regardless of what the model shows*" (POL_C2). Yet, the role of models should not be entirely neglected, since their results have brought a different effect – they have contributed to softening a negative approach of some policymakers towards the decarbonisation in general (POL_S2; POL_P1).

4.5 Sweden's climate policy: modelling towards net-zero emission by 2045

In 2017, the Swedish Climate Policy Framework, including Climate Act, set Sweden's net zero target for 2045 at the latest. *"Seven parties stand behind it, [and] it brought all the industry behind it"*, stated a policymaker involved in this process (SWE_P3), underlying the importance of the climate reform for Sweden. Different experts and scientists from the energy field were involved in the process (SWE_P1), and modelling played an important role for arriving at this ambitious target.

In December 2014, the Swedish government decided to commission the Cross-Party Committee on Environmental Objectives to propose a Climate Policy Framework (Swedish Ministry of Environment, 2016a) and a Climate and Clean Air Strategy (Swedish Ministry of Environment, 2016b). Within development of the proposals, the Technical University Luleå (LTU) used the energy system optimisation model TIMES-Sweden to conduct a scenario analysis for the Committee (Krook-Riekkola *et al.,* 2017; Krook-Riekkola and Sandberg, 2018).
In this respect, between 2015-2016, two modelling runs have been performed. The first one aimed *"to identify which kind of climate targets Sweden should have and to analyse the consequences of different targets"* (SWE_S1) and the second analysis defined intermediate emission pathways of sectors that are not covered by the EU emission trading system (ETS). More specifically, as one of policymakers clarified its objective: *"We wanted to look at the sector goal [...] and then we asked people using the TIMES model if they can model two trajectories or scenarios with or without the sectoral goals; and what is the relative cost of those two scenarios"* (SWE_P1). In this context, TIMES-Sweden had been also soft-linked to the general equilibrium model EMEC (Östblom and Berg, 2006), which appeared to be challenging and only partially suitable, because of its limited ability to consider long-term targets (Krook-

Riekkola *et al.*, 2013). This shortcoming faced a criticism from some of involved parties, as expressed by a policymaker from the Ministry: *"[t]o my understanding it creates more problems than it solves. [...] It is not useful for me and it actually creates the opposite, it creates a feeling of problem with the energy transition"* (SWE_P3).
Nevertheless, the modelling analysis has supported the Swedish government in answering the question what climate target(s) to commit to. An involved modeller confirmed the significance of the TIMES-modelling as following: *"[...] the results were showing to reduce when in which sector. And what I just recently got feedback on is, that this graph was in the end important to agree on the target [of net-zero in 2045 at the latest]"* (SWE_S4). The final climate policy framework mentions conclusions from the scenario analysis (Swedish Ministry of Environment, 2016a) and the appendix of climate policy strategy includes results of the TIMES-Sweden analysis, as well as it describes the models usage and its limitations (Swedish Ministry of Environment, 2016b).

In the next years, between 2017-2018, TIMES-Sweden has been used for evaluating the impacts of different climate mitigation measures for the Swedish Environmental Protection Agency. In this context, the interviews revealed that the modelling intended to actively discuss the relevance of energy models in making political decisions. One of the involved modellers admitted that the main purpose of the collaboration was to *"see how these kinds of models can be useful when steering towards those climate goals"* (SWE_S1). This process revealed that models should be able to answer three main questions to inform governmental decision-making: "What measures (policies and/or actions) are needed? Where (in which sectors)? And when (in time)?" (personal communication [10.03.30]; SWE_S1; SWE_P1).

In 2020, LTU conducted another scenario analysis with TIMES-Sweden to evaluate the government's climate policy action plan, which is presented every fourth year to describe how the climate goals are to be achieved. At the time of conducting this research, it was an ongoing work for the Swedish Climate Policy Council, which assesses the action plan developed by the government and ensures that the government's policies are in line with the climate goals. Yet, the actual impact of the TIMES modelling exercise is unclear due to the tight time schedule in delivering the assessment report to the government (SWE_P1, SWE_S1). Furthermore, TIMES-Sweden is supposed to be used also by industrial actors associated under the industry-initiative Fossil Free Sweden, in order to analyse the industry's roadmaps to decarbonisation.

The TIMES-Sweden modelling process over the last five years (**Figure 6**) has been characterised by a close collaboration between different governmental institutions and scientists: research questions were defined; the model itself was introduced and assumptions discussed; scenarios to be run were designed; and at the end, results were discussed and interpreted together (SWE_P1; SWE_P2; SWE_S1). One modeller underlined the importance of models in facilitating discussion and boosting a mutual learning process: *"I have worked now quite some years with energy system models, developed models and made analysis, but I have to say that the process before the calculations is almost as possible as the process after"* (SWE_S4). On the contrary, some stakeholders recognised also downsides of the stakeholder-informed modelling process, which was underlined by one policymaker: *"But we were all a bit worried that using an energy model like TIMES would be time-consuming, and it might not be suitable to answer the questions we are having"* (SWE_P1). Nevertheless, such process enables decision-makers at lower-governmental levels to take influence. Especially the agencies, such as the Environmental Protection Agency or the Swedish Energy Agency, that do themselves or commission modelling have a substantial influence on policy decisions, as one of the interviewees described: *"Swedish agencies are in comparison to most other countries quite powerful and big and they have resources to do the right analysis"* (SWE_P1). For example, the Swedish Energy Agency has been doing long-term scenarios with the MARKAL-NORDIC model (Unger, 2000) for different sectors, calculating long-term developments of the energy system, and supporting the policy formation process for many years (SWE_S1; SWE_P4). However, the influence from ministries on energy modelling is quite limited. *"We can't influence them so much [...] but we can influence what we do out of these results from a policy perspective",* as one policymaker said (SWE_P3).

In the context of the Swedish climate policy, energy modelling has assisted Swedish policymaking by assessing and setting targets, evaluating measures, and verifying results. The latter *"is a very important factor not to be underestimated. Our assumptions could have just well-been wrong"*, said one policymaker (SWE_P1). *"Models have generally a large impact on policymaking in Sweden, I would say. It's not the only tool but it is a very important tool"*, confirmed another interviewee (SWE_P1). However, many interviewees put a question mark behind the actual impact of models in policymaking (SWE_S4; SWE_S1; SWE_P2SWE_P3). While the analysis is done within the agencies, final political decisions are made at the ministries and in the parliament. In the end, computer models meet the mental models of policymakers. As expressed by one of the scientists: *"much is steered by what politicians think themselves [...] and I think a part disappears due to other considerations, which have then more weight than the results from our models"* (SWE_S3). Thus, it is essential to understand how policymaking is done − upon what information − and what information models would need to be able to deliver (SWE_P1).

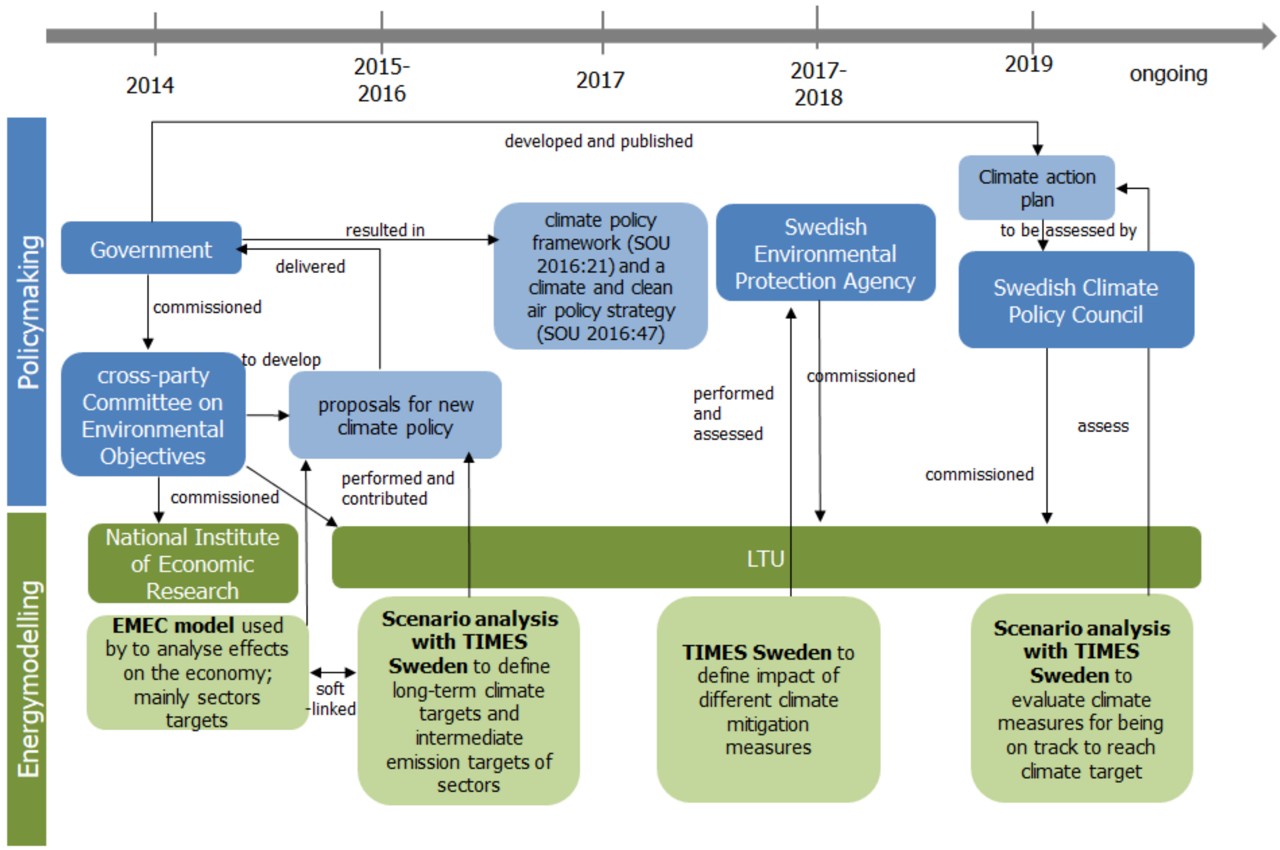

Figure 6: *Timeline of energy modelling tools, supporting Swedish climate policymaking*

5 Discussion

With this deliverable, we demonstrate that models are used and have an impact on policymaking, especially in terms of delivering information on what targets to commit to and functioning as tools for joint exploration of and negotiation about policy options. We also show that policymakers influence models and modellers, especially by taking control over the framework conditions of modelling performed, and by deciding about the use of modelling study results.

Table 2 synthesises the key findings of the interaction. Overall, energy modelling and policymaking can influence each other 'for the good and for the bad': they can foster radical policy changes and ambitious target setting, or they can be instrumentalised to justify inaction and radical no-change, respectively.

5.1 Modelling (non)influence on policymaking

We show that different models are used in policymaking with different purposes, and they influence policymaking (cf.

Table 2). First, we find that models' influence on policymaking depends on the countries' experience in using energy models, as well as the context in which these models are applied. Whereas in the EU, Germany and Sweden energy modelling has been broadly applied in policymaking for many years, in Greece and Poland the intensified utilisation of energy modelling in the policymaking realm is rather a new phenomenon, directly responding to the EU obligations. On the one hand such differences might result from structural conditions of investigated cases, such as the availability of capacities and resources linked to modelling. On the other hand, they can be an effect of the overall energy policy directions. The EU, Germany and Sweden have pursued more ambitious decarbonisation policies, which required the development and application of sophisticated tools supporting the policy decisions. In contrast, a long-standing 'attachment' to fossil fuel-based energy systems in Greece and Poland did not require the use of models that would support low-carbon transition. In opposite, if energy modelling was used, then only to legitimise the *status quo* in the existing energy system, like the Polish case revealed.

Second, we find that models influence and support energy policymaking processes along the policy-cycle. While they are used to formulate/adjust and legitimise policies (Germany, Sweden) or to evaluate the targets and policies (EU, Germany, Sweden), modelling has the largest influence in the early phases of the policy-making process, where the agenda and targets are being set (

Table 2). Models are especially useful when they are set up to directly answer specific questions that policymakers might have, i.e. to explore the implications of options that they are considering. In contrast, they are less useful when they tell policymakers what course of action, from the modeller's perspective, would be best.

We also demonstrate a higher influence of modelling studies that were commissioned by the policymaking sphere, in order to base on and back-up decisions by science. Consequently, not surprisingly, they have the greatest potential to create policy impact, which partially results from the institutional rules; but it also allows policymakers to take influence on the modelling (see section 5.2). Also non-commissioned studies have been found to play a role − even if a minor one – especially, to receive an overview of the scientific perspective.

Furthermore, we confirm – in line with previous research (Rembrandt *et al.*, 2016; Geels *et al.*, 2018; Gilbert *et al.*, 2018) – the influence of modelling tools as 'laboratories of sustainable transition' by allowing different stakeholders to analyse problems, discover energy futures, as well as negotiate and define solutions jointly. Here, modelling can equalise the positions of different actors in the policymaking process, as long as they build their arguments based on reliable and credible results of energy modelling in order to proof and validate proposals delivered by policymakers. Accordingly, we find that the importance of modelling goes beyond its understanding as 'results producing tools' or even 'number generators' (Pfenninger *et al.,* 2014), towards 'facilitation tools' for stakeholder processes under the energy transition framework.

In contrast and in line with previous research (McIntosh *et al.,* 2007; Kolkman *et al.*, 2016; Pfenninger *et al.*, 2018), we find different reasons why models are not used and thus have no influence in policymaking. Modelling processes have been perceived as very complex, time-consuming, resource-intensive processes, involving many actors. This fact can eventually raise the question about the balance between the engagement's benefits vs. expected results. Broadening the participation for many actors creates trust in and acceptance of modelling in policymaking (Kolkman *et al.*, 2016), and it improves the quality of the modelling, since its results can be validated and more diverse policy options can be developed. Furthermore, the unavailability of data, as well as the lack of model transparency and open access of energy models limits model use. Consequently, it underlines the importance of open data and open-source models to increase the access and understanding of models in the policy sphere. This would also serve the increasing interest of policymakers in exploring and better understanding the model functionalities, design, and assumptions.

In addition, we find that models influence is limited because modelling competes with other information sources. Although modelling plays increasingly important role in energy policymaking, scepticism remained regarding its actual impact, when it comes to final policy decisions. In line with Ellenbeck and Lilliestam (2019), we reveal that computer models meet mental models of policymakers, who make final decision based on their understanding of the 'reality'. Therefore, in the energy policymaking, models and modelling play rather a supportive than a decisive role. In this context, it is normal and important that different actors bring additional perspectives into the discussion to enable a holistic consideration of the energy transition. However, depending on the country, some of political decisions are still expected to be taken without any modelling support.

5.2 Policymaking (non)influence on modelling

We show how policymakers influence modelling (cf.
Table 2). First, we demonstrate that policymakers can influence model developments, objectives, and directions of modelling performed, especially in the context of 'in-government' or commissioned modelling. The EC has analytical units performing modelling[7] (as, for example, in the UK; see: Taylor *et al.*, 2014), whereas in our case studies, responsible ministries commissioned model-based studies. Such 'in-government' modelling may increase the chances that results are turned into policy action, however, it also arises the question to what extent it limits the diversity of modelling to be performed and to be taken into consideration. Furthermore, government-commissioned studies often have specific policy questions and mandates in mind. For example, the German case showed that the ministries needed them to support their existing and develop new arguments. Nevertheless, all case studies confirmed the general scientific independence of modellers.

We reveal that existing 'rules of the game' in the policymaking process have a fundamental influence on who is chosen to conduct the modelling and who is allowed to give input and provide feedback. In all our cases, modelling was delivered by renowned and acknowledged entities, or by well-recognised modelling tools delivering the modelling. At the same time, this procedure can, however, impact the legitimacy and credibility of modelling, as in the Polish case, where state-agency-performed modelling raised questions about a privileged position of these agencies and data monopoly. Consequently, this fact underlines the importance of open data as well as open-source models, for a more diversified model use and the comparability of model results.

Finally, an even a higher level of the policymakers' influence is reflected by their power over how models and their results are politically used. In the case of Poland, a modelling-based study

[7] But some parts of modelling are also performed by external subcontractors or models' owners, like in case of the PRIMES-model.

from more than a decade ago got high political attention and was used to justify inaction, underpinning the national energy policy until today. Also, the Swedish case confirmed that the government can decide on how to politically utilise the modelling results. This implies that governments have the control to use modelling-based results in the way it serves them most. This issue creates a risk of instrumentalisation of energy modelling, which we believe should be critically reflected upon, not to underpin the general importance that models can have.

5.3 Limitations and future research

We are aware that with this study, we have encompassed only a snapshot of the very complex energy modelling and energy policymaking nexus. We considered specific policymaking and modelling processes within five case studies, and our dataset is limited to a number of policy documents and 32 interviews. Moreover, within this paper we have not tackled other important aspects of the investigated interaction, like the drivers and barriers of the energy modelling utilisation in policymaking, or the needs of policymakers and other stakeholders for modelling the European energy transition. These gaps call for further research to be addressed within WP1 (specifically D1.2).

5.4 Implications

Our research shows that models are used in policymaking, and energy modelling and policymaking influence each other for ambitious and non-ambitious climate and energy policy. Both aspects hold implications for enhanced transdisciplinary and open-source modelling.

First, models should be more often used as facilitations tools within stakeholder engagement processes to catalyse the political and societal debate on different possible energy futures. Transdisciplinary modelling can foster result-open and legitimised modelling results. Moreover, the simultaneous use of several models, ideally by different teams, can ensure not only diversity but also disparity among the used models.

Second, transparency of models is absolutely imperative for creating trust and increasing model use. Opening of the black boxes (Pfenninger *et al.*, 2017) and providing open access models, as intended with the projects SENTINEL or openENTRANCE[8], can foster model understanding, trust and use. Importantly, all interested stakeholders from the energy sphere should have an equal and understandable access to such tools, even if they are not modelling experts and developers. In this regard, open-access models and an open-access modelling platform, such as the projects like SENTINEL or openENTRANCE are aiming at, could deliver comparable and

[8] https://openentrance.eu/

credible results for European and national policymaking. Furthermore, strong modelling communities, bringing together modellers and policymakers, such as the Energy Modelling Platform for Europe (EMP-E)[9], can potentially enable collaborations between modellers and policymakers, supporting a sound policymaking that is based on the best scientific knowledge.

If the objectives of the Paris Agreement, the Energy Union Strategy, and the European Green Deal are going to be achieved, modelling is required that goes beyond the current mainstream. The required 'radical' change of energy system must be, however, manifested in the modellers' and policy-makers' mental models in order to make its way into computer-based modelling tools. And even then, models can assist in exploring different energy futures, but in the end, it requires political will to accelerate ambitious climate and energy policy action.

[9] http://www.energymodellingplatform.eu/

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No *837089*.

Table 2: *Synthesis table of the interaction between policymaking and modelling*

Case study	Aim of the policy-model interaction process	Models used	Relative influence and effect of modelling on policymaking	Relative influence and effect of policymaking on modelling
			Significant: modelling results made it into final policy documents, or demonstratively influenced final policy decision; *Meaningful:* modelling results were used within negotiation processes; *Moderate:* modelling results were used at some point of the policy-making process; *Low:* modelling was conducted but did not have any substantial influence in the policy-making process	*Significant:* policymakers determined modelling process; *Meaningful:* policymakers were closely involved in the modelling process; *Moderate:* policymakers were partially involved in the modelling process; *Low:* policymakers were not meaningfully involved in the modelling process
EU's renewable energy target revision **(2016-2018)**	Renewable energy target setting within two processes: the impact assessment of the EC's proposal of the Renewable Energy Directive reform in November 2016 (27% of RES), and the European Parliament's request to recalculate the impact assessment assuming higher RES (and energy efficiency) targets	PRIMES modelling set E3ME GEM-E3 FORECAST Invert Green-X Astra-EC	*Meaningful* – Modelling opened up the discussion about a higher renewable energy target. Modelling supported higher renewable energy target setting and its results were used during the negotiations over the final target final decision.	*Moderate* – European Parliament requested the European Commission to conduct a new, model-based impact assessment with more ambitious renewables target, but did not intervene into this process.
Germany's renewable energy feed-in tariff reform	Defining reduction rate of photovoltaic feed-in tariff; scenario-based medium- and long-term economic assessment of renewable energy deployment	ARES (Excel-based simulation model)	*Moderate* – Modelling informed the Renewable Energy Act experience report. No modelling influence in final negotiation phase revealed.	*Moderate* – Federal Environment Ministry commissioned model-based studies. Ministry defined open research question on renewable energy potential and its societal costs. Ministry provided few instructions on model assumptions. Meetings took place between modellers and Federal

Case study	Aim of the policy-model interaction process	Models used	Relative influence and effect of modelling on policymaking	Relative influence and effect of policymaking on modelling
(2012)				Environment Ministry.
	Renewable energy target setting; short-term economic assessment of renewables-based merit-order-effect	PowerACE (electricity market model)	*Significant* – Modelling resulted in a scientific dissent, which caused controversy between ministries and heated up the political debate; scientific dissent reflected in ministries is unresolved until present. No modelling influence in final negotiation phase.	*Meaningful* – German Environment Ministry commissioned model-based study to verify its idea of a renewable energy-based merit-order-effect.
Greece' decision to phase-out coal (2019)	Energy objectives and target settings for NECP	TIMES-GR (energy system optimisation model)	*Significant* – Modelling results made it into the final policy document of the NECP.	*Meaningful* – Ministry of Energy and Environment called for modelling to evaluate under which conditions the Government's political decision to phase-out coal could be feasible. Policymakers were closely involved in the modelling process. The collaboration involved different stages of communication, such as meetings purely of modelling purposes and data verification, as well as the participation in a wider roundtable with the Ministry and the consultation panel on the NECP. Policy influence was especially significant during in initial stages for the definition of the specific input assumptions and constraints that needed to be considered.
	Evaluating the operation of the power system (i.e., limitations), once the lignite-fired power plants are decommissioned, in selected years in the modelling horizon until 2035	Dispa-SET (Power system simulation model)	*Meaningful* – Modelling results were used within negotiation processes to support the feasibility of the political decision to phase-out coal from the technical perspective of the power system.	
	Analysis of technical aspects of the power system operation under high renewable energy penetration. Specialised model-based study on the introduction of electric vehicles and the potential effects for the power system. Energy target settings for NECP	ANTARES (Power system simulation model)	*Significant* – Modelling results made it into the final policy document of the NECP: decisions taken for the renewables target in the transport sector were explicitly based on modelling results.	
	Long-term climate and energy targets setting until 2050	PRIMES (Energy system model)	*Significant* – Modelling results made it into the final policy document of the Long-Term Strategy to 2050: decisions taken for the energy targets until 2050 were explicitly based on modelling results	*Meaningful* – Government demanded for expansion of modelling scenarios to explore climate-neutrality pathways of both 2^{o} C and 1.5^{o} C

Case study	Aim of the policy-model interaction process	Models used	Relative influence and effect of modelling on policymaking	Relative influence and effect of policymaking on modelling
Poland's obstruction towards decarbonised future (2008-2020)	Analysis of the impact of the 2020 EU's climate and energy package on the Polish economy (2008)	CGE-PL (general equilibrium model for analysis of the impact on the economy and employment) PROSK-E EFOM-PL	*Significant* – the results of the modelling-based study for many years cemented the carbon-lock in energy policymaking in Poland, presenting decarbonisation policies as an expensive burden to economic development	*Not enough information to evaluate*
Poland's obstruction towards decarbonised future (2008-2020)	Main energy policy objectives and target settings for strategic energy policy documents: NECP and Energy Policy of Poland by 2040	STEAM_PL (Set of Tools for Energy Demand Analysis and Modelling) MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) CGE	*Low* – Modelling did not play a decisive role in final decisions about the main directions and targets of energy policy in Poland in the next decades	*Significant* – Policymaking sphere determined the final energy objectives of strategic documents, the Ministries commissioned modelling mostly to well-known external entities and the final target setting was largely based on input collected from the energy industry

Case study	Aim of the policy-model interaction process	Models used	Relative influence and effect of modelling on policymaking	Relative influence and effect of policymaking on modelling
Sweden's development of the climate policy framework and beyond (2015-2020)	Climate target setting; development of pathways to reach target; assessment of policy measures to reach goals; assessment of economic impacts of intermediate climate targets	TIMES-Sweden (energy system optimisation model)	*Significant* – Several scenario analysis have been completed in the context of the Swedish climate framework. Modelling has contributed to the final target setting. Modelling has supported the evaluation of the climate action plan, supporting toward meeting the climate goals. Modelling results made it into the final documents of the Swedish policy framework (SOU 2016:21, :47).	*Meaningful* – Modelling commissioned by government and governmental agencies. Several meetings between cross-ministerial committee and gov. institutions. Close collaboration in defining research questions, introducing the model, discussing assumptions, designing scenarios, and discussing and interpreting results.
		EMEC (general equilibrium model of Sweden)	*Not enough information available to evaluate.* Modelling conducted to assess the economic feasibility of the climate framework.	*Not enough information available to evaluate.* Modelling commissioned in context of climate policy framework.

Appendix 1

Questionnaire for the interviews

POLICYMAKERS / OTHER DECISIONMAKERS		
Area of investigation/ *Remarks*		**Question**

Energy policy decision-making	1.	Introductory question: Could you please briefly state what do you think are key events in politics but also beyond that have determined the energy policy in [country/EU] in the last 20 years?
	1.1	Generally speaking, what are key aspects for you that determine your choices and decisions in the energy policy / energy questions? (such as tools, models, events, or powerful actors/lobbies)
Questions regarding energy model use *(model → policy)*	2.	Do you use energy models and/or results of energy modelling, while making decisions in the energy policy field? No: Why not? Yes: What for? How do you use them? (policy instruments, strategic policy objectives, political positions, negotiations etc.- policy design, policy justification, policy evaluation?[10]) Which models do you use? Why do you use those models? To what extent did past energy model advances in terms of model complexity, e.g. endogenised learning and high-resolution models, influence your use of energy models in policy-making / in your work? Is there a specific procedure how models are involved in the development of policy documents / position papers? If yes, how does this process look like?
Case study	2.1.	Following I would like to focus on the specific process of [the introduction of XX / decision about XX / XX]. In your opinion, what were the key reasons that have led to the political decision? Who were the most relevant people involved? *[potential other specific case study question(s)]* In the framework of the process XX, different model-based studies [from XX] have been completed. What was the goal of implementing those modelling studies? In your opinion, to what extent did these (energy) models/ their results impact the outcome of the policy-making process in this concrete example? To what extend did these energy models influence you/ your positioning in the decision-making process?
Question regarding energy model development (policy → model)	3.	Have you been involved in the development of energy models by the scientific community? *If yes:* What was the goal of the collaboration? What was your role in the development process of the energy model? How did the collaboration between you and researchers look like?

Case study	3.1	In the framework of the commissioned/implemented modelling studies by the government/association/agency … How did the collaboration between you and researchers look like in that specific case?
Question about energy model demands Preferences and priorities of stakeholders regarding the model's scope	4.	What are the current and future challenges or aspects of the energy transition, which should be integrated in future energy models?
These questions to be treated as dealing with the model's output	5.	In your opinion, what kind of information should an energy model deliver to make good decisions about the energy policy?
Design development process of energy models	6.	What conditions must be given that increase the chance that you would use the models or the results, respectively, in future policy-making / your work?
Finalising questions	7.	Did we miss to talk about anything relevant to the research context?
	8.	Would you be interested to be updated about the further process of the SENTINEL project? If yes, how? We will organise a workshop on prioritising user demands for SENTINEL. Would you be interested in participating?
	9.	In the backdrop of the interview, can you recommend any other interview partner who could provide valuable input to our research?

MODELLERS (SENTINEL + EXTERN)		
Area of investigation/ *Remarks*		**Question**
Energy policy decision making	1.	Introductory question: Could you please briefly state what do you think were key events in politics and beyond that have determined the energy policy in [country/EU] in the last 20 years?
	1.1	What do you think are key aspects that determine decisions and positioning in energy policy? (such as tools, models, events, or powerful actors/lobbies) Dependence on energy field; local circumstances, cultural situation, political set-up, goal of the policy; strenghth of the civil society
Question regarding energy model use (model → policy)	2.	To what extent, do you think, energy models and/or their results are being used in energy policymaking? Again depends on the context, energy planning some areas can do perfectly fine, capacity and resources of countries, an weather they have experts to translate models; Most of the energy policies are very much data-driven; economic models based on data; but climate change there

		In your opinion, what is the interface between models and policy? To what extent did past energy model advances in terms of model complexity, e.g. endogenised learning and high-resolution models, influence the use of energy models in policy-making? (endogenised learning and high-resolution models) Do you know, whether there is a specific process or a procedure formalising how models are involved in the development of policy documents / position papers? *If yes,* how does this process look like?
Case study	2.1	Following I would like to focus on the specific process of [the introduction of XX / decision about XX / XX]. In your opinion, what were the key reasons that have led to the political decision? Who were the most relevant people involved? *[potential other specific case study question(s)]* In the framework of the process XX, different model-based studies [from XX] have been completed. What was the goal of implementing those modelling studies? Could you describe how the energy model XX and its results have been used in energy policy-making? (policy design, justification, evaluation/monitoring) Do you know by whom it has been used? Have you been consulted to give advice on the model usage?
Question regarding energy model development (policy → model)	3.	Have you ever participated in a work dedicated to designing energy policies, where you have used energy models/ results of energy models? What was the aim of the model integration? How was this process designed? Who did commission this work? Has anyone else been involved? If yes, who?
Case study	3.1	In the framework of the commissioned/implemented modelling studies by the government/association/agency … How did the collaboration between you and politician look like in that specific case? Did you have the feeling that the political decision was already made? Have you been asked to change specific parameters in order to achieve desirable results (by whom?)?
Question about energy model demands Preferences and priorities of stakeholders regarding the model's scope	4.	What are the current and future challenges or aspects of the energy transition which should be integrated in future energy planning models? Many; data; socio-economical ground: market voluntarity; human behaviour; most transport model take human preferences into account; carbon lock-in – what is happening with existing infrastructures; can renewable energy provides continues
These questions to be treated as dealing with the model's output	5.	In your opinion, what kind of information should an energy model deliver now and in the future to inform decision-making (processes) in energy policy? System model: energy consumption and demand data, energy supply data, emission data; GDP,

		employment, public budget
Design development process of new energy models	6	In your opinion, how should the process of model development be designed to increase the chance of the later model use in policy-making? Not very sure; can dissimilated to stakeholders → impact on very high (indirect approach); direct approach: different meeting with EU stakeholder; different conferences bringing policy-makers together; problem: debate in department as well as policy-makers are influenced; so this influences broader IPPC "knowledge co-production" → trying to involve Do you think model transparency is important? Do you think that standardised methods are essential? Do you think different data sources are an issue?
Finalising questions	7.	Did we miss to talk about anything relevant to the research context?
	8.	Can you recommend any other interview partner who could provide valuable input to our research?

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