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Representation of institutions and actors in models

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1. Introduction

A transition towards a low-carbon and sustainable economy requires fundamental transformations and coordinated policy action. These transformations can involve different degrees of reconfiguration across technologies, infrastructures, industrial structure, business models, dominant ideas and cultural discourses, distribution of resources and power, modes of production and consumption, and institutions. All these factors influence the effectiveness of environmental and climate policies as well as the process leading to their adoption (Hughes and Lipscy 2013). Although investments can be somewhat steered by policymakers through creating incentives and regulations, the broader institutional setting, such as governance transparency and effectiveness, business environment, political regime, lobbying and vested interests also play an important role (Grin et al, 2010).

Several types of models are used to provide insight into transition pathways to sustainable low-carbon societies, including Integrated Assessment Models (IAMs), energy system models, and simulation models, such as Agent-Based Models (ABMs). These models all differ with regard to their representation of institutions and actors. This deliverable maps the different representations of institutions and actors in models applied in the PATWHAYS project. It focuses on two IAMs, one energy system model, and one ABM. The objective is to outline opportunities to introduce more realism in models with respect to actor heterogeneity and the role of institutions.

IAM has become a key analytical approach used to explore future scenarios leading to pre-defined global environmental and sustainability goals. IAMs describe the complex interactions between human, natural, and climate systems. They also provide insights on possible interactions between sectors and different sustainability goals (e.g. energy, food, water, and climate), linkages across topics (e.g. consequences of climate policy for land use), scales and regions (from global to subnational level, often geographically explicit), but also on indirect economic linkages (e.g. sectoral shifts and rebound effects as stated by van Vuuren and Kok 2012). In addition, scenario analysis allows us to examine the relationship between near-term decisions and long-term trends and goals by taking into account relevant inertia. These scenarios provide support to high-level decision-making in the fields of environment, sustainable development, and transition towards low-carbon economies.

IAMs have simplified representations of both the human and natural systems. With regard to the human systems, most IAMs are outcome-oriented and focus on the consequences of exogenously specified policies, with limited attention to the processes and the social interactions leading to those outcomes (Hofman et al. 2004). The representation of non-technological factors such as interactions among actors and interest groups, political economy factors, and institutions, remains stylized, as they are rather more difficult to capture in the mathematical equations of the models (van Vuuren and Kok 2012). They also lack detail in the representation of consumer behavior and external drivers affecting policy effectiveness such actor heterogeneity, institutions and governance. The representation of governance and institutions is limited to the actions of the state or the government, generally represented as a social planner implementing regulations and policies. Moreover, policies are often simply represented by a global uniform carbon tax or price applied to all sectors and regions, assuming cost-optimization over sectors, regions, and time (Clarke et al. 2009 and Kriegler et al. 2013a) with the main goal of providing insight into cost-efficient reduction strategies. In order to provide insight into the consequences of more realistic situations, a number of studies have introduced second-best elements such as delayed or fragmented policy scenarios or limiting the implementation of technologies in selected scenarios (Kriegler et al. 2013, 2013a, 2014, Tavoni et al. 2013). Yet, these second-best scenarios are only a (linear) reflection of the behavior of relevant actors and do not address the institutional factors. Once the policy is adopted, its effectiveness is generally assumed to be unaffected by the institutional framework. The newly adopted scenario framework Shared Socioeconomic Pathways (SSPs; van Vuuren et al. 2015 and O' Neil et al. 2015) acknowledges the importance of policy and institutions as important dimensions by introducing the concept of Shared Policy Assumptions (Kriegler et al., 2014a). These assumptions describe three attributes of climate policies: 1) climate policy goals, 2) policy regimes and measures, and, 3) a description how implementation limits and obstacles are addressed. However, the formulation of Shared Policy Assumptions on a global and century scale can become complex and the climate policy landscape is not described in detail. Therefore it can be concluded that policy and institutional narratives have not been explicitly taken into account in IAMs[1]. Some IAMs have either explicitly or implicitly dedicated more attention to the role of different actors and actor heterogeneity, as reviewed by Krey (2014) and Wilson and McCollum (2014). Examples of heterogeneities that have been included in models include the urban-rural divide, income distribution, or household composition (Ekholm et al. 2010; van Ruijven et al. 2011; Eom et al. 2012; O'Neil et al. 2012; Krey et al. 2012; and Melnikov et al. 2012).

Energy system models have a detailed bottom-up representation of the energy system or a part of it, e.g. the electricity market. Energy system models have a stronger focus on detailed technological changes while the macroeconomic system is modeled exogenously, thus disregarding potential inter-sectoral feedbacks. Demand is usually an exogenous input to the model, and market prices are calculated endogenously. Energy system models can be categorized into three major types; optimization models, equilibrium models, and simulation models (Ventosa et al. 2005). Institutions and actors can be included only in a limited, highly indirect way, for example by defining the exogenous constraints and costs. As information costs, transaction costs, and other market failures are not included, this approach tends to underestimate the costs related to systemic changes (Sensfuß, 2007).

ABMs are dedicated models that analyze the more behavioral-realistic decision making of different agents (actors and institutions). They provide an explicit representation of agent heterogeneity as well as of interaction across agents (Epstein and Axtell, 1996). ABMs are designed to describe the interactions among different actors that operate according to prescribed behavioral rules and can capture emergent phenomena (Farmer et al. 2015). The models' results strongly depend on the parameterization of the agents. Results from all models generally depend on input parameters but ABMs also require data on the preferences and decision-making process of the agents, for which empirical data is often scarce. Furthermore, the reaction to significant changes can usually be based on empirical data but they have to be estimated. For example, the construction of solar heating systems in Germany has been rather limited.

As illustration, an ABM aimed at depicting the diffusion of renewable energy in the residential sector could be based on a number of factors. The solar heating systems might be too expensive, the residents might not know enough about the technology, or they could be opposing renewables energies for aesthetic reasons. The data necessary for calibrating the model could be obtained through a survey. However, the reasons for a slow diffusion might be very different in other parts of Europe, decreasing its transferability. For these reasons, most ABMs focus on a relatively small region or depict only parts of the energy system, for example investments into renewable electricity or improvements of buildings. Capturing both the complex technical aspects of energy systems and the behavioral/social aspects for a large region in a single model is beyond the computational power available to the researchers' active in this field.

[1] https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about

The differences in the representation of institutions and actors between IAMs, energy system models, and ABMs as discussed above arise from their different objectives. IAMs are intended to illustrate long-term, global emissions and technology pathways; energy system models are intended to provide more technologically detailed information on the energy system; while ABMs are intended to illustrate possible pathways of change at the level of individual decision making.

Although quantitative modeling approaches will continue to be relevant as a reference for policymakers, the increasing focus on implementation and the transition dynamics toward long-term objectives requires more attention to scenarios with an explicit consideration of how the changes will take place and how they can be accelerated. Opportunities to improve the behavioral realism, the degree of heterogeneity, and the representation of institutional and governance factors can be created by fostering collaboration across different disciplines, between modelers, empirical economists, and policy analysts.

The report is organized as follows. Section 2 introduces the key concepts related to actors and institutions used in the rest of the document. Section 3 provides a deeper discussion on models' assumptions about actors and institutions by drawing on four different models used in the Pathways project[2]. Section 4 summarizes possible routes of going forward and Section 5 concludes.

[2] http://www.pathways-project.eu/

2. Definitions of institutions

The notion of institutions has been used with different connotations across disciplines involved in sustainability studies and transition scenarios. A broad notion of institutions refer to institutions and governance (Turnheim et al. 2015) and captures the key processes of steering and decision-making in a way that gives emphasis to the role of different actors beyond the state and government, including actors, organizations, structures, networks, and relationships that contribute to decision-making and influencing societal processes. This broad definition of institutions builds on three key dimensions: 1) actors and networks, 2) processes, modes, and approaches, and 3) objectives, outcomes and criteria of relevance to understand and influence transition dynamics towards desirable directions. The first dimension includes governments, institutions, actions of the state or the government, and governance (e.g. the role of non-state actors, such as businesses and non-governmental organizations in the process of societal steering, Jordan 2008). The second dimension is about the processes and tools that can be used to implement policy decisions, and can broadly be framed as the institutional dimension. The third dimension is about the objectives and goals behind steering and intervention strategies. It encompasses questions about the objective of steering, the rationale for steering, and the evaluation criteria to be used.

Within the discipline of sociology, Scott (1995) defines institutions as referring to a broad set of regulatory, cultural-cognitive, and normative rules (Table 1).

Table 1: Different types of institutions (Scott 1995)

	Regulative (a)	Normative (b)	Socio-cognitive (c)
Examples	Formal rules, laws, sanctions, incentive structures, reward and cost structures, governance systems, power systems, protocols, standards, procedures	Values, norms, role expectations, authority systems, duty, codes of conduct	Priorities, problem agendas, beliefs, bodies of knowledge (paradigms), models of reality, categories, classifications, jargon/language, search heuristics
Basis of compliance	Expedience	Social obligation	Taken for granted
Mechanisms	Coercive (force, punishments)	Normative pressure (social sanctions such as 'shaming')	Mimetic, learning, imitation
Logic	Instrumentality (creating stability, 'rules of the game')	Appropriateness, becoming part of the group ('how we do things')	Orthodoxy (shared ideas, concepts)

In models, institutions are often represented by exogenous decision rules describing the decision process of aggregate/representative actors. Formal regulatory institutions, generally formulated by national or transnational political organizations, are the main type of institutional change commonly implemented by IAMs in transition scenarios. The main institutional driver of changes in regulatory institutions is in the form of different climate policy instruments (e.g. carbon tax vs. emission trading scheme) and policy targets, which can also be sector or technology specific (e.g. a PV subsidy). Normative and socio-cognitive institutions are implicitly embedded in model assumptions and parameter choices. One such example is the discount factor, which is used to evaluate future versus present consumption as well as investments in final good and energy technologies. Lowering the discount factor in models puts more weight on future relative to current costs and benefits, and therefore favors technologies with high initial investment such as wind power, which after the initial investments are carried out delivers power at almost zero costs.

The definition of institutions used by IAMs is close to the definition used by the applied economic literature. The economic literature generally refers to institutions as the rules of how markets operate. Economic institutions perform functions such as establishing and protecting property rights, facilitating transactions, permitting economic co-operation and organization (Acemoglu and Robinson 2010). The literature distinguishes between legal, political, and economic institutions (Acemoglu et al. 2005). Legal institutions take the form of legislature, public or state-devised legal institutions, and private legal institutions. Political institutions shape policy decisions by constraining the set of feasible choices of the decision-makers and by creating and enforcing laws and of governmental policy making. Governance is defined as the traditions and institutions that determine how authority is exercised in a country (Kaufmann et al. 2000). Dixit (2009) defines economic governance as structure and functioning of the institutions that support economic activities and transactions by protecting property rights, enforcing contracts, and taking collective action to provide physical and organizational infrastructure. The literature uses a number of different institutional and governance quantitative indicators measured at the national level (Dasgupta and De Cian 2016). The most commonly used indicators are the Polity IV indicators, the World Governance Indicators (rule of law, voice and accountability, government effectiveness, and control of corruption), the Freedom House Index, and corruption perception from Transparency International. Within the broader definition of governance used by socio-transition studies, these indicators refer to a narrower definition of institutions and governance as referring only to the actions of the state or of the government.

In socio-transition studies, agency tends to be conceptualized as a dimension of governance, whereas we refer to agency as the explicit or implicit representation of actors in the models, as well as to the decision-making process describing the decisions. Socio-transition studies emphasize the role of multiple actors, types of behavior and preferences. Actors and networks are generally represented at different levels to account for the difference between actions of the state or the government and the role of non-state actors, such as businesses and nongovernmental organizations in the process of societal steering. In the models considered in the next section the behavior of actors is primarily determined by technological factors, but depending on the model it can also be influenced by internal drivers such as attitudes, values, habits, as well as external drivers and contextual factors such as institutions, regulations, and social norms.

3. Model assumptions on actors and institutions. A deeper discussion using four example models

This section describes the characterization of actors and institutions in the four models used in the PATHWAYS project[3]. It includes two IAMs: IMAGE (Stehfest, van Vuuren et al. 2014), WITCH (Emmerling et al. 2016); one energy-system model, PowerACE[4], and one agent-based model, MATISSE-KK (Köhler et al. 2009)[5].

3.1 Actors

IAMs, energy-system models, and ABMs represent actors, their heterogeneity and decision–making, in a very different way (Table 2). Beginning with the description of actor representation in cost-oriented models[6], in WITCH and PowerACE decisions are taken by one or more social planners, who make a top-down decision between a broad set of investment choices and consumption. In WITCH regional social planners maximize a welfare function and choose the intertemporal resource allocation between consumption and investments. In PowerACE, a European social planner minimizes total system costs across technologies and across EU countries. In IMAGE, decisions about technologies are made based on the relative costs of an ensemble of choices which are specified per region and vary dynamically over time or are manually changed exogenously by a social planner. The relative costs consist of explicit (e.g. capital, O&M) and implicit (e.g. preferences) costs factors, thus combining technology economics with actor-based preferences. In this so-called multinomial logit approach, the factor representing the sensitivity to price differences thus creates heterogeneity in consumer preferences.

Table 2: Action positioning and strategies in different types of models

Action positioning and strategies	WITCH Optimization IAM	IMAGE Simulation IAM	MATISSE-KK Agent-based model	PowerACE Optimization energy system model
Actors	Aggregate regional social planners	Implicitly represented, decisions are described for individual markets. Differentiation between urban and rural households.	Agents or behaviors are modeled explicitly, consumers, niches, regime	Aggregate European social planner
Decision variables	Investments	Investments and technologies	Niche and Regime: Direction of technological change Consumer: Technology - lifestyles adoption	Investments and dispatch
Decision making	Constrained welfare maximization	Constrained cost minimization	Niches: change the technology-lifestyle characteristics to survive Regimes: maximize market share Consumers: adopt the regime or a niche lifestyle/technology	Constrained cost minimization

[3] See http://www.pathways-project.eu/
[4] www.enertile.eu
[5] LEAP is not described in this section because it is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data structures.
[6] By cost-oriented models we refer to models that make decisions based on explicit (e.g. preferences) and implicit (e.g. capital, O&M) cost parameters.

For cost-oriented models, regardless of whether they have a social planner or limited/static actor representation, it can be argued that a multitude of actors are implicitly represented in the different investment decisions. Table 3 provides an example of how different technology cost components can be associated with different actors.

- **Technology cost specific components:** several different agents will be involved in decisions regarding the choice of which power plant to invest in, including regulators, different electric power companies, consumers, and various types of NGOs. Consider, for example, investments in solar PV, large utilities might decide to start investing in large-scale PV themselves. Alternatively, consumers can also install PV as small-scaled rooftop PV. Depending on the respective scenarios, two technologically similar results have to be interpreted in different ways. In PowerACE, large-scale PV and rooftop PV are distinguished as separate technologies and to some degree different interests can be represented (e.g. the decision by consumers to either use power from the grid or invest in PV, but also the interest of regulators to keep a manageable power system). However, in IMAGE and WITCH, the different forms of PV are not (yet) represented as individual technologies.
- **Non-cost specific components:** Various non-cost related factors may represent individuals or groups of actors deciding on the course of society (again in less tangible forms). For example, scenarios can be designed around the choice whether a more radical or limited use of a specific technology or service is desired (conditional settings), emulating a managerial decision process in a specific region, sector or supply-chain.

Table 3: Examples of implicit actors in models

Technology cost items represented in models	Implicit actor associated actor
Purchasing price	Manufacturers / R&D
Fuel cost	OPEC
Preferences	Consumer
Capital costs	Investors
O&M costs	Mechanics
CO2 tax	Government
System integration costs	Energy companies
Cost curves	Research institutes
Conditional settings	Politics

A detailed and explicit representation of actors can be found in the MATISSE-KK model, which incorporates niches and the regime as individual agents. A regime refers to the dominant structure consisting of the dominant culture and practices in a system. The regime in mobility is the conventional internal combustion engine (ICE), which the majority use for most of their mobility needs. Niches refer to individuals or small group of actors with local practices, which differ from the regime. Consumers choose whether to adopt the regime or a niche lifestyle/technology. A large number of simple agents whose function is to allocate support to the regime or a niche determine the relative strength of the regime and niches. The MATISSE-KK ABM is intended to address changes in society through changes in mobility patterns or lifestyles. These changes are modeled as the decisions of households to keep the current pattern of mobility or to change it.

3.2 Decision making

A common element across the four models is that the adoption or investment in technologies plays a central role. Yet, the decision process describing how the choice is made (e.g. decision making, Table 2) varies significantly across models. Full optimization models with perfect foresight (WITCH and PowerACE) have full future knowledge and they optimize investment decisions taking the whole time horizon into account. In WITCH, investments decisions are based on country-specific returns on investment (endogenous in the model), which in turn are affected by exogenously specified capital and operation and maintenance costs. WITCH builds on the neoclassical economic theory, which views agents as rational and having a clear objective they know how to achieve by optimizing. Both WITCH and PowerACE rely on a rational choice mode and optimizing decision-making rules in the form of either welfare maximization or cost minimization. Simulation models such as IMAGE assume no future knowledge and optimize investment decisions year by year in a recursive-dynamic way. Investment choices are made based on relative technology costs, assuming a fixed discount factor (by default set at 10%). Technology costs also includes a perceived factor, which is calibrated based on historical investment data.

ABMs such as MATISSE-KK specify different rules and can differentiate them by type of agents. Consumers decide about the adoption of the regime or niche technologies based on a set of attributes (practices) including include environmental performances (e.g. emissions), technology costs, demand split, ICT use, and the structure of the built environment with regards to provision for the different transport modes. Consumers choose regime or niches technologies/lifestyles based on their attractiveness, given their preferences. The technologies or lifestyles form niches and a regime, which are also represented as agents in the model. The regime and niches change their practices as technology improves and depending upon the support that the technology/lifestyle is receiving from the consumers. Preferences can be influenced by the contextual factors provided by the landscape, which is exogenously characterized. Landscape signals change the preferences of simple agents and hence their support decisions and can also change the fitness of the regime and niches.

3.3 Decision variables

We can identify contextual and technology factors or drivers that influence the decision to use/adopt alternative technologies across all models (Table 4). Technology factors describe the characteristics, costs, and environmental performance of technologies in terms of lifetime, efficiency, learning, and emission performance. Contextual factors include social and behavioral changes or regulatory changes, such as the implementation of climate policy or of technology subsidies. They can be implemented as external impulses or shocks imposed by modelers (e.g. by constraining the availability of a specific technology to reflect societal or political shifts), as exogenous changes in model parameters (e.g. by changing the substitution possibilities between technologies), or can be translated into (perceived) price-based factors (e.g. preferences for a specific technologies can be simulated by adjusting the interest rate for those technologies). Contextual factors also include institutional dimensions, which are discussed in Section 3.4.

With the exception of ABMs, the representation of agency and actor heterogeneity remains very limited. Limitations concern the lack of heterogeneity in agency, the weak empirical foundation of behavioral parameters and rules, the decision criteria being most often based on rational choice models, and the assumption of perfect knowledge of the objective to achieve.

Table 4: Examples of contextual factors in different types of models

Contextual factors	IMAGE	WITCH	MATISSE-KK	PowerACE
Social and behavioral change	Explicit and implicit non-monetary parameters changing the preference hierarchy for technologies and services (see Table 6 for more detailed overview)	Constant Elasticity of Substitution (CES) structure describing the degree of substitutability between alternative energy technologies, learning rates describing the speed of learning and its outcome Vehicle Ownership Growth Elasticity Kilometre demand	Rates of change of preference parameters (e.g. consumer preferences and niche strategies) Changes in relative prices, changes in relative emissions performance, changes in service level of alternative modes, changes in urban form	Interest rate driving investment choice in specific energy technologies Preference for technologies Unavailability of technologies
Regulatory change (intervention, governance)	Carbon/energy tax Subsidies Standards Prescribed technology market shares Emission targets	CO2 costs Carbon tax	Changes in relative prices, changes in relative emissions performance, changes in service level of alternative modes, changes in urban form	Adjustments in land use, technology and fuel prices or emission prices /limits

Note: The list reported in the table is not meant to be exhaustive but to provide illustrative examples.

3.4 Institutions

In all the models examined in this paper, institutions tend to be represented in an exogenous and aggregate way. Models represent the three types of institutions (Table 1) with a different degree of detail (Table 5). Formal regulatory institutions, generally formulated by national or transnational political organizations, are the main type of institutional changes commonly implemented by IAMs in transition scenarios. When implemented, regulations are commonly assumed to be effective at achieving the objective and they create a better or worse context for economic, environmental, and technological development, which can be measured and projected in a quantitative way. Whereas the economic-oriented approach of models tends to focus on the effects of regulations and policy prescriptions, institutional change in transition is also about beliefs, mindsets, preferences, as well as normative aspirations and the notion of what is good. Although more difficult to measure at the aggregate scale at which models operate, these two dimensions are implicitly included in models.

In optimizing macroeconomic models normative assumptions are embedded in the welfare function. The welfare function is used for intertemporal optimization, the process to evaluate the trade-off between current and future consumption. The representative agent of the models, a benevolent national or supranational government, decides the allocation of resources between consumptions and savings. Similar to the individual decision consumption and savings today, this decision depends on the subjective degree of risk aversion and the importance given to future consumption. A similar reasoning applies when considering the decision between investing in clean energy in order to reduce the future damages from climate change or to achieve a long-term mitigation target. Models generally specify parameters, which affect discounting of the future (the pure rate of time preference describing the weight of future generations in intertemporal welfare considerations and the intertemporal elasticity of substitution describing the willingness to smooth consumption over time). Socio-cognitive elements, for example about preferences for energy technologies due to a redefinition of what is good (e.g. phasing out of nuclear power, opposition to CCS, and services versus ownership) can be represented in an implicit way through changes in preference parameters, ad-hoc adjustments in costs, or exogenous shifts imposed by modelers.

Table 5: Representation of institutions in different types of models

Institutional change	WITCH	IMAGE	MATISSE-KK	PowerACE
Regulatory	Formal regulatory institutions as exogenous policy targets or instruments.	Formal regulatory institutions as exogenous policy targets or instruments.	Formal regulatory institutions as costs and environmental performance of the regime/niche.	Formal regulatory institutions as exogenous policy targets or instruments.
Normative & Socio-cognitive	Discounting, given by 1) the weight assigned to future generations in the intertemporal welfare function 2) the willingness to smooth consumption over time. Discounting does affect the outcome in this optimization procedure.	Exogenous discount rate. Although the model formally does not optimize over time, it includes an iteratively process to find the cheapest pathway to achieve a set climate target. Discounting does affect the outcome in this optimization procedure. Preferences for energy technologies based on relative costs: cheap technologies gain a higher market share. Costs include a (positive or negative) premium factor, which can also be interpreted as a subsidy, tax, or preference for a certain technology.	**Normative** Weighting of support for different technologies-lifestyles. **Socio-cognitive** Weighting of climate issues in consumers' decisions.	Not applicable

Normative institutions in the sense of values regarding lifestyle expectations of roles for individuals in energy and mobility systems and markets can be addressed explicitly in ABMs. The MATISSE-KK model has consumer agents characterized as having different weights for different mobility lifestyles. The acceptance of households as power suppliers into the grid can also be represented by the inclusion of consumer power producers. Changes in norms about energy and mobility behavior (e.g. lowering indoor temperatures to save on energy use or a driving style that minimize energy use rather than driving as fast as possible) can be modeled by modifying energy and fuel demand functions for the relevant technologies. This can be done for a representative consumer/producer and for a distribution of consumer and producer decision-making types.

Socio-cognitive institutions, referring to priorities, problem agendas, and beliefs can be represented in IAMs implicitly by specifying different preferences for energy technologies based on relative costs, for example cheap technologies gain a higher market share. A premium factor can be included to calibrate against historical data in order to modify costs. The premium factor can also be interpreted as a subsidy, tax, or preference for a certain technology. Indeed, from historical data it is clear that some technologies have higher shares than you would expect from costs only. In MATISSE-KK socio-cognitive institutions are represented more explicitly, for example by weighting of climate issues in consumers' decisions.

Overall we can conclude that the representation of institutions in models is stylized. ABMs perhaps offer a richer framework for characterizing institutional heterogeneity, though mostly in an exogenous way as specified by the modeler. Whereas institutions affect the decision process in models, even in ABMs interaction across actors cannot affect the broader institutional setting. Although the elements of models can be associated with different assumptions of agency or institutions can be identified; modelers usually exogenously specify these.

The need to improve the representation of the behavioral and institutional components in IAMs is being explored by a growing number of new research projects[7]. Work in this direction is needed because the increasing focus on implementation and the transition dynamics toward long-term objectives requires more attention on how the changes will take place and how they can be accelerated. Opportunities to improve the behavioral realism, the degree of heterogeneity, and the representation of institutional and governance factors can be created by fostering collaboration across different disciplines, between modelers, empirical economists, and policy analysts. The next section discusses possible routes of going forward in the modeling of actor heterogeneity and institutions.

[7] See for example COBHAM (http://cordis.europa.eu/project/rcn/191138_en.html) and ADVANCE (http://www.fp7-advance.eu/, Wilson and Mcollum 2014).

4. Improving the representation of actor heterogeneity and institutions in models

Section 4.1 discusses the opportunities for improving the representation of actors in IAMs and energy-system models by means of gradual or incremental changes within the structure of existing models and through the interaction with models such as ABMs, which already present a characterization of different actors. Section 4.2 discusses whether the existing framework of IAMs, energy-system models, and ABMs can attend to the kinds of institutional dimensions outlined in Table 1 or whether the analysis of the governance of transition pathways should instead rely on a partnership with other approaches.

4.1 Improving the representation of actor heterogeneity in models

As discussed in Section 2, models rely on mathematical equations, variables, and parameters to quantitatively describe contextual factors that, in addition to price-driven and technological factors, influence models' choices. The values of these parameters are often assumed to be uniform within and across regions, as well as across scenarios. When creating different climate policy scenarios, models generally vary the regulatory or technological dimension (Kriegler et al. 2013; 2013a; 2014; Tavoni et al. 2013), but social and behavioral factors are often left unchanged. Only a limited notion of behavioural factors is described for scenarios that explicitly focus on demand reduction (see e.g. Riahi et al. 2013). This is generally achieved via improved technological efficiency and does not elaborate on how this could be obtained via behavioral change. Attempts to make behavioral factors more explicit are more on an ad-hoc and exogenous basis, such as (1) changing the input parameters in the model and assumptions over time or (2) by capping model calculations to a (lower) empirically found value (see e.g. van Sluisveld et al. 2016). Stabilization scenarios are often characterized by incremental changes and technological substitution without requiring major reconfiguration in the underlying societal configuration of actors.

The PATHWAYS project has explored opportunities to simulate broader regime changes entailing actors' reconfiguration by changing key model assumptions and parameters connected to social and behavioral factors, and implicitly to different actors. Specifically, the project has examined two transition pathways characterized by the interplay of incumbent actors versus a broader change in preferences and lifestyle. As addressed before, models with a strong focus on cost optimization can model social and behavioral changes only implicitly and in an exogenous and static way. As a result, certain input parameters need to be reinterpreted to represent (exogenously defined) social developments or actor preferences. It has to be emphasized that all efforts oriented toward a better representation of institutions and agencies have to work around this fundamental challenge. In Table 6 we elaborate on the parameters in WITCH, IMAGE, PowerACE, and MATISSE-KK that have been identified to implement changes in preferences, lifestyles, and social factors across the domains electricity, mobility, and heat.

- **In the electricity domain**, to emulate an increased interest for solar-PV systems the WITCH, IMAGE and PowerACE models introduced external impulses to represent regulatory (e.g. subsidy) and technological changes (e.g. faster learning associated with social learning reinforcing technical learning) by modifying the cost of PV and thus the penetration and momentum of that particular technological option. In PowerACE, a change in preferences reflecting higher willingness of small actors to invest was simulated by lowering the cost and the interest rate for photovoltaic sources, which can be interpreted as representing two aspects of preferences. Government support programs can initialize low interest rates or lower costs. This might include special state-aided loans to encourage investment or feed-in-tariffs. Second, low interest can be seen as a high acceptance among private investors, who lower their profit expectations in favor of investing in a new promising technology. The low interest rate thus can also represent a situation in which the investor is willing to accept a relatively low profit to support the technology. However, the same cannot be said for the incumbent investors, who would not be willing (and in many cases not even allowed) to pursue an unprofitable investment.

- In the **mobility** domain the IMAGE model mostly focuses on the allocation to various transport modes and the composition of the vehicle fleet for each mode. Actor heterogeneity can thus only be expressed as a reconsideration of preferences for modes and vehicles used to meet the total travel demand. Some degree of behavioral change can be implemented by tweaking specific parameters, such as vehicle occupancy rates, time, and money budgets for travel and preference factors that increase the weight on one mode or vehicle over the other. In that sense IMAGE can emulate mode shifts and car sharing. IMAGE has simulated car sharing by increasing the vehicle occupancy rate and by increasing the preferences for public transportation. In WITCH, a slower increase in vehicle ownership, an increase in the number of occupants per vehicle, and a decrease in travel demand have been implemented in order to simulate the switch from private modes to public transport and a urban reconfiguration according to a compact city scheme. In MATISSE-KK, a change to either car sharing, domination of a public transport based lifestyle or a mobility lifestyle based on cycling and walking requires not only a change in preferences towards CO_2 emissions but also a change in consumer preferences towards mixed use urban structures and towards less private mechanized mobility. This is also a change in preferences away from private conventional car ownership.
  Some further developments have taken place in IMAGE to increase the heterogeneity of actors involved in the transport sector, explicating several types of “consumer groups” that either decide, amongst others, to jump the gun (the “hipster”) or wait it out until markets have developed (the “laggard”). The decision element of these consumer groups remains by large the same as within the rest of the model, determining the choice based on total relative costs (capital + social costs), though attempts are made to make it more internally dynamic (via conditioning it on market developments).

- In contrast to the electricity domain, the IMAGE model has a more “people”-oriented focus for the **buildings** sector – addressing a wide range of energy service demands such as cooking, heating, and appliance energy use. Therefore this domain allows for greater actor representation and behavioral heterogeneity. For instance, the formulation for demand for heating explicitly requires a factor representing total floor space that needs to be heated (Isaac and van Vuuren, 2009). As IMAGE makes an explicit distinction between urban and rural areas, differences in homeownership are taken into account. However, in the light of heating technology options being used, the choices are limited in the IMAGE model – as the assumptions only utilize efficiency rates of boilers (the only technology (using various energy carriers) that is represented is the “boiler”). In the course of the PATHWAYS project an additional heating technology was added to the portfolio that taps from the electricity energy carrier (air source heat pump), but the market penetration rate remains an economic decision of the model responding to fuel price change.

Table 6: Examples of interventions changes to simulate different actor behaviors in different types of models

		IMAGE	WITCH	PowerACE	MATISSE-KK
Electricity	PV	Equalize PV price to overall electricity price	Learning rate +25%, floor cost -12.5%	Lower interest rate Higher land availability	
Mobility	Car sharing	Increased vehicle occupancy	Increased vehicle occupancy		Government support and publicity for car sarin organizations. Restrictions and taxes on private car use, leading to increased costs and lower convenience of driving you own ICE car.
	Transportation mode	Reducing available travel budget per person Increased preference for public transport	Lower travel demand and vehicle ownership growth		Change in lifestyle, with less car use, more emphasis on environment, more emphasis on mixed zones and public transport
Heat	Low-energy housing	15% energy reduction due to improved insulation			
	Behavioral change/ Smart metering	Change base temperature by 1˚C No growth of appliance ownership after 2010 No tumble dryer after 2010 More efficient use of appliances			
	Lower size of dwelling	Floor space is fixed to 2010 values (rural 50m2/cap and urban 40m2/cap)			

Another strategy for improving actor heterogeneity in models is to rely on linkages between different tools, different models, or different disciplines. In PATHWAYS we have explored which opportunities exist in connecting ABMs and IAMs, in combining energy simulation tools and simulation models, and in integrating initiative based learning and modeling. In the remaining of this section we briefly described these three approaches.

- **ABMs and IAMs:** In principle it is possible to develop Agent-Based IAMs. The simplest possibility would be to have two different types of agents rather than the single representative agent or the centralized social welfare maximizer. However, this would represent a change in the underlying theory, which would require a reconsideration of other principles of the model as well. A less drastic approach is to use the results of ABMs to inform the calibration of the IAMs. For example, results from an ABM could be used to adapt the rate of technology adoption in the IAMs, something that has not been done yet to our knowledge.Secondly, the IAMs could consider a wider range of solutions for society than the technological substitutions currently assessed. This could be achieved by defining these lifestyle solutions and their emissions and price characteristics as part of the choice sets in the IAM. In the field of passenger transport, an example of such a lifestyle change could entail a change from personal automobiles to public intermodal transport. This could be achieved by changes in the preference structure of the consumers and by changes in the generalized costs of the different modes. In the field of energy, this could entail a shift from buying energy as a consumer to becoming a combined supplier and consumer, with an automated energy management system optimizing a combination of decentralized generation, energy storage and energy purchase, depending on the real time current prices and costs.

- **Empirical evidence and modeling tools:** In the specific context of the PATHWAYS project, the rather ad-hoc interventions summarized in Table 6 have been implemented in a homogeneous way across model regions in order to simulate different scenarios, or different transition storylines. Similar approaches, however, could be used to introduce more heterogeneity in preferences and behaviors across sectors and regions, and they could be substantiated by empirical evidence. There is indeed a broad empirical literature on microeconomic behaviors related to technology adoption highlighting the great variety of technical and non-technical determinants of technology investments and adoption that could be used for this purpose (Mundaca et al. 2010; also see Wilson and McCollum 2014 for a review).

- **Initiative-based learning and modeling tools:** Another incremental strategy to improve the realism of actor influences in IAMs is to use the evidence from initiative-based learning to improve the representation of certain process. De Cian et al. (PATHWAYS Deliverable D3.4) explore whether the evidence from initiative-based learning can be combined with IAMs to offer a more realistic representation of learning dynamics in the context of solar PV technologies. The paper discusses how initiative-based learning and IAM conceptualize learning in a very different way. Whereas the former approach highlights learning mechanisms involving the interaction among agents and actors (social learning), the latter emphasizes the learning mechanisms related to the process of production and use of specific technologies (learning-by-doing). IAMs rely on the empirical evidence to parameterize the learning curves describing learning-by-doing dynamics, but the empirical estimates 1) span a very broad range and 2) are not able to disentangle the role less tangible forms of learning, such as social learning. The omission of variables, such as social learning, that could reinforce learning leading to biased estimates, has important implications in terms of model-based scenarios of the future penetration of technologies, future energy transition, and projected energy systems. A more systematic analysis of a larger sample of case studies, with a great attention to how short-run learning dynamics unfold over time could yield patterns with a more general validity that could be used by IAMs. In turn, IAMs need to assess the sensitivity that learning dynamics have on energy and technology scenarios and could interpret the results in light of the insights provided by other disciplines, such as initiative-based learning.

The extent to which models and disciplines can be linked is very case-dependent but it is generally entails harmonizing to a set of similar measures applied (represented by a modeling protocol) or to emulating similar (aggregated) trends (e.g. emission trajectories).

4.2 Improving the representation of institutions in models

Contextual factors such as institutions influence the behavior both at the aggregate and individual levels (Urry 2008 and Rudel et al. 2011). Accounting for the influence of institutions as defined in section 2 on individual behavior would require deeper structural changes in models. State-of-the-art models have opportunities to improve the institutional heterogeneity across regions and scenarios. Those opportunities can arise from a deeper connection with the applied economic literature on this topic.

The applied economic literature on the environment and institutions can offer empirical guidance by establishing quantitative patterns and stylized facts that can be used to improve models' representation of institutions and actors. Models' conceptualization of governance and institutions comes close to the approach adopted in mainstream economics, which has traditionally been interested in decision-making and steering within the boundaries of the state and government. The applied economic literature on the environment and institutions examines relationships between institutions, or more broadly political economy factors and indicators of policy adoption, policy effectiveness, and environmental outcomes in a quantitative way. They rely on observed cross-sectional, time series, or panel data, and use of natural experiments in some cases. Although such reduced-form approaches cannot represent all mechanisms at stake, they can establish the existence of robust relationships between, for example, governance indicators and environmental outcomes. Yet, they can examine the role of different factors jointly, while controlling for confounding factors. They can provide empirical evidence on reduced-form relationships between "key decisions" (e.g. R&D investments, policy stringency) or "key outcomes" (e.g. energy intensity, green investments, emissions) represented in quantitative system models and external drivers, such as institutional or political economy factors, with the granularity and the spatial scale that is relevant to most models, namely at the aggregate national or world regional level. This approach often relies on a set of "hypotheses", often grounded in theoretical frameworks, which are then formalized into a simple model testing a causal relationship between quantifiable variables. The empirical hypotheses translated into simple reduced-form equations can nevertheless be based on theories building on a broader view of the interactions between internal and external drivers (e.g. system of innovation approach emphasizing how innovation is the result of the interaction between different factors, including training, public policy, institutions and socio-technical transition emphasizing the relationship between technology, infrastructure, and society in the supply and demand of energy).

The well-established literature on institutions, governance, and the environment has evaluated the impacts of institutions and governance on a range of environmental performance indicators and on policy adoption. Dasgupta and De Cian (2016) review 55 papers on the topic, and find that 41 of them use performance indicators such as emissions (methane, carbon dioxide, sulphur dioxide, and nitrogen dioxide), other pollutants (carbon monoxide, chlorofluorocarbon, and lead), deforestation, land degradation, and protected areas. Only 5 studies out of 39 analyze the impacts on green investments, while 16 papers look at the impact of institutions and governance on policy adoption, 8 of which use policy stringency as dependent variable. The remaining 8 papers focus on the decision to participate into international or multilateral environmental agreements.

The main institutional and governance indicators that have been used in the empirical literature can be broadly grouped into democracy, civil and political freedom, corruption, and governance. Commonly used institutional indicators are democracy indicators of Polity IV (2011), Worldwide Governance Indicators (WGI, Kauffman et al. 2010), and governance indicators and civil and political freedom indicators from Freedom House. Civil and political freedom indicators were widely used in the early stages of this literature as a proxy for democracy or democratic characteristics, whereas more recent papers have moved to the democracy, autocracy, and governance indicators of Polity IV and WGI. Governance indicators such as rule of law are mostly from WGI and corruption perception from Transparency International (TI, 2015). Indicators such as lobbying (Fredriksson et al. 2004; Fredriksson et al. 2007; Anadón 2012; and Dasgupta, De Cian, and Verdolini 2016), veto power (Fredriksson and Millimet 2007), and composition of parliamentary systems (Neumayer 2003; Fredriksson and Wollscheid 2007) have also been used, though less frequently. Three main results are highlighted by the empirical literature:

1. Democracy, civil and political freedom, transparency, and free flow of information allow the electorate to exert policy pressure on the government and facilitate or constraint the ability of governments to implement such measures. Democratic countries and open societies are more likely to provide public goods such as environmental protection (Hughes and Lipscy 2013) and Dasgupta and Mäler (1995) suggest that civil and political rights are rather influential in ensuring environmental quality, especially in comparison to authoritarian regimes. This implies that more democratic countries are generally associated with more participation into international environmental agreements and with better performance in terms of environmental indicators.
2. Good governance encourages the adoption of environmental policies and generally leads to better environmental outcomes.
3. Corruption can be a channel for environmental degradation, as it could lead to a sub-optimal use of resources and inefficiencies.

These results suggest that institutional factors, such as corruption, transparency of governments, the quality of bureaucratic quality and speed, are likely to influence the ability to implement environmental policies, the type of policy chosen, policy stringency, as well as the effectiveness of the policy implemented. This is in contrast for example with what generally is assumed by models, where environmental policies, once implemented, are equally effective across regions. Additional empirical evidence on how institutions influence environmental policies on energy-related investments could be used by models to regionally differentiate policy effectiveness. This could be operationalized by differentiating relevant parameters (e.g. R&D productivity) across regions.

Despite the existence of quite a broad empirical literature on institutions and the environment, to our knowledge this literature has been used neither implicitly (e.g. in the development of qualitative narratives, O' Neill et al. 2015) nor explicitly in models. The empirical evidence available in the current literature might not be suitable to be directly used in models, either because the empirical model is not directly comparable to the equations used in the model or because the indicators used are not represented in the model. For example, although the existing empirical literature is very broad, it has focused physical performance indicators or on dated policy adoption choices (e.g. signature of the Kyoto Protocol). This suggests that, in order to be included in models, the empirical study should be specifically designed. An example showing how the empirical evidence can be tailored and used in models is given by Iyer et al. (2015), which uses historical data to conclude that investment risks are higher in regions with inferior institutions. This result was then used to differentiate investment risks across regions in an IAM to assess the implications for regional mitigation costs.

Future empirical research could explore the role of institutions in contexts that are more relevant for sustainability transition studies. Possible issues include R&D investments, electricity generation from renewable sources such as hydropower, geothermal, solar, tides, wind, biomass, and biofuels or installed capacity of these sources, or more generally energy efficiency improvements or decarbonization patterns. Understanding the drivers of policy adoption and stringency and how institutions influences these decisions are issues that need to be investigated further, especially in the context of climate and renewable policies. New data on policies, such as the Environmental Policy Stringency dataset by OECD (Botta and Koźluk, 2014) offer opportunities to investigate relationships between institutional factors affect policy stringency. Questions of potential interest include whether the broader institutional setting affects decisions on the type of instruments and whether there is a causal relationship between indicators of institutional quality and policy stringency.

A few examples going in this direction exist; Verdolini and Vona (2015) look at the impact of market structure or risk of doing business on investment in renewable energy. Masini and Menichetti (2013) examine the impacts of non-financial factors in Renewable Energy (RE) investments, including behavioral (priori belief, propensity for radical technologies, and investors' knowledge of the RE operational context) and institutional factors (institutional pressure from peers, consultants, and published sources of information). The authors find that the behavioral context plays an important role in shaping the incentive to invest in RE and the beliefs about technical feasibility and proven performance seem to be particularly important. Dasgupta, De Cian, and Verdolini (2016) investigate the effects of environmental policy, institutions, political orientation, and lobbying on energy innovation and find that these factors significantly affect the incentives to innovate and create cleaner energy efficient technologies, suggesting that environmental policy effectiveness is influenced by institutional quality, government's political orientation, and the size of energy intensive sectors in the economy.

A parameter of high relevance in IAMs is energy intensity. IAM-based scenarios suggest strong absolute convergence in energy intensity across regions certainly in the long run, but also in the short run, but the empirical evidence actually does not necessarily supports this assumption (Le Pen and Sévi 2010), with the hypothesis of conditional convergence more likely. It means that countries tend to converge in energy intensity if they share common characteristics. Introducing more realism in the characterization of energy intensity convergence can improve the reliability of assessments of climate policies using models. Comprehending the institutional factors that hinder convergence is also important to understand which complementary measures need to be implemented in order to ensure policy effectiveness. Ongoing research (De Cian, Emmerling, Malpede in prep.) is exploring the influence of institutional factors on energy intensity dynamics and analyzing the implications of accounting for heterogeneity in regional dynamics for transition scenarios. Model-based scenarios assume strong convergence in energy intensity across regions, requiring improvements rates that for some regions (e.g. energy exporters) to far exceed the historically observed rates. The question is why those regions have lagged behind in terms of energy efficiency. Is it reasonable to assume that those reasons will disappear in the future? If not, what are the implications of considering the institutional barriers that have prevented energy intensity convergence also in future scenarios?

Other processes that some IAMs represent that could benefit from a closer interaction with the empirical evidence are R&D dynamics and the impact of environmental policy on R&D investments. The WITCH model represents endogenous technological change in energy efficient technologies in a homogeneous way across model regions. The underlying assumption is that climate policies will be equally effective around the globe; whereas Dasgupta, De Cian, and Verdolini (2016) show that governance effectiveness influences the impact of environmental policies on innovation investments.

Introducing endogenous dynamics of institutions more explicitly in the models used in transition scenarios would require structural changes in IAMs. Depicting both large energy systems and more complex social systems in the same model would imply extremely high computational requirements and extensive result evaluation processes. Schmitt (2014) developed a numerical IAM to analyse how endogenous political turnover between governments with heterogeneous preferences with respect to the level of greenhouse emissions affect climate change mitigation policies. The model used in the paper builds on WITCH but a number of simplifications are required in order to keep the problem computationally tractable. The multi-regional dimension is abandoned for a single region version of the model, endogenous technical change is also excluded, and the hybrid representation of the energy sector has been simplified to two types of capital stocks - clean and dirty.

5. Conclusions

Introducing more realism with respect to the representation of actors and institutions in modeling is important to improve the usefulness of quantitative scenarios. The increasing focus on implementation and transition dynamics towards long-term objectives requires more attention to scenarios with an explicit consideration of how the changes will take place and how they can be accelerated. This deliverable elaborates on the opportunities to improve the behavioral realism, the degree of heterogeneity, and the representation of institutional and actors in models. Furthermore, it illustrates how such opportunities can arise from the collaboration between different disciplines, modelers, empirical economists, and policy analysts.

IAMs refer to governance as the actions of the state or of the government, while socio-transition studies use a broader definition of governance. In socio-transition studies, agency tends to be conceptualized as a dimension of governance, whereas in IAM, agency is generally defined as the explicit or implicit representation of actors in the models, as well as to the decision-making process describing the decisions. In IAMs the behavior of actors is primarily determined by technological factors, but depending on the model it can also be influenced by internal drivers such as attitudes, values, habits, as well as external drivers and contextual factors such as institutions, regulations, and social norms.

In existing modeling frameworks, incremental improvements are available by incorporating a more heterogeneous actor representation. This deliverable underlines that combined exercises using several models will likely lead to a number of opportunities for incremental improvement in the representation of actors and institutions. Cost-oriented models utilize one or more social planners who make a top-down decision based on a broad set of investment choices and consumption parameters. However, some of these costs factors can also be reinterpreted as implicit proxy parameters for actor representation. The experience from the PATHWAYS project has highlighted a number of model assumptions and parameters in the electricity, heat, and mobility domains that could be differentiated across regions and across actors, using existing or dedicated empirical data and studies.

Modeling frameworks could also integrate concepts and evidence from other disciplines and tools. The main critique for incremental actor representation improvement is its ad-hoc, exogenous and static implementation of actors in dynamic modeling. Another strategy for improving actor heterogeneity in models could rely on linkages between different approaches or different models. In PATHWAYS, we have explored which opportunities exist in connecting ABMs and IAMs and in integrating initiative-based learning and modeling. The extent to which models and disciplines can be linked is case-dependent but is characterized in general by harmonizing to a set of similar measures applied (represented by a modeling protocol) or to emulating similar (aggregated) trends (e.g. emission trajectories).

Regarding the institutional dimension, opportunities for incremental improvements are offered in applied economic literature on institutions and governance, which could be used to differentiate policy changes to different technologies between regions. Moreover, theory could be used to model simple relationships between aggregate institutional indicators, investments and other key outcome variables already represented in models (e.g. R&D or energy intensity). The current report, however seems to suggest that the existing empirical evidence is rarely directly usable in models. Therefore, new, dedicated empirical studies should be designed for the purpose of improving behavioral realism in models.

Further research could expand the understanding on integrating institutions and actors in quantitative scenario work. Simulation models allow the integration of a much wider combination of real life aspects and dynamics. This leads to an increased complexity in the model restricting them to smaller fields of application (e.g. sectoral analysis). The respective weaknesses are inherent in the approaches and existing models are unable to cover all aspects of energy transition simultaneously. Therefore, in future exercises, a well-defined combination of models covering the same field (e.g. electricity, heat) complemented with other social science approaches could deliver new insights. Such an approach would also allow combining the strengths of the different approaches rather than trying to work around their respective weaknesses.

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