Energy system analytics and good governance - *U4RIA goals of Energy Modelling for Policy Support*

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Abstract

Energy modelling is the process of using mathematical models to develop abstractions and then seek insights into future energy systems. It can be an abstract academic activity. Or, it can insert threads that influence our development. We argue therefore, that energy modelling that provides policy support (EMoPS) should not only be grounded in rigorous analytics, but also in good governance principles. As, together with other policy actions, it should be accountable.

Almost all aspects of society and much of its impact on the environment are influenced by our use of energy. In this context, EMoPS can inspire, motivate, calibrate, and 'post assess' energy policy. But, such modeling is often undertaken by too few analysts under time and resource pressure. Building on the advances of 'class leaders', we propose that EMoPS should reach for practical goals — including engagement and accountability with the communities it involves, and those it will later affect. (We use the term Ubuntu, meaning 'I am because you are' to capture this interdependency). We argue that Ubuntu, together with retrievability, repeatability, reconstructability, interoperability and auditability (U4RIA) of EMoPS should be used to signal the beginnings of a new default practice. We demonstrate how the U4RIA principles can contribute in practice using recent modelling of aspirational energy futures by Costa Rica as a case study. This modelling effort includes community involvement and interfaces and integrates stakeholder involvement. It leaves a trail that allows for its auditing and accountability, while building capacity and sustainable institutional memory.

1. Introduction

Energy Modelling for Policy Support (EMoPS) is more than simply an analytical activity — it affects and involves communities. Including those involved in real time in the EMoPS proces, and those outside of the EMoPS process, who may be affected by its outcomes at some later time.

Communities in focus include those involved in the analytical and policy formulation work itself, subsequent (energy dependent) service users, those locally and internationally who are impacted by the uptake of energy system development, as well as project developers and financiers. Energy is not an end in and of itself, but a means to supply — in the context of financial and non-monetary costs — energy services. Energy demands are thus driven by other sectors and determine wider production possibilities.

With its policy impact EMoPS, which can influence energy system configuration and service costs — influences key aspects of societal development, and its constituencies. For these reasons, EMoPS should be held accountable through adherence to good governance as well as rigorous scientific practice.

The significance of integrated modelling

EMoPS is in part an analytical activity that, via mathematical abstractions programmed into computer models, projects internally consistent scenarios of energy system development. As an academic activity,

it requires scientific rigour. Its analytical components include links with scientific bodies of knowledge and analysts often interact with specialists from other domains.

EMoPS scenarios (one of several modelling artifacts [1,2] noted in the supplementary online material (SOM)) typically provide directly, or with additional analysis, explicit quantitative pictures of: technology and infrastructure configurations; energy security and trade levels; direct and secondary market implications and investment provisions; emissions trajectories; revenue and public subsidy requirements; and life-style implications. Scenarios enable a 'thought-experiment space' that allows one to run through various futures that may be driven by new policies and evaluate the effect of sets of policies. One common practice is to develop aspirational end-points for those scenarios and then model to investigate normative scenarios of how one might get there — a technique known as backcasting.[3]

Aspects of scenarios have relevance to large sets of communities. They can also be translated into a 'language' that is understood by each community — though they are often domain specific. Scenarios can also be loaded with tacit judgments that are not necessarily made explicit.[4]

No existing guidelines govern the identification of the relevant communities, the identification of the scenario elements and aspirations of importance to those communities, their active translation and appropriate interface of that community with an EMoPS process. Neither are the costs nor benefits of potential guidelines articulated, should they indeed be adopted. This despite widespread, often tacit agreement of the value of scenarios for those communities.[5]

The communities affected

Aside from those that will later be potentially affected, all specific communities associated with the EMoPS ecosystem of activities and scenarios produced need support for the health of the activity. These may include: the energy modelling team and broader energy modelling community; energy policy analysts that bridge the policy process with EMoPS; a (formal or informal) coordination group that enables strategic intelligence and manages information flows with key external communities; a coordination group of a broader participation process; and, the funders that support the EMoPS process. The latter might arise from dedicated government budgets or external support agencies.

From EMoPS scenarios, the implications and 'underpinning goals' of different futures are articulated, and their implications for affected communities sketched (Table 1). The communities that are represented (or can be represented in those sketches) include various policy organs; direct energy industry suppliers and indirect (energy) service users; civil society and international actors. Here, internationals are at least divided into business, development, environment, and energy(-system) trading partners. Consider for example, multinational energy companies, the UNFCCC, countries with electricity and gas interconnectors, respectively as examples.

Table 1: Affected communities across domains (to the right), ending in those that control infrastructure spend, and actors (descending)

Socio-Economic Accountability	Sector accountability ⟶		
	Energy Sector	... Other domains ...	Finance/Economics/Development
	Energy Policy Modellers	... Modellers ...	Economic Development Modellers
	Energy Policy Makers	... Policy Makers ...	Development Policy Makers
	Energy system investors	... Investors ...	(Broad based) Investors
	Energy dependent business	... Business ...	(Broad based) Business
	Civil Society (inc voters, environmental NGOs, consumer groups, unitions etc.)	... Civil Society ...	(Broad based) Civil Society
	Internationals (inc business, development, environmental, trading partners)	... Internationals ...	(Broad based) Internationals

Four critical observations arise

1. **Opaque analysis**: even when deeply domain specific, despite a growth of efforts to combat this, *the modelling process often remains a 'black box'.*[6] That means that it is often impossible to develop sensible knowledge management within a national modelling team. When active knowledge management is missing due to opacity, it is not feasible to create an ecosystem with institutions and research centres that could increase national competence and capacity. That results in continuous wasted effort. In developing country contexts, wasted resources and negative consequences are reported.[7]

2. **Community cooperation**: the level of involvement of socio-economic actors is necessarily constrained as resource, time, and other factors create impractical overheads. The benefits of competent cooperation and co-creation are well known, including the potential for increased accountability [8] and ownership.[9] But various levels of cooperation with the modelling team are possible. A stylised representation is given by in figure 1.[10] Yet many EMoPS activities are without appropriately defined analytical and organisational workflows. They have no explicit interface for community participation. As such even *'light'* cooperation can be difficult.

3. **Downstream matters**: the impact of the resulting energy policy from EMoPS is not trivial. And the continuum from EMoPS to implementation is often broken. This can range from the translation of energy model results into energy policy to energy policy that is incoherent and contradictory to policy

in other areas. A common example of the former is the implementation of non-market mechanisms to proxy the output of a market model, creating inaccuracies. A common example of the latter is the dependence on indirect fossil fuel taxes for national development revenue, while efforts are made to reduce fossil fuel consumption for reasons of GHG mitigation.

4. **Appropriate answerability**: accountability for related national development financing (as it relates to EMoPS and its output) is lacking. Money might be directly wasted [7] as there may be no simple knowledge management process in the analytical team. As its insights might not be scrutinizable, the resulting (much larger indirect) investments and the broader development they drive are at risk as a result. (That is not to say that an 'exemplary' EMoPS will produce scenarios that perfectly 'predict' future needs. Although it might be built on the best available information, it is still imperfect knowledge.[12] However, if its outputs and process cannot be scrutinized and built upon, it is not possible to know if due diligence was applied.)

2. Interacting With Affected Communities

The information exchange interfaces between analytical modelers and potentially affected communities are steadily improving in most cases.

Firstly there is an acknowledgment of the need for an interface.[13] Existing 'interfaces' are overwhelmingly community or sub-community specific.[14] At national and global level there is a move to improve communication with the finance and economic sectors, with two notable examples being:

- The Network for Greening the Financial System (NGFS) explorer [15] provides a tailored view for the financial sector of a limited set of global integrated assessment models' quantification of investments required to transform the energy system.
- The 2050 platform[16] uses a simple spreadsheet 'dashboard', to be used across modelling tools and country studies, with a common 'language' for cross-country comparisons — characterising a limited set of transparent technical economic transformations and serving as an aggregator in a bottom-up approach, where the global vision emerges as a composite of sectoral and national pathways.

We discern four general forms of interface, represented by:

- The Climate Calculator by the UK Department of Energy and Climate Change (DECC) [17] provides a systematic calibration of sub-sector policy ambition and a set of fixed reports. The approach used a simple accounting model by default, but allows for the introduction of other approaches.[18] Fully open source, it is deployed by at least 24 national governments.[19]
- Gamification to reach a broader audience, are typically designed to interactively communicate the relationships between key drivers — their interaction and the resulting outcomes can instill intuition and help dispel myths.[20]

- Ad hoc dashboards are popular, these might range from standardised static graphics (typically covering capacity and production metrics) to Sankey charts to dynamic systems with varying levels of interactivity.
- The subsequent dialogue and discussion between client and modeller. Although unless carefully minuted, this can increase opacity when bilateral and private.

The design of these interfaces are often driven by the terms of reference of the study in question, which may be in the form of 'long term energy scenario' procurement,[21] or within the tradition of the modellers, which will have elements of specific requirements. A development of importance is the databasing of results in a manner that the interfaces discussed above can be developed using standard web APIs — with one community resource being the Open Energy Platform (OEP).[22]

While interfaces are being developed, simply having an interface might not be sufficient. It may require that the EMoPS process actively interface with the target communities as part of its analytical or organisational workflow for effective stakeholder engagement.

Auditability and good governance

Accountability is "the fact of being responsible for what you do and able to give a satisfactory reason for it, or the degree to which this happens".[23]

At a minimum, a critical component of EMoPS accountability is auditability. As the EMoPS process directly uses and indirectly influences taxpayer money — this is an important first step. (Indeed the initial trial of U4RIA guidelines focuses on ensuring accountability to the community funding the analytical activity in question.)

To be substantially sustainable, the EMoPS process requires basic knowledge management in the energy modelling team. With all EMoPS elements available for uptake when staff change, new modelling efforts, or modellers, can build on the old. Accountability can go further, to deliberate multi-sector, multi-stakeholder/community modelling cooperation. That cooperation might be unilateral or be part of joint action, with associated burdens, benefits, and required interfacing. Auditability provides a minimum level of accountability and requires that documentation be part of the modelling process.

To move to practical action, an initial set of guidelines have been developed and are being trialled. These guidelines include a template to be annexed to terms of reference (ToR) of EMoPS projects. The introduction of the guidelines and ToR annex trial is to overcome short term incentives that mitigate against some forms of accountability-by-default when EMoPS is undertaken in the short term. (Some incentives and the draft ToR annex are noted in SOM7.) The guidelines are labelled 'U4RIA'.

U4RIA stands for Ubuntu, Retrievability, Rusability, Repeatability, Reconstructability, Interoperability and Auditability. Where Ubuntu is derived from the nguni word relating to our shared humanity.

3. Analytic And Governance Principles

U4RIA extends previous 'best practice'[24] and advances in transparency [25] by placing an emphasis on active mapping of affected communities, identification of common information andits translation, and the EMoPS process interface with those communities. Analytically it applies aspects of FAIR principles[26].

Bookended by Ubuntu and Auditability, the U4RIA goals provide a set of guidelines and best practices for EMoPS. Specifically,U4RIA introduces guidelines to promote the following:

- **Ubuntu**: requires identifying those to whom EMoPS should be accountable and to what degree. This will include: their role in the organisational workflow, determining the EMoPS output of relevance, and its translation and interface requirements in relation to EMoPS digital workflows.
- **Retrievability:** functional retrievability is necessary. Noting that even published data are often neither easily findable nor accessible.
- **Reusability:** we note that though elements of EMoPS might be reusable, common licensing constraints (noted in SOM6) make this difficult.
- **Repeatability**: though elements of EMoPS might be retrievable, lack of an explicit and user-friendly digital workflow, make repeatability functionally difficult.
- **Reconstructability:** extends 'repeatability' to include the instructions for how to rebuild the EMoPS elements, such as input data, model relations and resulting scenarios. This is done with appropriate 'digital' metadata, as well as appropriately documented digital and organisational workflows. Organisational workflows are required to reconstruct stakeholder input (noting that this may result in difference with different circumstance)
- **Interoperability:** allows for scenario outputs to be (1) tested by other models or approaches and (2) their compatibility to sub-sector or broader integration with other modelling for policy support. An example of sub-sector integration includes technical operations required to integrate high levels of renewable energy technologies (RET) into a power system. An example of broader integration would include assessing potential tax revenue changes associated with (subsidised) EVs replacing (more heavily taxed) fossil-fueled cars.
- **Auditability:** is essential as EMoPS is part of the policy process it needs to be held accountable to good governance principles. Those include direct accountability to the internal or external funder of EMoPS, as well as to society more broadly.

Selected benefits of Retrievability, Reusability, Repeatability, Reconstructability, Interoperability and Auditability delineated by some key affected communities are detailed in SOM5.

4. Case Study Costa Rica

Since 2018, Costa Rica has run a public engagement process to determine the preferred trajectory of its energy system (and its entire economy) with the goal of reaching net-zero emissions by 2050, all discussed in its National Decarbonization Plan.[27] It was this application that first gave rise to the U4RIA principles.

Its modelling effort to develop an official EMoPS to support national energy policy includes:

- community involvement that builds human capacity and sustainable institutional memory and leaves a trail that allows for its auditing and accountability plus;
- interfaces and integration of stakeholders that pushed for U4RIA of the EMoPS process.

Community involvement

U4RIA is applied to the elements and workflows to allow for the sustainability of the EMoPS effort and its accountability to constituent communities.

Firstly the modelling team was developed and capacity built. Effort was made to ensure that local capacity was developed in a partnership between government and academia, with policy needs feeding research agendas. And with the academics plugging into broader modelling communities [28,29] that included academic partners, directors and engineers from energy-related organizations, NGOs, development banks, and civil society.

The need to produce an EMoPS tool suitable for multiple experts enables auditing and accountability. It also embraced the co-creation of common databases stored today here.[30]

Stakeholder involvement

Broader stakeholders were mapped by potential impact and included universities, government departments, electricity and oil companies, NGOs, and development banks.[27] And methods for communication were developed. These included the use of the 2050 template, custom presentations and workshops to allow for stakeholder appropriate translation.[31]

An organisational workflow (Fig. 3) was developed to ensure that the effort was collaborative scenarios were developed in response to stakeholder feedback (ibid).

Input data, the model code, and digital workflow scripts are easily retrieved from GitHub[32] archived with a specific workflow[33] allowing for retrieval, reuse and repeatability. In particular it was reused to develop an office national decarbonisation investment plan[34]. There is limited descriptive meta-data other than the

date stamping, which should be improved. A description of the tool covering its original version is available.[35]

Further, a publication describing the process has been peer reviewed was peer reviewed.[31] Interoperability was achieved by clear data and model (meta data) descriptions. Those include — with (semi and fully) automated data exchange — the link of the EMoPS to the GEM7, a transfer estimation module between actors,[36] and on-going effort to link the EMoPS with a high resolution power flow simulation of the electricity system. The second allowed for studies with fiscal options in line with decarbonization goals housed in the finance ministry with development banks partnership, and subsequent loans.[37]

The combination allows for aspects of an audit of the organisational and analytical workflow. This has resulted in subsequent work to build on that effort that can be used to support national commitments and multi-donor bank development loans.

Parallel efforts are undertaken in Cyprus — developed together with IRENA,[38] and used for European Union reporting obligations.[39] However, as confidentiality constraints on certain data prevented some U4RIA goals from being achieved, an open and public equivalent of key data was developed.[40]

Comparable efforts across global, regional and non-governmental domains are being developed to support the transition to U4RIA focused EMoPS. Notable examples include the Open Energy Outlook project covering the United States [41,42] and similar initiatives being undertaken broadly within the openmod [25] community.

5. Conclusion And Next Steps

We argue that U4RIA development and adoption is a step toward making energy modelling for policy support more accountable. As there are limited applications of good governance and FAIR scientific principles, to EMoPS, it is necessary that U4RIA is trialed and developed. Though experience gained in Costa Rica, the beginnings of 'how' this might be done are suggested. Meanwhile a working document was presented (see SOM7) that is being trialled and refined. It is based on existing World Bank Group standards, and extended by the German Corporation for International Cooperation (GIZ) for application. A round table process to capture lessons and revisions for this document is currently underway.

The benefits of moving toward a more inclusive and fully open analysis of climate and energy policies include better quality analysis, better knowledge retention, enhanced public accountability, and potentially improved public acceptance.

Declarations

improve the efficacy of the science policy interface and provide draft terms of reference' for good practice and, in particular, when procuring energy modelling services for policy support from third-party organizations.

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References

1. Mirakyan, A. & Guio, R. D. A methodology in innovative support of the integrated energy planning preparation and orientation phase. *Energy* **78**, 916–927 (2014).

2. Mirakyan, A. & De Guio, R. Integrated energy planning in cities and territories: A review of methods and tools. *Renew. Sustain. Energy Rev.* **22**, 289–297 (2013).

3. Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T. & Finnveden, G. Scenario types and techniques: Towards a user's guide. *Futures* **38**, 723–739 (2006).

4. Bistline, J., Budolfson, M. & Francis, B. Deepening transparency about value-laden assumptions in energy and environmental modelling: improving best practices for both modellers and non-modellers. *Clim. Policy* 1–15 (2020).

5. Hughes, N. Towards improving the relevance of scenarios for public policy questions: A proposed methodological framework for policy relevant low carbon scenarios. *Technol. Forecast. Soc. Change* **80**, 687–698 (2013).

6. Pfenninger, S. *et al.* Opening the black box of energy modelling: Strategies and lessons learned. *Energy Strategy Rev.* **19**, 63–71 (2018).

7. Full article: Building capacity for 'energy for development' in Africa: four decades and counting. https://www.tandfonline.com/doi/full/10.1080/14693062.2020.1870915.

8. Gouillart, F. & Hallett, T. Co-Creation in Government. *Stanford Social Innovation Review* vol. 13 (2015).

9. Carmichael, R., Gross, R., Hanna, R., Rhodes, A. & Green, T. The Demand Response Technology Cluster: Accelerating UK residential consumer engagement with time-of-use tariffs, electric vehicles and smart meters via digital comparison tools. *Renew. Sustain. Energy Rev.* **139**, 110701 (2021).

10. van Bruggen, A., Nikolic, I. & Kwakkel, J. Modeling with Stakeholders for Transformative Change. *Sustainability* **11**, 825 (2019).

11. Fuso Nerini, F. *et al.* Connecting climate action with other Sustainable Development Goals. *Nat. Sustain.* **2**, 674–680 (2019).

12. Schmidt-Scheele, R. 'Plausible' energy scenarios?! How users of scenarios assess uncertain futures. *Energy Strategy Rev.* **32**, 100571 (2020).

13. Berg, A. O., Clapp, C., Lannoo, E. & Peters, G. Climate scenarios demystified. A climate scenario guide for investors. *CICERO Rep.* (2018).

14. Weber, C. *et al.* Mitigation scenarios must cater to new users. *Nat. Clim. Change* **8**, 845–848 (2018).

15. NGFS Scenario Explorer. https://data.ene.iiasa.ac.at/ngfs/#/login?redirect=%2Fworkspaces.

16. Waisman, H. *et al.* A pathway design framework for national low greenhouse gas emission development strategies. *Nat. Clim. Change* **9**, 261–268 (2019).

17. DECC 2050 Calculator. http://2050-calculator-tool.decc.gov.uk/#/home.

18. Jan, K. David Mackey and the clever climate calculator. *Energy Strategy Rev.* **27**, 100429 (2020).

19. International outreach work of the 2050 Calculator. *GOV.UK* https://www.gov.uk/guidance/international-outreach-work-of-the-2050-calculator.

20. Mochizuki, J. *et al.* Simulation games as a catalyst for social learning: The case of the water-food-energy nexus game. *Glob. Environ. Change* **66**, 102204 (2021).

21. IRENA. *LONG-TERM ENERGY SCENARIOS for the clean energy transition*. (2019).

22. Reder, K. *et al.* Identification of user requirements for an energy scenario database. *Int. J. Sustain. Energy Plan. Manag.* **25**, 95–108 (2020).

23. accountable. https://dictionary.cambridge.org/dictionary/english/accountable.

24. DeCarolis, J. *et al.* Formalizing best practice for energy system optimization modelling. *Appl. Energy* **194**, 184–198 (2017).

25. openmod - Open Energy Modelling Initiative. https://openmod-initiative.org/.

26. Wilkinson, M. D. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data* **3**, 160018 (2016).

27. National Decarbonization Plan Costa Rica | UNFCCC. https://unfccc.int/documents/204474.

28. Bataille, C. *et al.* Net-zero deep decarbonization pathways in Latin America: Challenges and opportunities. *Energy Strategy Rev.* **30**, 100510 (2020).

29. OSeMOSYS Newsletter, June 2018. https://us17.campaign-archive.com/?u=5636f7d76bf07257ab9bea9df&id=882324cd74.

30. SINAMECC. http://www.sinamecc.go.cr/.

31. Godínez-Zamora, G. *et al.* Decarbonising the transport and energy sectors: Technical feasibility and socioeconomic impacts in Costa Rica. *Energy Strategy Rev.* **32**, 100573 (2020).

32. EPERLab/OSeMOSYS-CR. *GitHub* https://github.com/EPERLab/OSeMOSYS-CR.

33. The OSeMOSYS – CR model — OSeMOSYS-CR 1.0.a documentation. https://osemosys-cr.readthedocs.io/en/latest/.

34. Groves, D. G. *et al. The Benefits and Costs Of Decarbonizing Costa Rica's Economy: Informing the Implementation of Costa Rica's National Decarbonization Plan under Uncertainty*. (Inter-American Development Bank, 2020). doi:10.18235/0002867.

35. OpenMod. OpenMod Wiki OSeMOSYS. https://wiki.openmod-initiative.org/wiki/OSeMOSYS.

36. ¿Cuánto le va a costar a Costa Rica descarbonizar el sector transporte? *Sostenibilidad* https://blogs.iadb.org/sostenibilidad/es/cuanto-le-va-a-costar-a-costa-rica-descarbonizar-el-sector-transporte/ (2019).

37. Costa Rica's Decarbonization Plan provides a framework for the future - Sostenibilidad. https://blogs.iadb.org/sostenibilidad/en/costa-ricas-decarbonization-plan-provides-a-framework-for-the-future/.

38. Taliotis, C. *et al.* Renewable energy technology integration for the island of Cyprus: A cost-optimization approach. *Energy* **137**, 31–41 (2017).

39. GoC, G. of C. *Cyprus' Draft Integrated National Energy and Climate Plan for the period 2021-2030*. https://ec.europa.eu/energy/sites/ener/files/documents/cyprus_draftnecp.pdf (2019).

40. Taliotis, C. *et al.* Technoeconomic assumptions adopted for the development of a long-term electricity supply model for Cyprus. *Data Brief* **14**, 730–737 (2017).

41. Modeling – Open Energy Outlook. https://OpenEnergyOutlook.org/?page_id=12071.

42. DeCarolis, J. F. *et al.* Leveraging Open-Source Tools for Collaborative Macro-energy System Modeling Efforts. *Joule* **4**, 2523–2526 (2020).

43. Wang, N., Heijnen, P. W. & Imhof, P. J. A multi-actor perspective on multi-objective regional energy system planning. *Energy Policy* **143**, 111578 (2020).

44. Witt, T., Dumeier, M. & Geldermann, J. Combining scenario planning, energy system analysis, and multi-criteria analysis to develop and evaluate energy scenarios. *J. Clean. Prod.* **242**, 118414 (2020).

45. Moret, S., Babonneau, F., Bierlaire, M. & Maréchal, F. Decision support for strategic energy planning: A robust optimization framework. *Eur. J. Oper. Res.* **280**, 539–554 (2020).

46. Giudici, F., Castelletti, A., Giuliani, M. & Maier, H. R. An active learning approach for identifying the smallest subset of informative scenarios for robust planning under deep uncertainty. *Environ. Model. Softw.* **127**, 104681 (2020).

47. Park, T., Kim, C. & Kim, H. A real option-based model to valuate CDM projects under uncertain energy policies for emission trading. *Appl. Energy* **131**, 288–296 (2014).

48. Müller, B., Gardumi, F. & Hülk, L. Comprehensive representation of models for energy system analyses: Insights from the Energy Modelling Platform for Europe (EMP-E) 2017. *Energy Strategy Rev.* **21**, 82–87 (2018).

49. Krog, L. & Sperling, K. A comprehensive framework for strategic energy planning based on Danish and international insights. *Energy Strategy Rev.* **24**, 83–93 (2019).

50. Sharpe, D. G. V., Frank W. Geels, and Simon. Accelerating the low carbon transition. *Brookings* https://www.brookings.edu/research/accelerating-the-low-carbon-transition/ (2019).

51. Searl, M. F. *Energy Modeling: Art Science Practice*. (Routledge, 2016).

52. Long-term energy scenarios: First-year campaign findings. https://www.irena.org/publications/2019/May/LTES-First-year-campaign-findings.

53. Moving Towards the Enhanced Transparency Framework | UNFCCC. https://unfccc.int/enhanced-transparency-framework.

54. Stodden, V. The Legal Framework for Reproducible Scientific Research: Licensing and Copyright. *Comput. Sci. Eng.* **11**, 35–40 (2009).

55. Meeker, H. J. *Open source for business: a practical guide to open source software licensing.* (CreateSpace Independant publishing Platform, 2017).

56. Morrison, R. Energy system modeling: Public transparency, scientific reproducibility, and open development. *Energy Strategy Rev.* **20**, 49–63 (2018).

57. Ramalho, A. Ex Machina, Ex Auctore? Machines that create and how EU copyright law views them. *Kluwer Copyright Blog* http://copyrightblog.kluweriplaw.com/2018/11/12/ex-machina-ex-auctore-machines-that-create-and-how-eu-copyright-law-views-them/ (2018).

58. DCC, A. B. How to License Research Data. (2014).

59. Hirth, L. Open data for electricity modeling: Legal aspects. *Energy Strategy Rev.* **27**, 100433 (2020).

60. Lämmerhirt, D. Avoiding Data Use Silos. How Governments Can Simplify The Licensing Landscape. *Gov. Can Simpl. Licens. Landsc. Dec. 15 2017* (2017).

61. Roundtable Principles for Supporting Strategic Energy Planning | EEG. https://energyeconomicgrowth.org/content/roundtable-principles-supporting-strategic-energy-planning.
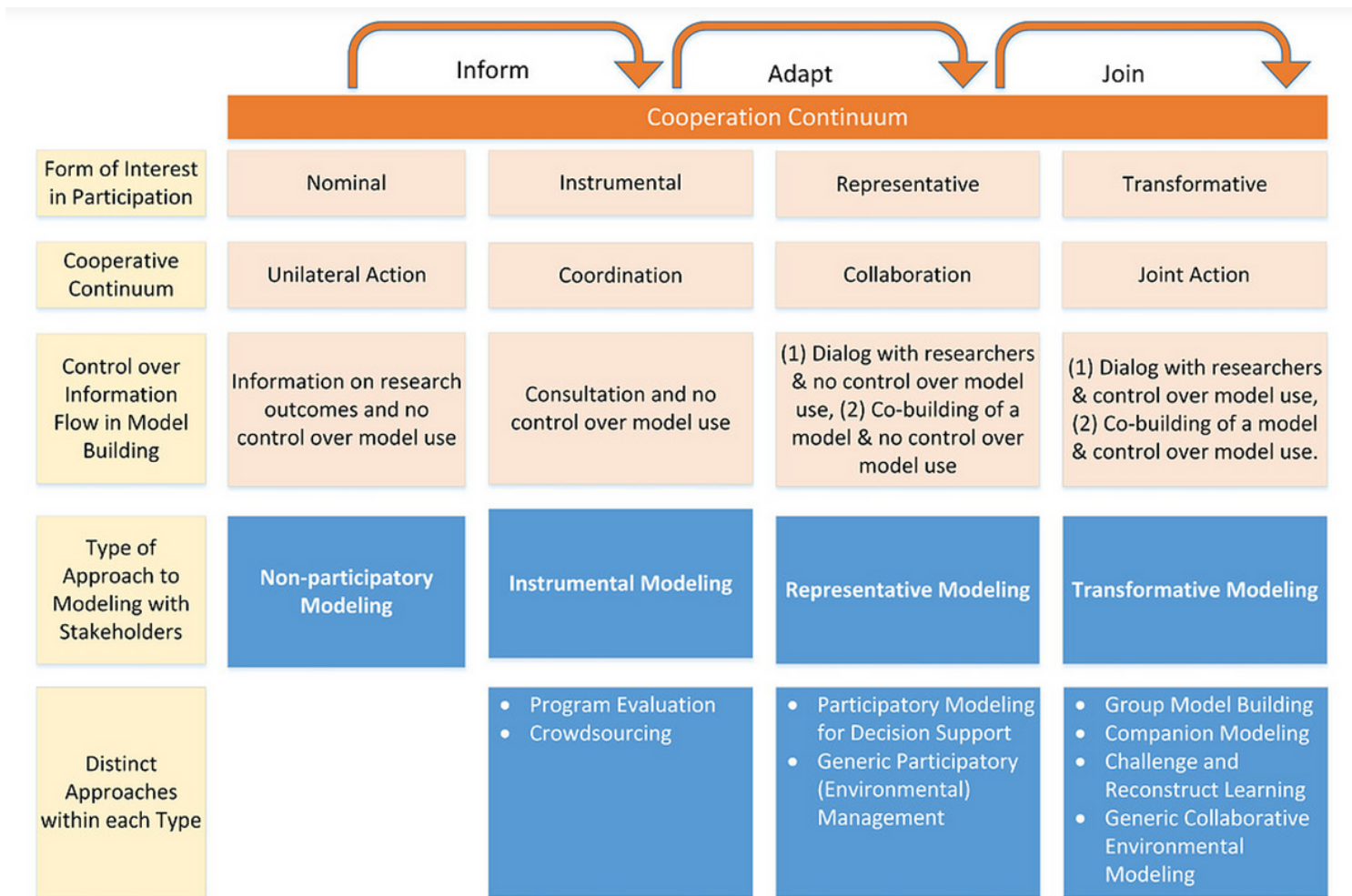
Figures

Figure 1

Modelling with stakeholders. Source10

Figure 2
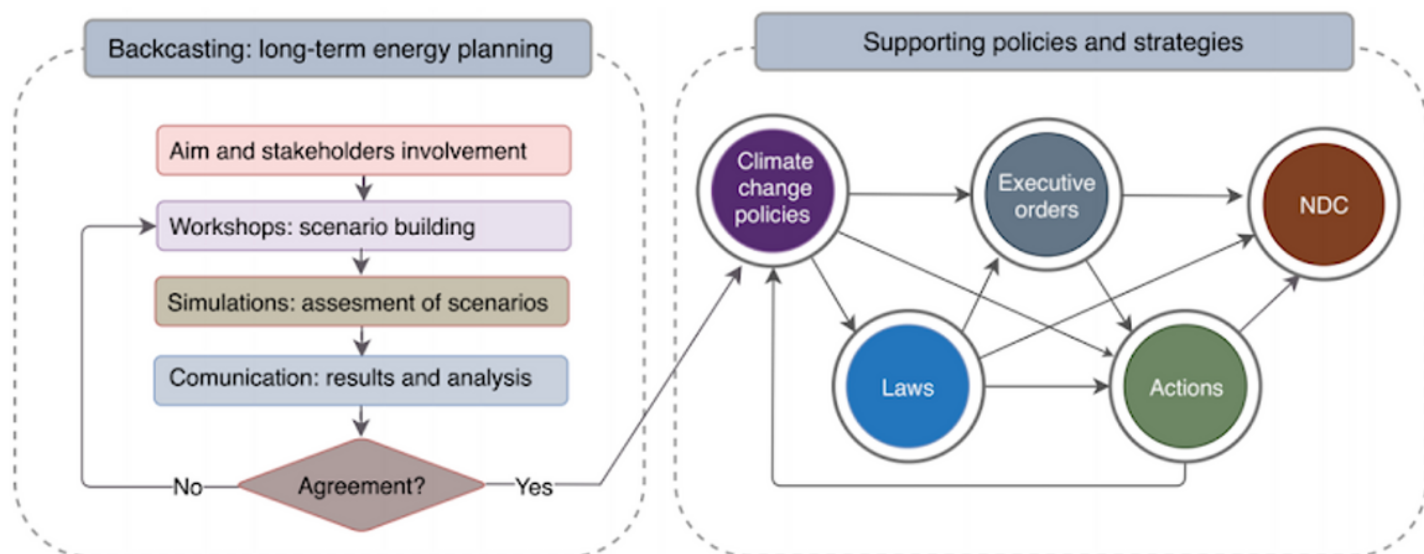
Energy development and its impact. Source11

Figure 3

Organisational workflow

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