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Transformative Metrics

Contributions to the Studies for Monitoring and Evaluating How Science, Technology, and Innovation Can Address Social and Environmental Challenges

GABRIEL VÉLEZ-CUARTAS, OSCAR YANDY ROMERO-GOYENECHE
(EDITORS)

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Facultad de Ciencias Sociales y Humanas

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Contents

Presentation

Gabriel Vélez Cuartas[1]
Oscar Yandy Romero-Goyeneche[2]

This book provides a fresh and comprehensive understanding of the most significant methodological advances in the study of transformative change through policy decision-making; this latter being commonly influenced by metrics and evaluation processes. In this vein, the book presents methodological approaches to the study of sustainable transitions by suggesting that these metrics and evaluation processes can play a new role. It contends that using these approaches in the implementation of policy programmes, projects, and interventions can offer a further reflexive perspective, which helps transformations to take place and enhance metrics' transformative potential.

We hope that this book stimulates further development of the emerging research agenda on transformative metrics. Discussion on this agenda began at the 'Transformative Metrics Workshop' organised by Universidad de Antioquia, the Science Policy Research Unit (SPRU)- University of Sussex, and the

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2. *PhD student from the Center for Global Challenges, Utrecht University. TIPC collaborator. E.mail:* o.y.romerogoyeneche@uu.nl

Transformative Innovation Policy Consortium (TIPC) in 2020.[3] This workshop sparked a dialogue between Europe and South America encouraging a joint effort in the development of methods and metrics that support transformative change in both regions. The search for methodological approaches that can address the complexities and uncertainties of social change was motivated by our concern regarding the global crisis of the current dominant trajectories of societal development. Therefore, the transformative metrics agenda aims to change how we live on our planet through the implementation of new strategies, practises, and values.

In particular, the agenda aims to re-position the role of science, technology, and innovation (STI) in our society. FIGURE 1 illustrates our understanding of transformative metrics. The evaluation of transformative experiments ('experimentation') can help enhance 'learning' and enable new 'interventions.' Transformative metrics can play a key role in this evaluation when uncovering synergies and trade-offs between diverse interventions. These, in turn, strengthen learning by enabling further reflexivity, e.g., by supporting policymakers to consider the suitability of their initial interventions or even their overarching aims.

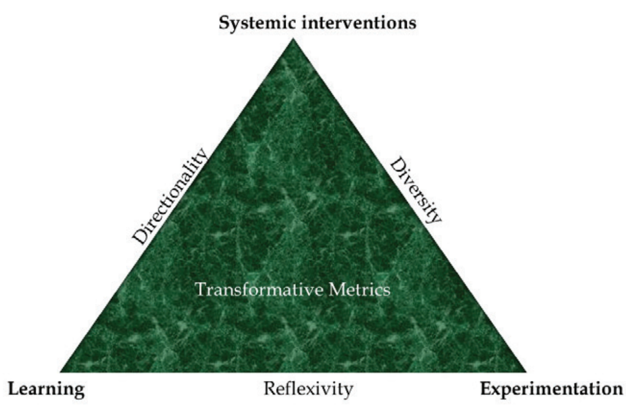

FIGURE 1. Transformative Metrics Framework

Source: Prepared by authors.

3. Universidad de Antioquia, Science Policy Research Unit of University of Sussex, and the Transformative Innovation Policy Consortium, *Transformative Metrics Workshop* (Medellín, Colombia, October 5–6, 2020).

FIGURE 1 also represents how transformative metrics might contribute to a dynamic process of evaluating experimentation within policy interventions, and therein promoting transformative change. Here, experimentation involves the exploratory development of new social practises and technologies to generate new ways of producing and consuming. As illustrated above, this exploratory development is followed by an evaluation of how experimental interventions such as these are impacting our society. FIGURE 1 presents three pillars of evaluation: systemic interventions, experimentation, and learning. Transformative metrics should contribute to an evaluation of the diversity of experiments and their interlinkages. This evaluation can foster reflexivity regarding experiments, and in this way enable learning. Learning may then result in new directionalities of system change.

Transformative metrics research agenda aims to identify common visions regarding the meaning of transformation. Following the United Nations Sustainable Development Goals (SDGs) call for 'transforming our world,' the terms 'transformation,' 'transition,' and 'societal change' have begun to be used more regularly. Furthermore, the term 'transformative change' has been increasingly adopted in STI (i.e., as transformative innovations or the third frame for STI). However, we are still far from an agreement regarding a concrete meaning of the term transformation. For instance, in the traditional economic field, transformation is associated with creative destruction in that it represents a never-ending source of energy and matter to feed the global economy. In contrast, ecological economics proposes that the rising use of materials and energy can trigger an increase in biodiversity loss and heighten the effects of climate change. Thereby, ecological economics suggests that transformative change is instead about re-embedding society within 'nature.'

Additionally, well-being and social justice are rarely considered within the dominant discourse of technological change. The dominant framework of technology believes that scientific knowledge and innovation can positively impact economic growth, which is then expected to solve all types of societal problems. This limited understanding of science and technology restricts our understanding of how knowledge could impact societies in multiple dimensions beyond economic growth. In this train of thought, research on developing metrics can support deliberation by requesting different actors to specify types of change associated with the representation of transformation.

All in all, this book contributes to the construction of a research agenda that can support necessary changes in our world. The measurement models that are presented here are rooted in transdisciplinary work, reflecting their connection to policy evaluation. In this line, the book compiles reflections about measurement and assessment tools built in situ. These reflections then bring the concepts of transformation and innovation to specific realities, recalibrating methodologies to adapt to new developments and reframe different discussions. Thus, this book does not offer recipes for measuring or evaluating change. Instead, it sparks a discussion regarding several approaches with the potential to increase reflexivity and promote transformative change.

Introduction

This book aims to stimulate a new research agenda that encourages existing and new methodological approaches to be applied in the study and promotion of social and technological change. Sustainability transition scholars have begun to search for new methods and indicators to examine transitions. On the other hand, there is a body of research on the Sustainable Development Goals (SDGs) and the United Nations Framework Convention on Climate Change (UNFCCC). Both agendas call for new indicators, models, and methodological approaches to evaluate their implementation. In this sense, the transitions research community has called for the development of a 'structured navigation' method and a 'formal model' to study transformation and sustainability agendas.[1]

This book emphasises the need for new metrics and techniques for visualisation and mapping based upon systems thinking, which will then lead to a more complex understanding of social and technological change. These new approaches to analysing transformative changes, which are either quantitative or qualitative, are needed to support transformation. New visualisations, metrics, and mapping techniques are paramount for greater learning, enabling policymakers to have the tools to deal with the grand challenges expressed in the SDGs and the UNFCCC. These approaches also have a political role despite

1. Jonathan Köhler, et al. 'An agenda for sustainability transitions research: State of the art and future directions,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 1–32. https://doi.org/10.1016/j.eist.2019.01.004.

relying on scientific models because they have a significant influence on how priorities and policies are established. Thus, they allow a better understanding beyond atomic recipes. In sum, such methods enable learning to navigate the transformation of recurrent system problems such as poverty, biodiversity loss, inequality, and the consequences of climate change.

Consequently, how can we develop indicators and methods to study socio-technical systems changes using sustainability transitions as a lens? To address this question, the book uses the most common theoretical framework in sustainability transitions, the multi-level perspective (MLP). This framework divides socio-technical systems into three domains: landscape (broader trends such as climate change), socio-technical regimes (dominant sub-systems e.g., fossil fuel energy), and socio-technical niches (alternatives to the prevailing system e.g., renewable energy). The MLP framework conceptualises transformation as occurring through three phases: building and nurturing niches (emergence phase), expanding and mainstreaming niches (growing phase), and opening up and unlocking regimes (niche institutionalisation phase). As a result, many processes can destabilise and expose regimes to allow niche emergence and growth such as landscape shocks or symbiotic/competitive interaction between niche and regime actors.

This book is divided into two sections. The first section, 'Transformative Frames,' presents five different conceptual and methodological approaches that can support the understanding and study of transformation. Chapter 1 introduces twelve transformative outcomes that summarise critical processes within the three phases of transformation outlined above. These transformative outcomes are then associated with both new and existing methods to monitor change processes. Chapter 2 discusses how current approaches to sustainability transitions can nurture the evaluation of the foregoing transformative outcomes considering the transformation of actor networks.

Chapter 3 highlights the necessity of embedding social directionalities within a socio-technical system and monitoring such integrations. Chapter 4 proposes metrics to study socio-technical systems' systematic transformation, focusing specifically on tipping points. It is important to note that such points characterise a qualitative change where niches become institutionalised and new rules and practises become dominant. Finally, Chapter 5 studies how regenerative value can foster positive actions towards climate change and stresses the importance of collaborative structures for nurturing transitions. Overall, Section 1 presents a selection of dimensions that may be measured to support a societal shift.

Section two, 'Developing Transformations,' describes a range of strategies for measurement and evaluation. The chapters in the second section present several case studies involving specific socio-technical changes and the evolution of niches towards sustainable shifts: climate change, energy, cities, as well as the interactions between science and social demands and local niches. In this light, Chapter 6 underlines the need for accurate metrics to support climate policy implementation and remarks on how existing quantitative metrics can be adapted to integrate multiple indicators. This chapter includes a concrete example of how landscape shock may trigger new policies and how metrics might help monitor regime destabilisation and niche development.

Chapters 7 to 10 apply a relational approach to the study of interactions within and between socio-technical niches, which is ground-breaking since cross socio-technical system interactions is an underdeveloped area in existing sustainable transitions literature.[2] Collectively, these chapters propose that a detailed study of socio-technical interactions can reveal how social actors build bridges across systems, shedding understanding on how new opportunities to address sustainable transitions emerge.

In this context, Chapter 7 posits the integration of energy systems by considering the coupling of natural gas and heating. This chapter presents energy system integration as a methodological approach to understanding the architecture of this sort of systems. Similarly, Chapter 8 considers the institutional and technological symbiotic interactions between energy and mobility within cities. The chapter proposes the combination of longitudinal analysis and

2. Ibid.

'neighbouring' analysis (identifying coupling between practises) using an analytical strategy to study these complex interactions.

Chapter 9 analyses the complex interactions between social demands and scientific knowledge production. The chapter uses knowledge mapping techniques to understand how research priorities in Kenya, Rwanda, and Tanzania are aligned with the main socio-economic challenges expressed in the SDGs. Finally, Chapter 10 studies how a social organisation can trigger niche building by generating alliances between diverse stakeholders in cities. This chapter discusses how external forces (landscape shocks) influence niche development using analysis of social networks as an empirical approach.

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Universidad de Antioquia, Science Policy Research Unit of University of Sussex, and the Transformative Innovation Policy Consortium. *Transformative Metrics Workshop*, Medellín, Colombia, October 5–6, 2020.

Section 1: Transformative Frames

1. The Evolution of Research and Innovation Policy Paradigms and Associated Evaluation and Indicator Frameworks

Christoph Brodnik[1]
Michael Dinges[2]

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1.1. Introduction

Research and Innovation (R&I) policy follows certain paradigms that provide a rationale for what it should achieve and its benefits and instruments best suited to attain them. While economic growth and competitiveness were the predominant reasons for innovation policy in the past, a new paradigm has solidified. This paradigm increasingly recognises that R&I policy plays a pivotal role in addressing deep and systemic challenges like the ones enshrined in the Sustainable Development Goals (SDGs). More specifically, the importance of R&I policies to simultaneously deal with economic competitiveness

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as well as with public health, social inclusion, and environmental protection is unequivocal. Lundin and Schwaag Serger summarise this development very clearly:

> The theoretical approach to innovation policy is shifting from a predominantly market or system failure rationale to a system or transformative change approach. Consequently, government efforts to promote innovation are moving from a more generic, reactive character – in which implicitly all innovation was seen as potentially contributing to economic growth and competitiveness and therefore 'good' – towards a more directional nature, with policymakers seeking to channel innovation efforts and support towards addressing societal challenges.[3]

Addressing societal challenges will require transformational changes in different sectors of society. The importance of research and innovation in realising such transformation is reflected in the resurging debate on missions. While addressing the foregoing challenges cannot be only relegated to R&I policy, missions underscore the importance of R&I and associated policy instruments in addressing persistent and wicked societal challenges.[4] Put it simple, missions intend to set ambitious objectives in which R&I plays a critical role through the pursuit of a portfolio encompassing programmes, projects, and support measures.

At present, there are examples of indicators that aim to systematically measure the influence of R&I activities on the realisation of overarching societal goals, for example, the SDGs or Agenda 2030. However, currently, there are no indicators at a more granular level (i.e., projects or programmes) that provide guidance and accountability on how they contribute to achieve system transformation. From an environmental perspective, the European Environment Agency (EEA) states that 'there is a gap between established monitoring, data

3. Nannan Lundin and Sylvia Schwaag Serger, *Agenda 2030 and A Transformative Innovation Policy: Conceptualizing and experimenting with transformative changes towards sustainability (Work in process)* (Transformative Innovation Policy Consortium and University of Sussex, 2018), 2.

4. Iris Wanzenböck, et al., 'A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space,' *Science and Public Policy* 47, no. 4 (August 2020): 474–89, https://doi.org/10.1093/scipol/scaa027 and indicators and the knowledge required to support transitions,'[5] which for Biggeri and Ferrannini entails that there exists 'an open space for innovative proposals for measurement seems to be available.'[6] Such new approaches are critical for two reasons: First, they help to further operationalise the concepts of transformative innovation policy guiding policy makers and legitimacy to decisions and actions. Second, they could contribute to the institutionalisation of this new paradigm by codifying and embedding a certain frame into policy discourses and gradually making it a social fact.[7]

To this end, this research paper provides an overview of the development of R&I policy paradigms over time, contributing to contemporary research and scientific discourse on Transformative Innovation Policy (TIP). Based on the characterisation of Schot and Steinmueller,[8] first, this chapter briefly outlines the main rationale of R&I policy paradigms and then it discusses the evaluation system and indicators associated with it. It is important to note that, to the best of the authors' knowledge, there is currently no fully solidified evaluation system and indicators for transformative innovation policy. These are currently under development and testing.[9] In contributing to this body of research, this chapter draws on the building blocks of TIP developed by Rogge, Pfluger, and Geels as well as Ghosh et al. to develop indicator categories for TIP.[10]

5. European Environment Agency, *The European environment — State and outlook 2015: Synthesis report* (Luxembourg: Publications Office of the European Union, 2015), 8.

6. Mario Biggeri and Andrea Ferrannini, *Framing R&I for transformative change towards sustainable development in the European Union* (Luxembourg: Publications Office of the European Union, 2020), 24.

7. Benoît Godin, *The making of science, technology and innovation policy: conceptual frameworks as narratives, 1945-2005* (Villa Falconieri: Centro Europeo dell'Educazione, 2009).

8. Johan Schot and W. Edward Steinmueller, 'Three frames for innovation policy: R&D, systems of innovation and transformative change,' *Research Policy* 47, no. 9 (August 2018): 1554–67. https://doi.org/10.1016/j.respol.2018.08.011

9. Biggeri and Ferrannini, *R&I for transformative change.*

10. Karoline S. Rogge, Benjamin Pfluger, and Frank W. Geels, 'Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050),' *Technological Forecasting and Social Change* 151, no. 4 (March 2018): 119259. https://doi.org/10.1016/j.techfore.2018.04.002; Bipashyee Ghosh, et al., 'Transformative outcomes: assessing and reorienting experimentation with transformative innovation policy,' *Science and Public Policy* 48, no. 5 (October 2021): 739–56. https://doi.org/10.1093/scipol/scab045

1.2. Paradigm 1: Science and Technology

The first paradigm can be subsumed under the term *science and technology* or the first frame of innovation policy.[11] This is because it is influenced by the importance of technological breakthroughs in winning the second world war, as well as an emergence of scientific management practises (i.e., Taylorism). Likewise, it is characterised by the domination of science and technology-driven innovation for the sake of national prowess and economic superiority.[12] In this paradigm, innovation is seen as the means to achieve economic growth, job security, or the realisation of ambitious technology missions (e.g., man on the moon). In short, it consists of a very linear model of innovation, namely: basic research → applied research → development.[13]

This paradigm became institutionalised through patent laws and the establishment of dedicated R&I departments and large-scale laboratories.[14] The need for this innovation policy was legitimised through a requirement to fix market failures and externalities that led to a less-than-ideal innovation output, limited the ability to commercialise scientific results, and hampered economic growth while reducing the ability to achieve missions.[15] In this vein, the negative consequences and side effects of the innovation process were acknowledged but could be remedied by conducting more research and producing more innovation. This understanding rendered innovation as good per se.[16] Finally, it is important to note that the main actors in this paradigm are scientists who are responsible for producing knowledge, state actors, for funding this process,

11. Schot and Steinmueller, 'Frames for innovation policy.'

12. Peter Biegelbauer and Matthias Weber, 'EU research, technological development and innovation policy,' in *Handbook of European Policies: Interpretive Approaches to the EU*, eds. Hubert Heinelt and Sybille Münch (Cheltenham: Edward Elgar Publishing, 2018).

13. Godin, *Science, technology and innovation.*

14. Gijs Diercks, Henrik Larsen, and Fred Steward, 'Transformative innovation policy: Addressing variety in an emerging policy paradigm,' *Research Policy* 48, no. 4 (May 2019): 880–94. https://doi.org/10.1016/j.respol.2018.10.028

15. K. Mathias Weber and Harald Rohracher, 'Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework,' *Research Policy* 41, no. 6 (July 2012): 1037–47. https://doi.org/10.1016/j.respol.2011.10.015

16. Schot and Steinmueller, 'Frames for innovation policy.'

and private actors, embodied as large corporations, for turning knowledge into commercially viable products.[17]

Overview of R&I Monitoring and Evaluation (M&E) System in Paradigm 1

In evaluations, the market failure rationale is closely linked to the concepts of input and output additionality. Input and output additionality analyses study the leverage effects of public funding for R&I in terms of private spending and technological performance. These evaluations focus on the effectiveness of the presumed intervention mechanism, namely, that public incentives increase R&I engagement in the business and that such additional publicly induced R&I activities lead to new products and processes improving Europe's technological performance.[18] Evaluation studies emphasising input and output additionality are by large summative, ex-post evaluations. While these evaluations are capable to analyse the effects of intervention by means of counterfactual econometric and bibliometric analysis, they tell little about the mechanisms that turn an intervention into a success or failure and are of limited use for learning and adaptation.

Overview of Indicators Associated with the M&E System in Paradigm 1

A very linear logic model was underpinning the R&I monitoring frameworks at that time that structured how we understood and measured the value of science, technology, and innovation (once conceptualised in economic terms). The model postulates that innovation starts with basic research, then it adds applied research, after that, it brings development, and it ends with production and diffusion. Hence, only R&D is implied in this paradigm.

A landmark of R&I indicators at that time is the first version of the Frascati Manual conceived in 1963. According to Freeman and Soete, this manual tried to distinguish between research and experimental development and related scientific activities.[19] Moreover, it targeted national statisticians for standardising

17. Ibid.

18. Dirk Czarnitzki and Katrin Hussinger, 'Input and output additionality of R&I subsidies,' *Applied Economics* 50, no. 12 (2018): 1324–41. http://bitly.ws/rhGY

19. Christopher Freeman and Luc Soete, 'Developing science, technology and innovation indicators: What we can learn from the past,' *Research Policy* 38, no. 4, (May 2009): 583–89. https://doi.org/10.1016/j.respol.2009.01.018

surveys and offering a statistical answer and an accounting framework to three policy issues of the time: the allocation of resources to science (i.e., how much the government should invest in science), the balance between choices or priorities (i.e., where to invest), and the efficiency of research (i.e., the results).[20] Thanks to this manual, and for the first time, the collection of standardised statistics was possible, allowing for cross-country comparison.

The main criterion for what was measured (part of R&I) and what was not (not considered part of R&I) consisted of the distinction between novelty and routine. Whilst this was a relatively straightforward criterion for distinction at that time, it led to the exclusion of many activities that would be considered integral in the contemporary understanding of R&I and typically be associated with development. As a result, several aspects of scientific and technical activities at the enterprise level, including consultancy, project feasibility studies, design and engineering, production engineering, quality control, training, and information services were left out and not measured.[21] The rationale for the foregoing criterion is R&I was seen as a specialised activity carried out in specialised private and public institutions. Indeed, a great part of technological progress appeared attributable to research and development work performed in specialised laboratories or pilot plants by full-time qualified staff, while other actors were only seen as important for uptake and diffusion.

The measurement focus was input-oriented and concerned two types of statistics: the financial resources invested in R&I and the human resources related to research activities. A key statistic indicator was that national science budget or gross domestic expenditures on R&I (GERD) conceptualised as the sum of the R&I expenditure in the four main economic sectors: business, university, government, and non-profits.[22] Therefore, it gave rise to the GERD/GDP ratio as a measure of the intensity or efforts of a country or economic sector. The input measure of R&I expenditures gradually became the most widely used measure of innovation (mostly technological) performance of sectors, countries, or firms.

20. Godin, *Science, technology and innovation.*

21. Ibid.

22. Ibid.

In the 1970s and 1980s, there was a substantial increase in the resources devoted to the study of R&I itself. Many governments started to measure R&I activities and the industry itself started to increasingly recognise the role of R&I for comparative strength.[23] This led to a broader perspective on what should be measured and how to interpret it. Innovation itself began to become an increasingly important focal point and the notion of R&I which was seen at that time as industrial research and experimental development input, was increasingly recognised as too narrow. This is because, through the work of business schools and economists, non- R&I-related activities like production and diffusion also became important elements to be measured.

The revision of the Frascati Manual also started to include output indicators that had not been previously included as it was deemed impossible for a standardised format based on available data. It took until 1981 for output indicators to be introduced in R&I statistics. These included patents, technological payments, high technology trade, and productivity. From this point onwards an input-output approach to measuring R&I developed. This approach was predominately concerned with measuring upstream and downstream quantities and establishing a relationship between them.[24] To a large extent, such underlying logic of measurement is attributed to the econometric model of the production function, which links, in basic terms, the quantity of produced goods (outputs) to the quantities of inputs. In short, it stipulated that research leads to economic growth and productivity, placing a premium on investment as a means to achieve growth.

1.3. Paradigm 2: Innovation Systems

In response to the shortcomings of the previous linear approach to innovation, a new paradigm emerged taking on an innovation systems perspective.[25] Rather than just the production of knowledge through science, the actual use

23. Freeman and Soete, 'Science, technology and innovation.'

24. Godin, *Science, technology and innovation.*

25. Diercks, Larsen, and Steward, 'Transformative innovation policy.'

of knowledge moved to the fore, and so did the interactions between different types of actors, in particular, in science and industry.[26] An important focal point for this perspective was how a constellation of different actors and the interactions among them can strengthen the adoption of innovation in the everyday practises of businesses or end-users.[27] The emphasis on learning and collaboration between heterogeneous actors brought new interaction forms to the fore, namely, the capabilities of firms to absorb knowledge and experience from others as well as entrepreneurship as a critical driver for innovative ideas.[28] In addition, the rationale for policy intervention was not only the failure of the but also of an innovation system. This latter limits the ability to make use of knowledge due to weak or malfunctioning links and framework conditions between government, industry, and university.[29] Still, a major premise or assumption that underpinned this paradigm and its associated framework was that science, technology, and innovation are always good – for individuals and good for society at large.[30]

In this paradigm, the role of government is to create beneficial framework conditions so that all sorts of innovation output emerge while the benefits of innovation are still constrained by relatively narrow economic rationales.[31] As such, the innovation system paradigm has also been recognised as insufficient to address the nature and complexity of societal challenges. This is because it is mainly directed at optimising an innovation system for economic purposes largely neglecting other social or environmental goals.[32] The vast majority of the innovation systems literature continues to regard innovation as positive per

26. Doris Schartinger, et al., 'Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants,' *Research Policy* 31, no. 3 (March 2002): 303–28. https://doi.org/10.1016/S0048-7333(01)00111-1

27. Diercks, Larsen, and Steward, 'Transformative innovation policy.'

28. Ibid.

29. Weber and Rohracher, 'Research, technology and innovation.'

30. Godin, *Science, technology and innovation.*

31. Diercks, Larsen, and Steward, 'Transformative innovation policy.'

32. Schot and Steinmueller, 'Frames for innovation policy.'

se even though recent contributions have started to take matters of directionality into account.[33]

Overview of R&I Monitoring and Evaluation System in Paradigm 2

In evaluations, the system failure rationale is closely linked to the concept of behavioural additionality. This concept attempted to widen traditional perspectives in evaluation methods based on input and output additionality and to link them with the policy framework of the national innovation system.[34] Behavioural additionality is considered as the core of an evolutionary/structuralist view which urges policy action to increase the cognitive capacities of agents and/or to resolve exploration, exploitation, selection, system, and knowledge processing failures, rather than simply addressing those of the market.[35] The emergence of the concept of behavioural additionality was strongly needed – as it in fact expressed a 'catching-up' of policy and evaluation theory on already widely applied practises of policy makers to explicitly target behavioural changes in the design of policy instruments.[36]

The focus on behavioural additionality emphasised a resource-based view of the firm[37] and the interactions with public research organisations and collaborators along the value chain. Evaluations of R&I public policies increasingly focussed on the network structures that emerged through public interventions (e.g., the inclusion of new actors and their role in the networks) and the capabilities acquired by the organisations.

33. Marko P. Hekkert, et al,, 'Mission-oriented innovation systems,' *Environmental Innovation and Societal Transitions* 34 (January 2020): 76–79. https://doi.org/10.1016/j.eist.2019.11.011

34. Jan Larosse, 'Conceptual and Empirical Challenges of Evaluating the Effectiveness of Innovation Policies with Behavioural Additionality (The Case of IWT R&D Subsidies),' in *Innovation Science Technology: 'Making the Difference.' The vealuation of 'Behavioral Additionality' of R&D Subsidies*, eds. Ann Van de Bremt and Jan Larosse (Brussels: IWT Observatory, 2004), 57–69.

35. Abdullah Gök and Jakob Edler, 'The use of behavioural additionality evaluation in innovation policy making,' *Research Evaluation* 21, no. 4 (2012): 306–18. https://dx.doi.org/10.2139/ssrn.1980648

36. Ibid.

37. Luke Georghiou and Clarysse Bart, 'Behavioural additionality of R&D grants: introduction and synthesis,' in *Government R&D Funding and Company Behaviour: Measuring Behavioural Additionality*, ed. Organisation for Economic Cooperation and Development (Paris: OECD Publishing, 2006), 9–38. https://doi.org/10.1787/9789264025851-en

Overview of Indicators Associated with the M&E System in Paradigm 2

From a monitoring and evaluation perspective, the National Innovation System concepts took on centre stage in R&I policy-making discourse and practise[38]. However, the concept was ambiguous and 'statisticians simply did not have the appropriate tools to measure [it].'[39] What was used in the beginning was based on the Frascati Manual – R&I expenditure and manpower. In this stage, the flows of these resources between sectors as performers of research activities moved to the fore. Nevertheless, these measures were also regarded as insufficient to measure the diversity and complexity of innovation systems, and new ones such as the innovation survey were developed.[40] Here, new concepts such as the globalisation of research activities, networks of collaborators, clusters, and the role of users emerged. A common denominator, however, was an attempt to measure knowledge flows between entities through surveys. For industry alliances, indicators such as inter-firm research cooperation arose. For industry-university interactions, indicators such as cooperative industry/university R&I, industry/university co-patents, or industry/university co-publications were developed. Similarly, indicators for technology diffusion such as technology used by industry or indicators related to personnel mobility (e.g., the indicator movement of technical personnel among industry, university, and research) were created.[41]

Another landmark of R&I indicators under this paradigm is the Oslo Manual which harmonised innovation-output indicators, leading to a better understanding of both, the science and technology system and the changing nature of the innovation process itself.[42] Its first edition marked a synthesis of the experiences from a broad group of innovation surveys in the late 1980s.[43] It focused on product and process innovation in manufacturing industries and

38. Godin, *Science, technology and innovation*.

39. Ibid., 9.

40. Ibid.

41. Ibid.

42. Freeman and Soete, 'Science, technology and innovation.'

43. Carter Bloch, 'Assessing recent development in innovation measurement: The third edition of the Oslo Manual,' *Science and Public Policy* 34, no. 1 (February 2007): 23–34. https://doi.org/10.3152/030234207X190487 provided a unified framework for collecting this data at the firm level.[44] In its second version, the manual also included innovation in the services sector, which extended to marketing and organisational innovations in its third version.[45] Again, the experiences that were gained through the increase in using national innovation surveys by a range of different countries directly informed the adaptations of the manual and the implementation of the associated community innovation surveys (CIS).

While the system approach has been increasingly recognised and used in R&I policy evaluation, Borrás and Laatsit highlight that only six out of the EU28 countries have developed system-oriented innovation policy evaluation practises (i.e., the Netherlands, Austria, Finland, Germany, Ireland, and Sweden), suggesting system-oriented innovation policy evaluation is not yet the norm in the European Union.[46] In this vein, Borrás and Laatsit argue that 'the limited systemic approach in evaluation means that most policymakers in Europe lack a very important source for policy learning, namely, the source that is based on a careful assessment of their innovation system and policies' performance.'[47]

1.4. Paradigm 3: Transformative Innovation Policy

Most recently, a new field of innovation policy research emerged that is concerned with the role of innovation policy in addressing grand societal challenges. The emergence of this new policy paradigm is based on the recognition that traditional assumptions, goals, instruments, and governance models in research and innovation policy are ill-equipped to address wicked social and environmental challenges.[48] The new innovation policy paradigm is the attempt to better align innovation policy objectives with the social and environmental

44. Ibid.

45. Ibid.

46. Susana Borrás and Mart Laatsit, 'Towards system oriented innovation policy evaluation? Evidence from EU28 member states,' *Research Policy* 48, no. 1, (February 2019): 312–21. https://doi.org/10.1016/j.respol.2018.08.020

47. Ibid., 319.

48. Schot and Steinmueller, 'Frames for innovation policy.'

challenges that prevail.[49] This policy paradigm builds n the two most established innovation policy paradigms and is understood as an additional layer, rather than a complete replacement of older innovation policy paradigms.[50] In fact, a well-functioning innovation ecosystem, in the traditional sense of well-distributed roles and responsibilities across different sectors and levels of government and thematic domains, is the fundament on which more ambitious strategic ambitions can be placed.[51]

In the emerging third frame, the transformation-challenge rationale, the focus of the intervention moves beyond the sphere of R&I policy because solving grand societal challenges cannot be relegated to this policy field alone. Moreover, transformative innovation policy (TIP) adds something to the innovation policy space that was thus far crucially missing: a normative purpose and directionality that goes beyond the general focus on competitive, economic growth, and fixing market and systems failures.[52] Moreover, it departs from the assumption that innovation is always good and that social and environmental negative externalities can be managed ex-post by the state. On the contrary, this paradigm postulates that innovation is not positive per se and that it can lead to more problems than it solves by strengthening existing path dependencies and thereby, perpetuating severe social inequalities and negative environmental consequences.[53] Transformative innovation policy is not only about the transformation of different sectors (e.g., energy and food) but also about fundamental changes in the logic and function of knowledge and innovation systems themselves.[54]

Lastly, Rogge, Pfluger, and Geels posit what TIP should entail and what its evaluation and monitoring should focus on. These authors argue that for TIP

49. Ibid.

50. Diercks, Larsen, and Steward, 'Transformative innovation policy.'

51. Andrea Ricci and Matthias Weber, *Beyond the Horizon. Foresight in support of the preparation of the European Union's future policy in research and Innovation* (UE: European Commission, 2018).

52. Weber and Rohracher, 'Research, technology and innovation.'

53. Johan Schot and Laur Kanger, 'Deep transitions: Emergence, acceleration, stabilization and directionality,' *Research Policy* 47, no. 6 (March 2018): 1045–59. https://doi.org/10.1016/j.respol.2018.03.009

54. Stefan Kuhlmann and Arie Rip, 'Next-generation innovation policy and Grand Challenges,' *Science and Public Policy 45*, no. 4 (February 2018): 448–54. https://doi.org/10.1093/SCIPOL/SCY011 to become effective, it requires greater attention to 1) strategic long-term policymaking with clear direction for desired change that is built on inclusive and anticipatory deliberation; 2) targeted instruments for the creation and destruction side of transition processes (i.e., niche building and regime destabilisation); and 3) the support of new or adjusted existing institutional arrangements, framework conditions, and governance structures conducive to sustainability transitions.[55]

Overview of R&I Monitoring and Evaluation System in Paradigm 3

The purposes for evaluation associated with paradigms 1 and 2 are aimed at understanding and judging the appropriateness, relevance, efficiency, and impact of an intervention in order to provide accountability to the government, taxpayers, and society more broadly.[56] This summative aspect of R&I evaluation is still valid for TIP because of its societal and environmental ramifications. Although this poses fundamental difficulties in the evaluation of such policy (e.g., causalities and assumptions, etc.) excluding this aspect could be problematic.[57] There are other difficulties for TIP evaluation that stem from the long-time horizons between an intervention and the observation of desired changes as well as the link between evaluating a project/programme level and its wider system impact that the policy intervention is trying to achieve.[58]

However, TIP puts an even greater emphasis on the process of learning and the generation of strategic intelligence to adapt strategy and implementation of TIP – it, therefore, places a premium on the formative aspects of evaluation. One recent conceptual advancement in this space is the evaluation approach put forward by Molas-Gallart et al. that is based on socio-technical systems theory and is purely formative. These authors describe this approach as 'part and parcel of a different way of defining and implementing policy, through which

55. Rogge, Pfluger, and Geels, 'Transformative policy mixes.'

56. Erick Arnold, et al., 'How should we evaluate complex programmes for innovation and socio- technical transitions?' Technopolis Group, June 15, 2018, http://bitly.ws/rhGc

57. Ibid.

58. Jordi Molas-Gallart, et al., 'A Formative Approach to the Evaluation of Transformative Innovation Policy,' *Research Evaluation* 30, no. 4 (October 2021): 431–42. https://doi.org/10.1093/reseval/rvab016 the different stakeholders in a policy monitor and reassess policy results as they happen. It is a form of Real Time monitoring embedded in the policy process.'[59]

Molas-Gallart et al. propose a set of principles for the evaluation of TIPs: 1) adopt a formative approach to evaluation; 2) integrate evaluation with policy design and implementation; 3) the evaluation process should be inclusive and participatory; 4) use a mix of methods and techniques; 5) use a nested approach to assess multi-level TIPs; and 6) use a flexible theory of change. These principles adhere to all levels of evaluating TIPs (project, programme, and policy) and have direct implications for the development of indicators for evaluating TIPs. Most notably, the formative approach sustains the reflexive and participatory process that leads to the particularly important indicator development. The authors stress that 'this process is very different from the requirement to find easily quantifiable and difficult to 'game' indicators, which can also allow a comparative measure (usually against a benchmark).'[60] Instead, the process of developing indicators with participants is at the core of the formative logic, and therefore, it becomes part of the TIP intervention itself. Therefore, indicators are a tool to guide the process of reflexive deliberation 'used to inform assessment by the project participants of the degree to which they are making progress into the desired trajectory of change.'[61]

Overview of Indicators Associated with the M&E System in Paradigm 3

The existing sets of indicators associated with Paradigms 1 and 2 described above embrace the concept of transformative innovation policy only to a very limited extent.[62] While there are examples and initiatives of indicators that aim to systematically measure the influence of R&I activities on the realisation of overarching societal goals (such as the SDGs or Agenda 2030) they are currently

59. Molas-Gallart, et al., 'Evaluation of Transformative Innovation.'.

60. Jordi Molas-Gallart, et al. *A Formative Approach to the Evaluation of Transformative Innovation Policy (Working paper)* (Utrecht: Utrecht University, 2020), 20.

61. Ibid., 20.

62. Biggeri and Ferrannini, *R&I for transformative change*.

not well established. There is either a conceptual ambiguity or the data is currently neither available nor systematically collected.[63]

The following section puts forward a set of measurement categories and indicators for this paradigm considering the following building blocks of transformative innovation policy: directionality and participation as well as niche development and regime destabilisation.[64]

Directionality and Participation

This building block of TIP encapsulates the need for an overarching policy strategy with long-term and quantifiable targets and principles for achieving them.[65] Indicators aimed at tracking long-term, challenge-led, and aspirational achievements (e.g., societal missions) are currently developed by different researcher institutes and research projects.[66] Another, a rather well-established body of indicators takes the Sustainable Development Goals (SDG) as a starting point for directionality. For example, the Eurostat SDG indicator comprises 100 indicators structured by the 17 SDG and allows for a statistical representation of SDG trends in the EU countries over the past 5 –15 years.[67] More specifically, a subset of indicator categories related to R&I for achieving the SDGs are:

- Government support for agricultural research and development (SDG#2, zero hunger).
- Gross domestic expenditure on R&I by sector (SDG#9, industry, innovation, and infrastructure).
- Employment in high- and medium-high technology manufacturing and knowledge-intensive services (SDG#9, industry, innovation, and infrastructure).

63. Ibid.

64. Rogge, Pfluger, and Geels, 'Transformative policy mixes.'

65. Ibid.

66. Two examples of these are: for TIPC: http://www.tipconsortium.net/research-projects/proportion-project-prototyping-an-indicator-framework-on-system-innovation/. And for Fraunhofer ISI: https://www.isi.fraunhofer.de/en/competence-center/politik-gesellschaft/projekte/htf2025.html#tabpanel-843723930

67. 'Sustainable Development Goals –Overview,' Eurostat: Your key to European statistics, accessed March 9, 2022. http://bitly.ws/rhH6

- R&I personnel by sector (SDG#9, industry, innovation, and infrastructure).
- Patent applications to the European Patent Office (SDG#9, industry, innovation, and infrastructure).

A starting point for approaching another aspect in this TIP building block (i.e., participation) are existing indicators developed for responsible research and innovation (RRI). In this sense, a few indicators are available. Focusing again on indicators developed in and for the European context, this chapter draws on the report *Metrics and indicators of Responsible Research and Innovation*:[68]

- Models of public involvement in S&T decision-making.
- Policy-oriented engagement with science.
- R&I democratisation index.
- National infrastructure for the involvement of citizens and societal actors in research and innovation.
- Citizen preferences for active participation in S&T decision-making.
- Dedicated resources for public engagement.
- Embedment of public engagement activities in the funding structure of key public research funding agencies.
- Public engagement elements as evaluative criteria in research proposal evaluations.

Niche Development & Regime Destabilisation

This second element of TIP points to the need for transformative innovation policy to target multiple failures (i.e., market, system, transformative) through different types of instruments that support technology-push, demand-pull, and systemic development. This needs to be realised through niche development as well as regime destabilisation.[69] To further specify these fundamental processes

68. Tine Ravn, Mathias W. Nielsen, and Niels Mejlgaard, *Metrics and indicators of Responsible Research and Innovation (Progress Report)* (EU: European Commission, 2015). http://dx.doi.org/10.13140/RG.2.2.12773.40165

69. Bruno Turnheim and Frank W. Geels, 'Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913-1997),' *Energy Policy* 50 (November 2012): 35–49.

of transformation change, we draw on the transformative outcomes concept because it provides more granular categories which specify important leverage points for niche development and regime destabilisation,[70] allowing for a systematic and functional approach to the monitoring of this TIP building block.

Ghosh et al. posit three core transformative processes in sociotechnical transitions: 1) building or nurturing niches; 2) expanding and mainstreaming niches; and 3) opening up and unlocking regimes. These authors pose a set of twelve transformative outcomes across these processes for transformative change. While transformative outcomes are described in detail in Ghosh et al. the focus here is only on potential indicator categories for them.[71] (See TABLE 1 for an overview).

Process 1. Building and Nurturing Niches

The first process is about the birth and early adoption of new and more sustainable practises in niches. Such practises are promising in potential but rather poorly represented and therefore, they require protection and support. In this vein, Gosh, et al., have identified four transformative outcomes to progress alternative practises, namely: 1) shielding 2) learning 3) networking, and 4) managing expectations.[72] They are defined below:

1) Shielding: It consists of protecting new and more sustainable practises from external influences and helping them grow. Shielding refers to the creation of protective conditions in which innovation can emerge and grow. Potential indicator categories for shielding are:

- R&I budget and subsidies for niche innovation.
- Fiscal support for niches (e.g., taxation).
- Public/Collective purchasing and procurement of niche innovations.
- Voluntary agreements with niche actors.

https://doi.org/10.1016/j.enpol.2012.04.060; Paula Kivimaa and Florian Kern. 'Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions,' *Research Policy* 45, no. 1 (February 2016): 205–17. https://doi.org/10.1016/j.respol.2015.09.008

70. Ghosh, et al., 'Transformative outcomes.'

71. Ghosh, et al., 'Transformative outcomes.'

72. Ibid.

- Supportive regulation for niches.
- Experiments aimed at changing framework conditions (e.g., regulatory sandboxes).

2) Learning: It entails providing regular opportunities for discussing experiences, obstacles, and needs related to a new practise as well as challenging related values and assumptions that people might have. The development of actionable knowledge is a prerequisite for learning. Actionable knowledge is evidence that provides practical guidance on how to solve sustainability problems.[73] Two types of knowledge are important in this regard:[74]

a) Analytical descriptive knowledge about the current system and associated sustainability problems. Possible indicator categories for this type of knowledge are:

- Different types of system maps (e.g., policy landscape, project portfolios, etc.).
- Scientific publications (including conference papers or discussion papers).
- Grey Literature.
- Datasets and databases of environmental or problem-related data.

b) Normative knowledge about sustainability goals and desirable system states. Potential indicator categories for this type of knowledge are:

- Visions.
- Problem framings.
- Scenarios (qualitative, quantitative, or mixed).

73. Christopher Luederitz, et al., 'Learning through evaluation - A tentative evaluative scheme for sustainability transition experiments,' *Journal of Cleaner Production* 169 (December 2017): 61–76. https://doi.org/10.1016/j.jclepro.2016.09.005

74. Arnim Wiek, Kay Braden, and Forrest Nigel, 'Worth the trouble?!: An evaluative scheme for urban sustainability transition labs (USTLs) and an application to the USTL in Phoenix, Arizona,' in *Urban Sustainability Transitions*, eds. Niki Frantzeskaki, et al. (New York: Routledge, 2017), 227–56.

These different forms of knowledge need to be internalised and activated (through deep learning), which ultimately enables actors to act in more sustainable ways in their everyday decision-making and routine practises. This is embodied in the notion of capacities of stakeholders which ultimately allows them to exercise this new knowledge.[75] Luederitz et al. point to three particularly important capacity areas for deep learning:

a) Capacities to develop effective sustainability interventions. Possible indicator categories for this type of capacity are:

- Stakeholder track-record in deploying sustainability initiatives.
- Existence of spin-offs/follow-up projects.

b) Practical skills and knowledge that incorporate sustainability in routine actions. Possible indicator categories for this type of capacity are:

- Evidence that sustainability has been anchored in routines beyond intervention.
- Evidence that sustainability has been anchored in strategies beyond intervention.

c) Interpersonal skills for developing coalitions and alliances. A potential indicator category for this type of capacity is:

- New networks and coalitions that are maintained beyond the project/intervention.

3) Networking: It concerns protecting and progressing new practises by gaining the interest of more people and creating connections between them. Individual actors and actor networks are critical for supporting transformative change processes.[76] At the individual level, championing transformational

75. Wiek, Braden, and Nigel, 'Worth the trouble?'

76. Jacco Farla, et al., 'Sustainability transitions in the making: A closer look at actors, strategies and resources,' *Technological Forecasting and Social Change* 79, no. 6 (July 2012): 991–98. http://dx.doi.org/10.1016/j.techfore.2012.02.001

change is polycentric, top-down as well as bottom-up, and anchored in the local and social context in order to instigate and leverage collective processes (e.g., discourses, social learning, etc.).[77] Possible indicator categories are:

- Number of champions.
- Type of champions (individual, organisational, etc.).
- Position/embeddedness of champions in a network.

Actor networks are critical because they enable them to develop a shared purpose and understanding of a problem and innovative solutions to explore different value propositions, develop relationships, and form coalitions.[78] Potential indicator categories that point to transformative networks are:

- Degree of formalisation of networks (from loosely connected individuals to formal networks).
- Autonomy and resources of networks.
- Heterogeneity of network.
- Inclusiveness of network.

Likewise, intermediaries have been put forward as key actors in developing and leveraging the transformative potential of networks. Possible indicator categories related to intermediary actors are:

- Presence and number of intermediaries.
- Changes in the type of intermediary (individual, organisation, etc.).
- Roles of intermediaries (niche-, regime-, process-, systemic intermediary).
- Position/embeddedness of intermediaries in a network.
- System aggregation level at which intermediaries operate (local, regional, national, international).

77. Marc Wolfram, 'Conceptualizing urban transformative capacity: A framework for research and policy,' *Cities* 51 (January 2016): 121–30. https://doi.org/10.1016/j.cities.2015.11.011

78. Ibid.

4) Navigating expectations: It refers to the fact that navigating and converging expectations of different actors, the legitimacy of new practises is developed, and their potential explored. Collective expectations are a critical resource in innovation processes and can have an important impact on the direction and speed of innovation.[79] In this train of thoughts, narratives and visions are important elements that determine expectations. Potential indicator categories for narratives that can influence expectation dynamics are:

- Presence of a new narrative or signs of an emerging narrative in different outlets (e.g., media, scientific, political, industry publications).
- Wider framing of solution for sustainability issues (i.e., from a narrow problem-solution framing towards a framing that conveys a wider or all-encompassing meaning)
- Changes to advocating narrative/counter-narrative.
- Coalitions around particular framings and narratives.
- Potential indicators for visions are:
- Directionality of existing visions/new visions.
- Increase in reach/buy-in of visions.
- Quality of vision (e.g., co-developed, widely shared, transformational aspirations, etc.)

Process 2: Expanding and Mainstreaming Niches

For transformative change to happen, new and more sustainable practises need to expand in scope and scale. This relates to a process in which alternative practises grow stronger and lead to the reconfiguration or disappearance of more dominant ones. Ultimately, new and more sustainable practises replace previously dominant ones and become the new mainstream. Four transformative outcomes to mainstream new and more sustainable practises have been identified, namely: 1) upscaling, 2) replication, 3) circulation, and 4) institutionalisation.[80]

79. Farla, et al., 'Sustainability transitions.'

80. Ghosh, et al., 'Transformative outcomes.'

Upscaling: It involves conducting deliberate action to get more users involved in new and more sustainable practises. A shared goal among transition projects/initiatives is that they provide generalisable evidence and knowledge on the application of solutions beyond a specific context.[81] This means that practises in transition experiments should be prone to be utilised by different stakeholders beyond the initiative/project in order to address similar challenges either at a different level of the system (i.e., upscaling) or in different contexts (i.e., replicating). Potential indicator categories for upscaling are:

- Number of stakeholders/stakeholder groups that engage with new practise.
- Changes in the number of practises adopted in a specific area/sector and at a certain level (local, national, transnational).
- Changes in the speed of adoption of practise in a specific area/sector and at a certain level (local, national, transnational).

Evaluating this outcome could also mean however to assess the potential of an intervention/experiment to be scalable in the first place, which in terms of Luederitz et al., refers to the scalable properties of a solution.[82] A possible indicator category for these properties could be:

- Cost for an additional application of practise.
- Valorisation of practise by stakeholders.

Replication: It means transferring the new and more sustainable practises to another location. Replication is a particular type of upscaling where the emulating niche is geographically disconnected from the original one. In this vein, it is important for the expansion of niches but it is not a straightforward process. This is because niches are context-specific so replicating niches requires

81. Joannette Jacqueline Bos, Rebecca R. Brown, and Megan A. Farrelly, 'A design framework for creating social learning situations,' *Global Environmental Change* 23, no. 2 (April 2013): 398–412. https://doi.org/10.1016/j.gloenvcha.2012.12.003

82. Luederitz, et al., 'Learning through evaluation.'

adjustments leading to own shielding, learning, and networking strategies. Indicator categories for replication include:

- Practise is applied in different settings/circumstances.
- Independence of practise from cultural (e.g., user preferences) or structural (e.g., governance arrangements) particularities.

Circulation: It encompasses the exchange of knowledge, ideas, and resources between multiple related alternative practises. Circulation of resources (i.e., ideas, rules, products, tools, and people) beyond original niches is a process that facilitates replication. The circulation of such resources triggers learning processes that allow for the embedding of niches in local contexts. Potential indicator categories in this regard comprise:

- Knowledge and experience collection and synthesis.
- External knowledge and experience accessibility.
- Knowledge and experience sharing among stakeholders.

Institutionalisation: It implies turning new and more sustainable practises into more permanent and more widely available ones. Institutionalising is embedding a new practise in established institutional frameworks (cognitive, normative, regulative) across the formal and informal realms.[83] Potential indicator categories for institutionalisation are:

- Guidelines for best practises are developed.
- New standards are developed.
- Existing standards are adapted.
- New laws are developed.
- Existing laws are adapted.
- Practise features in emerging/dominant discourse.

83. Lea Fuenfschilling and Bernhard Truffer, 'The structuration of socio-technical regimes—Conceptual foundations from institutional theory,' *Research Policy* 43, no. 4 (May 2014): 772–91. https://doi.org/10.1016/j.respol.2013.10.010

Process 3: Opening up and unlocking regimes

The ultimate aim is to replace dominant and unsustainable practises. New and more sustainable practises can only become dominant when significant individuals or organisations open up for change, and they have the will to make alternative practises competitive. Such openings provide innovative practises with windows of opportunity to challenge entrenched practise while claiming more space for themselves. The four transformative outcomes to opening up and unlocking dominant practises are: 1) readjusting and destabilising regimes; 2) unlearning and intrinsic learning; 3) strengthening interactions between alternatives and dominators; and 4) changing perceptions of landscape pressures such as the climate crisis.[84]

1) Readjusting and destabilising regimes: It entails disrupting and weakening dominant practises. This can be done by changing one of the dominant dimensions, for example, through the introduction of new policies. Destabilisation refers to the unlocking of path dependencies and a softening of established and entrenched configurations in a socio-technical system. Destabilisation can either happen through top-down (e.g., phase-out policies) or it can be driven more bottom-up (e.g., the salience of societal movements).

From a top-down perspective, some potential indicator categories are:

- Phase-out policies.
- Bans on entrenched practises.
- Removal of subsidies of entrenched practises.
- Targeted financial incentives for alternative practises.

On the other hand, possible indicators from a bottom-up perspective are:

- Public demonstrations, rallies, or marches.
- Boycotts.
- Petitions.

84. Ghosh, et al., 'Transformative outcomes.'

- Media campaigns.
- Public debates.
- Emerging discourses and metaphors.

2) Unlearning and deep learning of regime actors: Dominant actors question their assumptions and change their view on the potential of new and more sustainable practises and the ability of the dominant practise to respond to threats and opportunities, such as climate change and digitalisation. Regime openings create windows of opportunity for the consolidation and upscaling of niches. The opening of a regime refers to a process whereby regimes scape lock-ins and dependency on past trajectories. Thus, opening up is important to enable regime actors to see alternative options and new opportunities and pressures clearly. A regime starts to open up when actors begin to question their own assumptions, cognitive beliefs, and values, or the very institutional core of the regime. In this regard, indicator categories encompass:

- Evidence that new problem framings are being adopted by regime actors, e.g., in regime publications and advertisement campaigns.
- Evidence of changes in the direction of routine (R&I) search processes (i.e., moving into previously unexplored areas of knowledge).
- Existence of re-skilling, retrofitting, and repurposing programmes.

3) Strengthening regime-niche interactions: It refers to the frequency and quality of interactions between empowered actors from the niche and the regime on a non-competitive basis. Transitions research has shown that processes of opening up and unlocking regimes are often characterised by interactions of regime actors with niche actors. The increased number of interactions between niches and regimes is a sign of regime destabilisation and further evidence of the opening up of regimes to niches. Indicator categories for such interactions are:

- Establishment of partnerships and collaborations between regime and niches.

- Corporate venture capital initiatives for niche innovations.
- Merges and acquisitions between the regime and niche actors (e.g., firms).

4) Changing perceptions of landscape pressures: In this case, dominant actors reach the point of view that immediate action is warranted, and new emerging and more sustainable narratives need to be promoted. In the multi-level perspective, the landscape comprises macro processes, i.e., long-term and slow-moving trends such as climate change or rapid external shocks like the COVID-19 pandemic. Within these processes, regime and niche actors have little agency to change them (at least in the short term) because they directly influence the contexts of niches and regimes. On the other hand, different landscape trends may or may not align to destabilise a regime. Yet, the regime perception that these trends are increasingly overwhelming, either threatening or creating opportunities for a regime to transform, is critical in a socio-technical transition. Indicator categories for such changing perceptions of landscape pressures include:

- New regime discourses and narratives (framing) around a landscape trend (e.g., climate change).
- Announcement of new strategies, products, or services that seek to address pressure or benefit from an opportunity at the landscape level.

Institutional and Governance Adjustments

Transformative innovation policy calls for new institutional arrangements and governance structures that are oriented towards the achievement of societal goals and include governments, market actors, and civil society.[85] Here, the subset of composite RRI indicators developed by Ravn et al. provides a valuable starting point.[86] Examples of indicator categories are:

85. Rogge, Pfluger, and Geels, 'Transformative policy mixes.'

86. Ravn, Nielsen, and Mejlgaard, *Metrics and indicators*.

- Governance for responsible research and innovation.
- Existence of formal governance structures for RRI within research funding and performing organisations.
- Share of research funding and performing organisations promoting RRI.

Other indicator categories in this space can be drawn from more industry-specific indexes. These would need to be adapted however if a TIP has a specific sector focus. One example that can inform TIP indicators in this space is the water-sensitive city index. [87] While this index was developed for tracking transformative processes in the urban water management sector, certain themes such as cross-sectoral collaboration, equity in decision making, or the importance of natural resources in regulatory frameworks are elements that provide valuable guidance on developing TIP indicators more generally. In this sense, the water sensitive city index[88] identifies the following indicator categories in the area of good governance:

- Knowledge, skills, and organisational capacity.
- Water is a key element in city planning and design.
- Cross-sector institutional arrangements and processes.
- Public engagement, participation, and transparency.
- Leadership, long-term vision, and commitment.
- Water resourcing and funding to deliver broad societal value.
- Equitable representation of perspectives.

87. Beck, Lindsey, et al., 'Beyond Benchmarking: A Water Sensitive Cities Index,' paper presented at the *OzWater Conference*, Melbourne, Australia, May 2016. http://bitly.ws/rhGd; Briony Rogers, et al., 'Water Sensitive Cities Index: A diagnostic tool to assess water sensitivity and guide management actions,' *Water Research* 186 (November 2020): 116411. https://doi.org/10.1016/j.watres.2020.116411

88. Ibid.

TABLE 1. Indicator Categories for Transformative Outcomes[89]

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
Building and nurturing niches	Shielding: protecting new and more sustainable practises from external influences and helping them grow.	• R&I budget and subsidies for niche innovation. • Fiscal support for niches (e.g., taxation). • Public/Collective purchasing and procurement of niche innovations. • Voluntary agreements with niche actors. • Supportive regulation for niches. • Experiments aimed at changing framework conditions (e.g., regulatory sandboxes).	• Business and government expenditures in r&i (euros). • Subsidies and tax credits (euros). • Procurement contracts (euros). • The stringency of the regulation (qual.). • The number of experiments (count.).
	Learning: providing regular opportunities for discussing experiences, obstacles, and needs related to a new practise as well as challenging related values and assumptions that people might have.	• Analytical descriptive knowledge about the current system and associated sustainability problems: • Different types of system maps (e.g., policy landscape, project portfolios, etc.). • Scientific publications (including conference papers or discussion papers). • Grey literature • Datasets and databases of environmental or problem-related data.	• Network maps (qual./visual). • The number of publications per year (count.). • Types of framing: technological, • behavioural, economic, etc. (qual.). • The number of projects (count). • The number of routines and strategies (count.). • The number of coalitions (count.).

89. This was developed with Penna, C. C. R., Schot, J., Romero, O., Brodnik, C., Dinges, M., Weber, M., & Matti, C. (2020). EIT Climate KIC Report: Methodological aspects of the prototype of the indicator framework for systemic change and transformation.

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
		• Normative knowledge about sustainability goals and desirable system states: • Visions. • Problem framings. • Scenarios (qualitative, quantitative, or mixed). • Capacities to develop effective sustainability interventions: • Stakeholder track record in deploying sustainability initiatives. • Existence of spin-offs/follow-up projects. • Practical skills and knowledge that incorporate sustainability in routine actions: • Evidence that sustainability has been anchored in routines beyond intervention. • Evidence that sustainability has been anchored in strategies beyond intervention • Interpersonal skills for developing coalitions and alliances. • New networks and coalitions that are maintained beyond the project/intervention.	
	Networking: protecting and progressing new practises by gaining the interest of more people and creating connections between them.	• Champions / Individuals: • The number of champions. • Type of champions (individual, organisational, etc.). • Position/embeddedness of champions in a network.	• The number of champions (count.). • Network metrics (indexes/quant.). • Number [count.] and type of intermediaries (qual.).

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
		• Actors' networks: • Degree of formalisation of networks (from loosely connected individuals to formal networks). • Autonomy and resources of networks. • Heterogeneity of network. • Inclusiveness of network. • Intermediaries: • Presence and number of intermediaries. • Changes in the type of intermediary (individual, organisation, etc.). • Roles of intermediaries (niche-, regime-, process-, systemic intermediary). • Position/embeddedness of intermediaries in a network. • System aggregation level at which intermediaries operate (local, regional, national, international).	
	Navigating expectations: navigating and converging expectations of different actors the legitimacy of new practises is developed, and their potential explored.	• Narratives: • Presence of a new narrative or signs of an emerging narrative in different outlets (e.g., media, scientific, political, industry publications). • Framing of solutions to sustainability issues widens (from a narrow problem-solution to a wider meaning). • Changes to advocating narrative/counter-narrative.	• The number of newspaper articles (count.). • The number of parliamentary discussions (count.). • Opinion polls (qual.-quant.). • Semantic metrics for narratives (qual.-quant.) • The number of different coalitions (qual.).

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
		• Coalitions around particular framings and narratives. • Visions: • Directionality of existing visions/new visions. • Increase in reach/buy-in of visions. • 'Quality' of vision (e.g., co-developed, widely shared, transformational aspirations, etc.).	
Expanding and mainstreaming niches	Upscaling: conducting deliberate action to get more users involved in new and more sustainable practises.	• Scaling: • The number of stakeholders/stakeholder groups that engage with new practise. • Changes in the number of practises adopted in a specific area/sector and at a certain level (local, national, transnational). • Changes in the speed of adoption of practise in a specific area/sector and at a certain level (local, national, transnational). • Scalable potential: • Cost for an additional application of practise. • Valorisation of practise by stakeholders.	• Demand size for a niche (euros). • Cost estimate for niche practise adoption (euros).
	Replicating: transferring the new and more sustainable practises to another location.	• Replicating: • Practise is applied in different settings/ circumstances. • Replication potential: • Independence of practise from cultural (e.g., user preferences) or structural (e.g., governance arrangements) particularities.	• Number of different geographical markets for niches (count.).

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
	Circulating: exchanging knowledge, ideas, and resources between multiple related alternatives practises.	• Knowledge and experience collection and synthesis. • External knowledge and experience accessibility. • Knowledge and experience sharing among stakeholders.	• The number of accesses to a website (count.). • The number of attendees in a workshop (count.). • The number of recipients of newsletters (count.).
	Institutionalising: turning new and more sustainable practises into more permanent and more widely available ones.	• Guidelines for best practises are developed. • New standards are developed. • Existing standards are adapted. • New laws are developed. • Existing laws are adapted. • Practise features in emerging/dominant discourse.	• The number of guidelines, standards, laws, etc. (count.).
Opening-up and unlocking Regimes	De-aligning and destabilising regimes: disrupting and weakening dominant practises. This can be done by changing one of the dominant dimensions for example through the introduction of new policies.	• Top-down: • Phase-out policies. • Bans on entrenched practises. • Removal of subsidies of entrenched practises. • Targeted financial incentives for alternative practises. • Bottom-up: • Public demonstrations, rallies, or marches. • Boycotts. • Petitions. • Media campaigns. • Public debates. • Emerging discourses and metaphors.	• Number and stringency of policies (count. and qualitative). • The number of grassroot events (count.). • Opinion polls (qual.-quant.).

Process	Transformative Outcome	Indicator Categories	Example of Indicators for Some of the Categories [unit]
	Unlearning and deep learning in regimes: dominant actors question their assumptions and change their view on the potential of new and more	• Evidence that new problem framings are being adopted by regime actors, e.g., in regime publications and advertisement campaigns. • Evidence of changes in the direction of routine (R&I) search processes (i.e., moving into previously unexplored areas of knowledge);.	• Types of media and marketing campaigns (qual.). • The number of patents (beyond regimes core area) (count.). • The number of programmes (count.).
	sustainable practises and the ability of the dominant practise to respond to threats and opportunities, such as climate change and digitalisation.	• Existence of re-skilling, retrofitting, and repurposing programmes.	
	Strengthening regime-niche interactions: frequency and quality of interactions between empowered actors from the niche and the regime on a non-competitive basis.	• Establishment of partnerships and collaborations between regimes and niches. • Corporate venture capital initiatives for niche innovations. • Merges and acquisitions (M&A) between the regime and niche actors (e.g., firms).	• The number of partnerships (count.) size of venture capital funds (euros). • Number and size of M&A (count. / euros).
	Changing perceptions of landscape pressures: dominant actors to reach the point of view that immediate action is warranted, and new emerging more sustainable narratives need to be promoted.	• New regime discourses and narratives (framing) around a landscape trend (e.g., climate change). • Announcement of new strategies, products, or services that seek to address a pressure or benefit from an opportunity at the landscape level.	• Semantic metrics (qual.-quant.). • The number of announcements (count.).

Source: Prepared by authors in collaboration with Penna et al.[90].

90. Ibid.

1.5. Discussion and Concluding Remarks

As described by Schot and Steinmueller, innovation policy has thus far been dominated by two frames: a linear way of supporting R&I on one hand and a more multi-faceted way of developing innovation systems on the other.[91] This chapter highlights that both frames are characterised by well-established evaluation approaches and indicator frameworks. Nonetheless, a new and transformative innovation policy frame is emerging and has been increasingly recognised in innovation research and policymaking. This third framework of innovation policy thus does not have a fully solidified monitoring and evaluation approach yet, which entails a lack of indicators for assessing innovation policy concerning system transformation.

To this end, this chapter puts forward a theory-based approach to developing indicator categories that draw heavily on TIP building blocks as well as transformative outcomes.[92] Importantly, however, the indicator categories (see TABLE 1) posited here are informed by a range of different sources and they are by no means exhaustive or definitive. As such, they shall serve as a theory-based and conceptual starting point for further developing TIP indicators. As TABLE 1 indicates, development can be achieved in some instances by using well-established indicators (e.g., R&I expenditure, journal publications, or patents) while others will require new techniques (e.g., data mining, semantic analysis, network analysis) or new data sets. In any case, these indicators cannot always be easily interpreted and will need sense-making. To this end, a transformative theory of change can be relevant in structuring and guiding such a process.

Clearly, an important next step would be the empirical testing, application, and validation of these indicators with TIP initiatives in order to fill those categories with life.[93] For this process, it will be paramount to adapt and tailor the indicator categories to the scale and nature of the TIP (e.g., project, programme,

91. Schot and Steinmueller, 'Frames for innovation policy.'

92. Rogge, Pfluger, and Geels, 'Transformative policy mixes;' Ghosh, et al., 'Transformative outcomes.'

93. Note that such work is currently undertaken in the MOTION project which is applying and testing some of these indicator categories with TIP initiatives: http://www.tipconsortium.net/experiment/the-motion-project/

or instrument) to facilitate learning and reflection with them. This is critical, from an evaluation point of view where proponents such Molas-Gallart et al. and Dinges et al. stress the importance of a formative approach as the basis for improving the transformative potential of a policy.[94]

This chapter argues that without this bottom-up adaptation, indicator categories are prone to the risk of becoming too abstract and meaningless for fostering learning about an intervention. In this train of thought, it is crucial to co-create this adaptation process with TIP initiatives by working closely with TIP initiatives when indicator categories are developed, tailored, and applied. Hence, the co-creation of indicators becomes itself important learning and thus highly formative evaluation intervention. It thereby creates indicators that are meaningful and relevant to TIP actors, which is key for their usefulness and application. Besides, because the issue of causality is particularly pertinent in matters of transformation and complex system dynamics, this chapter claims that tailoring indicators through a co-creation approach can strengthen the robustness of an indicator and the phenomenon it seeks to capture and track.

An additional argument for such an approach ought to be made considering that it is grounded in a paradox of measuring transformation: some signs of transformation must change their meaning as the transformation unfolds. In other words, what can be considered a signal for transformation at one point in time can be reckoned as a signal for new stability at a later point in time. For this reason, this chapter advocates for a bottom-up and tailor-made approach to indicator development that is better able to adapt itself to the phases of a change process and capture changes in meaning.

It is worth acknowledging that such a tailor-made approach requires time and effort and poses challenges. This is particularly the case when multiple TIPs need to be evaluated from a portfolio perspective (e.g., multiple projects as part of a programme or call). Furthermore, it is important to note that while formativeness

94. Molas-Gallart, et al., 'Evaluation of Transformative Innovation;' Michael Dinges, Susanne Meyer, and Christoph Brodnik, 'Key Elements of Evaluation Frameworks for Transformative R&I Programmes in Europe,' *Journal for Research and Technology Policy Evaluation* 51 (November 2020): 26–40. https://doi.org/10.22163/fteval.2020.489

is paramount, accountability cannot be disregarded when it comes to policy – particularly when an intervention aims to be transformational. Bottom-up tailoring, however, would make accountability objectives more difficult to achieve and opens avenues for TIP actors to take part in the process by acting strategically. These issues raise the question: to what extent a generalisation of TIP indicators can and should be achieved and how practicable the tailoring of indicators for formative evaluation in TIP really is? Further empirical and theoretical work will be required to answer this question and to work towards an operational, generally applicable, and yet context-sensitive indicator framework for TIP monitoring and evaluation. As this is an exploratory research paper, it is expected that the indicator framework put forward here is useful for categorising measuring targets and signals for TIP. In doing so, it aims to effectively support the sense-making processes of this important innovation policy paradigm.

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2. Evaluating Transformative Innovation Policy Outcomes as Unfolding Processes Of Change In Socio-Technical Configurations

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2.1. Introduction

According to recent literature, a new, transformative innovation policy (TIP) paradigm is emerging, which implies a shift in focus from economic growth to addressing broad societal goals and 'grand challenges.'[3] The new paradigm

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comes with a broader view of the innovation process, building on writings on sustainability transitions (e.g., the multi-level perspective),[4] and additional rationales for policy intervention in innovation processes, such as transformational systems failures.[5] This indicates a shift in policy theory, which also needs to be reflected in policy evaluation.[6] However, evaluation practises are still very much based on a linear view of the innovation process,[7] with a focus on policy outputs rather than outcomes or final impacts.[8] As such, TIP implies several challenges for policy evaluation.[9] Most notably, a TIP-oriented evaluation framework would have to address (i) directionality and (ii) behavioural additionality.

Regarding directionality, TIP implies that there is a much clearer view of the intended impact of a policy intervention than in previous policy paradigms in that it targets a particular societal challenge or socio-technical transition rather than innovation in general. Indeed, the TIP paradigm implies a shift towards purposive and directional innovation.[10] Instead of considering all innovation outcomes as equally good, as in previous paradigms, TIP emphasises the need to assess whether achieved innovation outcomes are sustainable or not and whether innovation policy contributes to addressing specific societal

4. Frank W. Geels, 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study,' *Research Policy* 31, no. 8–9 (December 2002): 1257–74. https://doi.org/10.1016/S0048-7333(02)00062-8

5. K. Matthias Weber and Harald Rohracher, 'Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework,' *Research Policy* 41, no. 6 (July 2012): 1037–47. https://doi.org/10.1016/j.respol.2011.10.015

6. Jordi Molas-Gallart and Andrew Davies, 'Toward theory-led evaluation: The experience of European science, technology, and innovation policies,' *American Journal of Evaluation* 27, no. 1 (March 2006): 64–82. https://doi.org/10.1177%2F1098214005281701

7. Effie Amanatidou, et al., 'Using Evaluation Research as a Means for Policy Analysis in a 'New' Mission-Oriented Policy Context,' *Minerva* 52 (December 2014): 419–38. https://doi.org/10.1007/s11024-014-9258-x; Molas-Gallart and Davies, 'Toward theory-led evaluation.'

8. You-Na Lee, 'Evaluating and extending innovation indicators for innovation policy,' *Research Evaluation* 24, no. 4 (October 2015): 471–88. https://doi.org/10.1093/reseval/rvv017

9. Amanatidou, et al., 'Using Evaluation Research;' Carolina R. Haddad, et al., 'Transformative innovation policy: A systematic review,' *Environmental Innovation and Societal Transitions* 43 (June 2022): 14–40. https://doi.org/10.1016/j.eist.2022.03.002

10. Diercks, Larsen, and Steward, 'Transformative innovation policy;' Weber and Rohracher, 'Research, technology and innovation.'

needs, demands, and challenges.[11] Therefore, directionality is about addressing neglected questions such as 'which way?' 'who says?' and 'why?' and not only 'yes or no?' 'how much?' and 'how fast?'[12] However, how to incorporate directionality in policy evaluation remains understudied. While several authors acknowledge the need to address 'directionality failures,'[13] few provide any details on how to operationalise it apart from assessing the capacity of the actors in the targeted system to build a shared vision[14] or investigating the challenges that emerge from actors' interests and capabilities, networks, and institution.[15]

In turn, the concept of behavioural additionality refers to the assessment of actor changes (i.e., firm) behaviour following a policy intervention and was proposed to address perceived shortcomings of traditional input-output evaluation.[16] In a TIP context, behavioural change should, however, not only be studied at the level of firms but also at the system level.[17] Accordingly, evaluations should focus on explaining how specific interventions cause certain intended and unintended impacts on targeted systems and also take feedback loops between policy outputs, outcomes,

11. Jakob Edler and Wouter P. Boon, '"The next generation of innovation policy: Directionality and the role of demand-oriented instruments"—Introduction to the special section,' *Science and Public Policy* 45, no. 4 (August 2018): 433–34. https://doi.org/10.1093/scipol/scy026; Weber and Rohracher, 'Research, technology and innovation.'

12. Andy Stirling, *Direction, distribution and diversity! Pluralising progress in innovation, sustainability and development* (Brighton: STEPS Centre, 2009).

13. Weber and Rohracher, 'Research, technology and innovation.'

14. Markus Bugge, et al., 'Governing system innovation: assisted living experiments in the UK and Norway,' *European Planning Studies* 25, no. 12 (July 2017): 2138–56. https://doi.org/10.1080/09654313.2017.1349078; Markus M. Bugge, Lars Coenen, and Are Branstad, 'Governing socio-technical change: Orchestrating demand for assisted living in ageing societies,' *Science and Public Policy* 45, no 4 (February 2018): 468–79. https://doi.org/10.1093/scipol/scy010; Lisa Scordato, et al., 'Policy mixes for the sustainability transition of the pulp and paper industry in Sweden,' *Journal of Cleaner Production* 183 (May 2018): 1216–27. https://doi.org/10.1016/j.jclepro.2018.02.212

15. Markus Grillitsch, et al., 'Innovation policy for system-wide transformation: The case of strategic innovation programmes (SIPs) in Sweden,' *Research Policy* 48, no. 4 (May 2019): 1048–61. https://doi.org/10.1016/j.respol.2018.10.004

16. See for example: Timothy J. Buisseret, Hugh M. Cameron, and Luke Georghiou, 'What difference does it make? Additionality in the public support of R&D in large firms,' *International Journal of Technology Management* 10, no. 4–6 (1995): 587–600. http://bitly.ws/rnoq. Also check: Luke Georghiou and Bart Clarysse, 'Introduction and Synthesis,' in *Government R&D Funding and Company Behaviour: Measuring Behavioural Additionality*, ed. OECD (Paris: OECD Publishing, 2006), 9–38.

17. Abdullah Gök. *Evolutionary Approach to Innovation Policy Evaluation: Behavioural Additionality and Organisational Routines*. PhD diss. University of Manchester, 2011. http://bitly.ws/rnbz and impacts into account.[18] Some frameworks have already been proposed for performing such systems analysis in relation to individual policy programmes or more complex policy mixes, drawing on key transition-related frameworks such as the multi-level perspective (MLP), strategic niche management (SNM), the technological innovation systems (TIS) approach, and/or combinations of these.[19] These previous attempts have highlighted important evaluation aspects but have two main shortcomings. First, they do not explicitly capture behavioural changes in all three dimensions of a targeted socio-technical configuration, i.e., socio-technical systems, actor networks, and institutions,[20] but rather focus on one or a few of them. Second, the more comprehensive frameworks combine different existing frameworks without considering conceptual overlaps between them, which has resulted in unclear distinctions between processes as well as notable redundancies.

Against this background, the purpose of this chapter is to identify a set of non-overlapping key transformative processes, which captures both directionality and behavioural additionality. We suggest that this set of processes can be used as a framework to evaluate the outcomes of transformative innovation policy in terms of changes in all three dimensions of targeted socio-technical configurations. For this purpose, we draw on the literature on innovation system functions and socio-technical transitions (MLP and SNM).

18. Amanatidou, et al., 'Using Evaluation Research;' Erick Arnold, et al., 'How should we evaluate complex programmes for innovation and socio- technical transitions?' Technopolis Group, June 15, 2018, http://bitly.ws/rnqi; Florian Kern and Karoline S. Rogge, 'Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey,' *Environmental Innovation and Societal Transitions* 27 (June 2018): 102–17. https://doi.org/10.1016/j.eist.2017.11.001

19. Examples of this are: Matthijs J. Janssen, 'What bangs for your buck? Assessing the design and impact of Dutch transformative policy,' *Technological Forecasting and Social Change* 138 (January 2019): 78–94. https://doi.org/10.1016/j.techfore.2018.08.011; Florian Kern, 'Using the multi-level perspective on socio-technical transitions to assess innovation policy,' *Technological Forecasting and Social Change* 79, no. 2 (February 2012): 298–310. https://doi.org/10.1016/j.techfore.2011.07.004; Paula, Kivimaa, Hanna-Liisa Kangas, and David Lazarevic, 'Client-oriented evaluation of "creative destruction" in policy mixes: Finnish policies on building energy efficiency transition,' *Energy Research & Social Science* 33 (November 2017): 115–27. https://doi.org/10.1016/j.erss.2017.09.002; Paula Kivimaa and Florian Kern, 'Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions,' *Research Policy* 45, no. 1 (February 2016): 205–17. https://doi.org/10.1016/j.respol.2015.09.008; Paula Kivimaa and Venla Virkamäki. 'Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in Finland,' *Environmental Policy and Governance* 24, no. 1 (January 2014): 28–41. https://doi.org/10.1002/eet.1629; Scordato, et al., 'Policy mixes.'

20. Frank W. Geels, 'From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory,' *Research Policy* 33, no. 6–7 (September 2004): 897-920. https://doi.org/10.1016/j.respol.2004.01.015

2.2. Main Theoretical Building Blocks

In a general sense, policy evaluation 'is about comparing the intended and actual effects of public policies and can refer to insights regarding policy outcomes and/or impacts.'[21] We adopt a 'realistic' approach to evaluation that focuses on understanding both the outcomes and impacts of policy intervention, including its underlying processes and mechanisms.[22] The realistic approach combines elements from 'positivist' and 'constructivist' views on evaluation. The former sees the evaluator as an objective analyst of events and stresses the importance of basing evaluations on facts rather than value judgements.[23] In contrast, the latter defends the idea of multiple realities and the importance of focusing on the 'claims, concerns and issues of stakeholders,'[24] and sees the evaluator as more of a mediator and co-producer of social constructs.[25] Realistic evaluations are also theory-led, which in the context of innovation policy implies that the goals, outcomes, and impacts of the focal policy should be assessed in relation to relevant conceptualisations of innovation and its underlying processes and mechanisms.[26] Regarding transformative innovation policy, our opinion is that the most relevant conceptualisations are the three main frameworks used in the field of sustainability transitions: the multi-level perspective, strategic niche management, and technological innovation systems.[27] This is also in line with

21. Christoph Knill and Jale Tosun, *Public Policy: A New Introduction*, 1st ed. (London: Red Globe Press, 2012), 175.

22. Pawson, Ray, 'Evidence-based Policy: The Promise of "Realist Synthesis,"' *Evaluation* 8, no. 3 (July 2002): 340–58. https://doi.org/10.1177%2F135638902401462448; Pawson, Ray, *The Science of Evaluation: a Realist Manifesto*, (London: SAGE Publications, 2013); Pawson, Ray, and Tilley, Nicholas, *Realistic Evaluation*, (London: SAGE Publications, 1997).

23. Amanatidou, et al., 'Using Evaluation Research;' Christina A. Christie and Marvin C. Alkin, 'An Evaluation Theory Tree,' in *Evaluation Roots: A Wider Perspective of Theorists' Views and Influences*, 2nd edition, ed. Marvin C. Alkin (Thousand Oaks: SAGE Publications, 2013), 20–74.

24. Egon G. Guba and Yvonna S. Lincoln, *Fourth Generation Evaluation*. Thousand Oaks: SAGE Publications, 1989, 50.

25. Amanatidou, et al., 'Using Evaluation Research.'

26. Molas-Gallart and Davies, 'Toward theory-led evaluation.'

27. Jonathan Köhler, et al., 'An agenda for sustainability transitions research: State of the art and future directions,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 1–32. https://doi.org/10.1016/j.eist.2019.01.004; Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955–67. https://doi.org/10.1016/j.respol.2012.02.013. A fourth sustainability transitions-related framework, some of the previous attempts to develop an evaluation framework, as mentioned in the introduction.

The Multi-level Perspective (MLP)

In the MLP framework, transitions are conceptualised as major changes in the socio-technical configurations through which important sectoral societal functions are fulfilled,[28] which unfold at multiple levels: niche, regime, and landscape.[29] Since policy can mainly influence the niche and regime levels, we focus on these. On the one hand, socio-technical transitions are dependent on the development and upscaling of new technologies and solutions. In the transition literature, this is assumed to happen through the gradual build-up and institutionalisation of socio-technical 'niches.' Niches can be thought of as 'protected spaces' that temporarily shelter emerging innovations from mainstream selection pressures.[30] As such, they allow promising technologies to be developed and used in an experimental setting, where technology, user practises, and regulations can be explored in a co-evolutionary way,[31] and they can, thus, be seen as 'local breeding spaces for new technologies.'[32] On the other hand, the transitions literature emphasises the stability and inertia of established socio-technical configurations, which originate from socio-technical systems, actor networks, and regime rules.[33] Socio-technical transitions, therefore, require 'windows of opportunity' to open up the regime

transitions management, was excluded here since it prescribes a set of activities that policymakers should use to shape transitions but does not provide much guidance on how to describe and analyse transition processes as such.

28. Geels, 'Technological transitions;' Geels, 'Sectoral systems of innovation.'

29. Geels, 'Technological transitions.'

30. Adrian Smith and Rob Raven, 'What is protective space? Reconsidering niches in transitions to sustainability,' *Research Policy* 41, no. 6 (July 2012): 1025–36. https://doi.org/10.1016/j.respol.2011.12.012; Adrian Smith, Jean-Peter Voß, and John Grin, 'Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges,' *Research Policy* 39, no. 4 (May 2010): 435–48. https://doi.org/10.1016/j.respol.2010.01.023

31. Johan Schot and Frank W. Geels, 'Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy,' *Technology Analysis & Strategic Management* 20, no. 5 (October 2008): 537–54. https://doi.org/10.1080/09537320802292651

32. René Kemp, Johan Schot, and Remco Hoogma, 'Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management,' *Technology Analysis & Strategic Management* 10, no. 2 (January 1998): 185. https://doi.org/10.1080/09537329808524310

33. Geels, 'Sectoral systems of innovation.'

to allow niche innovations to breakthrough.[34] This implies that some (or all) elements of the established socio-technical configurations, and in particular the regime, have to be weakened.[35]

Taken together, this means that we need to consider both niche development and regime destabilisation processes when assessing the behavioural additionality of transformative innovation policies. Niche development processes are described in more detail in the strategic niche management framework and will, therefore, not be discussed more here. Regime destabilisation has recently begun to receive increased attention in the literature, and there are now a few frameworks that address this issue in more detail. Some of these associate regime-level change primarily with a weakening (or reconfiguration) of core regime rules,[36] while others also include changes in actor networks and/or socio-technical systems.[37]

While the sustainability transition notion implies a direction towards a more sustainable socio-technical configuration, extant literature does not provide much guidance on how to assess that directionality. However, it has been suggested that one way forward could be to identify '"the right" transformation pathway(s) ... for relevant (sub-)systems.'[38] Such pathways can, for example, be described in terms of four archetypes: transformation (re-orientation), technological substitution, de- and re-alignment, and reconfiguration.[39] According to Geels et al., these

34. Geels, 'Technological transitions.'

35. Bruno Turnheim and Frank W. Geels, 'The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967),' *Research Policy* 42, no. 10 (December 2013): 1749–67. https://doi.org/10.1016/j.respol.2013.04.009

36. Bipashyee Ghosh and Johan Schot, 'Towards a novel regime change framework: Studying mobility transitions in public transport regimes in an Indian megacity,' *Energy Research & Social Science* 51 (May 2019): 82–95. https://doi.org/10.1016/j.erss.2018.12.001; Turnheim and Geels, 'The destabilisation of existing regimes.'

37. Kern, 'Using the multi-level perspective;' Kivimaa and Kern, 'Destruction or niche support?' David Lazarevic, Petrus Kautto, and Riina Antikainen, 'Finland's wood-frame multi-storey construction innovation system: Analysing motors of creative destruction,' *Forest Policy and Economics* 110 (January 2020): 101861. https://doi.org/10.1016/j.forpol.2019.01.006

38. Michael P. Schlaile, et al., 'Innovation systems for transformations towards sustainability? Taking the normative dimension seriously,' *Sustainability* 9, no. 12 (December 2017): 6. https://doi.org/10.3390/su9122253

39. Frank W. Geels, et al., 'The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–

differ regarding the type and degree of change they imply in the targeted socio-technical configuration with regard to technology (e.g., incremental vs modular vs architectural/radical innovation), actor networks (e.g., the relative importance of new entrants vs established actors and the relationship between them (competitive vs collaborative or complementary), and institutions (e.g., whether new institutions replace existing ones or are added to them).[40]

Strategic Niche Management (SNM)

The SNM framework is closely related to the MLP but focuses mainly on the niche level. It involves a clear governance aspect in that it suggests that strategically managing niches is 'a possible (or even necessary) strategy for governments to manage the transition process to a different regime.'[41] An overall argument is that protected spaces are required for entrepreneurs and system builders to experiment with new technology in relation to user practises, demonstrate its viability, and attract funding- This also entails achieving the institutional adaptations needed to eventually allow for a widespread diffusion.[42]

There are several conceptualisations of niche development, including the early work by Kemp, Schot, and Hoogma[43] as well as later elaborations of their framework by other scholars that identify three main niche development processes: learning processes, articulation of expectations and visions, and the enrolment of commitments from a growing network of actors.[44] In more recent literature, three

2014),' *Research Policy* 45, no. 4 (May 2016): 896–913. https://doi.org/10.1016/j.respol.2016.01.015; Frank W. Geels and Johan Schot, 'Typology of socio-technical transition pathways,' *Research Policy* 36, no. 3 (April 2007): 399–417. https://doi.org/10.1016/j.respol.2007.01.003

40. According to the original framework, the pathways differ in terms of the timing and nature of the multi-level interactions involved.

41. Kemp, Schot, and Hoogma, 'Regime shifts to sustainability': 185.

42. Schot and Geels, 'Strategic niche management.'

43. Kemp, Schot, and Hoogma, 'Regime shifts to sustainability.'

44. Examples of this are: Frank Geels and Rob Raven, 'Non-linearity and Expectations in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973–2003),' *Technology Analysis & Strategic Management* 18, no. 3-4 (August 2006): 375–92. https://doi.org/10.1080/09537320600777143; Schot and Geels, 'Strategic niche management;' Smith, Voß, and Grin, 'Innovation studies and sustainability.' Kemp, Schot, and Hoogma identified three aims of strategic niche management: (i) to articulate necessary technological and institutional changes and adaptations; (ii) to set learning processes in motion in relation to different technological options; (iii) to stimulate the development and diffusion of these and other, complementary technologies; and (iv) to build a semi-coordinated constituency around a new technology.

properties of niches as protected spaces have been identified, namely: shielding, nurturing, and empowering.[45] Shielding implies that niches protect the emerging innovation from selection pressures in the mainstream market or other relevant selection environments[46] and, thus, create a space for experimentation.[47] Nurturing corresponds to the three main niche development processes described above.[48] Third, empowering refers to different processes that improve the competitiveness of niche innovations and remove shielding. This occurs either by adapting the niche innovation to fit current selection environments (fit-and-conform processes) or by institutionalising shielding to make mainstream selection environments more agreeable to the niche innovation (i.e., stretch-and-transform processes).[49] Based on this framework, a number of subsequent articles have described, operationalised, and analysed niche-level processes in more detail. We draw on these writings to develop our framework in the next section.

In spite of its governance focus, the SNM framework primarily describes niche development as a bottom-up process without much clear directionality. However, as mentioned above, it considers the development of a common vision among niche stakeholders as an important part of that process. It also sheds some light on how niches can contribute to modifying transition pathways as it highlights some of the non-technical factors that lead to changes in the regime.[50]

Technological Innovation Systems (TIS)

The TIS framework builds on earlier work on technological systems, which focuses on the innovation performance of 'a network of agents interacting in a

45. Smith and Raven, 'What is protective space?'

46. Ibid.

47. Bram Verhees, et al., 'The development of solar PV in The Netherlands: A case of survival in unfriendly contexts,' *Renewable and Sustainable Energy Reviews* 19 (March 2013): 275–89. https://doi.org/10.1016/j.rser.2012.11.011

48. Rolf Naber, et al., 'Scaling up sustainable energy innovations,' *Energy Policy* 110 (November 2017): 342–54. https://doi.org/10.1016/j.enpol.2017.07.056; Rob Raven, et al., 'Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases,' *Environmental Innovation and Societal Transitions* 18 (March 2016): 164–80. https://doi.org/10.1016/j.eist.2015.02.002; Verhees, et al., 'The development of solar PV.'

49. Raven, et al., 'Niche construction and empowerment;' Verhees, et al., 'The development of solar PV.'

50. Schot and Geels, 'Strategic niche management.'

specific economic/industrial area.'[51] In the context of sustainability transitions, this framework has primarily been used to analyse the development and diffusion of emerging technologies in the energy and transport sectors.[52]

In the TIS literature, innovation outcomes have been conceptualised in both structural and functional terms. Some literature describes processes that contribute to the structural build-up of new systems such as actor entry, network formation, and institutional adaptation.[53] Regarding functionality, seven key processes have been identified that contribute to the development, diffusion, and utilisation of new technologies and, thus, to changes in the socio-technical system of a sector: (1) knowledge development and diffusion, (2) entrepreneurial experimentation, (3) guidance of the direction of search, (4) market formation, (5) legitimation, (6) resource mobilisation, and (7) development of positive externalities.[54] These are closely related to niche nurturing, as described in the SNM.[55]

Several frameworks use the functions as a basis for analysing the impact of policy on the innovation outcomes of specific innovation systems.[56] However, these frameworks do not address changes in established socio-technical

51. Bo Carlsson and Rikard Stankiewicz, 'On the nature, function and composition of technological systems,' *Journal of Evolutionary Economics* 1 (June 1991): 93–118. https://link.springer.com/article/10.1007/BF01224915

52. Anna Bergek, 'Technological Innovation Systems: a review of recent findings and suggestions for future research,' in *Handbook of Sustainable Innovation*, eds. Frank Boons and Andrew McMeekin (Cheltenham: Edvard Elgar Publishing, 2019), 200–18; Köhler, et al., 'An agenda for sustainability.'

53. Staffan Jacobsson and Anna Bergek, 'Transforming the energy sector: the evolution of technological systems in renewable energy technology,' *Industrial and Corporate Change* 13, no. 5 (October 2004): 815–49. https://doi.org/10.1093/icc/dth032; Staffan Jacobsson and Anna Johnson, 'The Diffusion of Renewable Energy Technology: An Analytical Framework and Key Issues for Research,' *Energy Policy* 28, no. 9 (July 2000): 625–40. https://doi.org/10.1016/S0301-4215(00)00041-0. Some authors also include the accumulation of knowledge and artifacts among the structural processes. Take for example: Anna Bergek, Staffan Jacobsson, and Björn A. Sandén, '"Legitimation" and "development of positive externalities": Two key processes in the formation phase of technological innovation systems,' *Technology Analysis and Strategic Management* 20, no. 5 (September 2008): 575–92. https://doi.org/10.1080/09537320802292768

54. Anna Bergek, et al., 'Analyzing the functional dynamics of technological innovation systems: A scheme of analysis,' *Research Policy* 37, no. 3 (April 2008): 407–29. https://doi.org/10.1016/j.respol.2007.12.003

55. Smith and Raven, 'What is protective space?'

56. Staffan Jacobsson and Eugenia Perez Vico, 'Towards a systemic framework for capturing and explaining the effects of academic R&D,' *Technology Analysis and Strategic Management* 22, no. 7 (September 2010): 765–87. https://doi.org/10.1080/09537325.2010.511140; Janssen, 'What bangs for your buck?' Kivimaa and Virkamäki, 'Policy mixes, policy interplay.'

configurations. Moreover, like most other innovation system approaches, the current conceptualisation of the TIS framework does not contain any explicit element of directionality apart from the researcher's choice of which technologies to analyse. In fact, for the most part, it treats all innovation outcomes as essentially positive and does not necessarily consider their relevance for solving important societal challenges.[57] Recently, some attempts to conceptualise directionality have been made, for example in the form of mission-oriented innovation systems,[58] but, as discussed in the next section, these do not exploit the full potential of the functions framework to incorporate directionality.

Summary

As the review in this section shows, capturing behavioural additionality involves analysing a broad set of potential innovation outcomes that span several dimensions of the focal sectoral socio-technical configuration (i.e., socio-technical system, actor networks, and rules) as well as different levels of analysis (i.e., niche and regime). It also has both structural and functional features. MLP, SNM, and TIS have all identified relevant processes that can be used for this purpose, sometimes overlapping and complementing each other. Therefore, we suggest that it would be useful to integrate previous conceptualisations into one comprehensive evaluation framework.

2.3. Suggested Framework: Three Clusters of Transformative Processes

We define a transition as a reconfiguration of the socio-technical configuration that is associated with the social sector targeted by a particular transformative policy intervention, which is to be evaluated. Since this configuration is defined at the sectoral level, it might contain several more or less distinct technologies, actor networks, and sets of institutions, which can be analysed both as one system and as different sub-systems depending on the focus of the evaluation.

57. Schot and Steinmueller, 'Three frames for innovation;' Weber and Rohracher, 'Research, technology and innovation.'

58. Marko P., Hekkert, et al., 'Mission-oriented innovation systems,' *Environmental Innovation and Societal Transitions* 34 (March 2020): 76–79. https://doi.org/10.1016/j.eist.2019.11.011

In order to make a summative evaluation of the policy intervention in question, we need to assess its impact on the elements of the targeted socio-technical configuration – systems, actors, and institutions[59]– and compare it with the desired impact, as described in the implicit and explicit goals of the intervention and/or more general policy objectives. However, in a more formative evaluation setting – or an early transition phase – we argue that it is more relevant to trace the policy intervention's influence on a number of key intermediate transformative processes associated with each configuration element. As mentioned in the previous section, we have used insights from the MLP, SNM, and TIS frameworks to identify a set of such processes. The potential to combine the MLP, SNM, and TIS approaches has been explored elsewhere.[60] Still, what distinguishes our approach is that we scrutinise each conceptualisation at the level of individual processes in order to create an integrated (i.e., non-overlapping) list of relevant transformative processes that could be used to assess the outcomes of a transformative innovation policy programme. It should be noted that the functions framework mainly contributes to knowledge about processes related to changes in the socio-technical system dimension. In contrast, the MLP and SNM frameworks mainly boost knowledge about processes resulting in changes in actor networks and institutions.

We integrate directionality in two ways. First, we add a 'directionality filter' to each function in order to be able to capture innovation processes related to different socio-technical systems within the sectoral configuration (established as well as emerging). This enables us to assess the innovation dynamics of different technologies and, thus, their relative rate of improvement, diffusion, and/or decline. Second, by explicitly considering changes in actor networks and institutions related to emerging as well as existing sub-configurations, we can assess the relative importance of new versus established actors and the type and degree of change happening in the institutional framework. Based on these

59. Geels, 'Sectoral systems of innovation.'

60. Kivimaa, Kangas, and Lazarevic, 'Client-oriented evaluation;' Jochen Markard and Bernhard Truffer, 'Technological innovation systems and the multi-level perspective: Towards an integrated framework,' *Research Policy* 37, no. 4 (May 2008): 596–615. https://doi.org/10.1016/j.respol.2008.01.004; Weber and Rohracher, 'Research, technology and innovation.'

directionality considerations, a preliminary evaluation can be made of whether the transition seems to be going in the 'right' direction in relation to policy goals and objectives (although this is not in focus here).

Socio-technical Systems

We assume that, in many cases, the main goal of a TIP intervention is to induce changes in a focal socio-technical system that needs to be replaced or reconfigured in order for the targeted sector to become more sustainable. This requires innovation both in terms of improvements in established technologies and the development and diffusion of new technologies. As described in the second section, this is captured well by innovation system functions,[61] which can be applied at different system levels (i.e., sectors as well as individual technologies or groups of related technologies)[62] and might be used to analyse innovation processes related to both new and emerging technology fields.[63] In our framework, we use them to examine all technologies that (potentially) contribute to the overall societal function of the sector. In the energy sector, for example, we would consider innovation (or lack thereof) in established technologies such as coal, nuclear, or hydropower as well as various less established technologies such as wind, solar, and marine power.

61. Bergek, 'Technological Innovation Systems;' Bergek, et al., 'Analyzing the functional dynamics;' It should be noted that several authors, as mentioned in the second section, have already used the functions as a basis for assessing the effects of policy. See for example: Janssen, 'What bangs for your buck?' Kivimaa and Kern, 'Destruction or niche support?' Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame.'

62. Anna Bergek and Staffan Jacobsson, 'The Emergence of a Growth Industry: A Comparative Analysis of the German, Dutch and Swedish Wind Turbine Industries,' in *Change, Transformation and Development,* eds. J. Stan Metcalfe and Uwe Cantner (Heidelberg: Physica-Verlag, 2003), 197–227; Anna Johnson and Staffan Jacobsson, 'Inducement and Blocking Mechanisms in the Development of a New Industry: The Case of Renewable Energy Technology in Sweden,' In *Technology and the Market: Demand, Users and Innovation*, eds. Rod Coombs, et al. (Cheltenham/Northhampton: Edward Elgar, 2001), 89–112.

63. See for example: Bo Carlsson, ed., *Technological Systems and Economic Performance: The Case of Factory Automation* (Dordrecht: Kluwer Academic Publishers, 1995); Ulrich Dewald and Matthias Achternbosch, 'Why more sustainable cements failed so far? Disruptive innovations and their barriers in a basic industry,' *Environmental Innovation and Societal Transitions* 19 (June 2016): 15–30. https://doi.org/10.1016/j.eist.2015.10.001; Daniel Gabaldón Estevan and Marko P. Hekkert, 'How does the innovation system in the Spanish ceramic tile sector function?' *Boletín de la Sociedad Española de Cerámica y Vidrio* 52, no. 3 (April 2013): 151–58. http://dx.doi.org/10.3989/cyv.202013. Nevertheless, this contrasts with perspectives comparing TISs with (global) niches (see Smith and Raven, 'What is protective space?') or arguing that the functions framework is only useful for analyzing emerging technologies (see Markard and Truffer, 'Technological innovation systems.')

We depart from the list of functions presented by Bergek et al.[64] and further developed by Bergek[65] and Bergek et al.[66], which includes (1) the development and diffusion of knowledge within the system; (2) entrepreneurial experimentation to reduce technological, market, and political uncertainty; (3) the formation of markets; (4) guidance of actors' search processes; (5) mobilisation of financial, human, and physical resources; (6) legitimation of technologies and actors; and (7) the development of positive external economies (see TABLE 2, second column, for a detailed definition of each function). By analysing these processes, analysts – or evaluators – can identify functional system weaknesses as well as the influence of policy on each process, i.e., behavioural additionality. In the words of Janssen, '... policy contributions to the building of technological innovation systems are in fact the 'bangs' [for the buck] auditors and evaluators should be looking for.'[67] The functions can also capture what is going on in an innovation system long before any concrete outputs in terms of new technologies, products, or processes become visible and, therefore, allow for formative evaluation.[68]

When comparing this list with the niche-level shielding, nurturing, and empowering processes identified in the SNM literature and the regime destabilisation processes described in relation to the MLP framework, we find that almost all processes that refer to change in the socio-technical system are covered by the functions (see Appendix A).[69] Regarding shielding, technology-

64. Bergek, et al., 'Analyzing the functional dynamics.'

65. Bergek, 'Technological Innovation Systems.'

66. Anna Bergek, et al., 'Sustainability transitions in coastal shipping: The role of regime segmentation,' *Transportation Research Interdisciplinary Perspectives* 12 (December 2021): 100497. https://doi.org/10.1016/j.trip.2021.100497

67. Janssen, 'What bangs for your buck?': 79.

68. Anna Bergek, et al., 'Functionality of innovation systems as a rationale and guide in innovation policy,' in *The Theory and Practice of Innovation Policy,* eds. Ruud E. Smits, Stefan Kuhlmann, and Phillip Shapira (Cheltenham: Edward Elgar, 2010), 117–46.

69. This contradicts previous claims that the functions underplay the importance of shielding against mainstream selection pressures and cannot explain mass-market diffusion (See Smith and Raven, 'What is protective space?'; Smith, Voß, and Grin, 'Innovation studies and sustainability.') – at least as far as the socio-technical system is concerned. Note also that the dynamics of market formation (including the importance of nursing markets) is a recurring topic in the TIS literature (see Björn A. Andersson and Staffan Jacobsson, 'Monitoring and assessing technology choice: the case of solar cells,' *Energy Policy* 28, no. 14 (November 2000): 1037–49. https://doi.org/10.1016/S0301-4215(00)00090-2; Anna Bergek, 'Technological dynamics and policy: how to derive policy prescriptions,' (lecture, 3rd Lundvall Symposium: Innovation specific RD&D support is covered by the 'resource mobilisation' function and possibly also by the 'knowledge development and diffusion' and 'entrepreneurial experimentation' if the mobilised resources are used for that.[70] The creation and exploitation of 'real'[71] and policy-induced[72] niche markets are covered by 'market formation.' With regard to nurturing, research, development, prototyping, piloting, and demonstration of niche innovations are covered by the 'knowledge development and diffusion' and 'entrepreneurial experimentation' functions; public support for such activities[73] by 'resource mobilisation;' and learning between niches (at the level of the 'global' niche)[74] by 'knowledge development and diffusion.' Regarding empowering, both infrastructure changes[75] and public support targeting price-performance improvements[76] are included in 'resource mobilisation.'[77]

Similarly, most of the regime-level processes related to changes in a socio-technical system can be connected to the functions. Changes and improvements in established socio-technical systems are mainly related to 'resource mobilisation.' For example, public investment support or loans for

Policy - Can it Make a Difference? Ålborg, DK: University of Aalborg, January 2014); Anna Bergek, 'The role of entrepreneurship and markets for sustainable innovation,' in *Creating a sustainable economy: an institutional and evolutionary approach to environmental policy*, ed. Gerardo Marletto (Abingdon: Routledge, 2012), 205–30.

70. Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment;' Smith and Raven, 'What is protective space?'

71. Smith and Raven, 'What is protective space?' Raven, et al., 'Niche construction and empowerment;' Verhees, et al., 'The development of solar PV.'

72. Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment;' Smith and Raven, 'What is protective space?'

73. Kern, 'Using the multi-level perspective;' Verhees, et al., 'The development of solar PV.'

74. Smith and Raven, 'What is protective space?'

75. Bugge, et al., 'Governing system innovation;' Raven, et al., 'Niche construction and empowerment.'

76. Raven, et al., 'Niche construction and empowerment;' Kern, 'Using the multi-level perspective;' Verhees, et al., 'The development of solar PV.'

77. It should be noted that from an innovation system perspective, price-performance improvement, product and process innovations (see Bruno Turnheim and Frank W. Geels, 'Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997),' *Energy Policy* 50 (November 2012): 35–49. https://doi.org/10.1016/j.enpol.2012.04.060; Turnheim and Geels, 'The destabilisation of existing regimes') and efficiency improvements are considered outputs of the innovation process rather than as transformative processes in themselves.

efficiency improvements[78] are covered by (financial) 'resource mobilisation,' and changes in existing infrastructures and production plants[79] or investments in new complementary infrastructure[80] are both covered by (physical) 'resource mobilisation.' Aspects of a strategic reorientation of incumbent actors that are covered by the functions include a build-up of new competences and skills[81] and new operations[82] that are embedded in (human and physical) resource mobilisation. In turn, the build-up of new knowledge[83] and replacement of existing knowledge[84] could be seen as 'knowledge development and diffusion.' In addition, diversification to new product markets[85] and experimentation with new technologies[86] are covered by 'guidance of the direction of search' and 'entrepreneurial experimentation' respectively. Finally, reduced resource flows to established technologies in the form of declining markets or shifts in investment patterns[87] can be captured by 'market formation' or 'guidance of the direction of search,' depending on how and why the reduction occurs.

In order for the foregoing connections to become apparent, we need to explicitly account for directionality in the functions so that we can see whether they support emerging or established technologies or both. In the original framework, directionality is mainly accounted for in the function 'guidance of the direction of search,' which includes the processes by which actors decide in what direction to search for new opportunities and to what technologies and markets they allocate their resources.[88] Yet, this does not fully capture all aspects of direction-

78. Kern, 'Using the multi-level perspective.'

79. Ibid.

80. Ghosh and Schot, 'Towards a novel regime change.'

81. Kivimaa and Kern, 'Destruction or niche support?' Turnheim and Geels, 'The destabilisation of existing regimes.'

82. Turnheim and Geels, 'The destabilisation of existing regimes.'

83. Ibid.

84. Kivimaa and Kern, 'Destruction or niche support?'

85. Turnheim and Geels, 'The destabilisation of existing regimes.'

86. Kivimaa, Kangas, and Lazarevic, 'Client-oriented evaluation;' Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame.'

87. Turnheim and Geels, 'Regime destabilization;' Turnheim and Geels, 'The destabilisation of existing regimes.'

88. Bergek, et al., 'Analyzing the functional dynamics.'

ality described in the second section, as it mainly refers to supply-side actors. We, therefore, propose that a directionality filter should instead be applied to each function, reflecting an understanding of directionality as an emergent property of the functional dynamics of the system (i.e., a bottom-up perspective on directionality).[89] For example, instead of just describing knowledge development related to a particular technology, all knowledge development processes in the focal sector could be analysed with regard to whether they support established technologies or niche technologies (and which niche technologies). Similarly, the market formation could include an analysis of for which technologies markets are formed (and how). Due to space limitations, we refrain from discussing all the functions in the text, but a summary of the main directionality aspects for each function is presented in TABLE 2 (see the third column).[90]

TABLE 2. Transformative Processes (Functions) Related to Socio-technical Change.

Function	Description	Examples of directionality aspects
Knowledge development and diffusion	Broadening and deepening of the knowledge base of a TIS, sharing of knowledge between actors within the system, and new combinations of knowledge because of these processes.	For which technologies is knowledge developed? What technological/societal problems are knowledge development efforts targeting? By and for whom is knowledge developed?

89. See for example: Xiao-Shan Yap and Bernhard Truffer, 'Shaping selection environments for industrial catch-up and sustainability transitions: A systemic perspective on endogenizing windows of opportunity,' *Research Policy* 48, no. 4 (May 2019): 1030–47. https://doi.org/10.1016/j.respol.2018.10.002

90. Thus, in contrast to Hekkert, et al., 'Mission-oriented innovation systems,' we do not think it is necessary to introduce an entirely new system concept. Our notion of a sector-level innovation system also differs in other ways from their concept of 'mission-oriented innovation systems.' Most notably, in contrast to MIS a sector-level TIS is not limited to innovation activities aimed at specific societal challenges but captures the main innovation- and transitions-related processes in a particular societal sector. It therefore captures developments in different directions (including recreating the regime) and does not require these developments to be coordinated by policy makers or other actors.

Function	Description	Examples of directionality aspects
Entrepreneurial experimentation	Problem-solving and uncertainty reduction through real-world trial-and-error experiments at different scales with new technologies, applications, and strategies.	Which technologies are experimented with and why? Who is experimenting with what and why? What sources of uncertainty are experiments targeting?
Market formation	The opening up of a space or an arena in which goods and services can be exchanged in (semi-) structured ways between suppliers and buyers, e.g., articulation of demand and preferences, product positioning, standard-setting, and development of rules of exchange.	Which segments are expanding vs declining and why? What customer needs are articulated vs ignored and by whom? Which segments and technologies do actors' market strategies target?
Guidance of the direction of search	Mechanisms that influence the decision-making processes to allocate resources in firms and other organizations to incentivise or pressure innovative work in a particular field.	To which technologies are actors allocating their resources and why? To which technologies, markets, and business models are actors allocating their resources and why?
Resource mobilisation	The system's acquisition of different types of resources for the development, diffusion, and utilisation of new technologies, products, and processes, most notably capital, competence and manpower, and complementary assets (e.g., infrastructure).	To what extent is resource mobilisation generic or technology-specific? Which technologies benefit the most from current resource endowments and why? To what extent and how can new technologies exploit existing infrastructures and complementary technologies?
Legitimation	The process of gaining regulative, normative, and cognitive legitimacy for the new technology, its proponents, and the TIS as such in the eyes of relevant stakeholders, i.e., increasingly being perceived as complying with rules and regulations, societal norms, and values, and cognitive frames.	Which technologies and actors are gaining vs. losing legitimacy in the eyes of which stakeholders and why? Which regulations and support systems are gaining vs. losing legitimacy in the eyes of which stakeholders and why?

Function	Description	Examples of directionality aspects
Development of positive externalities	The creation of system-level utilities (or resources), such as pooled labour markets, complementary technologies, and specialised suppliers, which are available also to system actors that did not contribute to building them up.	Which technologies benefit from which externalities and why? Which actors benefit from which externalities and why? Which self-reinforcing mechanisms support or hinder different technologies?

Source: The second column was prepared by authors based on Bergek[91] and Bergek et al.[92] (which draw on Bergek et al.[93]). The third column is our own conceptualisation.

Actor Networks

As mentioned in the second section, the TIS framework includes structural dynamics, including changes in an actor network, but has mainly focused on the emergence of new systems (primarily in terms of entry of actors along the entire value chain). We, therefore, build this part of our framework mainly on the MLP and SNM frameworks (see Appendix A TABLES 5 and 6).[94]

With regard to the regime level, the entry of new firms into the market (with a resulting redistribution of market shares) can rattle incumbent actors and challenge their stable position (potentially to the point that they are forced to exit the market entirely).[95] Such new entrants can come from niches[96] or other industries or countries. A new entry can also be enabled by more fundamental, policy-driven market reforms (e.g., the liberalisation of the electricity market).[97] In addition, new partnerships might be formed between new or

91. Bergek, 'Technological Innovation Systems.'

92. Bergek, et al., 'Sustainability transitions.'

93. Bergek, et al., 'Analyzing the functional dynamics.'

94. As can be seen in Tables 5 and 6 (Appendix A), the processes we identify here are related to the functions in that they may influence them (but they do not have to). It should also be noted that while 'guidance of the direction of search' covers the emergence of incentives for actors to enter a niche- or regime-level actor network, their actual entry and the subsequent formation of networks are structural rather than functional processes.

95. Kern, 'Using the multi-level perspective;' Kivimaa and Kern, 'Destruction or niche support?' Turnheim and Geels, 'The destabilisation of existing regimes.'

96. Kern, 'Using the multi-level perspective.'

97. Turnheim and Geels, 'Regime destabilization.'

established market actors as a result of business model innovation.[98] Finally, the literature highlights the need to reduce the power of incumbent actors in policy networks, either by deliberately breaking up established networks or by developing new ones dedicated to system change.[99] The creation of change advocates within established organisations can also be a way to stimulate destabilisation of the policy system.[100]

As for the niche level, the SNM especially highlights the importance of enrolling commitments from a growing network of actors. For shielding, key processes include the involvement of strong actors that provide support and protection,[101] provision of technology-specific business support to new actors,[102] and the establishment of demand-side collective initiatives such as buying cooperatives.[103] In relation to nurturing, the literature emphasises the entry of powerful actors,[104] the formation of broad and deep networks[105] as well as 'global' networks to support cross-niche learning,[106] and fostering of a wider societal engagement, for example in terms of NGOs or academics.[107] Finally, regarding empowering, the formation and strengthening of powerful advocacy coalitions and networks, which can prevent the niche from being captured by vested interests and ensure protection, are key processes.[108] They could include the involvement of government bodies that enable niche upscaling.[109]

98. Ibid.

99. Kivimaa and Kern, 'Destruction or niche support?' Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame.'

100. Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame.'

101. Bugge, et al., 'Governing system innovation;'

102. Kern, 'Using the multi-level perspective;' Smith and Raven, 'What is protective space?' Raven, et al., 'Niche construction and empowerment.'

103. Raven, et al., 'Niche construction and empowerment.'

104. Kern, 'Using the multi-level perspective.'

105. Naber, et al., 'Scaling up sustainable energy innovations;' Verhees, et al., 'The development of solar PV.'

106. Smith and Raven, 'What is protective space?'

107. Kern, 'Using the multi-level perspective.'

108. Smith and Raven, 'What is protective space?'

109. Bugge, et al., 'Governing system innovation.'

If we synthesise these insights from the MLP and SNM frameworks, we can identify four main transformative processes related to changes in actor networks, which are relevant for both the niche and the regime level: entry of new actors; formation of new knowledge, technology, and business networks; configuration (and de-configuration) of political networks; and development of political capacity and change advocacy (see TABLE 3). To account for directionality, each of these processes should be analysed from the point of view of whether they strengthen established actor networks or work towards the establishment of new or fundamentally reconfigured networks in the focal sector.

TABLE 3. Transformative Processes (Outcomes) Related to Actor Networks (Synthesis)

Processes (outcomes)	Niche-level processes	Regime-level processes
Entry of new actors	Entry/involvement of powerful actors (including policy) to get support and allow for up-scaling. Generation of (and support to) new firms and businesses.	Entry of niche actors. Entry of actors from other industries and countries. Replacement of incumbents by new actors.
Formation of new knowledge/ technology/business networks	Forging new relationships and networks and facilitating interaction. Formation (and maintenance) of broad networks, i.e., networks consisting of actors from different domains. Formation (and maintenance) of deep networks, i.e., networks with high resource commitment from network members. Development of 'global' networks that support the exchange and interpretation of specific lessons and experiences between niches.	New partnerships to enable business model innovation. The emergence of new customer groups/segments.
Configuration and de-configuration of political networks	Formation of 'discourse coalitions' including (industrial, administrative, and grassroots)	Balancing the power of incumbents, e.g., by inviting niche actors to advisory

Processes (outcomes)	Niche-level processes	Regime-level processes
	advocates accumulating resources and political power. Fostering wider societal engagement.	councils, etc. Breaking-up of existing policy networks.
Development of political capacity and change advocacy	Development of political capacity to avoid capture by vested interests.	Development of new fora/organisations to support policy change. Emergence/creation of change advocates in established (policy) organisations.

Source: Prepared by authors based on Bugge et al.; Kern; Kivimaa and Kern, Raven et al.; Smith and Raven; Ghosh and Schot; Turnheim and Geels; Naber et al., Verhees et al.; Lazarevic, Kautto, and Antikainen. (See Appendix A).[110]

Institutions

As for actors, the TIS framework recognises the importance of institutional change but has not given much explicit attention to it. We, therefore, build this part of our framework mainly on the MLP and SNM frameworks. (See Appendix A for a complete account of the identified processes.)

The literature highlights several processes of institutional change at the level of the regime. With regard to formal institutions, radical policy reforms (e.g., market liberalisation) or the implementation of control policies, such as taxes or bans, can exert direct destabilisation pressures on established technologies and actors.[111] According to these authors, withdrawal of support to established technologies and actors, such as the removal of subsidies, can also challenge their established position. Destabilisation can also be stimulated by changes in existing regulations and standards that (indirectly) favour incumbent

110. Bugge, et al., 'Governing system innovation;' Kern, 'Using the multi-level perspective;' Kivimaa and Kern, 'Destruction or niche support?' Raven, et al., 'Niche construction and empower ment;' Smith and Raven, 'What is protective space?' Ghosh and Schot, 'Towards a novel regime change;' Turnheim and Geels, 'The destabilisation of existing regimes;' Naber, et al., 'Scaling up sustainable energy innovations.'

111. Kivimaa and Kern, 'Destruction or niche support?' Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame;' Turnheim and Geels, 'The destabilisation of existing regimes.'

technologies.[112] With regard to informal institutions, changes in belief systems, societal norms, and culture can result in the de-legitimation of established technologies and industries.[113] While such changes can be difficult to trace empirically, the articulation of new visions about the future and raised public awareness of the need for change,[114] changed user preferences (and buying patterns),[115] and active lobbying or public contestation against the regime[116] can be more visible signs that the regime is under pressure to change. Finally, changes in cognitive rules, including problem agendas,[117] industry identity and business models,[118] and organisational practises[119] are necessary for a transition to be realised.

At the niche level, key institutional processes related to shielding include framing the new technology to make it fit the values of key stakeholders or society in general,[120] lobbying to get political support or temporal exemptions from existing rules and standards,[121] or identifying technology-specific market stimulation.[122] With regard to nurturing, the articulation of clear and robust (i.e., shared) expectations and visions is one of the key niche development processes.[123] In addition, the literature discusses institutional aspects of learning, such as questioning established assumptions about the technology,[124] standardisation,[125] and

112. Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame;' Kern, 'Using the multi-level perspective.'

113. Kern, 'Using the multi-level perspective;' Turnheim and Geels, 'The destabilisation of existing regimes.'

114. Kern, 'Using the multi-level perspective.'

115. Turnheim and Geels, 'The destabilisation of existing regimes.'

116. Ibid.

117. Kern, 'Using the multi-level perspective.'

118. Ibid.

119. Lazarevic, Kautto, and Antikainen, 'Finland's wood-frame;' Turnheim and Geels, 'The destabilisation of existing regimes.'

120. Smith and Raven, 'What is protective space?'

121. Ibid.; Verhees, et al., 'The development of solar PV.'

122. Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment;' Smith and Raven, 'What is protective space?'

123. Naber, et al., 'Scaling up sustainable energy innovations;' Verhees, et al., 'The development of solar PV.'

124. Verhees, et al., 'The development of solar PV;' Kern, 'Using the multi-level perspective.'

125. Verhees, et al., 'The development of solar PV;' Bugge, et al., 'Governing system innovation.'

overcoming different organisational practises.[126] Finally, regarding empowering, two strategies are highlighted: fit-and-conform and stretch-and-transform. The former includes the development of public policies aiming at price-performance improvements,[127] institutional reforms to transform the regime,[128] articulating flexible narratives,[129] and framing shielding and nurturing measures as temporary.[130] The latter comprises more far-going institutional changes such as the design of policy to incentivise actors to engage in niche solutions,[131] lobbying for institutional reform,[132] or the creation of new institutions.[133]

If we synthesise these insights from the MLP and SNM frameworks, we can identify four main transformative processes related to changes in institutions, which are relevant for both the niche and the regime level. These are the articulation of visions and expectations; framing and redefinition of values, norms, and practises; mobilisation and de-mobilisation of (political) support); and introduction of new regulations (see TABLE 4). To account for directionality, each of these processes should be analysed from the point of view of whether they strengthen established institutions or work towards the establishment of new or fundamentally reconfigured institutional frameworks.

TABLE 4. Transformative Processes Related to Institutions

Sub-dimensions	Niche-level processes	Regime-level processes
Articulation of visions and expectations	Articulation of clear, specific, and shared visions and expectations between members.	Articulation of new visions and expectations about the future.

126. Bugge, et al., 'Governing system innovation.'
127. Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment.'
128. Smith and Raven, 'What is protective space?'
129. Raven, et al., 'Niche construction and empowerment.'
130. Verhees, et al., 'The development of solar PV.'
131. Smith and Raven, 'What is protective space?'
132. Ibid.; Verhees, et al., 'The development of solar PV;' Raven, et al., 'Niche construction and empowerment.'
133. Raven, et al., 'Niche construction and empowerment.'

Sub-dimensions	Niche-level processes	Regime-level processes
Framing and redefinition of values, norms, and practises	Questioning assumptions about problem definitions, function, or desirability of the technology. Articulating narratives and enacting new discourses to fit contemporary objectives and values of (powerful) stakeholders. Framing shielding and nurturing as temporary and promoting that innovation will be competitive under conventional criteria.	Raised public awareness of the need for change. Broad cultural changes or changes in underlying values that challenge the regime. Changes in industry mission, identity, and confidence. Changes in organisational practises.
Mobilisation and de-mobilisation of (political) support)	Lobbying to achieve explicit political support. Overcoming initial reluctance. Arguing for temporal exemptions from existing rules and standards.	Reduction or removal of subsidies, funding, and protective measures. Changes in regulations that favour established technologies or hinder new ones (e.g., building codes or siting rules). Lobbying, framing, or public contestation against the regime. Attempts to influence policy development and change.
Introduction of new regulations	Development of institutional reforms. Identification and implementation of technology-specific policy instruments.	Restructuring of markets (e.g., liberalisation or regulation). Implementation of control policies (e.g., taxes, import restrictions, emissions regulations, bans, or plans for phase-out of specific technologies).

Source: Prepared by authors based on Naber et al.; Verhees et al.; Ghosh and Schot; Kern; Raven et al.; Smith and Raven; Turnheim and Geels; Lazarevic, Kautto, and Antikainen; Bugge et al.; Kivimaa and Kern. (See Appendix A). [134]

134. Naber, et al., 'Scaling up sustainable energy innovations;' Verhees, et al., 'The development of solar PV;' Ghosh and Schot, 'Towards a novel regime change;' Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment;' Smith and Raven, 'What is protective space?' Turnheim and Geels, 'Regime destabilization;' Turnheim and Geels, 'The destabilisation of existing regimes;' Lazarevic,

Summary

To sum up, we have identified three sets of transition-related processes that can be used as a means to analyse the transformative outcomes of an innovation policy programme. These include seven functions that describe processes related to changes in socio-technical systems, four processes related to changes in actor networks, and four processes associated with changes in institutions (see FIGURE 2). We have also argued that each of these processes should be scrutinised from a directionality point of view to determine whether they contribute to strengthen the existing socio-technical configuration, the development of new configurations, or both.

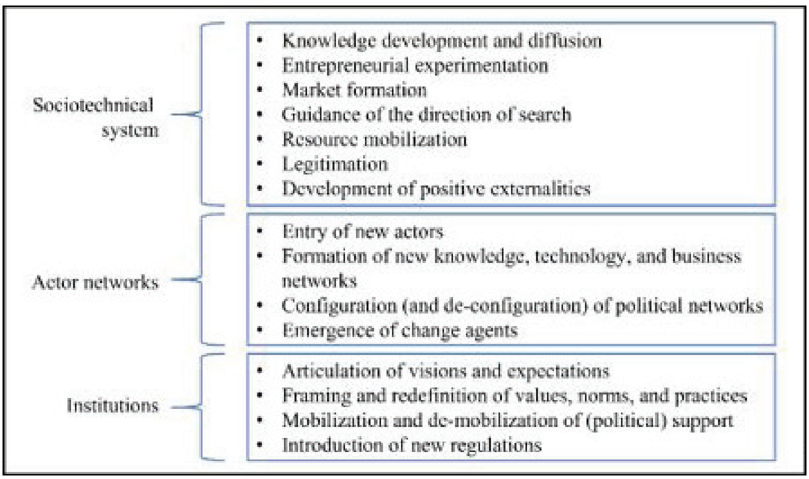

FIGURE 2. Three Sets of Transformative Processes

Source: Prepared by authors.

2.4. Concluding Discussion

The purpose of this paper was to identify a set of non-overlapping key transformative processes that capture both directionality and behavioural additionality and can be used as a framework to evaluate the outcomes of transformative

Kautto, and Antikainen, 'Finland's wood-frame;' Bugge, et al., 'Governing system innovation;' Kivimaa and Kern, 'Destruction or niche support?'

innovation policy. We drew on the literature on innovation system functions and socio-technical transitions (MLP and SNM) to achieve this purpose and took measures to avoid unnecessary overlaps between different frameworks.

The suggested evaluation framework is composed of three sets of transformative processes corresponding to the main elements of socio-technical configurations (see FIGURE 2). Regarding socio-technical systems, we argued that previously identified innovation functions (i.e., 'knowledge development and diffusion,' 'entrepreneurial experimentation,' 'market formation,' 'guidance of the direction of search,' 'resource mobilisation,' 'legitimation,' and 'development of positive externalities'), cover the most important processes both for emerging and established technologies. Still, a directionality filter needs to be added to understand which technologies benefit from the functional dynamics in a sector. Concerning actor networks and institutions, we identified four processes for each element, which are relevant for studying changes in both new and emerging configurations: 'entry of new actors,' 'formation of new knowledge, technology, and business networks,' 'configuration (and de-configuration) of political networks,' 'development of political capacity and change advocacy,' 'articulation of visions and expectations,' 'framing and redefinition of values, norms, and practises,' 'mobilisation and de-mobilisation of (political) support),' and 'introduction of new regulations.' Just as for the functions, analysts should pay special attention to whether these processes support existing configurations or result in a more radical reconfiguration of the focal sectoral socio-technical configuration.

A directionality-sensitive analysis focusing on the identified processes would pave the way for comparing emerging developments with the goals of the policy and broader societal expectations. Such comparisons should stress the pathway(s) the processes seem to be supporting and whether they seem to be driving the transition in the staked-out direction. This can be done even before it is possible to identify any real impacts in terms of a complete reconfiguration of the targeted sectoral socio-technical configuration or improvements in its sustainability performance. Policymakers could then use this information as part of their policy learning process, which could result in revised policy goals, changes in the overall policy mix, and/or redesign of the evaluated intervention.

This chapter has focused on the conceptual development of the framework. The next step is to test it on one or more empirical cases in order to identify operationalisation problems not yet considered. Likewise, testing it can indicate further conceptual and methodological developments needed. As for us, we will also consult policymakers and evaluation practitioners to get their perspectives on the practical applicability and usefulness of the framework.

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Appendix A: Niche- and Regime-level Processes Derived from the Reviewed Literature

TABLE 5. Niche-level Processes

Configuration element	Niche protection mechanism	Operationalisation/indicators or examples from empirical studies	Related function(s)*
Socio-technical system	Shielding	Dedicated (technology-/niche-specific) RD&D support (Kern; Raven et al. 2016; Smith and Raven)	• Resource mobilisation • Entrepreneurial experimentation
		Implementation of technology-specific investment subsidies, public procurement, and other market niche protection measures (Kern; Raven et al.; Smith and Raven)	• Market formation
		Exploitation of 'real' niche markets, e.g., segments willing to pay higher prices or accept lower performance or places outside the reach of existing infrastructures (Raven et al.; Smith and Raven; Verhees et al.)	• Market formation
	Nurturing	(Support to) Research, development, prototyping, piloting, and demonstration of niche innovations (e.g., RD&D funding, direct co-investment, technology acceleration projects) (Kern; Verhees et al.)	• Knowledge development and diffusion • Entrepreneurial experimentation • Resource mobilisation
		Exchange and interpretation of specific lessons and experiences between niches (at the level of the 'global' niche) (Smith and Raven)	• Knowledge development and diffusion
		Standardisation (to ensure interoperability) (Bugge et al.; Verhees et al.)	• *à Legitimation*

Configuration element	Niche protection mechanism	Operationalisation/indicators or examples from empirical studies	Related function(s)*
	Empowering	Infrastructural changes (Bugge et al.; Raven et al.)	• Resource mobilisation
		R&D and public support targeting or achieving price-performance improvements of niche innovations in terms of quality, functionality, production cost, etc. (Kern; Raven et al.; Verhees et al.)	• Resource mobilisation
Actor network	Shielding	Establishment of private technology-specific incubator units/programmes (Raven et al.; Smith and Raven)	• *à Entrepreneurial experimentation*
		Establishment of collective buying cooperatives (Raven et al.)	• *à Market formation*
		Support to help companies identify and exploit market opportunities (Kern)	• *à Market formation*
		Involvement of strong actors (that guarantee support) (Bugge et al.)	• *à Legitimation*
	Nurturing	Formation (and maintenance) of broad networks, i.e., networks consisting of actors from different domains (Naber et al.; Verhees et al.)	• *à Knowledge diffusion* • *à Guidance of the direction of search*
		Formation (and maintenance) of deep networks, i.e., networks consisting with high resource commitment from network members (Naber et al.; Verhees et al.)	• *à Resource mobilisation* • *à Guidance of the direction of search*
		Development of 'global' networks (that support exchange and interpretation of specific lessons and experiences between niches) (Smith and Raven)	• *à Knowledge development and diffusion*
		Entry of powerful actors (incl. policy) into the support network of the niche (Kern)	• *à Guidance of the direction of search*

Configuration element	Niche protection mechanism	Operationalisation/indicators or examples from empirical studies	Related function(s)*
		Business support to (new) companies (Kern)	
		Fostering wider societal engagement of, e.g., NGOs or academics (Kern)	• à *Legitimation*
	Empowering	Involvement of government bodies (to allow for upscaling) (Bugge et al.)	
		Development of political capacity to avoid protective space becoming captured by vested interests and to ensure protection stimulates the dynamic accumulation of innovative capabilities (Smith and Raven)	• à *Legitimation*
		Formation of networks of (industrial, administrative, and grassroots) advocates accumulating resources and political power (Smith and Raven)	• à *Resource mobilisation* • à *Legitimation*
		Create capabilities and attract resources that empower participation in political debates (Smith and Raven)	• Resource mobilisation
Institutions	Shielding	Re-framing the technology to fit contemporary political objectives or values of specific stakeholder groups (Smith and Raven)	• Legitimation
		Identification of technology-specific investment subsidies, public procurement, and other market niche protection measures (Kern; Raven et al.; Smith and Raven)	
		(Arguing for) Temporal exemptions from existing rules and standards (Smith and Raven; Verhees et al.)	• Legitimation

Configuration element	**Niche protection mechanism**	**Operationalisation/indicators or examples from empirical studies**	**Related function(s)***
		Enacting new media discourses linking technologies with high-tech values in society (Smith and Raven)	• *à Legitimation*
		Lobbying to achieve explicit political support (Smith and Raven)	• Legitimation
	Nurturing	Questioning assumptions about problem definitions, function, or desirability of the technology (Kern; Naber et al.; Verhees et al.)	• *à Guidance of the direction of search* • *à Legitimation*
		Standardisation (to ensure interoperability) (Bugge et al.; Verhees et al.)	• *à Legitimation*
		Overcoming initial reluctance (Bugge et al.)	• Legitimation
		Overcoming different organisational practises (Bugge et al.)	• (Legitimation)
		Articulation of clear, specific, and shared expectations and visions between members (Naber et al.; Verhees et al.)	• *à Legitimation* • *à Guidance of the direction of search*
	Empowering	R&D and public support targeting or achieving price-performance improvements of niche innovations in terms of quality, functionality, production cost, etc. (Kern; Raven et al.; Verhees et al.)	• Resource mobilisation • Knowledge development • Entrepreneurial experimentation
		Development of institutional reforms that transform incumbent regimes (Smith and Raven)	
		Articulation of narratives in flexible ways (to attract powerful actors) (Raven et al.)	• *à Legitimation* • *à Guidance of the direction of search*

Configuration element	Niche protection mechanism	Operationalisation/indicators or examples from empirical studies	Related function(s)*
		Framing shielding and nurturing as temporary and promoting that innovation will be competitive under conventional criteria (Verhees et al.)	• Legitimation
		Policies (environmental regulations, fiscal measures, quotas, etc.) that incentivise (regime) actors to invest in niche solutions (Smith and Raven)	• Guidance of the direction of search
		Arguing for and achieving public or private institutional reform (e.g., changing regulatory frameworks) or creating new (technology-specific) institutions (Kern; Raven et al.; Smith and Raven; Verhees et al.)	

Source: Prepared by authors based on Kern; Raven et al.; Smith and Raven; Verhees et al.; Bugge et al.; Naber et al..[135]

(*) → means that the process in question might eventually contribute to the function in question but has no immediate influence on it.

135. Kern, 'Using the multi-level perspective;' Raven, et al., 'Niche construction and empowerment;' Smith and Raven, 'What is protective space?' Verhees, et al., 'The development of solar PV;' Bugge, et al., 'Governing system innovation;' Naber, et al., 'Scaling up sustainable energy innovations.'

TABLE 6. Regime Destabilisation Processes

Regime-level processes			
Configuration element	**Type of change**	**Operationalisation/indicators or examples from empirical study**	**Related function(s)***
Sociotechnical system	Changes in technical systems	Changes in existing production plants and infrastructure (Kern)	• Resource mobilisation
		Investments in new complementary infrastructure (Ghosh and Schot)	• Resource mobilisation
	Reduced resource flows to established technologies	Declining markets (export and domestic) (Turnheim and Geels)	• Market formation
		Shifts in investment patterns (Turnheim and Geels)	• Guidance of the direction of search • Market formation
	Improvements of established technologies	(Incremental) product and process innovation (Turnheim and Geels)	• *Innovation output*
		Efficiency improvements and modernisation of existing technologies and plants (Turnheim and Geels)	• *Innovation output*
		Public investment support or loans for efficiency improvements (Kern)	• Resource mobilisation
	Strategic reorientation incumbent actors wrt technology	Build-up of new technical knowledge, competences and operations (Turnheim and Geels)	• Knowledge development • Resource mobilisation
		Replacement of existing skills and knowledge (Kivimaa and Kern)	• Knowledge development) • Resource mobilisation
		Experimentation with new technologies (Kivimaa et al.; Lazarevic et al.)	• Entrepreneurial experimentation

Regime-level processes			
Configuration element	**Type of change**	**Operationalisation/indicators or examples from empirical study**	**Related function(s)***
		Diversification to new product markets (Turnheim and Geels)	• Guidance of the direction of search
Actor networks	Entry of new actors into mainstream market	Entry of niche actors (Ghosh and Schot; Kern; Turnheim and Geels)	
		Entry of actors from other industries and countries (Turnheim and Geels)	
		Replacement of incumbents by new actors (Kivimaa and Kern)	
	Development of new business networks	New partnerships to enable business model innovation (Turnheim and Geels)	
		Emergence of new customer groups/segments (Ghosh and Schot)	• Market formation
	Reconfiguration of policy networks	Balancing the power of incumbents, e.g., by inviting niche actors to advisory councils etc. (Kivimaa and Kern; Lazarevic et al.)	
		Breaking-up of existing policy networks (Kivimaa and Kern; Lazarevic et al.)	
	Emergence of change advocacy (within the regime)	Development of new fora/ organisations to support policy change (Kivimaa and Kern; Lazarevic et al.)	• *à Legitimation*
		Emergence/creation of change advocates in established (policy) organisations (Lazarevic et al.)	• *à Legitimation*
Institutions	Introduction of new regulations that weaken the established socio-technical configuration	Restructuring of markets (e.g., liberalisation or regulation) (Ghosh and Schot; Kivimaa and Kern; Lazarevic et al.; Turnheim and Geels)	• *à Market formation*

Regime-level processes			
Configuration element	**Type of change**	**Operationalisation/indicators or examples from empirical study**	**Related function(s)***
		Implementation of control policies (e.g., taxes, import restrictions, emissions regulations, bans, or plans for phase-out of specific technologies) (Ghosh and Schot; Kivimaa and Kern; Lazarevic et al.; Turnheim and Geels)	• *à Market formation*
	Withdrawal of political support to established technologies and actors	Removal of subsidies, cuts in R&D funding or changes in tax laws (Kivimaa and Kern; Lazarevic et al.; Turnheim and Geels).	• *à Market formation* • *à Resource mobilisation*
		Reduction or removal of protective measures (Turnheim and Geels)	• *à Market formation*
	Changes in existing regulations and standards	Changes in regulations that favour established technologies or hinder new ones (e.g., building codes or siting rules) (Kern; Lazarevic et al.)	• *à Market formation*
		Attempts to influence policy development and change (Kern)	• *à Legitimation*
		Development of new (de facto) standards and technology specifications (Ghosh and Schot; Kern)	• Legitimation
	Changes in belief systems, societal norms, and culture	Raised public awareness of the need for change (Kern; Turnheim and Geels)	• *à Legitimation*
		Changes in user preferences (and buying patterns) (Ghosh and Schot; Turnheim and Geels)	• Market formation
		Lobbying, framing or public contestation against the regime (Turnheim and Geels)	• Legitimation

Regime-level processes			
Configuration element	**Type of change**	**Operationalisation/indicators or examples from empirical study**	**Related function(s)***
		Broad cultural changes or changes in underlying values that challenge the regime (Ghosh and Schot; Turnheim and Geels)	• *à Legitimation*
	Changes in cognitive rules	Articulation of new visions and expectations about the future (Ghosh and Schot; Kern)	• *à Legitimation*
		Changes in problem agendas (Kern)	• Guidance of the direction of search
		Changes in perceptions about stakeholders and relevant performance criteria (Ghosh and Schot)	• Guidance of the direction of search • Market formation
		Changes in industry mission, identity and confidence (Turnheim and Geels)	• *à Guidance of the direction of search*
		Changes in organisational practises (Lazarevic et al.; Turnheim and Geels)	• *à Guidance of the direction of search*

Source: Prepared by authors based on Kern; Ghosh and Schot; Turnheim and Geels; Kivimaa and Kern; Kivimaa, Kangas, and Lazarevic; Lazarevic, Kautto, and Antikainen.

(*) ⟶ means that the process in question might eventually contribute to the function in question but has no immediate influence on it.

3. Transformative Metrics for Responsible and Transformative Innovation: Putting People at the Centre. Exploring Windows for Change in a State Initiative on Gender and Innovation Monitoring within the European Merge of Governance Frames

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3.1. Introduction: Why Are Metrics so Relevant in Responsibility Promotion?

Metrics and indicators have a curious influence on our daily lives. Researchers, especially in some countries, are impelled to look for the impact factor of a publication according to current career structures. Public authorities and scientific and business institutions are trying to adjust the metrics to what is demanded by Brussels or other international authorities to access funds or to position themselves in some prestigious ranking. They are not unique motivators for action although they are sometimes set as incentives. If we talk about the nature of governance in the times we are living, metrics are part of the landscape, sometimes deemed as the trees that do not let us see the forest.

Metrics are also usually positioned as sources of transparency and equanimity, i.e., bearers of the objectivity that lack other types of data collected in a less systematic, periodic, or comparable way. Nonetheless, this has not always been the case. This is because they are part of what we know as 'new models of governance' grounded in European public policies at the end of the 90s through the implementation of the open method of coordination. This method was applied in scientific and innovation policies as well as in areas of explicit normative scope such as gender equality policies, generating a great profusion of indicators in both areas. Moreover, this governance framework fitted into previous frameworks, especially within multilevel governance, which years before had defined the relevance of having European or State institutions. Yet such frameworks concerned about those institutions closer to citizens, for instance, the regions or local governments (vertical level) and groups outside the political or business sphere and other groups of stakeholders or civic actors (horizontal level).[2]

It seems, however, that these forms of governance have not resolved and/or have fostered forms of inequality and distancing from citizenship, which new currents of governance focused on responsibility intend to redirect. Attention

2. Ian Bache, Ian Bartle, and Matthew Flinders, 'Multi-level governance,' in *Handbook on theories of governance*, eds. Christopher Ansell and Jacob Torfing (Cheltenham: Edward Elgar Publishing, 2016), 486–98.

to the Responsible Research and Innovation (RRI) literature points out three fundamental axes mostly: the orientation of science towards the major social challenges, the focus on co-creation and increase of citizen participation, and the reduction of the unexpected consequences of innovation.[3] [4] These respond to challenges such as climate change or social aspects such as the possible increase of political polarisation and power imbalances derived from the use of tech-based social networks.

In this scenario of juxtaposed governance frames, metrics play not only a relevant but a foundational role in the new policies of responsibility. For example, metrics were crucial in making corporate social responsibility (CSR) a way to encourage (without imposing) standards that facilitate knowing what 'responsibility' implies, allowing to compare companies and observe their progress. This, in turn, allowed visualising corporate responsibility statements that are often highly cosmetic. Building metrics was also one of the first initiatives for gender equality policies adopted following both the open method of coordination and gender mainstreaming governance frames that tend to soft measures promoted through benchmarking, avoiding other such legislation.[5] [6] Lastly, metrics have been used as an effective way to foster awareness about inequality showing its existence in our societies numerically. In summation, metrics are key to current normative or value-driven policies as well as to science and innovation policies considering the governance frames in place.

Nonetheless, metrics have limitations and unexpected effects. For this reason, the analysis of metrics yields interesting results on the visions, values, and

3. Richard Owen, et al., 'A framework for responsible innovation,' in *Responsible innovation: managing the responsible emergence of science and innovation in society*, eds Richard Owen, Jhon Bessant, and Maggy Heintz (Chichester: John Wiley & Sons, 2013), 27–50.

4. Richard Owen, Phil Macnaghten, and Jack Stilgoe, 'Responsible Research and Innovation: From Science in Society to Science for Society, with Society,' *Science and Public Policy* 39, no. 6 (December 2012): 751–60. https://doi.org/10.1093/scipol/scs093

5. Susana Borrás and Kerstin Jacobsson, 'The open method of co-ordination and new governance patterns in the EU,' *Journal of European Public Policy* 11, no. 2 (May 2004): 185–208. https://doi.org/10.1080/1350176042000194395

6. Isabel Bruno, Sophie Jacquot, and Lou Mandin, 'Europeanization through its instrumentation: Benchmarking, mainstreaming and the open method of co-ordination... toolbox or Pandora's box?' *Journal of European Public Policy* 13, no. 4 (August 2006): 519–36. https://doi.org/10.1080/13501760600693895 priorities that underlie policies. In this sense, my interest in this chapter is to address a specific dimension of policies: the construction of metrics in a responsible manner. In doing so, this work employs a responsible metrics approach to explore a case in development, namely: a pioneering initiative of innovation indicators with a gender perspective in Spain. It is an official experience that could lead to opening doors to change in innovation frames and monitoring.

3.2. The Responsible Research and Innovation (rri) Approach

Scientific and technological development generates benefits and risks, certainties, and uncertainties that must be managed. Usually addressed by risk management, some RRI perspectives intend to transcend such 'control' approaches arguing that these latter are limited because they are based on present evidence, and do not necessarily promote forward-looking reflection.[7] These viewpoints are relevant for the times we are living characterised by an increasing emphasis on profits linked to our capacity to impact and even damage future generations perhaps irreversibly.[8]

RRI perspectives anchored in specific ethical obligations, e.g., the EU principles of equality,[9] help us to study the 'right impacts' and 'socially desirable' contributions of science and innovation. In the European framework, RRI attempts to bring science and innovation closer to society via traditional and non-academic and non-industrial actors, using concepts such as co-creation, open science, and public engagement to improve the accessibility of science and encouraging non-scientific groups to participate in its development. Similarly, close visions like 'transformative innovation' insist on new approaches in the governance of sociotechnical transitions emphasising systemic endeavours.

7. Owen, et al., 'Framework for responsible innovation;' Owen, Macnaghten, and Stilgoe, 'Responsible Research and Innovation.'

8. Hans Jonas, *El principio de responsabilidad: Ensayo de una ética para la civilización tecnológica* (Barcelona: Herder, 1995).

9. Rene Von Schomberg, 'A vision of responsible research and innovation,' in *Responsible innovation: managing the responsible emergence of science and innovation in society*, eds. Richard Owen, Jhon Bessant, and Maggy Heintz (Chichester: John Wiley & Sons, 2013), 51–74.

Sustainability, for example, requires changing the regime and necessarily going beyond the initiatives of the organisations merely.[10]

In the current European framework, two RRI frames co-exist and interrelate. On one hand, a dimensions approach comprising aspects such as reflexivity, anticipation, responsiveness, inclusiveness, and openness, as guiding principles for all actors and activities of the innovation system.[11] On the other hand, the approach launched by the European Commission defines specific areas of intervention: governance, public engagement, ethics, science education, open access, and gender equality.[12] Even though the European Commission does not enact a consensual definition of what RRI entails or not, based on the cited key areas, they promote diverse initiatives to build RRI indicators. Some of the main ones are the RRI Expert Group, which finished its work in 2015, and the MORRI project, which concluded in 2018, conceived to support the Directorate-General for Research and Innovation (DG-RTD). Further work is needed as the first development of metrics was led by experts. Wider public consultation and further involvement of stakeholders affected by specific innovations or future, for instance, women and other diversity-oriented associations, citizen science groups, or NGOs.

The foregoing are recent attempts, thus their impact on governance and change-promotion of more responsibility in science and innovation systems is unknown. Yet, this might change thanks to more work on RRI metrics, e.g., the SUPER_MORRI project (ending in 2023) and other projects supported by European funds. Whatsoever, metrics construction ought to be aligned with some of the needs that responsible and transformative metrics proposals introduce in

10. Joan Schot and W. Edward Steinmueller, 'Three frames for innovation policy: R&D, systems of innovation and transformative change,' *Research Policy* 47, no. 9 (August 2018): 1554–67. https://doi.org/10.1016/j.respol.2018.08.011; Adrian Smith, Andy Stirling, and Frans Berkhout, 'The governance of sustainable socio-technical transitions,' *Research policy* 34, no. 10 (December 2005): 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

11. Jack Stilgoe, Richard Owen, and Phil Macnaghten, 'Developing a framework for responsible innovation,' *Research Policy* 42, no. 9 (November 2013): 1568–80. https://doi.org/10.1016/j.respol.2013.05.008.

12. European Commission. *Responsible Research and Innovation: Europe's Ability to Respond to Societal Challenges* (Brussels: European Union, 2014).

the diverse phases of development, from their conception to their final use 'in the wild,' that is, in the real world.[13]

3.3. Responsible and Transformative Metrics

Responsible metrics is not a research discipline but a concept that envisages the responsible shift in research and innovation policies in the realm of measurement and monitoring. The Leiden Manifesto[14] and The DORA Declaration[15]are at the origins of this new wave in an old debate. The following lines summarise a literature review gathering references from expert recommendations (eleven reports and papers) as well as from debates held in the SUPER_MORRI project.

A crucial concern is how data is increasingly used in science governance, substituting judgement. RRI has emerged thinking about unintended, unexpected, or damaging consequences of science and technology so, following this path, metrics literature reacts to bad consequences in the use of the indicators. Two examples of this are: the power given to the firms that have launched metrics (e.g., the owners of Web of Science and Scopus) and the use of metrics conceived for journals in individual researchers' career evaluations such as the quartiles of the journals. Its use negatively impacts researchers that work in fields or countries that have no Q1 journals, discouraging research in entire areas of knowledge.

Still, most of the literature pinpoints that the main problem is not indicators, but the policymaking and governance processes that distort its purposes and final uses which are frequently different from their initial conception. It has been remarked that indicators, instead of being used for informed decision-making, have been deployed to reduce the issues taken into consideration in the S&T policies.[16] The essential problem can be summarised as follows: 'These

13. Michel Callon, Pierre Lascoumes, and Yannick Barthe, *Acting in an uncertain world: An essay on technical democracy*, trans. Graham Burchell (Cambridge: The MIT Press, 2011); Ismael Rafols, 'S&T indicators in the wild: Contextualization and participation for responsible metrics,' *Research Evaluation* 28, no. 1 (January 2019): 7–22. https://doi.org/10.1093/reseval/rvy030

14. Diana Hicks, et al., 'Bibliometrics: The Leiden Manifesto for research metrics,' *Nature* 520 (April 2015): 429–31. https://doi.org/10.1038/520429a

15. 'The Declaration on Research Assessment,' American Society for Cell Biology, accessed May 18, 2022. https://sfdora.org/about-dora/

16. Barré, 2018.

artefacts [metrics] have no meaning by themselves, but receive their meaning from attributions in institutional practises.'[17] These practises have consequences in the outputs, in society, and directly on researchers and innovators. In the Metric Tide policy report, which is a milestone of the responsible metrics approach in the UK, the author claimed that 'metrics hold real power: they are constitutive of values, identities, and livelihoods. How to exercise that power to positive ends is the focus of [that] report.'[18] In a responsible exercise of power, bad consequences are at stake, but the core issue is the democratisation and public engagement in policies. This encompasses incorporating plural visions and acknowledging that current governance frames bring their values with their practises and instruments, specifically with monitoring.

In this train of thought, there are proposals to pursue responsible metrics that are quite practical and explicit in including more information about the indicators, their conception frames, possible issues informed by previous experiences in indicator use, and intrinsic limitations such as robustness within specific samples. A key recommendation is making explicit proxies and translations used in building indicators. The steps missing behind need an explanation that should accompany metrics.[19] For instance, when it comes to measuring 'research quality' diverse proxies are used such as the quality of the journals. Yet, for other actors, the idea of 'research quality' is more linked to the final impact on society. In this vein, we should be cautious with translations of social aspects to numbers.[20] Also, there are strong demands for contextualisation considering the diverse contexts where data come from and the inclusion of the ultimate justification and purposes of monitoring; it is not the same justification of

17. Loet Leydesdorff, Paul Wouters, and Lutz Bornmann, 'Professional and citizen bibliometrics: Complementarities and ambivalences in the development and use of indicators—a state-of-the-art report,' *Scientometrics* 109 (December 2016): 2129. https://doi.org/10.1007/s11192-016-2150-8

18. James Wilsdon, *The metric tide: Independent review of the role of metrics in research assessment and management* (London: SAGE Publications, 2015), 3.

19. Jochen Gläser and Grit Laudel, 'The social construction of bibliometric evaluations,' in *The Changing Governance of the Sciences,* eds. Richard Whitley and Jochen Gläser (Dordrecht: Springer, 2007), 101–23.

20. Andrea Saltelli and Monica Di Fiore, 'From sociology of quantification to ethics of quantification,' *Humanities and Social Sciences Communications* 7, no. 1 (August 2020): 69. https://doi.org/10.1057/s41599-020-00557-0 efficiency rather than of a research mission such as curiosity or social well-being.[21] Epistemologically, it is not possible to separate knowledge formation from decision-making, but experts usually do so when indicators, or other research outputs, are translated from 'laboratories' to macro cosmos in different stages.[22] In the light of the presented above, responsibility for metrics goes beyond experts that work proposing them. There needs to be a comprehensive approach to governance processes of science and innovation and the actors that take part in these processes.

Framed in the previous viewpoints, the following case shows an initiative led by the Spanish government that is close, in some respects, to a responsible metrics approach. I will discuss some reflections from practise and raise new questions. Overall, I will argue that the main connection between the initiative and a responsible shift in metrics is the participatory approach, including social actors as well as the usual innovation system actors to develop the monitoring initiative. Also, I will bring up its ultimate justification since it is oriented to societal impact, namely, knowing more about women's situation and the gender perspective in innovation.

3.4. Innovation Monitoring with A Gender Perspective: A Spanish Pioneer Initiative

In September 2019, The Women and Science Observatory, which is attached to the Ministry of Science and Innovation, launched an Innovation Commission. Its purpose was to fill the gap regarding innovation where little gender data is available, despite the efforts of monitoring initiatives in science with a gender perspective like the European Commission´s report 'She figures.' To fill the gap, the first task was to produce a report with an exploration of data needed and available. The global objective was to further develop periodic data series, thus establishing a monitoring initiative on gender and innovation similar to the existing one in science since 2007.[23] The Commission included different types of actors such as

21. Rafols, 'S&T indicators.'

22. Ibid.; Callon, Lascoumes, and Barthe, *An uncertain world*.

23. Unidad de Mujeres y Ciencia, *Académicas en cifras 2007* (Madrid: Ministerio de Educación y Ciencia, 2007).

two associations related to innovation and technology transfer, five equality and women entrepreneur associations, a university association, two university institutes, and twelve public bodies from different ministries. Examples of these latter were: the National Institute of Statistics, the National Telecommunications Observatory, the Centre for Technological and Industrial Development (CDTI), which manages the main innovation funds in the country, the Spanish Foundation for Science and Technology (FECYT), and the Directorate General for Labour.

The group was consulted to define relevant aspects to be monitored, for instance, gender and innovation in small and medium enterprises (SMEs), gendered innovative entrepreneurship, employment rates and their relationship with public funds for innovation and gender, social and public innovation, and innovation in feminised and masculinised sectors, among others. Research and data collection was allotted to scientists. Diverse meetings were held to present preliminary results and to redefine these aspects. The output was the report published by *Observatorio Mujeres, Ciencia e Innovación*[24] with results of interest for a more responsible innovation system:

- The monitoring effort showed profound gender gaps in indicators related to entrepreneurship, interactions and knowledge transfer, access to public resources, and women's participation in decision making. To illustrate this, indicators showed the low rate of women present in firms funded with large amounts of public resources for innovation, the highest female participation being 23% from 2014 to 2018. An exception was support personnel: more than 70% of technical transfer support staff were women in 2018. The gender gap is much higher than in science where most of the institutions are public bodies.
- Findings pointed out that women are not participating in technological innovation like men. Likewise, they evidenced that data about non-technological innovation is not available as though other types of innovation were not relevant. Public innovation or data coming from

24. Observatorio Mujeres, Ciencia e Innovación, *Mujeres e Innovación 2020* (Madrid: Ministerio de Ciencia e Innovación de España, 2020).

other institutions than firms was not collected either. Other institutional environments count largely more on women than the business sector, so it was not possible to trace women's contribution to innovation since current data just focused on technological firms.

- The report worked mostly with primary data collected specifically for the initiative because there is no existing data on the human factor in the innovation surveys, such as the surveys launched by OECD, EUROSTAT, or the Spanish National Institute of Statistics.

Both the bad results in terms of gender balance and the scarcity of information led the Innovation Commission to start a process to include gendered data in the Spanish innovation survey that allow further gender monitoring. Rates of men and women in diverse organisational positions, working conditions, and non-technological innovation registers were some of the ideas in debate in the commission. From the viewpoint of the authors of the report, including myself, it is crucial to pay attention to the relying frames of innovation and the purposes of monitoring considering that the current focus leaves out possible women's contributions.

3.5. Discussion and Further Research

Based on the discussion above regarding responsible metrics, there exists a need for defining the role of metrics in the general governance frame of the policymaking bearing in mind why, how, and who participates in the phases of conception, data collection, use, and interpretation of the information. Defining a governance life cycle of metrics, it is needed to talk about responsible metrics, and also to specify the policy process that these will produce.

The case addressed here illustrates a first attempt in innovation metrics with a gender perspective, where actors that go beyond the Triple Helix, i.e., public administration main bodies, universities, and firms,[25] have participated. Concerned societal actors such as women associations, had participated also

25. Henry Etzkowitz and Loet Leydesdorff, 'The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university–industry–government relations,' *Research policy* 29, no. 2 (February 2000): 109–23. https://doi.org/10.1016/S0048-7333(99)00055-4 in defining relevant aspects to be measured. The justification for monitoring was to observe the gendered side of innovation, namely, a societal impact. The result of this experience is a very different picture from the usual innovation monitoring, where persons are not present, but firms' environment or public and private investments are.

Observatorio Mujeres, Ciencia e Innovación continues working on possible gendered questions to be included in the Spanish innovation survey. Their objective will be to palliate the lack of information. Nevertheless, the next steps are unknown so many questions arise about how to open windows for change in innovation monitoring and how new metrics are finally embedded in the governance of innovation policy in Spain.

To discuss the case, it is relevant to tackle the creation of a space to reflect with increased participation, i.e., a Quadruple Helix, revealing how the frames associated with innovation monitoring are not neutral. In this sense, the striking results can have a deeper impact beyond gender, promoting a profound reflection on how innovation is conceived in the monitoring frameworks. The case presented shows that, in its monitoring at the international, European, and national levels, the innovation concept is reduced to technology produced in the market. This limits responsible approaches to innovation both in Europe and other parts of the world where other types of innovation produced by other actors, such as social or public innovation, can be very relevant.[26] Also, the case shows that public engagement is needed to produce monitoring frames. Including some different actors with a specific social goal changes completely the frame, demanding crucial aspects not previously included: innovators' traits, capabilities, working conditions, social environment, or other data related to the human factor. The absence of human factor in the official innovation monitoring leads to thinking that the underlying vision about innovators and entrepreneurs is the 'Schumpeterian' one (i.e., deriving from Schumpeter's vi-

26. Vincent Blok and Pieter Lemmens, 'The emerging concept of responsible innovation. Three reasons why it is questionable and calls for a radical transformation of the concept of innovation,' in *Responsible Innovation 2,* eds. Bert-Jaap Koops, et al. (Cham: Springer, 2015), 19–35; Mario Pansera and Richard Owen, 'Innovation for de-growth: A case study of counter-hegemonic practices from Kerala, India,' *Journal of Cleaner Production* 197, no. 2 (October 2018): 1872–83. https://doi.org/10.1016/j.jclepro.2016.06.197

sion): they are 'naturally' forged, not depending on socioeconomic or cultural conditions, so the information about them is not relevant.[27] Gender results and the big gap detected show that it is not the case and if gender matters, other socioeconomic aspects related to the human factor do too.

There is increasing evidence about the aspects above in entrepreneurship and inventors research pinpointing the need for high-level connections and funds to succeed that come mostly from family status.[28] We are not just hiding women and other actors' possible innovations. If we do not track where possible innovators are, i.e., the people, what we are doing is blindly deciding where innovation is, firms in this case. Transcending the innovative Schumpeterian vision, we might look at innovators as conditioned by their environment and their socio-cultural traits. Therefore, these individuals undertake an innovation in different ways, considering that some groups face inequality in their innovative activities as gender research on innovation has shown it.[29] All in all, a better understanding of who innovates and in which contexts could be very relevant to promoting better innovation policies in our view.

Still, the foregoing does not just relate to the frames but also to the purposes of innovation policies themselves, and therefore, to the purposes of innovation monitoring. Current innovation monitoring has been useful to observe country efforts to support technological development in firms. Other purposes that do not rely upon linear assumptions of the well-distributed benefits of technology for society will appear if we ask for different actors than Triple Helix, as we have seen in this case analysed here. RRI policy started as a top-down process that remains mostly at the European or national level. Still, the innovation policy

27. Observatorio Mujeres, Ciencia e Innovación, *Mujeres e Innovación 2020*.

28. Candida Brush, et al., 'A gendered look at entrepreneurship ecosystems,' *Small Business Economics*, 53 (August 2019): 393–408. https://doi.org/10.1007/s11187-018-9992-9

29. Gry Alsos, Elisabet Ljunggren, and Ulla Hytti, 'Gender and innovation: State of the art and a research agenda,' *International Journal of gender and Entrepreneurship* 5, no. 3 (October 2013): 236–56. http://dx.doi.org/10.1108/IJGE-06-2013-0049; Lene Foss, Kristin Woll, and Mikko Moilanen, 'Creativity and implementations of new ideas: Do organisational structure, work environment and gender matter?' *International Journal of Gender and Entrepreneurship* 5, no. 3 (September 2013): 298–322. http://dx.doi.org/10.1108/IJGE-09-2012-0049; Barry Bozeman and Monica Gaughan, 'How do men and women differ in research collaborations? An analysis of the collaborative motives and strategies of academic researchers,' *Research Policy*, 40, no. 10 (December 2011): 1393–1402. https://doi.org/10.1016/j.respol.2011.07.002

envisages a multi-level approach that is already merged with the open method of coordination.

In this vein, accountability processes are produced within communities with actors that acknowledge each other.[30] This entails that such processes take place in specific territorial spaces like regions that are highly conditioned from other governance instruments coming from a top-down approach such as smart specialisation strategies; this is an influential instrument to receive European funds in the regions requiring its specific innovation indicators. Consequently, it introduces another question about monitoring purposes: 'For the sake of whom are working indicators at different levels?' If we ask specifically about responsible innovation monitoring, we should consider that transparency in fund distribution is not enough as a purpose, even if it is a very relevant one for public administrations.

Previous work has shown that co-creation initiatives in RRI with diverse stakeholders lead to different indicators from those developed at the European level[31] as well as those gender equality-oriented, suggesting both the need for the country to adapt to the measurements and the diverse actors' needs of different types of indicators. Diverse actors can have different responsibilities to promote a specific aspect and it can suppose diverse monitoring for each actor as planned, for instance, in the open science policy.[32] Likewise, the corporate social responsibility frame exists- as well as their monitoring initiatives- and its networks co-habit with innovative ones, especially in local or regional spheres. Yet, the use of complex or composed indicators could not be useful at the mezzo or micro-level (universities, groups, or projects), this sort of indicators

30. Rune Dahl Fitjar, Paul Benneworth, and Bjørn Terje Asheim, 'Towards regional responsible research and innovation? Integrating RRI and RIS3 in European innovation policy,' *Science and Public Policy* 46, no. 5 (October 2019): 772–83. https://doi.org/10.1093/scipol/scz029

31. Paula Otero-Hermida and Mónica García-Melón, 'Gender Equality Indicators for Research and Innovation from a Responsible Perspective: The Case of Spain,' *Sustainability* 10, no. 9 (August 2018): 2980. https://doi.org/10.3390/su10092980. ; Mónica García-Melón, et al., 'Indicators for monitoring responsible research and innovation in Spain; the case of Science Education,' paper presented at *25th International Conference on Multiple Criteria Decision Making, Istanbul, June 2019*. Digital.CSIC: http://hdl.handle.net/10261/212898

32. European Commission. *Progress on Open Science: towards a shared Research Knowledge System* (Publications Office of the European Union: Brussels, 2020).

being more useful at the macro level.[33] This is for avoiding misunderstandings, ensuring robustness, and favouring that non-expert actors might interpret the results.

Further research should shed light on the limits and potential of responsible metrics approaches within the previous merge of governance frames that conditions their life cycle and the policy-making process set to produce metrics and frames. Responsibility policies that have populated first the business world (CSR) and now science and innovation (RRI) have been juxtaposed in previous governance models in a way that may limit their principles, leading to contradictions. Specifically, new responsibility frames have adapted to soft-law initiatives that were promoted at the time by the open method of coordination, which proposes a framework and indicators but does not promote regulation. This latter often is understood not so much as a public good fruit of public debate but as an imposition to organisations and states that are difficult to apply in a highly globalised context.

This has been delicate in contexts such as the Green Deal where, for example, the prohibition of single-use plastics has been a long debate. Also, it has been contested via equality policies where new governance approaches related to the open method of coordination, i.e., gender mainstreaming, included limited perspectives that can hamper women's advance.[34] Equally, the multi-level frame has been criticised for generating policy networks that include more actors but not the parliamentary legitimate ones, becoming a path for building technical control over democracy.[35]

Paying attention to those aspects can be fundamental to promoting processes that count on diverse actors in plural and legitimate ways. Considering the case presented and the literature reviewed here, policy working groups

33. Ludo Waltman, 'Responsible metrics: One size doesn't fit all,' *In STI 2018 Conference Proceedings, Leiden, the Netherlands, 526–31, September 12–14, 2018*. Leiden: Centre for Science and Technology Studies.

34. Judith Squires, *The new politics of gender equality* (Basingstoke: Palgrave Macmillan, 2007).

35. Paul Stephenson, 'Twenty years of multi-level governance: "Where does it come from? What is it? Where is it going?"' *Journal of European Public Policy* 20, no. 6 (May 2013): 817–37. https://doi.org/10.1080/13501763.2013.781818; Jacqui True, and Michael Mintrom, 'Transnational networks and policy diffusion: The case of gender mainstreaming,' *International Studies Quarterly* 45, no. 1 (March 2001): 27–57. http://dx.doi.org/10.1111/0020-8833.00181 including experts, industry, and administration are not enough for bringing perspectives in the 'responsible shift' that is demanded to the innovation policies. New responsible policies may need co-creation for the governance processes and instruments such as metrics, but this will occur within the previous governance settings, which implies their limitations beyond metrics focus. To explore these aspects, we have found useful participatory decision-making research techniques in previous RRI metrics developments.[36] By the same token, probably we need specific approaches to the policy processes derived from co-creation. Collaborative and inclusive governance research frames count years of experience in observing empirically new governance settings that establish cross-boundary relations among diverse actors in different sectors.[37]

We are following this path to continue researching about Spanish gender and innovation case in which social engagement has occurred seeking to contribute to key questions about policy processes towards transformative monitoring, namely: Where are the windows for change in innovation governance and monitoring based on more responsibility? How are they working? This approach could also fit the exploration of other windows, further research and discussion will shed light. Finally, considering the gender results observed, focusing on the people, i.e., those persons that innovate and innovation beneficiaries, and their contexts, can be a good chance to start transformative and responsible metrics initiatives.

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4. Tipping Points In Transitions Of Socio-Economic Systems

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4.1. Introduction

There is a common understanding among academics of the need for a large-scale disruptive and rapid change to limit global warming to 1.5°C through reaching 80% zero-emission energy by 2030 and 100% by 2050.[4] Shifting to a new system is a central focus of transition research and has been on the agenda

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3. Mey, Franziska and Lilliestam Johan, *Deliverable 3.1: Policy and governance perspectives on tipping points - A literature review and analytical framework* (Potsdam: Institute for Advanced Sustainability Studies, 2020).

4. Indra Overland and Benjamin K. Sovacool, 'The misallocation of climate research funding,' *Energy Research and Social Science* 62 (April 2020): 101349. https://doi.org/10.1016/j.erss.2019.101349 for several decades. Sustainability transitions refer to large-scale societal changes deemed necessary to solve 'grand societal challenges.' A key concern of transition research is to understand and explain how to achieve radical systemic change in a way that major societal functions are maintained.[5] Indeed, in the face of global challenges, incremental improvements are no longer appropriate.[6] Instead, rapid and complete systemic transitions are required.[7]

Indeed, past transitions have demonstrated that social systems can rapidly tip into entirely different states. At some point in time, complex systems that developed over decades and centuries experienced a 'tipping point,' changing their trajectories to their current state. A classic example is the transition from horses to today's car-based mode of transport. This mobility change provided a number of benefits such as individual independence, flexibility, and increased range and speed of movement. The downside comes with air pollution, the dependency on petrol and diesel, and lock-in effects in shaping our living infrastructure, economies, and social interactions. Another example is the development of the textile industry in Germany (similarly to other western countries). This sector had reached a peak in the 1960s with almost 700,000 workers. Yet, processes of globalisation and deindustrialisation contributed to a significant decline in local production over the following decades. The textile industry faced a significant rise in competition (e.g., low labour costs) and international division of labour, tightened environmental and social regulations, and changing consumer behaviour. Today, almost all German textile

5. Frank. W. Geels, 'A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies,' *Journal of Transport Geography* 24 (September 2012): 471–82. https://doi.org/10.1016/j.jtrangeo.2012.01.021; Derk Loorbach, Niki Frantzeskaki, and Flor Avelino, 'Sustainability Transitions Research: Transforming Science and Practice for Societal Change,' *Annual Review of Environment and Resources* 42 (October 2017): 599–626. https://doi.org/10.1146/annurev-environ-102014-021340; Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955–67. https://doi.org/10.1016/j.respol.2012.02.013

6. Jonathan Köhler, et al., *A research agenda for the Sustainability Transitions Research Network.* (Sustainability Transitions Research Network Working Group, 2017). http://t.ly/Xl5G

7. Jochen Markard, Frank W. Geels, and Rob Raven, 'Challenges in the acceleration of sustainability transitions,' *Environmental Research Letters* 15, no. 8 (August 2020): 081001. https://doi.org/10.1088/1748-9326/ab9468; Daniel Rosenbloom, et al., 'Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help,' *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 16 (April 2020): 8664–68. https://doi.org/10.1073/pnas.2004093117 production has moved to develop countries leaving less than 30,000 employees only in the high-end textile section.[8] These examples indicate that tipping points can be found in various transition processes, yet what specifically triggers these processes remains ambiguous.

Transitions are influenced and often determined by deliberate political, economic, and civil society actions. However, there is a paucity of information regarding concrete sustainability interventions or leverage points that bring the required impact.[9] This is the case for transitions that are 'moving away' from something while less clearly moving towards something new.[10] For instance, the phase-out of coal can be a disruptive process specifically for localities with a strong dependence on the extractive industries, which produces winners (somewhere else and possibly locally) and losers (mainly locally).

We know that societies affected by such transitions sometimes enter a negative spiral, despite the will and actions of decision-makers on different levels to do the contrary. The economic downturn caused by the loss of a core economic activity causes social problems, which exacerbates the economic downturn, and so on. In other cases, regions may face initial problems as the core activity disappears, but they manage to enter a new, positive development trajectory: some interventions or developments trigger new activity, innovation, and growth, which in turn, causes social improvements and more economic activity, and so on. Hence, in some cases, regions spiral down, whereas, in others, they enter a new virtuous circle: at some point in time, following some interventions, regions tip to either positive or negative socio-economic patterns.

A better understanding of what makes these regions tip towards either positive or negative development trajectories is a prerequisite to enabling a 'just

8. Andreas Stamm, et al., *Soziale und ökologische Herausforderungen der globalen Textilwirtschaft* (Bonn: Deutsches Institut für Entwicklungspolitik gGmbH, 2019).

9. Christian Dorninger et al., 'Leverage points for sustainability transformation: a review on interventions in food and energy systems,' *Ecological Economics* 171 (May 2020): 106570. https://doi.org/10.1016/j.ecolecon.2019.106570

10. Benjamin K. Sovacool, 'How long will it take? Conceptualizing the temporal dynamics of energy transitions,' *Energy Research and Social Science* 13 (March 2016): 202–15. https://doi.org/10.1016/j.erss.2015.12.020

transition' as defined in the Paris Agreement.[11] Here, we propose an analytical framework and a set of indicators for identifying tipping points in socio-technical and socio-economic systems. For this, our guiding research question is 'what indicators will help to identify the moment ex-post when a system tips to a low carbon trajectory?'

4.2. Tipping Points

This section addresses a brief overview of the transition literature and the embedded tipping point research, the generic understanding of tipping points, and the findings of recent investigations for technical, social, and ecological tipping points.

Most likely, everyone has experienced a tipping point of some sort in their life since the latter can both apply to microscopic or large-scale situations. The media, popular writers, and many academics regularly refer to the term 'tipping points' when indicating a significant threshold. The concept was popularised by Gladwell, drawing on epidemic theory suggesting that little measures can result in contagious and fast-spreading changes in their environment once a certain threshold is reached.[12] He offered a number of examples of tipping points including the cleaning up of the New York subway that led to a significant drop in the crime rate in the city in the early 1990s. This involved small and seemingly trivial actions like removing graffiti and prosecuting fare evasion which were addressed as expressions of disorder that invited much more serious crime: reducing these small nuisances had big effects on local crime rates. Another example of the phenomenon is the increasing dissatisfaction with the economic situation in the former German Democratic Republic provoking mass protests and ultimately the collapse of the country. Another case in point could be the high number of people simultaneously infected with Covid-19 triggering the health systems in some countries to collapse. These examples

11. 'Paris Agreement,' conclusion date: December 12, 2015, United Nations Treaty Series Online, registration no. I-54113. http://unfccc.int/paris_agreement/items/9485.php

12. Malcolm Gladwell, 'The Tipping Point,' *New Yorker*, June 3, 1996. http://t.ly/lJp7 point to a pressing question: 'could we have known these events'? And if yes, by which metrics could we have known – how can we recognise upcoming tipping points?

Tipping Points in Academic Literature

The idea of tipping points, i.e., thresholds, critical junctures, or leverage points, is not new and has been applied in different disciplines to describe the dynamics of significant change.[13] The first academic use of the term tipping point dates to studies of neighbourhood segregation in the US in the 1950s. Mark Grodzins applied the phrase 'tip point' to a critical proportion of non-whites in a neighbourhood above which the fraction of whites precipitously declined to zero.[14] In the following years, the term was further applied and developed by economists and urban sociologists such as Eleanor Wolf, Thomas Schelling, and Jonathan Crane on similar social phenomena.[15] Importantly, Schelling emphasised two key characteristics of a tipping point as being a process that disturbs an original equilibrium and leads to an accelerated and irreversible change.[16]

In the last 15 years, natural scientists have formalised the concept in different disciplines and domains. In this vein, a tipping point is used to refer to a situation in which an ecosystem experiences a drastic shift to a new state causing significant changes to its biodiversity and ecosystem services. In the climate system, it is understood as 'a critical threshold' at which 'a small change in forcing triggers a strongly nonlinear response in the internal dynamics of part of

13. David J. Abson, et al., 'Leverage points for sustainability transformation,' *Ambio* 46, no. 1 (June 2016): 30–39. https://doi.org/10.1007/s13280-016-0800-y; Ruth Collier and David Collier, *Shaping the political arena: Critical junctures, the labor movement, and regime dynamics in Latin America* (Notre Dame: Notre Dame University Press, 2015); Jonathan Crane, 'The Epidemic Theory of Ghettos and Neighborhood Effects on Dropping Out and Teenage Childbearing,' *American Journal of Sociology* 96, no. 5 (March 1991): 1226–59. https://www.jstor.org/stable/2781341; Dorninger et al., 'Leverage points for sustainability;' Donella Meadows, 'Leverage Points Places to Intervene in a System,' accessed March 28, 2022. http://t.ly/eVtx; Paul Pierson, *Politics in time: history, institutions, and social analysis* (Princeton: Princeton University Press, 2004).

14. Mark Grodzins, 'Metropolitan Segregation,' *Scientific American* 197 no. 4 (October 1957): 33–41. https://www.jstor.org/stable/24941940

15. Eleanor P. Wolf, 'The Tipping-Point in Racially Changing Neighborhoods,' *Journal of the American Institute of Planners* 29, no. 3 (1963): 217–22. https://doi.org/10.1080/01944366308978066; Crane, 'Epidemic Theory of Ghettos;' Thomas Schelling, *Micromotives and Macrobehavior* (New York: Norton & Company, 1978).

16. Schelling, *Micromotives and Macrobehavior*.

the climate system, qualitatively changing its future state.'[17] In climate research, these authors introduced the term 'tipping elements' as large-scale components of the Earth system that may pass a tipping point such as the Arctic sea ice and the Greenland ice sheet.[18] This led them to analyse the potential risk of tipping the entire climate system and to highlight the challenges of anticipating these points and consequently, influencing climate policies.

By the same token, economists have also applied this concept. For instance, models have been developed to calculate the risks and costs of tipping points for ecosystems in response to changes in rainfall patterns, depletion of resources, and deforestation, among others. Thus, it has been found that a failure to address them can yield downward spiral situations in terms of the state of marginal sustainability and that interventions, e.g., payments for ecosystem services, are necessary to ensure the continued provision of global benefits from intact ecosystems and avoid tipping into less stable of beneficial natural system states.[19]

Tipping Point Research Embedded in Transition Literature

Over the last decades, the grand societal transitions have been investigated from multiple perspectives. For example, Loorbach, Frantzeskaki, and Avelino identified three major lines of research: the socio-technical, socio-institutional, and socio-ecological.[20] The socio-technical perspective is the most well-established field of transition applied research often through multi-level perspective analysis (MLP) to understand the (historical) emergence and dynamics of socio-technical regimes such as energy, water, and mobility. The second line is the socio-institutional approach where research focuses on formal and informal institutional structures such as regulations, norms, cultures, and practises

17. Timothy M. Lenton, 'Early warning of climate tipping points,' *Nature Climate Change* 1 (July 2011): 202. https://doi.org/10.1038/nclimate1143

18. Timothy M. Lenton, et al., 'Tipping elements in the Earth's climate system,' *Proceedings of the National Academy of Sciences* 105, no. 6 (March 2008): 1786–93. http://dx.doi.org/10.1073/pnas.0705414105

19. Sergio L. Franklin and Robert S. Pindyck, 'Tropical Forests, Tipping Points, and the Social Cost of Deforestation,' *Ecological Economics* 153 (November 2018): 161–71. https://doi.org/10.1016/j.ecolecon.2018.06.003; Rodrigo Harrison and Roger Lagunoff, 'Tipping points and business-as-usual in a global commons,' *Journal of Economic Behavior and Organization* 163 (July 2019): 386–408. https://doi.org/10.1016/j.jebo.2019.05.015; Lenton, et al., 'Tipping elements.'

20. Loorbach, Frantzeskaki, and Avelino, 'Sustainability Transitions Research.'

that involve transitional change. In this light, studies are concerned with the creation and impacts of path dependencies and how these are challenged by social innovations. The third line stresses the interplay between ecological systems and societal contexts resorting to insights from biophysical science. Here, major explanatory frameworks have emerged around the term 'resilience' or 'panarchy,'[21] and the boundaries of ecological systems which are marked by tipping points provoking shifts from one dynamic equilibrium to another.

Research across these three perspectives has emphasised contagious and fast-spreading social and technological change to accelerate global decarbonisation measures.[22] Indeed, applying the analytical lens of tipping points to socio-technical and socio-institutional systems can yield important insights into the general question of what is required to tip a system to a low carbon trajectory. Instead of a large-scale event, it might only need small changes to trigger a positive feedback loop and push a complex system into a new system state – pushing it over a tipping point.[23]

Tipping Points from The Socio-Ecological Perspective

A growing bulk of work linking ecosystems and social science is emerging from the socio-ecological approach of transition research. Here, scholars seek to identify critical thresholds in the interactions between the complex human society and biophysical systems to avoid undesirable transitions. For example, Fernández-Giménez et al. found that Mongolian steppes are close to ecological and cultural tipping points based on an analysis of time series data for climate, vegetation, and livestock and human population. They claimed that

21. Lance H. Gunderson and Crawford Holling, ed. *Panarchy: Understanding transformations in Human and Natural Systems* (Washington: Island Press, 2002).

22. Ilona. M. Otto, et al., 'Social tipping dynamics for stabilizing Earth's climate by 2050,' *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 5 (January 2020): 2354–65. https://doi.org/10.1073/pnas.1900577117; J. David Tàbara, et al., 'Positive tipping points in a rapidly warming world.' Current Opinion in Environmental Sustainability 31 (April 2018): 120–129. https://doi.org/10.1016/j.cosust.2018.01.012; J. David Tàbara, et al., 'On the Discovery and Enactment of Positive Socio-Ecological Tipping Points: Insights from Energy Systems Interventions in Bangladesh and Indonesia,' *Sustainability Science* 17, no. 2 (March 2022): 565–71. https://doi.org/10.1007/s11625-021-01050-6

23. Abson et al. 'Leverage Points for Sustainability;' J. Doyne Farmer, et al., 'Sensitive intervention points in the post-carbon transition,' *Science* 364, no. 6436 (April 2019): 132–34. https://doi.org/10.1126/science.aaw7287; Meadows, 'Leverage Points Places.'

rural-urban migration leads to loss of pastoral cultural and place identity, values, and traditional ecological knowledge. They applied the notion of tipping points as 'reversible and irreversible thresholds, regime shifts, and other long-term system-level changes, regardless of whether these changes are sudden or non-linear.'[24]

This understanding draws on the distinction made by Scheffer et al. between irreversible, catastrophic thresholds, and non-catastrophic thresholds that are potentially reversible.[25] Others have defined the concept more restrictively. Milkoreit et al., for example, see tipping points as moments 'within a socio-ecological system at which a small quantitative change inevitably triggers a non-linear change in the social component of the social-ecological system, driven by self-reinforcing positive-feedback mechanisms, that inevitably and often irreversibly lead to a qualitatively different state of the social system.'[26]

In a more socially-focused research line, the study by Lamberson and Page made the important distinction between direct tips and contextual tips.[27] The former occurs when a gradual change in the value of a variable causes a large discontinuous jump in the future.[28] Nonetheless, the authors particularly highlighted the importance of context tips that often make direct tips possible, for instance, when human rights conditions in a state deteriorate, creating the potential for an uprising. The authors pointed out that such uprising occurs when a gradual change in the value of one variable brings about a discontinuous jump in some other variable of interest – the system may tip, due to an event affecting only a particular part of the system.[29]

24. María E. Fernández-Giménez et al. 'Exploring Linked Ecological and Cultural Tipping Points in Mongolia,' *Anthropocene* 17 (March 2017): 47. https://doi.org/10.1016/j.ancene.2017.01.003

25. Marten Scheffer et al. 'Early-Warning Signals for Critical Transitions,' *Nature* 461 (September 2009): 53–59. https://doi.org/10.1038/nature08227

26. Manjana Milkoreit et al. 'Defining Tipping Points for Social-Ecological Systems Scholarship - An Interdisciplinary Literature Review,' *Environmental Research Letters* 13, no. 3 (March 2018): 10. https://doi.org/10.1088/1748-9326/aaaa75

27. P. J. Lamberson and Scott E. Page, 'Tipping Points,' *Quarterly Journal of Political Science* 7, no. 2 (April 2012): 175–208. https://doi.org/10.1561/100.00011061

28. Ibid.

29. Ibid.

The broader political and socio-economic structures can determine continuity (equilibrium) or change (punctuated equilibrium) and trigger either self-correcting or self-reinforcing feedback loops. A certain alignment, timing, and sequence of developments can create a critical juncture situation and ultimately, influence the outcomes. However, the significance of a critical juncture can only be established ex-post and regarding the specific historical legacy. Junctures are 'critical' because, once an option is selected, this development may become entrenched, locking the system into this particular trajectory and making it hard, or impossible in the short term, to enter a new development trajectory.

Positive Tipping Points and Tipping Interventions

In a distinct line of tipping research, increasing attention has been paid to the role of perception, narratives (discourse), and social capacities. For instance, Russill and Nyssa found that popular use of tipping points originates in a desire to reshape how the public views dangerous climate change.[30] This notion of urgency has been either welcomed (to accelerate action) or criticised. An example of this is Nuttal's work which evaluated the negative perception of 'a point of no return' in the climate discourse as too simplistic and scaremongering.[31] Russill and Nyssa suggested acknowledging the metaphorical character of tipping points and viewing them as change coming from the internal dynamics of a system rather than an external force.[32] This may actually entail that tipping points can be triggered and controlled.

Similarly, Tàbara et al. emphasised the potential influence of tipping points and the change created through conscious and deliberate processes, and hence they can be altered through learning and purposeful actions, for example, articulated in narratives.[33] They posited that there can be positive tipping points which may be understood as 'the moment in which both social and ecological

30. Chris Russill and Zoe Nyssa, 'The tipping point trend in climate change communication,' *Global Environmental Change* 19, no. 3 (August 2009): 336–44. https://doi.org/10.1016/j.gloenvcha.2009.04.001

31. Mark Nuttall, 'Tipping Points and the Human World: Living with Change and Thinking about the Future,' *Ambio* 41, no. 1 (January 2012): 96–105. https://doi.org/10.1007/s13280-011-0228-3

32. Russill and Nyssa, 'The tipping point trend.'

33. Tàbara, et al., 'Discovery and Enactment.'

systems together take new positive and intentional trajectories.'[34] This implies that tipping points can be influenced and brought about through purposeful measures and actions which can have major desirable systemic effects both on individual life trajectories as well as broader systems.

On the other hand, psychology and economic behaviours research has already shown that accumulation of effects due to social contagion, repetitive nudging, or direct intervention can lead to social tipping dynamics.[35] This is suggested in Gladwell's popular example from the New York subway cleaning but also tackled in other examples such as Crane's findings. He determined that a decrease in neighbourhood quality yields a sharp increase in the probability that an individual develops a social problem, namely: an increase in dropouts and teen childbearing rates. This was observed as a contagious dynamic when the number of workers with high-status jobs in the area decreased below 4%.[36]

The foregoing indicates that influencing social tipping points through purposeful interventions could be a way to prevent or avoid negative transition outcomes. An example of this is Otto et al.'s work that concluded that governance and policy interventions play an important role.[37] In this vein, they defined social tipping interventions as directed measures that 'can activate contagious processes of rapidly spreading technologies, behaviours, social norms, and structural reorganisation within their functional domains that we refer to as social tipping elements.'[38] Moreover, they contended that adaptation and deployment of existing clean energy technologies is a key element of the decarbonisation process. They added that a critical condition to trigger the tipping process is the moment when fossil-fuel-free energy production yields higher financial returns than the energy production based on fossil fuels. Interventions in this sense are redirecting national subsidy programmes to renewables

34. Ibid., 4.

35. Crane, 'Epidemic Theory of Ghettos;' Eugen Dimant, 'Contagion of Pro- and Anti-Social Behavior Among Peers and the Role of Social Proximity,' *Journal of Economic Psychology* 73 (August 2019): 66–88. https://doi.org/10.1016/j.joep.2019.04.009; Gladwell, 'The Tipping Point.'

36. Ibid.

37. Otto, et al., 'Social tipping dynamics.'

38. Ibid., 2354.

and low-carbon energy sources or removing the subsidies for fossil-fuel technologies.

In another study, Tàbara et al. found that both hand market-based intervention with robust grassroots institutions and hand small-scale initiatives can trigger positive tipping points and have transformative potential for the lives of rural poor in two case studies in Indonesia and Bangladesh. Based on this case study, they emphasised the need to pay attention to processes of social construction and to time dynamics. The authors particularly highlighted three elements for identifying tipping points: the conditions and capacities for a system to change, significant events or interventions shifting the system towards a different trajectory or systems' configuration, and the ultimate impact and structural effects derived from such transformation.

Concluding Summary

Overall, the literature reveals a great interest in the tipping point concept from different disciplines and research streams with a growing number of emergent frameworks and models. Despite the cacophony of definitions and interpretations, we find three overarching evolving themes:

1) Tipping points are moments of discontinuity occurring within a specific context triggered by the conjunction or alignment of developments (or variables). Thus, the system fundamentally, qualitatively, and irreversibly changes its structure and to a future governed by new feedback.
2) There are desired and undesired tipping points having specific positive or negative consequences for human societies. Yet, undesired tipping points have received more attention in the literature so far.
3) Because tipping points are considered to bring about rapid change, there is a great interest and also need to influence (some) tipping points to accelerate the transformation of socio-economic systems.

4.3. Framework and Indicators

Building on the literature, we understand tipping points as moments of discontinuity in which a given system of reference fundamentally and irreversibly changes its structure and future dynamics that are determined by context and specific interventions leading to either positive or negative impacts. Therefore, we believe that the added value in recognising tipping points is to determine why and when a system follows one or another trajectory. Likewise, this value befalls understanding the interventions and in which contexts they succeed, tipping a system to a low carbon trajectory.

For this purpose, we suggest a tiered approach comprising three dimensions: tipping impact, tipping context, and tipping interventions. The relationship is that tipping interventions may hit a specific context triggering a tipping point that, in turn, creates a bifurcation for a positive or negative trajectory, which ultimately, changes the context conditions (see FIGURE 3).

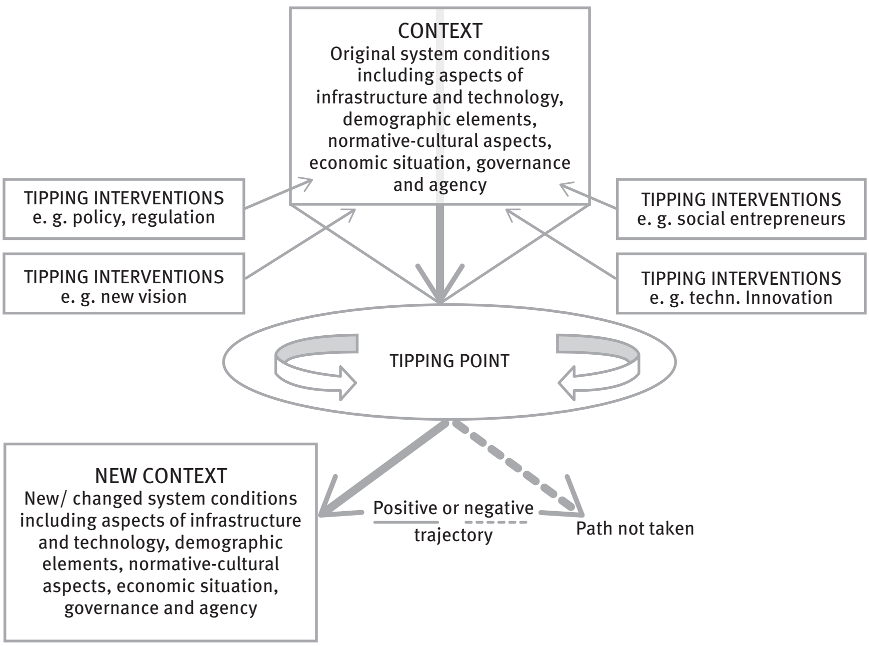

FIGURE 3. Preliminary Tipping Point Analysis Framework

Source: Prepared by authors.

To determine whether a tipping intervention is effective, attention must be paid not only to the intervention but also to the tipping context and desired impact (i.e., the new context, created by the new trajectory). The three dimensions are discussed below.

Tipping Impact: Positive Tipping Points

Early warnings of tipping points in social, economic, and governmental activities are inherently more difficult to spot.[39] Indeed, just as critical moments or junctures, tipping points can usually only be identified retrospectively in reference to the specific historical legacy or systemic change.[40] This is because tipping points produce specific development paths or trajectories. Furthermore, a change in the structural trends and dynamics of a system can be a measurement of the impact after a tipping point. This involves, for example, the development of a region in regard to economic growth and equality, employment, and migration, among others.

The literature has suggested that there are positive and negative tipping points allowing for qualitatively different developments and impacts over time.[41] As indicated by the adjectives positive and negative, there is a close connection between tipping points and a normative understanding of a desired future state of a system, which implies that what is positive for one actor may be negative for another. For instance, a tipping transition to renewables is positive for environmentalists and the solar industry, but likely negative for the oil industry. However, the term tipping point is also used to describe 'positive feedback processes' that constitute sources of increasing returns and self-reinforcing processes.[42] For example, Lenton et al. refer to tipping points and positive feed-

39. Tim O'Riordan and Tim Lenton, 'Tackling tipping points,' *British Academy Review* 18 (Summer 2011): 21–27. http://bitly.ws/rxL3

40. Giovanni Capoccia, 'Critical junctures and institutional change,' in *Advances in Comparative-Historical Analysis*, eds. James Mahoney and Kathleen Thelen (Cambridge: Cambridge University Press, 2015), 147–79; Collier and Collier, *Shaping the political arena*; Paul Pierson, *Politics in time*.

41. Roope O. Kaaronen and Nikita Strelkovskii, 'Cultural Evolution of Sustainable Behaviors: Pro-environmental Tipping Points in an Agent-Based Model,' *One Earth* 2, no. 1 (January 2020): 85–97. https://doi.org/10.1016/j.oneear.2020.01.003; Tàbara, et al., 'Positive tipping points.'

42. Lenton, et al., 'Tipping elements;' Jochen Markard, 'The life cycle of technological innovation systems.' *Technological Forecasting and Social Change* 153 (October 2020): 119407. https://doi.org/10.1016/j.techfore.2018.07.045; Paul Pierson, *Politics in time*; Gregory C. Unruh, 'Understanding carbon lock-in,' *Energy Policy* 28, no. 12 (October 2000): 817–30. https://doi.org/10.1016/S0301-4215(00)00070-7 back processes triggering changes in the Earth systems such as the melting of the poles' sea-ice.[43]

Similarly, in socio-technical systems, a 'change in gear' is associated with a 'chain reaction of positive feedback loops ... setting in motion a process of cumulative causation.'[44] Institutionalists and economists refer to increasing returns and 'positive feedback' processes as path-dependent processes. This means that a step in a particular direction may generate a positive feedback loop, increasing the pay-off for additional movement in the same direction.[45] On the other hand, the negative feedback loop is associated with a lack of positive feedback or the presence of barriers/forces against change.

In general, positive tipping points can be associated with examples like the approval of the Charter of Human Rights or the abolition of slavery.[46] Kaaronen and Strelkovskii highlight that it is important for sustainability transitions to leverage social systems into tipping points, where societies exhibit positive-feedback loops in the application of sustainable practise including behaviour and cultural traits.[47] In a socio-technical system, the production and storage of energy is a key tipping element.[48] In this case, a positive tipping point constitutes the endogenous and rapid transition to renewable energy sources.[49]

Positive tipping points in a socio-economic system can be related to a positive trajectory in regard to livelihoods and configuration of the domestic economies as well as education, resources, and migration. For example, Tàbara found that a

43. Lenton, et al., 'Tipping elements.'

44. Staffan Jacobsson and Volkmar Lauber, 'The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology,' *Energy Policy* 34, no. 3 (February 2006): 260. https://doi.org/10.1016/j.enpol.2004.08.029

45. Douglass C. North, *Institutions, Institutional Change and Economic Performance* (Cambridge: Cambridge University Press, 1990); Douglass C. North, 'Economic Performance Through Time,' *American Economic Association* 84, no. 3 (June 1994): 359–68. https://www.jstor.org/stable/2118057; Paul Pierson, 'Increasing Returns, Path Dependence, and the Study of Politics,' *American Political Science Review* 94, no. 2 (June 2000): 251–267. https://doi.org/10.2307/2586011; Richard W. Scott, *Institutions and Organizations: Ideas, Interests, and Identities*, 4th ed. (Thousand Oaks, California: SAGE Publications, Inc., 2014).

46. Tàbara, et al., 'Positive tipping points.'

47. Kaaronen and Strelkovskii, 'Cultural Evolution.'

48. Otto, et al., 'Social tipping dynamics.'

49. Tàbara, et al., 'Positive tipping points.'

combined approach of introducing solar home systems, capacity building, and social entrepreneurship in Bangladesh might trigger systemic effects and lead to many other positive effects on education, use of time and resources.[50] We suggest that positive tipping points in socio-economic systems bring qualitative improvement to individual or community life which includes higher (or not reduced) income, better (or not impaired) health, education, and local economic development.

Nevertheless, there are challenges in measuring impact indicators. Firstly, it is necessary to capture the timing of change which requires comparable and long-term data series. Obtaining these for quantitative data could be easier (yet not always), while qualitative data is harder to collect for longer-term developments. Secondly, systemic changes are subject to individual and collective perception and influence the labelling of a certain tipping point into positive or negative. For instance, the reunification in Germany was a significant tipping point in the lives of East-Germans (less so for West-Germans) and the long-run effects have been perceived very differently depending on individual (or community) situations. In addition, data about the different perceptions could be more difficult to obtain. Thirdly, the importance of a tipping point might only be determined in the long term, which will have a direct impact on selecting a timeframe for analysis. Fourthly, tipping points are not necessarily 'points' but can also be stretches of time during which sequences of events unfold. Put it simple, the complexity of social systems can make it challenging to identify causality and datasets for measurement.

Tipping Context

As illustrated in FIGURE 3, the impact of a tipping point is understood as a fundamental intended or unintended change in the (initial) context of a system, recognising that transitions are non-linear and involve context-dependent evolutionary processes with emergent properties.[51] Hence, explaining tipping

50. Tàbara, et al., 'Discovery and Enactment.'

51. Bruno Turnheim, et al., 'Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges,' *Global Environmental Change*, 35 (November 2015): 239–53. https://doi.org/10.1016/j.gloenvcha.2015.08.010

points requires the analysis and description of the broader context of the system. For example, industrial change in coal-phase out regions comprises economic and technical processes, but also political and cultural processes. Drawing on the triple embeddedness framework (TEF) of industrial change, industry actors are embedded in two selection environments (economic and socio-political) and structured by field-specific institutions.[52] Building on sociological and institutional theories,[53] the TEF also highlights the relevance of norms, beliefs, and interpretation as well as the identities of the actors involved. To illustrate this, the meaning associated with 'coal' (as in mining or power plants) as a source of something positive (e.g., economic growth, employment, and prosperity) or something negative (e.g., high pollutants, stranded assets, and drivers of climate change) can be an indicator of the transformative capacity of a region. Meaning and interpretation feed into narratives or visions that are the articulated form of plausible futures and may lead to the emergence of the desired outcomes.[54]

In order to understand the changes that happen in a socio-economic system we suggest investigating the following elements:

- Infrastructure and technology: What are the dominant physical and institutional arrangements in the region, e.g., roads, technology, and educational infrastructure?
- Demographics: Who lives in the region? What are their occupations?
- Normative-cultural aspects: What does the majority think about their region and the subject 'coal'? What are dominant and emerging narratives, frames, and visions?

52. Bruno Turnheim and Frank W. Geels, 'The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967),' *Research Policy* 42, no. 10 (December 2013): 1749–7. https://doi.org/10.1016/j.respol.2013.04.009; Bruno Turnheim and Frank W. Geels, 'Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997),' *Energy Policy* 50 (November 2012): 35–49. https://doi.org/10.1016/j.enpol.2012.04.060

53. Anthony Giddens, *The Constitution of Society: Outline of the Theory of Structuration* (Berkeley: University of California Press, 1984); Scott, *Institutions and organizations*.

54. Tàbara, et al., 'Discovery and Enactment.'

- Economic aspects: What are the local economic situation and dependencies? What are the human and social resources including individual income, poverty rates, GDP, skills, and expertise?
- Governance and agency: How is the region governed? Who are the relevant regional actors and what are their agendas? What is the level of social cohesion?

Tipping Interventions

What social tipping points – either positive or negative – often have in common is that they modify the opportunity space for action, modes of interaction, and the degrees of freedom of the agents within that system.[55] These changes are (often) triggered by deliberate small or larger interventions that might cause tipping points and eventually, social spreading effects. These interventions can come from government (policy intervention), industry (innovations), or social entrepreneurs (cultural, social, or economic intervention). For example, the introduction of the German Renewable Energy Act (EEG) triggered the growth of renewable energy in Germany and also led to substantial system responses in form of self-reinforcing market growth and cost improvement internationally.[56]

A key question for transition research is 'What the kinds of potential tipping interventions can bring about to pursue desired futures?' In this sense, Otto et al. posit small and big interventions producing small effects (i.e., changes in individual life trajectories) or large effects (i.e., broader system changes) (see TABLE 7). Hence, tipping points and tipping interventions can occur at many levels, including at the very micro-sociological one.[57]

TABLE 7. Examples of Intervention-And-Effect Relationships

55. Ibid.

56. Jacobsson and Lauber, 'Politics and policy;' Gregor Kungl and Frank W. Geels, *The Destabilisation of the German Electricity Industry (1998–2015)* (Stuttgart: University of Stuttgart, 2016). http://t.ly/Zfgb

57. Tàbara, et al., 'Discovery and Enactment.'

Intervention type	Small effect	Big effect
Small intervention	Incremental change for emission reduction through local climate policy. Unionised deals with mining companies for workers' compensation, further training, and ensuring workers are not neglected in the phase-out process e.g., in the Spanish transition deal.	Tipping effect for cost reduction of renewable energy from the German EEG so that PV becomes cheaper than coal power.
Big intervention	Inefficient interventions, e.g., the implementation of the European Carbon Emission Trading Scheme, leading to a marginal reduction of greenhouse gas emissions.[58] Potentially: The 2018 German Coal Commission, assigning a significant amount of money (€44 billion) for a relatively small remaining mining workforce and affected communities, and to compensate power mining companies for shutting down before 2038.	Potentially: big effect for reducing carbon emission by removing all government subsidies for fossil fuels industries Potentially: European Green Deal - Platform on Coal and Carbon-Intensive Regions – to ensure that these regions are supported in the transition period

Source: Adapted from Otto et al.[59]

In coal-phase out regions, interventions such as the abrupt closure of a coal mine, the introduction of a sustainable future vision, or policy support for diversifying the local economy can trigger social dynamics provoking either positive or negative tipping points. For example, Spain is in the process of phasing out its entire coal production after a landmark deal of €250,000,000 was

58. Anthony Patt and Johan Lilliestam, 'The Case against Carbon Prices,' *Joule* 2, no. 12 (December 2008): 2494–98. https://doi.org/10.1016/j.joule.2018.11.018

59. Otto, et al., 'Social tipping dynamics.'

struck between the government and unions in 2018, that money being invested in mining regions over the next decade.[60] Although the phase-out had already started in the 2000s, the closing of the industry (which has been ultimately effective) was a major disruption leading to a drastic reduction in employment and production levels. The mitigation measures adopted by the government to mitigate the negative impact on the affected zones through early retirements, and local infrastructure development have been less effective.[61]

Vis-à-vis the discussed above, we suggest investigating tipping interventions as deliberate actions from local, regional, and national actors. Doing so would allow the analysis of how actors seek to influence their socio-economic context through the introduction of new narratives, policies and regulations, and the creation of social networks.

4.4. Summary and Indicators

This chapter provided a preliminary analysis framework to investigate tipping points, their impact, context, and interventions in socio-technical and economic systems. Still, identifying social tipping points is a work in process. Thereby, we would like to conclude with a list of indicators to help identify them based on the three dimensions. It is relevant to note that much more theoretical and empirical work needs to be done from a transdisciplinary perspective for understanding how positive systemic changes can be triggered in deliberate and empowering modes by key agents in specific social circumstances.

Tipping points can be (mainly) identified ex-post in reference to fundamental and irreversible changes in the structure and dynamic of the socio-economic system. The following list of indicators is complemented by our suggestion on how they can be evaluated, if they potentially contribute to a positive or negative trajectory and if they can actually indicate a tipping point event.

60. Pablo Del Río, *Coal Transition in SPAIN* (IDDRI and Climate Strategies, 2017). https://doi.org/10.2523/94173-MS; Arthur Neslen, 'Spain to close most coalmines in €250m transition deal,' *Guardian*, October 26, 2018. https://t.ly/ntO5

61. Lucía Benavides, 'Spain's coal miners continue to wait for their country's "Green New Deal",' *World*. August 16, 2019. https://t.ly/ibVZ

!) Impact indicators: In order to identify positive or negative tipping points, we suggest investigating significant changes in structural trends and dynamics of:

- Population and migration (e.g., gender, education level, and age).
- Employment and unemployment rate.
- Income levels.
- GDP.

We see value in capturing all quantitative indicators over a time span of at least 30 to 50 years. The longer the timeframe the more likely it is to actually identify tipping points and not only context-related fluctuations. Significant population developments, e.g., migration in or out of a region, as well as a major increase or drop in employment rate can indicate either positive or negative tipping points. Similarly, a positive tipping point may be observed as, for example, the growth of the local population, whereas a negative tipping point could be observed as a population decline, either through emigration or decreasing birth rates. In this framework, the close of a major industry (e.g., coal mine) in a region is often followed by significant layoffs, an increase in the local unemployment rate, and shrinking income levels and GDP. In contrast, a positive tipping point is indicated when a region is able to buffer or intervene after a major event (e.g., close of a coal mine) and actually remain stable or grow in regard to population size, income levels (same or higher as in comparison to the national average), employment, and GDP. Nonetheless, these indicators should be addressed with caution since these are only quantitative figures and do not provide insights into the perception of the local community, which might provide a different picture.

2) Context indicators: In addition to the impact indicators above, we propose assessing changes in the following context-specific indicators:

- Political composition of the local and regional government.
- Number of NGOs, businesses, and other local organisations.

- Local narratives and visions of majority (and potentially emerging minority).

The tipping context can indicate the capacities for change and resilience of a system.[62] In order to investigate the context of a socio-economic system, a full account of the basic demographic, educational, and infrastructural information should be captured (see impact indicators, Appendix 1). How a region is governed is another question to consider, in particular, the indicator of the political composition of local and regional governments. For instance, the voting patterns can offer insights into the level of progressiveness and local attitudes influencing local decision-making and possible interventions. In addition, we suggest paying particular attention to local narratives and visions of local actors. These can point to envisioned changes (mainstream and emerging narratives) and help to identify potential key actors, change agents, and intervention points. A detailed overview of suggested context and impact (pre- and post-tipping) indicators is provided in TABLES 8 and 9 (see Appendix A).

Tipping context and impact are influenced by interventions. Hence, both should be analysed for the following interventions:[63]

- Industry interventions: Those close to a power plant or mine.
- Policy interventions: Introduction of pollution acts or renewable energy acts.
- Government elections at different levels.
- Public information campaigns by NGOs or governments on clean air or water and climate protection.
- Key agents: Local actors – social/ institutional entrepreneurs.

Tipping interventions are deliberate actions that influence the socio-economic context of a region through initiating certain processes (NGOs, industry, and government) or mitigating others (government and NGOs).

62. Tàbara, et al., 'Positive tipping points.'

63. Table 10 provides a detailed account of intervention indicators (See Appendix A).

This non-exhaustive list of indicators provides a starting point for seeking out tipping interventions in relation to significant systemic change.

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Appendix A

TABLE 8. Quantitative Indicators for The Context Pre- and Post-Tipping in Coal- Or Carbon-Intensive Regions.

Variable type	Variable examples	Possible questions
General context		
Demographics	Population. Composition of gender. Education levels. Age. Migration patterns. Life expectancy (only relevant over a longer time frame).	Who lives in the carbon-intensive regions (demographics, gender, and minorities)? What are they doing in terms of jobs and education? What migration patterns can be observed? (If any) What are the ongoing trends?
Socio-economic trends and changes	GDP. Household income levels. Poverty rate. Employment and unemployment levels.	What are the economic, social, and human resources and capacities available to transform the region?
Business/industry context		
Importance of incumbent dominant industry (e.g., coal and steel)	Number of employees/shares of local employment. Contribution to local GDP. Subsidies/subsidies relative to turnover and value-added. Production output (e.g., MW and tonnes of coal).	Who are the incumbents and dominant industry actors? How important are they for the local economy and employment market? What is the local economic contribution and value of the incumbent industry? How many public subsidies in relation to value-added do they receive?
Presence and importance of other sectors	Number of companies employing 10%, 20%, and 25% of the workforce. Share of public vs. private sector in: • Regional GDP. • Employment.	How important are other sectors (e.g., industry, service) for the region? How many people are employed in these sectors? What is the annual contribution to GDP by these sectors? Are these sectors supported by public policy?
	• Number of employees/shares of local employment. • Contribution to local GDP.	

Variable type	Variable examples	Possible questions
Presence and importance of green sectors	Number of employees/shares of local employment. Number of companies active in the regions. Contribution to local GDP. Subsidies/subsidies relative to turnover and value-added. Skills needed for expansion.	Are new 'green' companies present? Can they step up and grow into the niche left by the carbon-intensive business? How important are they for the local economy and employment market? What is the local economic contribution and value of the green industry? How many public subsidies in relation to value-added do they receive? Can the employees from the carbon-intensive industry be shifted or retrained to meet the needs of the green industry?
Political context		
Political composition of government	EU parliament. National government. State government. Local government.	Who are the governing actors and who is in opposition? What is their position on coal (i.e., carbon-intensive industries)? What role does coal play in legitimising their power?
Public opinion at the national, regional, and local level	Acceptance of climate science. Acceptance of renewable energy deployment. Support of government. Trust in government. Civil engagement and own participation in public consultations.	What sentiments do local and regional community members convey about questions of climate change, acceptance of renewable energy, trust in government bodies, and their participation in transformation processes?
Public budgets	Funding for different levels/ ministries and branches of government (total or spending per capita).	Is public investment supporting possible programmes? Does public investment support programmes that already exist? Can the region tap into them?

Variable type	Variable examples	Possible questions
	Climate protection. Energy funding/subsidies. Labour (retraining and upskilling measures). Social welfare. Research and education. Innovation. Public spending/investments relative to GDP. Local/municipal. Regional. National.	Are the public budgets balanced? Is there room for additional spending? Are existing investments or other structural change programmes available? How high is the public debt relative to GDP?
Societal context		
Civil society	Share of citizens active in local clubs (all types). Number/share of honorary posts. Number of charitable organisations.	Are citizens engaged in improving and shaping their community?
Environmental and social NGOs	Number of NGOs focusing on climate and environmental protection (e.g., anti-coal). Number of other associations and NGOs with a focus on coal (e.g., community support and advocacy).	Are citizens engaged in improving the environment in their community, region, country, or in general? What is their position on coal? What is their position and activities regarding the specific activity/industry that closed or was discontinued?
NGOs membership	Number of members (funding or active) in climate and environmental NGOs and other associates	What is the membership size of these NGOs? How many people actively engage or are they funding members? What political influence do these NGOs have?
Mining and steel/ Energy Unions	Number of members at the national, regional, and local levels.	What is the membership size of these unions at different levels? What is their position on coal?
CSR activities by local industry	Local industry funding/support for: Cultural events/activities Sport events/activities	How much funding does the local/ regional coal provide for regional cultural and sport events/activities?

Variable type	Variable examples	Possible questions
		How strong do local associations and community organisations depend on the local industry support?
Media discourse	Media coverage of coal (intensity). Number of newspaper articles. Number of public service TV (news) reports. Number of online newspaper articles or social media (e.g., Facebook and Instagram). Media coverage of coal (direction). Number of positive (pro-closing and pro-transition). and negative (anti-closing and anti-transition) newspaper articles. Number of positive/negative public service TV (news) reports.	How often does coal appear in the local news (newspapers, online news, and social media)?

Source: Prepared by authors.

TABLE 9. Qualitative Indicators for the Context Pre- and Post-Tipping in Coal- or Carbon-Intensive Regions.

Variable type	Variable examples	Possible questions
Perceptions and narratives about the present		
Frames	Frames used by actors in regard to: Coal. Local/ regional actors. Local community. Workers. Government. Industry. Civil society organisations (NGOs and unions). Media.	What are the dominant and minority frames used in election campaigns, public speeches and public events, parliament discussions, parliamentary inquiries, industry advertisements, presentations at industry events and public fairs, and political media articles and social media?

Variable type	Variable examples	Possible questions
		How do these frames legitimise/ delegitimise coal (i.e., carbon-intensive industries) as a regional economic resource? What do people associate with coal?
Self-image	Self-perception: What do people think about their place in that region and that region's place in the world? Who are 'we'?	Who are we? What do we do? What can (not) we do? What is our place in the world?
External perception	External perception: What do people outside the affected region think about it, its people, and what happens there? Who are 'they'?	Who are the people in the region? What do they do? What can (not) they do? What is their place in the world?
Perceptions about coal in the region	Narratives used by actors in regard to coal: Local/ regional actors. Local community/ workers. Government. Parliament. Industry and industry associations. Civil society organisations. NGOs. Unions. General national discourse. National media.	What is coal? Why is coal important? What problems are caused by coal? Is coal, in balance, good or bad?
Perceptions about coal beyond the region (e.g., in the capital)	Narratives used by actors in regard to coal: National actors: government and parliament. Industry and industry associations. Other industries. Civil society organisations. NGOs/Unions. General national discourse. National media.	What is coal? Why is coal important? What problems are caused by coal? Is coal, in balance, good or bad?

Variable type	Variable examples	Possible questions
Perceptions about the future		
Internal visions	Narrative visions put forth (e.g., dominant or minority) by local actors.	Who do we want to become? What do we want our region and community to develop into? What will we do in the future? What should be our place in the world?
External visions	Narrative visions put forth (e.g., dominant or minority) by national and European actors.	Who do we want the region to become? What do we want that this region or community develop into? What will they do in the future? What should be their place in the world?

Source: Prepared by authors.

TABLE 10. Intervention Indicators in Coal- or Carbon-Intensive Regions.

Intervention type	Intervention example	Intended effect
Policy interventions		
Public investments	Building new infrastructure (e.g., rail or road).	Improving transport of goods and people to/from the region; allowing longer commuting.
Investment support	Public-private partnerships.	Subsidies for private actors investing in the region to trigger investments in new economic activity; jobs creation.
	Soft loans.	Low-interest loans for regional investments to trigger new economic activity, and job creation.
Subsidies	Subsidies or tax exemptions for companies present.	Keeping companies in the region; maintaining employment.
	Subsidies or tax exemptions for companies expanding in or to the region.	Attracting further companies to the region; creating further jobs in already existing businesses.

Intervention type	Intervention example	Intended effect
Education	Funding universities and new university programmes.	Attracting young, qualified students to the region; creating the skills needed for the envisioned transition.
	Founding R&D institutes.	Attracting skilled R&D people to the region; triggering regional spin-offs.
Deliberation processes	Local engagement processes.	Building a new vision for the region.
Population management	Support for families moving away.	Reducing unemployment in affected regions; creating new opportunities for citizens and other regions.
	Lowering property tax; soft loans for buying property in regions.	Keeping population in the region by supporting house ownership.
Local interventions	Funding local initiatives and associations.	Supporting local social capital.
Business/industry interventions		
Investments	Expanding existing operations.	Expanding local value creation and new jobs.
	Found new operations	Expanding local value creation and new jobs.
	Relocating from other regions.	
Education	Re-training existing employees.	Enhancing skills and directing them towards what is needed in the future (keep existing employees hired).
	Training new employees.	Teaching new employees in necessary skills for future operations and the scope of companies.
	Working with the government to design new education programmes and university foci.	Teaching new employees necessary skills for future operations, the scope of companies, and the governmental vision for the region.
Entrepreneur initiatives	Start-ups and technology and business innovation.	Establishing a flexible and supportive business environment for start-ups and other entrepreneurial innovations.

Intervention type	Intervention example	Intended effect
Societal interventions		
Citizen initiatives	Network support for businesses and other stakeholders.	Creating a movement of orchestrated policy, business, and civil society actions to achieve a new vision for the region.
	Bottom-up visionary discussion processes.	Building a new vision for the region; building social trust and associational networks.
Education	Information campaigns about environmental awareness and health.	Raising awareness, educating, and building local social capacity.
Social networks	Collective action.	Supporting local initiatives and NGOs in order to create or maintain social capital.

Source: Prepared by authors.

5. Incentivising 'Regenerative Value' to Improve Sustainability Outcomes

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This chapter argues that whilst specific policy instruments, industry standards, and the Sustainable Development Goals (SDGs) have an important role to play in establishing climate targets, incentivising action and monitoring outcomes requires a more interdependent approach to drive green initiatives at all scales. This chapter puts forward a conceptual framework for mutually reinforcing mechanisms and incentives to promote 'regenerative value'[2] based on the measurement of net sustainability outputs across different dimensions.

Some have argued that the notion of capitals is an inappropriate approach that commodifies nature and other non-financial entities. In contrast, we suggest

1. *Development in Transition / Centre for the Understanding of Sustainable Prosperity (CUSP).* https://cusp.ac.uk/. *E-mail:* amy@developmentintransition.co

2. This term has already been coined and is being applied to encourage beyond economic valuation within mainstream organisations. See for instance: 'Regenerative Value Creation: A new logic for business & economy,' NOW Partners, accessed March 26, 2021, https://t.ly/pC9c that regenerative value can advance transition management and positive actions on climate change. However, this must be supported with appropriate political-institutional arrangements for an integrated economy with strong redistributive and incentivising components of the co-benefits of sustainable action. This includes greater information sharing amongst stakeholders on sustainability gains, incentives towards promoting climate action, matching of stakeholder needs and interests to maximise sustainability impact, and reconsidering 'value' at a systemic level. In addition, there is a role for indexing organisations, sectoral bodies, or communities that demonstrate positive sustainability action. Engaging with different actors to share insights, frustrations, and opportunities across 'scales' and 'sectors' could help to overcome institutional silos and encourage collaborative approaches to cultivate and capture sustainability transitions, particularly through peer-to-peer support in enhancing sustainability knowledge and action.

Under these conditions, regenerative value could, therefore, be a fundamental component of a post Covid-19 global recovery programme on a local and global scale. We explore these debates and some preliminary ideas posited by the author in previous publications to assess how this might be put into practise.

5.1. Introduction

How we can shape 'sustainable' development is a key question for our time. The means to achieve this end are complex and subject to competing visions of what needs to be done, by whom, at what speed, and on what scale. Now more than ever we require a robust framework to assess and guide the type of world we are actually and ideally 'transitioning' towards. The announcement of a Green New Deal for the EU and movements such as the Extinction Rebellion or Greta Thunberg's dramatic awareness-raising are highlighting this need and taking sustainable impact measurement to the forefront of civic and political discourse. Depending on which narratives of 'sustainable development' are invoked and by whom, the outcome may range from a more transformative agenda to encouraging a post-political 'fix.'[3] For instance, once heralded as a

3. Phil Allmendinger and Graham Haughton, 'Post-political spatial planning in England: a crisis of consensus?' *Transactions* 37, no. 1 (2012): 89–103. https://www.jstor.org/stable/41427930; Peter North, 'The promising urban buzzword, the notion of 'smart cities' has become tainted with democratic challenges associated with big-tech companies and countering a more outcomes-focused approach to civic enterprise, wellbeing-focused urban resilience strategies, and nature-based planning approaches.[4]

Speaking on the BBC's Question Time in December 2019,[5] Johnathan Bartlett, the England and Wales Green Party Co-Leader, said that If the climate were a bank, we would have bailed it out by now, highlighting the planet's reduced capacity to stave off negative feedback loops and the inability of financial systems alone to solve the climate crisis. Indeed, Weber refers to siloed and negative feedback loops within disparate, conflicting societal systems as 'utilitarian value,' where natural economic assets and services are valued (primarily in monetary terms) and appropriated from nature.[6] The need to address the unbalanced role of nature in economics has proliferated in recent years from calls for degrowth (decoupling of economic growth and socio-economic systems),[7] limits to growth,[8] regenerative economic theory valuing capital assets of the earth and sun as the life support machine of life on Earth,[9] and 'whole systems' perspectives[10] that incorporate social and economic impacts on natural resources beyond gross domestic product (GDP).

Politics of Climate Activism in the UK: A Social Movement Analysis,' *Environment and Planning A* 43, No. 7 (July 2011): 1581–98. https://doi.org/10.1068%2Fa43534

4. Sommer Mathis and Alexandra Kanik, 'Why you'll be hearing a lot less about "smart cities",' *City Monitor*, February 18, 2021. https://tinyurl.com/4k6jckhw

5. Jonathan Bartlett, BBC's Question Time in December 2019. Under 30s special hosted by Barnett, Emma in York. - BBC News Election Special. December 9, 2019, video. https://twitter.com/i/status/1204153591176413184

6. Jean-Louis Weber, 'Need for an Ecological Currency to Measure Ecosystem Capital Degradation,' Presented at the Conference *Transforming the Future of Money*, Inter-University Centre, Dubrovnik, November 18–20, 2019. http://shorturl.at/sIKL6

7. Filka Sekulova, et al., 'Degrowth: from theory to practice,' *Journal of Cleaner Production* 38 (January 2013): 1–6. https://doi.org/10.1016/j.jclepro.2012.06.022

8. Tim Jackson, *Wellbeing Matters: Tackling growth dependency (Briefing Paper No. 3)* (London: All-Party Parliamentary Group on Limits to Growth, 2020). https://tinyurl.com/4saf2anv; Tim Jackson, *Prosperity Without Growth? The Transition to a Sustainable Economy* (London: Sustainable Development Commission, 2002). https://tinyurl.com/2995pc3d

9. Herman E. Daly, 'Uneconomic Growth and the Built Environment,' in *Reshaping the Built Environment: Ecology, Ethics, and Economics*, ed. Charles J. Kibert (Washington: Island Press, 1999), 73–88.

10. Frank Dixon, *Global System Change: A Whole System Approach to Achieving Sustainability and Real Prosperity* (New York: Global System Change, 2017).

In this framework, Gibbons et al. suggest there is a need for 'regenerative development' models where development and design methodologies are centred on ecological, integrative principles.[11] These can help engender the necessary worldviews, processes, and components for meaningful sustainable development and enhance both living systems and human health, well-being, and happiness. In this vein, Bozesan claims that there is a need for integral investing if the SDGs are to be implemented within planetary boundaries.[12] Or as Snick puts it, the global socio-economic model should move towards sustainable regrowth, which enables further decoupling of economic growth and ecological restoration, with the potential for a future population increase when systems have been restored.[13] These calls mirror the increasing application of Raworth's doughnut economics framework that assesses ecological and social ceilings within which human activity should strive to work within,[14] a model that is steadily being applied by different sectors and local governments.[15]

One progressive approach within the UK devolved territory of Wales was to pass a Well-being of Future Generations (Wales) Act 2015 that covers government and public bodies. This set a statutory well-being goal for 'a globally responsible Wales,' as 'a nation which, when doing anything to improve the economic, social, environmental and cultural well-being of Wales, takes account of whether doing such a thing may make a positive contribution to global well-being.'[16] These well-being ambitions are measured by a series of national

11. Leah Gibbons, et al., 'Regenerative Development as an Integrative Paradigm and Methodology for Landscape Sustainability,' *Sustainability* 10, no. 6 (June 2018): 1910. https://doi.org/10.3390/su10061910

12. Mariana Bozesan, *Integral Investing: From Profit to Prosperity* (Munich: Springer, 2020); the readiness of organisations to follow this model of investing is suggested by Bozesan to be informed on individual and team assessment.

13. Anne Snick, 'EU Politics for sustainability: systemic lock-ins and opportunities,' in *European Union and sustainable development: challenges and prospects*, eds. Arnaud Diemer, et al. (Brussels: Oeconomia, 2017), 3–22.

14. Kate Raworth, *Doughnut Economics: Seven Ways to Think Like a 21st Century Economist,* ed. Joni Praded (Vermont: Chelsea Green Publishing, 2017).

15. For instance, Cornwall County Council (in southwest England) is applying doughnut thinking to shape their decision-making processes during project, policy, or service design as well as for commissioning and procurement and budget setting.

16. 'A Globally Responsible Wales,' Future Generations Commissioner for Wales, para. 1, accessed January 12, 2022. https://t.ly/Wymd.

indicators[17] and the Welsh Government has produced a range of targeted resources to help councils adapt to a new way of governing through well-being objectives.[18]

By the same token, economies are being shaped towards ethical markets at different scales. Dixon has argued that 'system change investing' is required to end 'myopic thinking' based on a reductionist logic of profit-seeking, ensuring that human endeavours respect the limits of nature and strengthen collective responsibility toward this end.[19] In this light, Zadek suggests that the financial sector has a duty to make low-carbon growth pay to investors but doing so effectively means reorientating the financial system to effect meaningful change.[20] Moreover, Ulrich urges 'integrative economic ethics,' which entails that modern economies need to develop ethical principles that regulate market competition.[21]

Today, there are many initiatives promoting environmental, sustainability, and governance (ESG) within investment platforms, e.g., the Equator Principles,[22] Global Impact Investment (GIIN),[23] Impact Reporting Investment Standard (IRIS),[24] and the Global Reporting Initiative (GRI),[25] all of

17. 'Wellbeing of Wales: National indicators. Data and summaries for each of the national well-being indicators,' Welsh Government, December 15, 2021. http://bitly.ws/rCFx

18. 'Well-being of Future Generations (Wales) Act: Guidance 2015,' Welsh Government, last modified May 28, 2020. https://t.ly/85eP

19. Dixon, *Global System Change,* 232.

20. Simon Zadek, 'Financing a Just Transition,' *Organization & Environment* 32, no. 1 (August 2018): 18–25. https://doi.org/10.1177%2F1086026618794176

21. Peter Ulrich, *Integrative Economic Ethics: Foundations of a Civilized Market Economy* (New York: Cambridge University Press).

22. 'About the Equator Principles,' Equator Principles Association, accessed May 23, 2022. http://bitly.ws/rCGC. The Equator Principles are a financial industry benchmark for determining, assessing, and managing environmental and social risk in projects.

23. 'What World Are You Investing In?' Global Impact Investment Network, accessed May 23, 2022. https://thegiin.org/. Membership to the GIIN network allows impact investment businesses to access information and resources to support the industry.

24. 'Impact Reporting Investment Standard (IRIS), Global Impact Investment Network, accessed May 23, 2022. https://iris.thegiin.org/. This system, which is related to the GIIN, measures and manages impact in the financial sector where social or environmental impact is a primary driver.

25. 'GRI Standards English Language,' Global Reporting Initiative, accessed May 23, 2022. http://bitly.ws/rD6Q. The Global Reporting Initiative is a reporting standard on various environmental, social and economic issues and can be applied across all organisations (universal standards) or are specific to different sectors (sector standards) or to specific topics (Topic Standards).

which are positive signs of greening of financial investment standards. At a global level, the Task Force for climate-related disclosure (TCFD) was created by the international Financial Stability Board to help standardise climate-related impact reporting among financial institutions. The UK's sustainable disclosure requirement (SDR) will also drive up the regulatory pressure for financial institutions to report against a green taxonomy, which had its roots in the EU green taxonomy framework and will be aligned to the TCFD.[26] From April 2022, large companies (with a turnover of GBP 500m and 500 employees) will be required to report climate-related impacts, the first G20 country to do so. At a micro-level, there are also emerging financial mechanisms to incentivise green action by individuals and organisations, and green crypto-currencies such as the ECO Coin[27] that while are currently niche ideas, could provide a potential mechanism to link financial and organisational systems to sustainable behaviours.

Yet, despite various policy initiatives and commitments, the global economy remains predominantly-growth centred.[28] Additionally, some scholars have asserted that the sustainability transitions literature, which explores the conditions to achieve more sustainable societies, so far has not fully engaged with research in environmental economics or considered the pricing of negative externalities.[29] Meanwhile, Avelino questions the 'reinforcive' aspects of 'borrowing' ideas from dominant global institutions, which may act to perpetuate established development practises at the expense of more transformative

26. See Josie Murdoch, Ana Musat, and Nick Mohlho, *Financing the Future: driving investment for net zero emissions and nature restoration* (London: Aldersgate Group, 2021). https://tinyurl.com/2yy6hdtf. They provide an excellent summary of how the UK's financial institutions should be reorientated to meaningfully contribute to net-zero policy targets and outcomes.

27. 'About,' ECO Coin, accessed May 22, 2022. https://www.ecocoin.com/. ECO Coins are earnt by taking actions that contribute towards a sustainable future in exchange for products, services, or experiences.

28. Derk Loorbach, et al., 'Transformative innovation and translocal diffusion,' *Environmental Innovation and Societal Transitions* 35 (June 2020): 251–60. https://doi.org/10.1016/j.eist.2020.01.009

29. Jeroen C.J.M. van den Bergh, 'A third option for climate policy within potential limits to growth,' *Nature Climate Change* 7, no. 2 (February 2017): 107–12. https://doi.org/10.1038/nclimate3113 approaches.[30] This, in turn, leads to inequalities, extending democratic deficits, or co-opting the appropriation of environmental governance discourse.[31]

Accordingly, what is needed is a broader conceptualisation of value and resources in the context of sustainable production and consumption where the institutional environment allows for such interaction to flourish.[32] As Reuter argues, transforming dominant cultural narratives will require a 'quantum leap in consciousness' to transform our attitude toward nature; doing so can simultaneously change our 'social ecology;'[33] that is, the way humans relate to one another to secure fairer outcomes. For resilient social and ecological systems to flourish, it required to have 'a high degree of diversification and the maintenance of a dynamic web of mutual interdependence relationships that capitalises from such diversity.'[34]

Yet, while its effects are localised at the community level, climate change works at a systemic level with epidemic tendencies, spreading rapidly across (social) ecosystems. Moreover, for communities to be resilient and liveable in the future, the onus needs to effectively link communities with comparable and meaningful measures of 'sustainability.' This is also to reduce the risk of a 'schizophrenic' green economy emerging where, as consumers, we prioritise material advancement that may be at odds with positive environmental outcomes. These observations highlight the need to rethink the nexus of values, democracy, and resource distribution toward an inclusive circular economy.

30. Flor Avelino, 'Power in Sustainability Transitions: Analysing power and (dis)empowerment in transformative change towards sustainability,' *Environmental Policy and Governance* 27, no. 6 (November/December 2017): 505–20. https://doi.org/10.1002/eet.1777

31. Eric Swyngedouw, 'The Non-political Politics of Climate Change,' *ACME: An International Journal for Critical Geographies* 12 no. 1 (2013): 1–8. http://bitly.ws/rD7r

32. Peter Bradley, 'An Institutional Economics Framework to Explore Sustainable Production and Consumption,' *Sustainable Production and Consumption 27* (July 2021): 1317–39. https://doi.org/10.1016/j.spc.2021.02.035.

33. Thomas Reuter, 'Principles of Sustainable Economy: An Anthropologist's Perspective,' *CADMUS* 3, no. 2 (May 2017): 146. http://bitly.ws/rHfP

34. Ibid., 131.

5.2. Defining and Measuring Transformative Innovations

Loorbach et al. define transformative innovations as 'shared activities, ideas, and objects across locally rooted sustainability initiatives that explore and develop alternatives to incumbent and (perceived) unsustainable regimes that they seek to challenge, alter or replace.'[35] They suggest that transformative innovations are stimulated through networking across scales, i.e., through 'translocal networks,' to share discourse, objects, and practises.[36] These authors outline how the TRANSformative Social Innovation Theory (TRANSIT) project[37] captured 450 'critical turning points' in a database, drawing on semi-structured interview data with 80 initiatives.[38] Meanwhile, the accelerating and rescaling transitions to sustainability project (ARTS) identified the mechanisms of growth and diffusion through which sustainability initiatives develop and found similarities between initiatives in terms of learning and exchange in different types of regions.[39]

This chapter suggests that introducing multi-level indicators of sustainability action can help to capture such similarities of learning and exchange and the extent turning points occur within and outside different systems. This could have a wider bearing on the study of 'deep transitions'[40] or the way societal systems interact and how value systems are created and transformed. In this train of thought, we explore the potential to quantify and thereby cultivate transformative innovations through the practise of monitoring and evaluation (M&E),

35. Loorbach, et al., 'Transformative innovation,' 252.

36. Ibid.

37. 'Transformative Social Innovation Theory,' TRANSformative Social Innovation Theory, accessed September 7, 2020, http://t.ly/PLz8; 'The TRANSIT Project,' Dutch Research Institute for Transitions, accessed September 7, 2020. https://t.ly/AOTT

38. Bonno Pel, et al. *The Critical Turning Points database; concept, methodology and dataset of an international Transformative Social Innovation comparison (Working Paper)* (TRANSformative Social Innovation Theory, 2017). http://bitly.ws/rFdK

39. Loorbach, et al., 'Transformative innovation.'

40. Laur Kanger and Johan Schot, 'Deep transitions: Theorizing the long-term patterns of socio-technical change,' *Environmental Innovation and Societal Transitions* 32 (September 2019): 7–21. https://doi.org/10.1016/j.eist.2018.07.006

a well-established field within international development and policy impact studies. More recently, sustainability transition studies have expanded to embed accountability and learning practises, encouraging reflective feedback and information sharing on results. For instance, Strasser et al.'s 3D framework emphasises the depth (impact), width (reach), and length (stability and duration) of transitions through a process of learning within networks.[41]

Though, while local governments may have routine sustainability monitoring procedures, these vary across countries and in some cases may be very weak or non-existent. Community-led initiatives sometimes may perceive M&E as onerous or lacking the resources and knowledge required to access evaluative tools,[42] which affects the extent they can commit to robust reflective processes. Particularly revealing is that international funding for data and statistics has been at half the level the UN suggests is required.[43]

5.3. Opportunities and Challenges of Using the SDGs for Transformative Action

Adopted in 2015 and agreed by 193 member states of the United Nations, the SDGs encompass a broad range of economic, social, and environmental dimensions of sustainable development. Likewise, they set specific targets for the implementation of 17 goals with an associated 169 targets. Many local councils have also declared climate (and sometimes ecological) emergencies as a means of publicly stating the need for more action to address sustainability. Indeed, the Local Government Association (LGA) and the UK Stakeholders for Sustainable Development (UKSSD) posed that when a local council has declared a climate emergency, the best way to galvanise action and change behaviour is

41. Tim Strasser, Joop de Kraker, and René Kemp, 'Developing the Transformative Capacity of Social Innovation through Learning: A Conceptual Framework and Research Agenda for the Roles of Network Leadership,' *Sustainability* 11, no. 5 (March 2019): 1304. https://doi.org/10.3390/su11051304

42. Amy Merritt and Tristan Stubbs, 'Incentives to Promote Green Citizenship in UK Transition Towns,' *Development* 55, no. 1 (March 2012): 96–103. https://doi.org/10.1057/dev.2011.113

43. United Nations. *The Sustainable Development Goals Report 2020* (Geneva: United Nations Statistics Division, 2020). https://tinyurl.com/2p9fsst8 to follow the SDGs since these latter enable councils and local people to think strategically, use a common language, and be accountable.[44]

The SDGs seek to capture the multi-dimensional aspects of sustainable development, with associated global indicators[45] reported mainly at the national scale, with approximately two indicators for each target (or 300 indicators in all). Governments are also free to develop their national indicators to track progress. At the city-scale and beyond, some local governments are departing from the discursive parameters of a growth-centred logic such as Liverpool City Council's (England) commissioning of a local group to map the Mayor's inclusive growth plan against targets and indicators of the SDGs.[46] Moreover, the UK's Thriving Places Index identifies the local conditions for wellbeing and measures whether those conditions are being delivered fairly and sustainably.[47] Furthermore, the Royal Town Planning Institute (RTPI) has produced a toolkit for UK and Irish planners to use in their work that focuses on outcome-based valuation within land-use and strategic planning aligned to the SDGs.[48]

However, the extent of monitoring and reporting of SDGs into local systems has been low. In addition, while initiatives such as the Thriving Places Index are extremely welcome to map the progress (or lack thereof) among and between urban areas, such information could be more explicitly tied to incentives that promote the sharing of best practise. This should be particularly done in 'least performing' or 'deprived' areas for encouraging people to share insights with others in the first place. At the same time, those deemed to be underperforming in some areas need to have resources available so that they can draw on a fair exchange of sustainability knowledge and practises. It is paramount

44. Local Government Association and the UK Stakeholders for Sustainable Development. *UN Sustainable Development Goals: A Guide for Councils* (London: Local Government Association, 2020). https://tinyurl.com/3h6vnufh

45. 'SDG Indicators,' United Nations Statistics Division, accessed September 14, 2020, https://t.ly/GEar

46. UK Government, *Voluntary National Review of Progress towards the Sustainable Development Goals: United Kingdom of Great Britain and Northern Ireland* (London: Department for International Development, and Foreign, Commonwealth & Development Office, 2019). http://shorturl.at/dkDGM

47. 'Thriving Places Index,' Centre for Thriving Places, accessed March 25, 20221, https://t.ly/05i5

48. 'Measuring What Matters: Planning Outcomes Research,' Royal Town Planning Institute, accessed January 17, 2022. http://t.ly/vqUK to incentivise people interested in similar issues to reach out and support one another through mutually supportive horizontal governance, which may cut across traditional administrative or national boundaries to include those grappling with similar issues, e.g., in a forum-based arena.

Meanwhile, the SDGs tend to focus on the symptoms of unequitable organisations, not the root causes of inequality, environmental unsustainability, or broader systemic constraints.[49] In fact, the SDGs may restrict more transformative approaches to economic growth: they do not call on governments to change the limited liability model of corporate governance, reform taxation systems, or orient economic systems to better reflect the true value of the environment.[50] An alternative to the SDGs is the One Planet Living (OPL) principles.[51] While these echo many of the objectives of the SDGs,[52] OPL principles emphasise *equity* overgrowth.[53]

Opportunities and shortfalls of current assessment processes reveal what is still required to develop a truly holistic framework for cultivating and measuring sustainable outcomes. Additional improvements relate to longer-term assessment and monitoring more broadly,[54] particularly where this involves assessing the health of ecosystems through a combination of selected indicators.[55] Much of global climate science is localised, whereby policy-makers seek to legitimise technical and political decisions often through co-production for stakeholders to situate local issues within broader climate change issues.[56] However, research indicates that there is little demand for climate projections

49. Dixon, *Global System Change.*

50. Ibid.

51. 'One Planet Living,' Bioregional, accessed September 7, 2020. http://t.ly/iSth

52. See 'The 17 Goals,' United Nations, accessed September 7, 2020. http://sdgs.un.org/goals

53. For example, SDG 8 'Decent Work and Economic Growth' compares to OPL 2 'Equity and local economy.'

54. Erika Y. Chin and John A. Kupfer, 'Prevalence of Ecological, Environmental, and Societal Objectives in Urban Greenway Master Plans,' *Southeastern Geographer* 59, no. 2 (Summer 2019): 153–71. https://doi.org/10.1353/sgo.2019.0013

55. Margaret A. Palmer and Catherine M. Febria, 'The Heartbeat of Ecosystems,' *Science* 336, no. 6087 (June 2012): 1393–94. https://doi.org/10.1126/science.1223250

56. Jason Corburn, 'Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science,' *Urban Studies* 46 no. 2 (February 2009): 413–27. http://dx.doi.org/10.1177/0042098008099361 to inform local planning adaptation due to existing policy and legal and regulatory frameworks hampered by changes in the regulatory environment and austerity measures.[57]

Against a backdrop of ever-changing governments and political priorities, can a harmonisation of approaches to sustainability reporting be achieved? How can this be incentivised and how much standardisation is desirable across different contexts? We suggest that M&E tools need to be integrated to respond to the challenge of capturing progress towards the SDGs whilst being able to be used by a range of different stakeholders in such a way that they promote a circular response to climate action. Such an endeavour requires greater attention to the transition governance around incentive structures, data management, and knowledge exchange for sustainability action.

5.4. Promising Avenues in Alternative Measurement of Transformative Metrics

Environmental, sustainability, and governance (ESG) factors are considered in investment decisions on an increasingly routine basis. Some frameworks such as total corporate responsibility (TCR), which was developed in 2003, seek to hold stakeholders accountable for their actions to engender system change. TCR includes metrics linked to higher-level economic, social, and political change, for instance, government influence working with the third sector and addressing system flaws. The EU Sustainable Finance Strategy includes a Green Deal for Europe which aims to reorder European production models and includes ecocide as a crime against humanity in international law with the Environmental Court of Justice empowered to track its progress. In turn, the European Investment Bank (EIB) will fund the Green Public Works programme to inject public investment into green infrastructure, housing, and community projects

57. Rosalie Callway, Tim Dixon, and Dragana Nikolic, 'Embedding green infrastructure evaluation in neighbourhood masterplans – does BREEAM communities change anything?' *Journal of Environmental Planning and Management* 62, no. 14 (February 2019): 2478–2505. https://doi.org/10.1080/09640568.2018.1563371; Susanne Lorenz, et al., 'Adaptation planning and the use of climate change projections in local government in England and Germany,' *Regional Environmental Change* 17 (February 2017): 425–35. https://doi.org/10.1007/s10113-016-1030-3 through green investment bonds issued by the EIB. In the UK, the Environment Bank aims to leverage funds that 'invest in nature' and work with housing and commercial developers, planning authorities, and landowners to find solutions to deliver biodiversity net gain, i.e., demonstrable enhancements to nature and biodiversity as a result of development, this latter concept being now enshrined in the UK's Environment Act 2021.[58] The Act also encourages local nature recovery strategies which will cover the whole of England, recognising the integrated function of ecosystem services and the need for strategic enhancements for nature in specific areas.

The measurement of such enhancements can be captured through natural capital-based approaches, which measure the stock of natural assets from which various goods and services may be derived and upon which humans and other forms of life depend. Various monitoring and natural capital accounting schemes have been established by the UN[59] and the Millennium Ecosystem Assessment (MEA) to measure ecosystem capacities, resilience, and economic accountability to nature. [60] In the UK, natural capital accounting is mainstreamed by national government agencies, e.g., Natural England,[61] and at the regional scale, such as the Greater Manchester Combined Authority.[62] These demonstrate the value of natural assets such as recreation and water to social outcomes such as amenity value, mental health and physical health, air quality, food, and flood risk.

Natural capital-based approaches can be classified into the provision of food and water, the regulating functions of natural ecosystems, supporting

58. UK Government. Environment Act 2021: https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted

59. 'System of Environmental Economic Accounting,' United Nations, accessed April 3, 2022. https://t.ly/N7vI

60. *Millennium Ecosystem Assessment, Ecosystems and human well-being: synthesis (Washington, DC: Island Press, 2005).* http://bitly.ws/rFgA

61. Natural England, *Accounting for National Nature Reserves: A Natural Capital Account of the National Nature Reserves managed by Natural England (NERR078), 2nd edition* (London: Natural England, 2019).

62. 'Natural Capital Account for Greater Manchester,' Economics for the Environment Consultancy, accessed April 4, 2022. https://shorturl.at/lrD16 lifeforms, and the cultural, spiritual, and recreational benefits to nature.[63] The late Colin Tingle coined the term 'naturegain'[64] to account for the added value nature gives us. Weber has also suggested that metrics of ecological value could be based on ecosystem capability units (ECU); these could measure public goods such as regulation of water, climate, air quality, biodiversity, and sustainability of assets and services as 'ecological value'[65] and 'ecosystem capability accounting.'[66] Weber posits that ECU is 'a composite currency to measure ecological values: ecosystem capability degradation and enhancement, ecological debts and receivables,'[67] which can be calculated in basic units (tons, m^3, or ha) and then be saved and transacted.

Nonetheless, the monetising of nature – and related emerging nature-based offsetting markets - has been critiqued by a number of scholars for its potential to commodify natural public good benefits. For instance, Victor affirms that valuations of the cost of environmental change have 'serious flaws in standard welfare economics.'[68] This is due to the way value is assumed within a rational choice theory of change.[69] Moreover, the notion of capital has encroached into non-market spheres that represent a neo-liberalisation of social value.[70] Additionally, Victor argues that there are issues with comparative calculations of abundant natural resources and their depletion, which makes definitions of monetary value arbitrary.[71] Likewise, another key concern is that 'estimates of the monetary value of ecosystem services are meaningful if and only if there are

63. Peter A. Victor, 'Cents and nonsense: A critical appraisal of the monetary valuation of nature,' *Ecosystem Services* 42 (April 2020): 101076. https://doi.org/10.1016/j.ecoser.2020.101076

64. Ecosystem Knowledge Network, *Involving local communities in the recognition of what nature does for people: Field visit to Lewes and Ouse Valley eco-nomics group* (Wallingford: Ecosystem Knowledge Network, 2014). http://bitly.ws/rFuG

65. Weber, 'Need an Ecological Currency.'

66. Jean-Louis Weber, 'Ecosystem Capability Accounting,' Ecosystem Capability Accounting, last modified November 25, 2014, http://www.ecosystemaccounting.net/

67. Weber, 'Need an Ecological Currency,' 6.

68. Victor, 'Cents and nonsense,' 1.

69. Ibid.

70. Ibid.; Marion Fourcade, 'Cents and Sensibility: Economic Valuation and the Nature of "Nature"', *American Journal of Sociology* 116, no. 6 (May 2011): 1721–77. http://dx.doi.org/10.1086/659640

71. Victor, 'Cents and nonsense.'

market-based substitutes available that people consider are sources of equivalent value.'[72]

Still, as Merritt and Stubbs point out, forms of exchange need not be driven solely by financial forms of exchange. Non-monetary forms of exchange such as Timebanking (where people exchange time and build up time credits through non-monetary exchanges with others to provide goods and services) also provide a form of resource exchange to facilitate sustainable action projects based on the long-term informal economic practise of bartering.[73] A more recent form of social exchange in the UK, borne out of the Covid-19 pandemic has been FurloughGo[74] whereby furloughed members of staff could offer their (voluntary) services to charities that need expertise and additional resources. The social movement SumOfUs has also established a Covid Support Network that aims to match unmet needs and people providing support.[75]

Consequently, there is potential to see beyond the term 'capital' as an intrinsically negative term. Rather, it is worth assessing how value mechanisms can encompass societal forms of value and exchange, including approaches that challenge neo-liberalism and solicit a move towards the sharing economy, or the 'new economy.' This latter term is a meta-narrative for communing, sharing, and regenerative economics. Here, value can be embedded in informal green monetary initiatives that can quantify ecosystem capital degradation impacts and incentivise their restoration such as ecological currencies. In this

72. Ibid., 2.

73. Amy Merritt and Tristan Stubbs, 'Complementing the Local and Global: Promoting Sustainability Action Through Linked Local-Level and Formal Sustainability Funding Mechanisms,' *Public Administration and Development* 32, no. 3 (June 2012): 278–91. https://doi.org/10.1002/pad.1630

74. Her Majesty's Revenue and Customs, 'Check if you can claim for your employees' wages through the Coronavirus Job Retention Scheme,' GOV.UK, last modified October 15, 2021, http://t.ly/xbw3. In the UK, the term 'furlough' was used to describe an employee who was temporarily not working as their employer has applied to the UK government's furlough scheme. This meant that staff, whose roles were affected by the pandemic (e.g., loss of demand for services offered in these roles such as hospitality or travel sectors), were paid a proportion of their salary by the government. In most cases, furloughed staff were permitted to work whilst receiving such government support although there were cases of 'flexible furlough,' i.e., staff worked on certain days if they were affected by the closure of schools.

75. This network was formed to act as a mechanism to bring together those in need and those offering assistance to meet unmet needs caused by the Covid-19 pandemic whereby SumOfUs created a centralised, global response system. Though, since the pandemic the platform appears to be mainly used by those seeking support in the Global South. See SumOfUs Covid Support Network. https://aid.sumofus.org/en vein, building upon Figge and Hahn's proposition of the term 'sustainability capital,'[76] we argue that generating a quantifiable and tradeable value of 'greening' could help to shift behaviours and system logics towards those that show a distinct move towards sustainable pathways. As we discuss below, positive externalities may be accrued by cultivating more regenerative value by means of which mutually reinforcing enhancements to people and the planet can be quantified, incentivised, and formalised. As NOW Partners suggest, initiatives such as B-Corps, which is a certification of 'social and environmental performance' lead to a 'new economic DNA' that recalibrates how organisations and individuals interact in positively transformational ways.[77]

However, while B-Corps are a necessary self-regulatory tool to reflect environmental and social business practises, the economic system still requires additional mechanisms to overcome free-riding 'by creating incentives to reward cooperation and to sanction violations.'[78] Below, we discuss how such institutional parameters might be established within (sustainable) market and beyond-market mechanisms to feed into a self-generating circular economy, in addition to incentivising transformative governance capabilities. We also document some indicative moves towards forms of regenerative value by way of an example of how quantification and exchange can engender a shift towards more sustainable outcomes.

5.5. Regenerative Value and Associated Governance Components

Regenerative value is similar to Weber's ECU to the extent that it assesses change according to measurable aspects of environmental value and Figge and Hahn's 'sustainability capital.' However, it also has a more extensive systemic reach. Regenerative value is proposed herein as 'a form of value that is produced when

76. Frank Figge and Tobias Hahn, 'The Cost of Sustainability Capital and the Creation of Sustainable Value by Companies,' *Journal of Industrial Ecology* 9, no. 4 (February 2008): 47–58. https://doi.org/10.1162/108819805775247936

77. 'The B business potential: Why multinationals become B Corps,' accessed March 26, 2021, https://t.ly/SzIK

78. Brian Walker, et al., 'Looming global-scale failures and missing institutions,' *Science* 325, no. 5946 (September 2009): 1345–46. https://doi.org/10.1126/science.1175325 other value dimensions act in tandem to produce sustainable outputs or outcomes, calculated and circulated through linked governance mechanisms that promote the common good.'[79] This concept extends the important research by Flora and Flora who proposed the idea of a 'community capitals framework' to help communities foster a systemic approach to generate positive outcomes in their communities by mapping different levels of different capitals via indicators, i.e., units of analysis that measure specific changes.[80] Yet, to avoid a charge of attributing these forms of social and environmental value within a capitalist framework, the figure below outlines the components of regenerative value based upon other types of 'values,' [81] rather than 'capitals.' The aggregate interaction in these different fields can be quantified through a regenerative value score through (common) indicators and reporting tools and exchanged by both financial and non-financial means to further incentivise sustainability action.

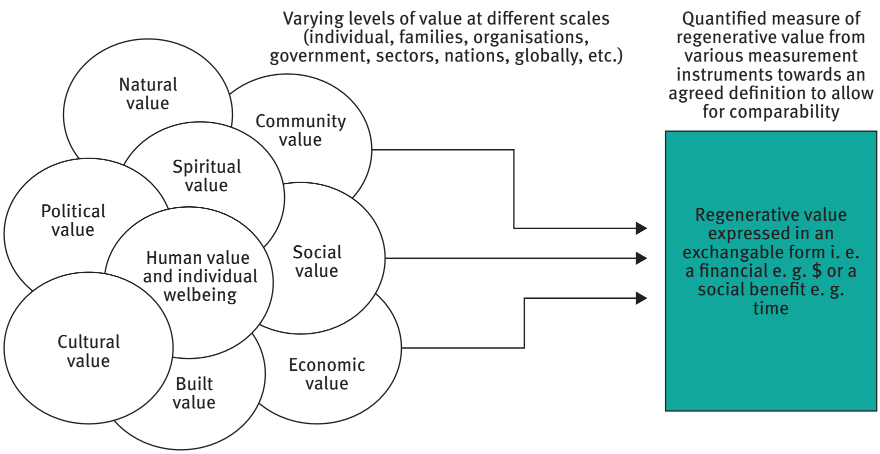

FIGURE 4. Inputs in a Regenerative Value Framework

Source: Prepared by the author based on Flora and Flora.[82]

79. Amy Burnett 'Regenerative and just planning,' 126.

80. Cornelia Butler Flora and Jan L. Flora, *Rural Communities: Legacy and Change, 3rd Edition* (Boulder: Westview Press, 2007).

81. Figure 4 also emphasises spiritual value as an important component that can be linked to well-being, community, social or natural value but could also transcend these as its own field.

82. Flora and Flora, *Rural Communities.*

Regenerative value could reduce carbon emissions, rejuvenate local economies, and drive action by circulating within the local economy and influencing national GDP to become more sensitive to environmental and social dimensions. This echoes a greening of municipal social activism pioneered by the US city of Cleveland (Ohio) and Preston (UK) where 'community wealth building'[83] cultivated partnerships with 'anchor institutions' to keep wealth in the area. Such an approach has also been suggested by Hines who speaks of *localisation* as 'a process which reverses the trend of globalisation by discriminating in favour of the local.'[84]

Those seeking paradigm shifts away from neo-liberal economics go further. The Post Carbon Institute, for example, suggests re-localisation as a greening of locally situated socio-economic systems, including local food, energy, currency, and governance tied to social equity.[85] Mechanisms to promote regenerative value might combine a locally rooted approach through the reinforcing links within systems that promote re-localisation at different scales tied to a more-than-local change agenda. Some illustrative examples of regenerative value in action are detailed in the table below.

To realise regenerative value and associated mechanisms at different scales this chapter revisits the author's previous ideas[86] and reflects on their suitability and potential adaptability to a post-Covid recovery model against some of the themes proposed by the Transformative Metrics October 2020 conference organisers.[87] Also, we draw on Bakker's insight that 'a better understanding of actor rationales can be of help to the design of incentives for actors to take part in niche activities (i.e., which incentives are likely to trigger different actors?).'[88]

83. See more information and many examples published by the US think tank at 'Community Wealth Building,' Democracy Collaborative, accessed May 23, 2022. https://democracycollaborative.org/cwb

84. Colin Hines, *A Global Look to the Local Replacing economic globalisation with democratic localisation* (London: IIED, 2003), 5.

85. 'Relocalize,' Post Carbon Institute, accessed May 27, 2019, https://www.postcarbon.org/relocalize/

86. See Merritt and Stubbs, 'Complementing the Local;' Merritt and Stubbs 'Incentives to Promote;' Burnett 'Regenerative and just planning.'

87. 'Transformative Metrics Workshop Call,' Transformative Innovation Policy Consortium, accessed January 17, 2022, http://t.ly/vLFK

88. Sjoerd Bakker, 'Actor rationales in sustainability transitions – Interests and expectations regarding electric vehicle recharging,' *Environmental Innovation and Societal Transitions* 13 (December 2014): 61. https://doi.org/10.1016/j.eist.2014.08.002

TABLE 11. Examples of Regenerative Value in Action

Sector	Examples	Details	Strengths	Weaknesses
Energy	Feed-in-Tariff	Policy incentive that rewards installation of renewable energy with a guaranteed financial reward over a specific time period (usually 20 years).	It encourages the uptake of renewable energy for domestic, commercial, and community energy.	It is dependent on government funding and support. Cuts can damage the renewable energy sector.
Housing	Green Leases Environment Bank	A 'green lease' incorporates clauses whereby the owner and the occupier undertake specific responsibilities/obligations with regard to the sustainable operation/occupation of a property, for example, energy efficiency measures, waste reduction/management, and water efficiency.	It fosters investment in green infrastructure in the real estate sector.	It may engender inequalities and prioritise those who may afford a green premium.
Finance	Green Bonds	Leverages investment and directs towards ESG outcomes.	It boosts the greening of the financial sector.	Some carbon-intensive investments may have a higher return.
	Eco-Coin	A cryptocurrency where credits are earned through sustainable actions; coins are stored in digital wallets accessible through a mobile platform. Sustainable actions are verified by and rewarded by certified vendors.	It incentivises the greening of consumer behaviour.	It is still relatively 'niche' and wider benefits are not mainstreamed. It may be a mismatch to vendor: consumer needs.

Sector	Examples	Details	Strengths	Weaknesses
Environment	Environmental Net Gain	A form of ecosystem-based payment that encourages a positive net environmental benefit.	It can help to realign and reaffirm nature-based approaches to mainstream development practise.	It depends on policy measures to be effectively implemented and regulated. It requires investment in local planning authorities and local/national policy alignment.
Indexing	Thriving Cities Index	It monitors well-being and sustainability metrics across towns and cities.	It allows comparability and monitoring of sustainability and well-being within and across places.	It is UK-based not global.
Data	ClimateView	ClimateView is a climate action technology company that combines scientific modelling, machine learning, and interface design to help cities understand and act on the complexities associated with climate change.	It mines data from extant published sources to inform sustainability baseline. It maps pathways associated with SDGs.	It lacks an integrative focus on well-being and nature. It works with some Global North cities, but with not a global approach yet.
Multisectoral	Social Value and the National TOMS metrics (themes, objectives, and measurement)	Under the UK's Public Services (Social Value Act 2012) under which public entities need to report their contribution to social and environmental outcomes, including well-being. A method of reporting and *measuring* social value to a consistent standard from the Social Value Portal.	It provides standardised metrics for quantifying social value for both public and private companies.	It converts values into proxy financial values, thus not moving beyond market valuation.

Source: Prepared by the author.

5.6. Targets and Incentives towards a Greening of the (Social) Economy: Recommendations to Cultivate Regenerative Value

Identifying Alignment between Social Needs and Socio-Technical Systems

The creation of regenerative value should be linked to both formal and informal value creation (e.g., taxation and the private sector: banks and formal investors), new financial innovations (including redistributive offset markets), and grassroots financing mechanisms (e.g., TimeBanking, community currencies, community share schemes, and peer-to-peer lending). The latter are crucial because they have the potential to account for the social dimension by way of a community-driven allocation of sustainability financing. Taxation linked to regenerative value and an embedded fair redistributive element could mean that governments play a key role in supporting community-led sustainability initiatives, incentivising action, and ensuring local-level ownership or capacity benefits towards sustainability action.[89] On the other hand, emerging offset markets for ecosystem services might be linked to the value of local currencies and local nature recovery strategy outcomes. This could help to quantify and price localised impacts of pollination, water purification, flood protection, and climate regulation on the local economy and environment.

Flows of regenerative value could be created from a tax on the extent to which services and products generate or deplete value dimensions. An example of this is organic farming that enhances biodiversity and can become more affordable if it is paid out of regenerative value tax on some products, e.g., that use unsustainable palm oil or cause soil depletion.[90] In this regard, price differentials, poverty, and inequality would need to be seriously considered but such a mechanism might help to redistribute the absorption of the impacts of negative agricultural practises onto companies rather than the end consumer.

89. Merritt and Stubbs, ‘Complementing the Local.’

90. See the UK’s Environment Act 2021 for progressive approaches to ending illegal deforestation: https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted

This, in turn, could make healthy food with a positive environmental benefit more affordable due to the dynamics of supply and demand.

A regenerative value label with the net value of embodied sustainability could be incorporated into the packaging of different products, services, or even buildings.[91] Having a regenerative value reward system that can be accumulated through purchases is one possibility. Other locally raised green taxes that promote low-carbon, equitable outcomes should also be explored. Measuring, through regenerative value metrics, the value of formal and informal exchanges and how these co-generate value will help identify and study misalignments and alignments between social needs and demands and broader socio-technical systems. Integrating regenerative value within doughnut economic models to further incentivise action is another possibility; that is, accounting for a definitive and exchangeable value for sustainable policies, goods, and services that work within planetary boundaries. However, policy measures would be required so that carbon liabilities rest with consumers of finished goods, not just producers, i.e., pricing unsustainable commodities and services so they become less desirable within an entire value chain.

Identifying the Structure of Current and Possible Future Socio-Technical Networks

If organisations register their skills, capacities, needs, and interests on a searchable platform, this might help locate resources to match stakeholders within systems. There are already many online 'sustainability action platforms' that aim to encourage lesson sharing and peer-to-peer support on sustainability issues.[92] Such platforms have the potential to further match individuals and groups to similar projects within communities in a given region, sector, or with communities across the world, either online or through an app, with obvious issues in literacy and access to the internet duly considered and addressed. This

91. See: Sophie Lavallée and Sylvain Plouffe, 'The ecolabel and sustainable development,' *The International Journal of Life Cycle Assessment* 9, no. 6 (January 2004): 349–54. http://dx.doi.org/10.1007/BF02979076

92. Oliver Bream-McIntosh, et al., *Can Sustainability Knowledge-Action Platforms Advance Multi-Level Sustainability Transitions? (Paper submitted for peer review)*. Zenodo, last modified January 18, 2022. https://doi.org/10.5281/zenodo.5873822 would allow for targeted 'capacity matchmaking' and help to pool resources to support sustainability initiatives.[93] All in all, using a platform to map these resources and connections in different contexts over time with social network analysis methods would help identify the structure of current, and possible future, socio-technical networks; data tagging to inform knowledge flows within networks can assist in this endeavour.

Participative Mapping and Resourcing as a Means to Catalyse Niche Innovation and Enhance the Potential for Scaling Up

Merritt and Stubbs suggest establishing 'community savings banks' (CSBs) if constituted as a cooperative, to leverage and collectively distribute sustainability resourcing. This could draw on both financial (economic-local and economic-national/international) and social (TimeBanking) resourcing schemes. Members, i.e., individuals or groups, might request time, grants, loans, or micro-credit from the CSB to fund local sustainability projects,[94] which may be decided through a form of public vote either in-person or online. For instance, the Local Entrepreneurs Forum in Frome, Somerset, and the Community of Dragons in Totnes, Devon (both towns in England) offer inspiration for a model that matches ideas and resources in specific places, but also in a global platform-based network. Inspired by a 'Dragons Den' format with the audience acting as the 'Dragons' pledging their support and assisting start-up projects, interesting projects and ideas can be resourced with financial and/or non-financial investment such as time and materials or through regenerative value.

The amount of time, resources offered, and consumed/absorbed over time through the CSB would indicate the health of grassroots initiatives compared to their relative outcomes and their capacity to generate regenerative value. Thus, this will provide a proxy of types of resources vs. effort expended to indicate the overall health of niches. Embedding an annual assessment of progress, or a health check might identify the reasons initiatives fail to scale up or decide not to follow particular actions.

93. Merritt and Stubbs, 'Incentives to Promote Green.'

94. Ibid.

Identifying and Analysing Interactions across Socio-Technical Systems

Monitoring different forms of value and financial flows (including intergovernmental transfers) through sustainability metrics (such as the SDGs) can also direct investments in climate mitigation and adaptation to address wider capacity issues within communities.[95] Merritt and Stubbs, also suggest establishing a local sustainability index (LSI) which could rank community progress in generating regenerative value similar to the FTSE4Good Index[96]. An LSI could capture localisation and community wealth building by monitoring impacts from the local private sector and could function at an organisational, sectoral, or governmental level. At the community level, there might be a redistributive element or a 'circular index' where those doing well in a given area support others doing less well to 'level up,' communicated extensively within communities and through a platform ecosystem. It could also include political sustainability indicators to move beyond the 'three-legged stool' of sustainability.[97]

Meanwhile, some Covid-19 response initiatives that have emerged to promote unmatched skills, resources, and experiences such as UK FurloughGo could inspire an integrated global sustainability platform that encourages sharing and the solidarity economy, if sufficiently linked to other formal and informal mechanisms. The take-up of ideas and resources and how these are applied and monitored through the platform could be used to measure the flows of resource exchange and intensity. This might be categorised by initiative and indicators to measure regenerative value as well as how niche and regimes interact, e.g. informed through an assessment of niche ('innovation') /regime ('incumbent institution') characteristics and how personal and organisational dynamics affect barriers to sustainability transitions over time. It is important to consider that what may be a niche for one actor may be mainstream for others.[98] In addition, there are a plethora of online sustainability platforms, and

95. Ibid.

96. 'FTSE4Good Index Series,' FTSE Russell, accessed September 15, 2020. http://bitly.ws/rHaF

97. Amy Burnett, 'Planning for Transitions? A case study of Frome, Somerset (UK),' PhD diss. University of Reading, 2019. https://doi.org/10.48683/1926.00085827

98. Ibid.

more work needs to be paid to the interoperability of existing platforms rather than reinventing the wheel.[99]

Analysis of Incremental and Radical Change as Fast or Smooth Transitions

One potential idea is to embed tags within indicators or outputs and outcomes to measure the flow of interdependencies towards outcomes and eventual pathways to impact. This might be explored with artificial intelligence to trace the use of keywords (tags) over time and their embeddedness in certain contexts, institutions, or organisational forms. A platform architecture could be tied to the LSI over time and generate a map of the patterns of relationships, ideas, and networks over a given period. The LSI could then inform which and how many resources need to be disbursed according to indicators that map these patterns, which may or may not relate to the SDGs (i.e., enabling customised monitoring of indicators like wellbeing indicators).[100]

Combining the elements discussed in this section, below we propose a lifecycle of the creation and redistribution of regenerative value:

5.7. Conclusion

This chapter has sought to depict a system of interlocking, socially and ecologically transformative mechanisms to embed metrics geared towards incentivising sustainable action through regenerative value and help coordinate behaviour change and cross-sectoral value alignment. Regenerative value is not meant to detract from intrinsic motivations to act sustainably (i.e., doing something because you want to). Rather, regenerative value seeks to complement this through a form of compensation for acting sustainably to encourage additional action above and beyond what those already engaged are doing and therefore, activate latent socio-cultural potential through additional and co-produced incentives.

99. Bream-Macintosh, et al., 'Sustainability Knowledge-Action Platforms.'

100. Safe; Healthy; Achieving; Nurtured; Active; Respected and Responsible; and Included. Collectively they are often referred to as SHANARRI. See also Bream-Macintosh, et al., 'Sustainability Knowledge-Action Platforms.'

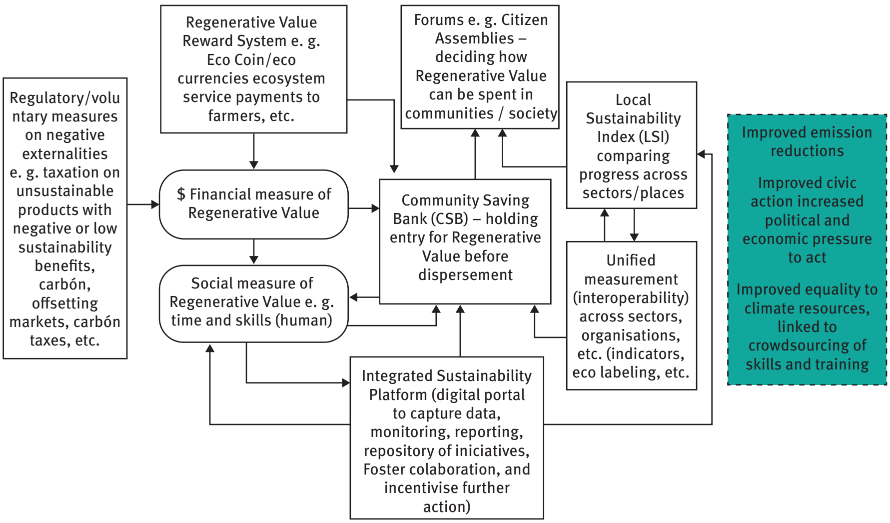

FIGURE 5. The Lifecycle of the Creation and Redistribution of Regenerative Value

Source: Prepared by the author based on the work of Merritt and Stubbs.[101]

This framework can work with the myriad of innovative and promising routes to transformation in our 'social ecology'[102] such as doughnut economics, B Corps, social value, and regenerative financial instruments as feed-in-tariffs, whilst stimulating inclusive and transparent decision-making on the mobilisation and allocation of sustainability resourcing. Effective monitoring where people feel part of an integrated framework and indexing of progress towards truly regenerative communities could also help to encourage circularity as the benchmark to work to. This would help to complement decentralisation and devolution ambitions by synergising creative partnerships and positive feedback loops to continually seek out regenerative value because it yields multiple benefits for people and the planet.

To be most effective, the initiatives discussed in this paper should be adopted on as a large scale as possible. All communities could create a co-produced local charter of values as a commitment to climate change, ecological health, and

101. Merritt and Stubbs, 'Complementing the Local;' Merritt and Stubbs, 'Incentives to Promote Green.'
102. Reuter, 'Principles of Sustainable Economy.'

socially responsible outcomes to help prepare for a regenerative economy and society. We need to find the right metrics to use that are simple enough and effective enough to account for what is important to us in every decision we make, which could be informed through a regenerative value score in the products we buy or the projects we invest in. In doing so, we could transcend financial metrics as the default mode of exchange and stimulate debate about how these values may be identified, created, and shared to boost a culture of regenerative value in the heart of our social ecosystems.

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Section 2:
Developing Transformations

6. Transformation and Enhancement of Climate Change Policy Indicators

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6.1. Introduction

To understand the effects of climate change policies not only on the environment but also on business and the economy, substantial effort has been devoted to creating climate policy indicators. Such indicators can be useful for addressing a major research question, namely: how do climate policies impact the economy and the environment? Likewise, in recent years there has been increasing interest in identifying reliable climate policy and governance indicators because of the explosion in green growth policies, especially in response to Covid-19.[3] Indeed, the amount of money earmarked for green growth is a major share. Policymakers thus need to know that this money is well spent and convey to their constituents the level of effectiveness. Similarly, investors and companies, in particular,

1. *University College London, Global Governance Institute. E-mail:* k.herman@ucl.ac.uk

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3. Caroline Kuzemko, et al., 'Covid-19 and the politics of sustainable energy transitions,' *Energy Research & Social Science* 68 (October 2020): 101685. https://doi.org/10.1016/j.erss.2020.101685 sustainably-minded investors and highly polluting companies have a big stake in how these emerging climate and green growth policies impact their businesses. Consequently, metrics for climate change governance are now more important than ever before.

Yet, we still do not have a good grasp on how firms and economies react to such policies.[4] Climate policy indicators should ideally be easy to calculate, produced annually, cardinal, and available to a large array of different pollutants.[5] Furthermore, these indicators ought not to only address certain sectors or industries but rather extend to broader parts of the economy and across countries.[6] More peripheral issues are the sensitivity to data revisions, variability in the data, and small sample issues.[7] These complexities and the numerous array of climate policies in place worldwide make indicators construction and transformation an arduous but important task.

To ameliorate the underlying issues of climate policy governance metrics and indicators, we suggest that machine learning (ML), pattern discovery, and deep learning (DL) techniques should be deployed. Whilst these methods are already well-developed in other fields of scholarship,[8] they have only just begun to be used within the climate change policy and governance space. This is the main crux of this chapter.

This chapter posits that transformative metrics are becoming increasingly relevant and important for climate and environmental governance, which is

4. Daniel J. Henderson and Daniel L. Millimet, 'Pollution Abatement Costs and Foreign Direct Investment Inflows to U.S. States: A Nonparametric Reassessment,' *The Review of Economics and Statistics* 89, no. 1 (February 2007): 178–83. https://doi.org/10.1162/rest.89.1.178; Claire Brunel and Arik Levinson, 'Measuring the stringency of environmental regulations,' *Review of Environmental Economics and Policy* 10, no. 1 (Winter 2016): 47–67. https://doi.org/10.1093/reep/rev019; Nicole M. Schmidt and Andreas Fleig, 'Global patterns of national climate policies: Analyzing 171 country portfolios on climate policy integration,' *Environmental Science & Policy* 84 (June 2018): 177–85. https://doi.org/10.1016/j.envsci.2018.03.003; David Popp, *Environmental policy and innovation: a decade of research* (Cambridge: National Bureau of Economic Research, 2019); Marzio Galeotti, et al., 'Environmental policy performance and its determinants: Application of a three-level random intercept model,' *Energy Policy* 114 (March 2018): 134–44. https://doi.org/10.1016/j.enpol.2017.11.053

5. Brunel and Levinson, 'Measuring the stringency.'

6. Ibid.; Galeotti, et al., 'Environmental policy performance.'

7. Michela Nardo, et al., *Tools for Composite Indicators Building*. (Ispra: Joint Research Centre European Commission, 2005).

8. Anil K. Jain, 'Data clustering: 50 years beyond K-means,' *Pattern Recognition Letters* 31, no. 8 (June 2010): 651–66. https://doi.org/10.1016/j.patrec.2009.09.011; Wright, et al., 'Sparse representation.'

aligned with the theme of this book. In this line, we explore how ML, pattern discovery, and DL can be used to enhance our understanding of the environmental and economic impacts of climate policies around the world. Building upon previous literature that explores some climate policy indicators,[9] we identify the main concerns researchers need to take into account when constructing indicators. Similarly, we discuss several previous transformations of climate policy indicators. In addition, we present a sample index using our transformation of existing indices, which demonstrates how our methods can work in practise. Finally, we suggest several directions for future research.

6.2. Background

Climate policies have become widespread throughout the world, addressing a number of complex environmental, economic, and social issues. Researchers have identified hundreds of environmental policy indicators such as the OECD's 'environmental policy stringency index' and Yale's 'environmental performance index,' many of which are specifically focused on climate policy.[10] Testament to the incredible diversity and dispersion of climate policies, researchers at the Grantham Research Institute on Climate Change have identified 2,122 climate laws across nearly every country in the world. Covering so much ground, climate policies are also quite heterogeneous.[11] There is no 'one size fits all' climate change policy. Consequently, measuring the economic and environmental impacts of climate policy has become exceedingly difficult.

Fortunately, governments, grantors, universities, and companies have already recognised the importance of having reliable climate policy indicators. This led to several relatively trustworthy indicators variously deployed to test

9. Rajesh Kumar Singh, et al., 'An overview of sustainability assessment methodologies,' *Ecological Indicators* 15, no. 1 (April 2012): 281–99. https://doi.org/10.1016/j.ecolind.2011.01.007

10. Singh, et al., 'An overview of sustainability;' Rajesh Kumar Singh, et al., 'An overview of sustainability assessment methodologies,' *Ecological Indicators* 9, no. 2 (March 2009): 189–212. https://doi.org/10.1016/j.ecolind.2008.05.011; Christoph Böhringer and Patrick E.P. Jochem, 'Measuring the immeasurable—A survey of sustainability indices,' *Ecological Economics* 63, no. 1 (June 2007): 1–8. https://doi.org/10.1016/j.ecolecon.2007.03.008

11. Singh, Rajesh Kumar, et al., 'Sustainability assessment methodologies.'

empirical research, give policy-makers an idea of how climate policy impacts the environment, and as a tool for investors and companies.[12] Some attempts have been made to transform 'off-the-shelf' climate policy indicators,[13] which we define as indicators that are already developed by governments, research institutes, and academics. Nevertheless, while the transformation of indicators can enhance the reliability and consistency of indicators, several aspects need to be considered before such transformation can be realised. In this section, we define some underlying issues that can occur during climate policy indicators transformation. We then introduce several climate policy indicators widely in use already. Lastly, we discuss previous transformations of climate policy and introduce our example to demonstrate how to expand upon these methods in future research.

The Demand for Climate Policy

How to achieve green growth through climate policies is becoming an increasingly pressing question for policymakers;[14] for instance, a renewed call for green recovery arose in 2020 in response to COVID-19.[15] Because green growth implies the fact that 'technological change and substitution will improve the ecological efficiency of the economy, and that governments can speed this process with the right regulations and incentives,'[16] green growth can be realised through climate policy, innovation, and industrial upgrading. This has led to a rising demand to understand the impacts of climate policies on the economy.

In this framework, a number of empirical models have been developed to understand how these policies impact innovation, growth, economy, and the

12. Stefan Ambec, 'Gaining competitive advantage with green policy,' in *Green Industrial Policy: Concept, Policies, Country Experiences*, eds. Tilman Altenburg and Claudia Assmann. (Geneva: UN Environment and German Development Institute, 2017), 38–50; Mark A. Cohen and Adeline Tubb, 'The Impact of Environmental Regulation on Firm and Country Competitiveness: A Meta-analysis of the Porter Hypothesis,' *Journal of the Association of Environmental and Resource Economists* 5, no. 2 (April 2018): 371–99. https://doi.org/10.1086/695613

13. Galeotti, et al., 'Environmental policy performance.'

14. Jonas Meckling and B. Allan Bentley, 'The evolution of ideas in global climate policy,' *Nature Climate Change* 10, no. 5 (May 2020): 434–38. https://doi.org/10.1038/s41558-020-0739-7

15. Kuzemko, et al., 'Covid-19 and the politics.'

16. Jason Hickel and Giorgos Kallis, 'Is Green Growth Possible?' New Political Economy 25, no. 4 (April 2019): 470. https://doi.org/10.1080/13563467.2019.1598964 environment.[17] Frequently, researchers seek to understand how climate policy induces innovation, development, deployment, and installation of renewable energy technologies that do not emit harmful greenhouse gases (GHGs) and which are thus a main component for meeting climate goals.[18] In general, empirical analyses involve designating the climate policy indicator as the main explanatory variable of interest.[19]

Climate Policy Measurement Issues

Despite the demand for reliable indicators, many remain problematic.[20] Indeed, in an influential article, Brunel and Levinson highlight some underpinning issues associated with the development of environmental and climate policy indicators.[21] They contend that, in the absence of more concerted efforts to address the complexities inherent to climate policy indicators, spurious and often contradictory empirical results will be common. In this vein, climate policy indicators are highly susceptible to human biases, which is the main motivation for writing this chapter.

Transformation and application of existing indicators while less susceptible, also face a number of difficulties. For these reasons, we suggest and demonstrate how ML, pattern discovery, and DL could be applied in these contexts. Whilst ML, pattern recognition, and DL are already widely used in related research,[22]

17. Stefan Ambec, et al., 'The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?' *Review of Environmental Economics And Policy* 7, no. 1 (Winter 2013): 2–22. https://doi.org/10.1093/reep/res016

18. Nick Johnstone, Ivan Haščič, and Margarita Kalamova, *Environmental Policy Design Characteristics and Technological Innovation: Evidence from Patent Data (Working Paper)* (Paris: OECD Publications, 2010). https://dx.doi.org/10.1787/5kmjstwtqwhd-en; Yana Rubashkina, Marzio Galeotti, and Elena Verdolini, 'Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors,' *Energy Policy* 83 (August 2015): 288–300. https://doi.org/10.1016/j.enpol.2015.02.014; Yun Wang, Xiaohua Sun, and Xu Guo, 'Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors,' Energy Policy 132 (2019): 611–19. https://doi.org/10.1016/j.enpol.2019.06.016

19. Ambec, et al., 'The Porter Hypothesis at 20.'

20. Cohen and Tubb, 'Impact of Environmental Regulation.'

21. Brunel and Levinson, 'Measuring the stringency.'

22. Jain, 'Data clustering;' John Wright, et al., 'Sparse representation for computer vision and pattern recognition,' *Proceedings of the IEEE* 98, no. 6 (June 2010): 1031–44. https://doi.org/10.1109/JPROC.2010.2044470 they are not extensively applied to climate policy yet. These methods can help identify, classify, and cluster climate policies based on public sentiment (e.g., on Twitter streams), aggregate and fine-tune satellite imagery (e.g., Carbon Space Inc.), which has been done for the UN Sustainable Development Goals (SDGs),[23] or automate the progress on emissions reductions of GHGs covered by the Kyoto Protocol.[24] Another recent technique is to automatically digest data submitted as Nationally Determined Contributions (NDCs) under the Paris Agreement, which was suggested recently by Franke et al.[25] These tools and methods are discussed later in this chapter. Immediately below we explain important considerations researchers should take during the construction of climate change policy indicators.

Brunel and Levinson identify four measurement issues that lead to underlying issues in climate policy indicators that occur during construction, transformation, and afterward application. These issue areas are (1) multidimensionality, (2) simultaneity, (3) industrial composition, and (4) capital vintage.[26] We briefly review their important arguments below. Subsequently, we explain different types and typologies of climate policies that are intrinsically important in the transformation and application of indicators.

Multidimensionality

Multidimensionality refers to the issue of space and geography. The geographical application of climate is paramount, especially because GHGs can freely travel across country borders after they are emitted. Indeed, this 'collective action' problem has bogged down multilateral climate change negotiations for

23. Nataliia, Kussul, et al., 'A workflow for Sustainable Development Goals indicators assessment based on high-resolution satellite data,' *International Journal of Digital Earth* (May 2019): 309–21. https://doi.org/10.1080/17538947.2019.1610807

24. Yongming Xu, et al., 'Evaluation of machine learning techniques with multiple remote sensing datasets in estimating monthly concentrations of ground-level PM2.5,' *Environmental Pollution* 242, part B (November 2018): 1417–26. https://doi.org/10.1016/j.envpol.2018.08.029

25. Laura Franke, Marco Schletz, and Søren Salomo. 'Designing a blockchain model for the Paris agreement's carbon market mechanism,' *Sustainability* 12, no. 3 (February 2020): 1068. https://doi.org/10.3390/su12031068

26. Brunel and Levinson, 'Measuring the stringency.'

decades.[27] Therefore, researchers must take into account location-specific aspects of climate policy (e.g., its intended geographical scope and target) during both the construction and application of climate policy indicators.

Simultaneity

Without due consideration of temporal differences (e.g., the length of time a policy has been in place, the stipulated target year for emissions reductions, and the intended longevity of a policy), the issue of simultaneity can result in a number of measurements and empirical modelling problems.[28] Concerted efforts are, thereby, required so that policymakers can compare policies over time and across jurisdictions. Indeed, the NDCs under the Paris Climate Agreement are intrinsically reliant compared to GHGs reduction targets at specified baseline (past) and future target dates.[29]

Capital Vintage and Industrial Composition

Climate policies can have widely varied impacts on technology and industrial trajectories. The stipulation that industrial equipment must emit fewer GHGs is, for instance, not a new policy concern. In various countries, limits on emissions from automobiles have been around since the 1970s. Still, older equipment and automobiles (e.g., 'vintage' ones) as well as heavily polluting industries (i.e., oil, gas, and cement, etc.), are not clearly impacted by these policies. Vintage equipment is usually not restricted as much as newer equipment by climate policy. Thus, these sectoral and technological considerations also need to be carefully integrated and applied for creating climate policy indicators.

Policy Flexibility, Innovation, and Technology

Beyond the sectoral, temporal, and qualitative differences germane to the impacts of climate policies, there are also specific 'points of incidence' that the

27. David Coen, Julia Kreienkamp, and Tom Pegram, *Global Climate Governance* (Cambridge: Cambridge University Press, 2020). https://doi.org/10.1017/9781108973250

28. Brunel and Levinson, 'Measuring the stringency.'

29. W. Pieter Pauw, et al., 'Beyond headline mitigation numbers: we need more transparent and comparable NDCs to achieve the Paris Agreement on climate change,' *Climatic Change* 147 (March 2018): 23–29. https://doi.org/10.1007/s10584-017-2122-x researcher should reckon. Points of incidence refer to where policy targets harm to the climate, identifying new technologies and innovations needed. Once identified, the point of incidence draws in innovators.[30] The aim is to encourage environmental-economic win-wins through innovation and industrial upgrading, which is one crux of green growth.[31]

Examples of climate policies that locate the point of incidence are, among others, performance standards, environmental taxes, or tradable air pollution permits. They are commonly used to encourage renewable energy innovation and deployment.[32] Hence, the state has a vital role to play to induce new climate technology innovations as well as disruptive clean energy transitions.[33] Well-crafted climate regulations can, moreover, signal inefficiencies, reduce uncertainty, and pressure firms to innovate. This has the effect of 'levelling the playing field' and reducing the costs of innovation-based learning.[34] Climate policy can, therefore, become a 'tool for competitive advantage […] for minimising ecological impacts of economic production while enhancing the competitiveness of firms.'[35]

Policy Stability versus Uncertainty

In terms of green growth, policy stability is critical. Much-needed climate technologies are inherently difficult and expensive to produce, which is the main reason that policy stability is so important. Unstable policies, however,

30. Adam B. Jaffe, Richard G. Newell, and Robert N. Stavins, 'Environmental Policy and Technological Change,' *Environmental and Resource Economics* 22, no 1 (February 2002): 41–70. https://doi.org/10.1023/A:1015519401088

31. Christian Binz, et al., 'Toward technology-sensitive catching-up policies: insights from renewable energy in China,' *World Development* 96 (August 2017): 418–37. https://doi.org/10.1016/j.worlddev.2017.03.027

32. Friedmann Polzin, et al., 'Public policy influence on renewable energy investments-A panel data study across OECD countries,' *Energy Policy* 80 (May 2015): 98–111. https://doi.org/10.1016/j.enpol.2015.01.026

33. Florian Egli, Nick Johnstone, and Carlo Menon, *Identifying and inducing breakthrough inventions: An application related to climate change mitigation* (Paris: OECD Publishing. 2015). https://dx.doi.org/10.1787/5js03zd40n37-en; Phil Johnstone and Peter Newell, 'Sustainability transitions and the state,' *Environmental Innovation and Societal Transitions* 27 (June 2018): 72–82. https://doi.org/10.1016/j.eist.2017.10.006; Phil Johnstone, et al., 'Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom,' *Energy Research & Social Science* 59 (January 2020): 101287. https://doi.org/10.1016/j.erss.2019.101287

34. Michael E. Porter and Claas van der Linde, 'Toward a New Conception of the Environment-Competitiveness Relationship,' *Journal of Economic Perspectives* 9, no. 4 (Fall 1995): 97–118. https://doi.org/10.1257/jep.9.4.97

35. Paul Shrivastava, 'Environmental technologies and competitive advantage,' *Strategic Management Journal* 16, no. 1 (1995): 183–200. https://doi.org/10.1002/smj.4250160923 effectively serve as a brake on innovation.[36] For example, the US, Canada, and Australia have had unstable climate change policies introducing at first stringent climate policy regulations repealed by successive governments, which has had some serious consequences for green innovation such as reversing the benefits of green growth.[37] On the other hand, evidence suggests that flexible and well-timed climate policy produces economic and climate win-wins.[38]

Popular Climate Policy Indicators

Overall, reliable climate policy indicators should be able to 'simplify, quantify, analyze and communicate the complex and complicated information (sic)'[39] underlying policy decisions and their constituent effects on the ground. As such, climate policy and governance indicators assess stringency, timing, efficacy, location, and other effects on the economy and the environment. In this light, several efforts have been made to approximate the impact of climate change policies at global and national levels.

Bättig, Brander, and Imboden make an important contribution in this respect. In their Climate Change Index, they aim to inform policymakers of the environmental changes that relate to policy for future scenarios.[40] While many efforts have been made to model future climate and economic impacts of climate policy through 'integrated assessment models,'[41] the advantage of Bättig,

36. Ivan Haščič, et al., 'Effects of environmental policy on the type of innovation,' *OECD Journal: Economic Studies 2009*, no. 1 (March 2009): 1–18. https://doi.org/10.1787/eco_studies-v2009-art2-en

37. Dani Rodrik, 'Green industrial policy,' *Oxford Review of Economic Policy* 30, no. 3 (Autumn 2014): 469–91. http://www.jstor.org/stable/43664659; Sam Fankhauser, et al., 'Who will win the green race? In search of environmental competitiveness and innovation,' *Global Environmental Change* 23, no. 5 (October 2013): 902–13. https://doi.org/10.1016/j.gloenvcha.2013.05.007

38. Daniel C. Esty and Andrew Winston, *Green to Gold: How Smart Companies Use Environmental Strategy to Innovate, Create Value, and Build Competitive Advantage*, rev. ed. (New Jersey: John Wiley & Sons, 2009); Angshuman Sarkar, 'Promoting Eco-Innovations To Leverage Sustainable Development Of Eco-Industry And Green Growth,' *European Journal of Sustainable Development* 2, no. 1 (February 2013): 171–224. https://doi.org/10.14207/ejsd.2013.v2n1p171; Stefan Ambec, 'Gaining competitive advantage.'

39. Singh, et al., 'An overview of sustainability,' 282.

40. Michèle B. Bättig, Simone Brander, and Dieter M. Imboden, 'Measuring countries' cooperation within the international climate change regime,' *Environmental Science & Policy* 11, no. 6 (October 2008): 478–89. https://doi.org/10.1016/j.envsci.2008.04.003

41. Ajay Gambhir, 'Planning a Low-Carbon Energy Transition: What Can and Can't the Models Tell Us?' *Joule* 3, no. 8 (August 2019): 1795–98. http://dx.doi.org/10.1016/j.joule.2019.07.016; Volker Krey, et al., 'Looking under the hood: A comparison of techno-economic assumptions across national and global integrated assessment models,' *Energy* 172 (April 2019): 1254–67. https://doi.org/10.1016/j.

Brander, and Imboden's approach is it posits a single index that aims at simplification and streamlining, which yields climate policy indicators much more useful for policy-makers.

By the same token, Li, Du, and Wei construct a national environmental policy stringency indicator based on environmental treaties. They find significant differences in climate policy indicators across countries. This is because, even though emissions mitigation has global goods benefits, it has varying costs depending on the country or region and the type of energy countries are switching away from.[42] In the same vein, Schmidt and Fleig conducted a comprehensive assessment of climate laws in 171 countries across 27 years. They show how climate policy stringency has increased significantly, especially with respect to energy supply and demand, but not as much for the transport sectors.[43] Likewise, their study indicates that variation across countries vis-a-vis climate policy depends on EU membership, the environmental vulnerability of a country, and, not surprisingly, income level.[44]

Climate policy simulation could also be an immensely important tool to develop and roll out green growth policies carefully. Simulations model a policy beforehand to understand its potential impacts. Before introducing a policy, for example, simulations could be run to determine how it might impact the economy, its firms, and innovators. In this regard, two questions are raised: 1) Will the potential policy induce firms to create innovative new environmental technologies? 2) Will it lead to end-of-pipe environmental technology solutions?[45] Sterman et al. experiment with this idea, simulating negotiations under the potential outcomes of the United Nations Framework Convention on

energy.2018.12.131; Damjan Krajnc and Peter Glavič, 'A model for integrated assessment of sustainable development,' *Resources, Conservation and Recycling* 43, no. 2 (January 2005): 189–208. https://doi.org/10.1016/j.resconrec.2004.06.002

42. Aijun Li, Nan Du, and Qian Wei, 'The cross-country implications of alternative climate policies,' *Energy Policy* 72 (September 2014): 155–63. https://doi.org/10.1016/j.enpol.2014.05.005

43. Schmidt and Fleig, 'Global patterns.'

44. Ibid.

45. Henrik Hammar and Åsa Löfgren, 'Explaining adoption of end of pipe solutions and clean technologies-Determinants of firms' investments for reducing emissions to air in four sectors in Sweden,' *Energy Policy* 38, no. 7 (July 2010): 3644–51. https://doi.org/10.1016/j.enpol.2010.02.041

Climate Change (UNFCCC) negotiations.[46] Similarly, Doukas and Nikas pose an 'expert decision support system' that breaks down linguistic elements in climate negotiations and seeks to draw together the disparate strands of literature on decision-making for climate policy.[47] Yet, though promising, this body of literature remains underdeveloped.

While the approaches above allow measuring environmental 'outputs,' Bernauer and Böhmelt take a slightly different approach. They rank countries according to their participation in the Kyoto Protocol (e.g., climate policy inputs).[48] The purpose of this ranking is to assess the stringency of country-level climate policy. Using the Climate Change Cooperation Index (C3-I), they attempt to measure political behavior and greenhouse gas emissions (outputs and outcomes),[49] this indicator making an important contribution to the literature.[50] Lastly, researchers from German-Watch have created the popular Climate Change Performance Index (CCPI).[51] The CCPI provides a time-series indicator covering 57 countries and the European Union. It divides its index into GHGs, renewable energy, energy usage, and climate policy.

In this section, we reviewed how spatial, temporal, geographical, and qualitative differences can lead to widely differentiated effects of climate policies on the ground. Likewise, we discussed some relevant climate policy indices other researchers have already developed. In the following section, we explore several examples of climate policy transformation. Additionally, we address some techniques that can be applied to enhance climate policy indicators. Lastly, we

46. John Sterman, et al., 'World climate: A role-play simulation of climate negotiations,' *Simulation & Gaming* 46, no. 3-4 (June 2015): 348-82. https://doi.org/10.1177%2F1046878113514935

47. Haris Doukas and Alexandros Nikas. 'Decision support models in climate policy,' *European Journal of Operational Research* 280, no. 1 (January 2020): 1–24. https://doi.org/10.1016/j.ejor.2019.01.017

48. Thomas Bernauer and Tobias Böhmelt, 'National climate policies in international comparison: The Climate Change Cooperation Index,' *Environmental Science & Policy* 25 (January 2013): 196–206. https://doi.org/10.1016/j.envsci.2012.09.007

49. Ibid.

50. Erick Lachapelle and Matthew Paterson, 'Drivers of national climate policy,' *Climate Policy* 13, no. 5 (September 2013): 547–71. https://doi.org/10.1080/14693062.2013.811333

51. Jan Burck, Franziska, Marten, and Christoph Bals, *The Climate Change Performance Index: Background and Methodology 2016* (Bonn: GermanWatch, 2016); Bernauer and Böhmelt, 'National climate policies;' Jan Burck, Christoph Bals, and Simone Ackermann, *The Climate Change Performance Index: Background and Methodology 2009* (Bonn: GermanWatch, 2009).

describe the development and transformation of our own three indices (i.e., the green growth investment potential indicator, the revised UNFCCC cooperation indicator, and the climate policy stability indicator).

6.3. Climate Policy Indicator Transformation

In the previous section, we addressed important considerations researchers should account for when building and transforming climate policy indicators. In this section, we discuss several important contributions to climate policy indicator transformation and posit a transformation and development of a composite climate and green growth index. In the final section of this chapter, we discuss some implications and further methods that can be deployed.

Dimensionality Reduction

Climate governance involves multiple socio-economic, political, and policy decisions.[52] It is a complex process predicated on a number of policy inputs and outputs. Thus, the issue of high dimensionality in climate policy indicators often arises. These problems are referred to as 'endogeneity' and 'auto-correlation' in quantitative empirical models.[53] Elsewhere, these issues have similarly been raised and recognised as problematic for some time.[54] To mitigate these concerns, researchers can reduce the dimensions of the input variables with the effect of providing more robust output indicators.[55] After a climate policy index is created, for instance, such dimension-reduction techniques can be performed. In this vein, transformations involve re-scaling, normalisation, different weighting, and aggregation techniques. Hence, indicator transformation re-calibrates an indicator to fit a specific policy or research question.

52. Bruno Turnheim, Paula Kivimaa, and Frans Berkhout, eds., *Innovating climate governance: moving beyond experiments* (Cambridge University Press, 2018).

53. Cohen and Tubb, 'Impact of Environmental Regulation.'

54. David F. Andrews, 'Plots of high-dimensional data,' *Biometrics* 28, no. 1 (March 1972): 125–36. http://dx.doi.org/10.2307/2528964

55. Angel Hsu and Alisa Zomer, 'Environmental performance index,' Wiley StatsRef: Statistics Reference Online, last modified November 13, 2016. https://doi.org/10.1002/9781118445112.stat03789.pub2

Another method to deal with multi-dimensionality or auto-correlation during indicator transformation is building a composite indicator.[56] This method incorporates a discrete weighting system over a set of variables.[57] Composite indicators have been used to mitigate the multidimensionality issues raised above.[58] Importantly, nonetheless, even with composite indicators, several research decisions are required and if they are not carefully implemented, these can lead to biases. In short, a reduction of dimensions allows for more meaningful empirical analysis to be done. It is particularly useful for cross-country or cross-industry analysis, which indeed are a main goal of the NDCs under the Paris Climate Agreement.[59] Other tools for indicator transformation, apart from creating composite indicators, are discussed below.

Transformation and Application

Our argument throughout this chapter is that automated approaches can reduce much of the inherent biases in climate policy indicators cited as a recurrent underlying issue that has permeated the scholarship.[60] To reduce potential biases, researchers have successfully deployed tools to enhance existing climate policy indicators. Dimension reduction techniques, which take high dimensional data and reduce these data to smaller dimensions, can be employed through factor analysis and polychoric correlation or by means of principal component analysis (PCA) based on Spearman correlations. Also, pre-cleaning methods such as using Cronbach's alpha to determine the reliability of input values might be utilised.[61] Below we discuss some of these transformations, and at the end of this section, we present our sample transformation.

56. Frederik Booysen, 'An Overview and Evaluation of Composite Indices of Development,' *Social Indicators Research* 59 (August 2002): 115–51. https://doi.org/10.1023/A:1016275505152; Nardo, et al., *Tools for Composite Indicators*.

57. Booysen, 'An Overview and Evaluation.'

58. Ibid.; Nardo, et al., *Tools for Composite Indicators*; Brunel and Levinson, 'Measuring the stringency.'

59. Pauw, et al., 'Beyond headline mitigation numbers.'

60. Cohen and Tubb, 'Impact of Environmental Regulation.'

61. Galeotti, et al., 'Environmental policy performance;' Francesco Nicolli and Francesco Vona, 'The evolution of renewable energy policy in OECD countries: aggregate indicators and determinants,' In *Political Economy and Instruments of Environmental Politics*, eds. Friedrich Schneider, Andrea Kollmann, and Johannes Reichl, (Cambridge: The MIT Press, 2015), 117–48.

Decomposition: Principal Component Analysis and Climate Policies

To effectively address the different typologies of climate policies that can co-exist within an economy and to estimate how such policy differences impart widely differing effects, Kalamova and Johnstone cluster climate policies by the 'points of incidence' and targeted policy dimensions. They break down the climate policy indicator by price-based, voluntary, and quantity-based policies.[62] In this manner, they reduce some selection bias while also reducing underpinning correlations in the data.[63] After clustering the climate policies according to their specific point of incidence, they reduce correlations and dimensions by applying PCA.

In general, PCA involves identifying the directions of variables referred to as principal components (PCs) or orthogonal sub-indices. These explain most of the variance in the data. Concerning indicators, PCs make up linear combinations of the broader policy variables and are particularly well suited to deal with variation in the index data. This has the effect of removing extraneous or over-correlated data. In technical parlance, this is done by developing a covariance matrix of the data and performing eigen-decomposition on the covariance matrix. The eigenvectors are then sorted from largest to smallest corresponding eigenvectors to 'transform a given set of variables into a composite set of components that are orthogonal to, i.e., totally uncorrelated with, each other [and requires] no particular assumptions.'[64] However, skewness and kurtosis can violate the normality assumption; if this occurs, PCA can bias the results. To counteract this, a maximum likelihood estimator is used to fit the data to a continuous normal distribution before calculating the correlation matrix. In this line, beyond Johnstone et al., others have applied PCA to the OECD's Environmental Policy Index. We briefly discuss this below.

62. Margarita Kalamova and Nick Johnstone, 'Environmental Policy Stringency and Foreign Direct Investment,' in *A Handbook of Globalisation and Environmental Policy, Second Edition*, eds. Frank Wijen et al. (Northampton: Edward Elgar Publishing, 2012), 34–56.

63. Ibid.

64. Bernard J. Morzuch, 'Principal components and the problem of multicollinearity,' *Journal of the Northeastern Agricultural Economics Council* 9, no. 1 (April 1980): 81–83. http://bitly.ws/rIDT

Transformation: The OECD's Environmental Policy Index (EPS)

PCA has also been applied to uncover latent variables that contribute to climate policy indicators. It has likewise helped to explain the underpinning distribution in multivariate data in the OECD's Environmental Policy Stringency Index (EPS), initially developed by researchers at the OECD.[65] The OECD's EPS is widely used as a climate policy stringency proxy.[66] The indicator is divided into non-market-based (NMB) and market-based (MB) instruments. NMB policies include emissions standards limits (e.g., SOX, NOX, particulate matters, and sulfur content of diesel) and government energy-related R&D expenditures as a percentage of GDP. Market-based policies include feed-in tariffs (e.g., solar and wind energy), taxes (e.g., on CO2, SOX, NOX, and diesel), certificates (e.g., white, green, and CO2), and the presence of deposit and refund schemes (DRS). All EPS variables are continuous except DRS because they are dichotomous. EPS covers 33 countries (OECD countries and the 'BRICS,' i.e., Brazil, Russia, India, China, and South Africa). Diverse variables contribute to this indicator such as dealing with greenhouse gas emissions, renewable energy, and other noxious atmospheric substances. For this reason, the EPS could more appropriately be defined as a climate rather than an environmental policy indicator.

While the EPS has been an important indicator in empirical climate policy research, some underlying problems arise with correlation and dimensionality. One main impediment is that it is composed of both continuous and discrete input variables. To address some of the issues of correlation and dimensionality, it can be transformed before empirical and modelling usage. Accordingly,

65. Enrico Botta and Tomasz Koźluk *Measuring environmental policy stringency in OECD countries: A composite index approach (Working Paper)* (Paris: OECD Publishing, 2014). https://doi.org/10.1787/5jxrjnc45gvg-en; Nicolli and Vona. 'Evolution of renewable energy policy.'

66. Nicolli and Vona. 'Evolution of renewable energy policy;' Tomasz Kozluk and Vera Zipperer, 'Environmental policies and productivity growth,' *OECD Journal: Economic Studies* 2014, no. 1 (March 2015): 155–85. https://doi.org/10.1787/eco_studies-2014-5jz2drqml75j; Popp, *Environmental policy and innovation*; Kyle Stuart Herman and Jun Xiang, 'Environmental regulatory spillovers, institutions, and clean technology innovation: A panel of 32 countries over 16 years,' *Energy Research & Social Science* 62 (April 2020): 101363. https://doi.org/10.1016/j.erss.2019.101363; Kyle Stuart Herman and Jun Xiang, 'Induced innovation in clean energy technologies from foreign environmental policy stringency?' *Technological Forecasting and Social Change* 147 (October 2019): 198–207. https://doi.org/10.1016/j.techfore.2019.07.006

researchers have taken the EPS' 15 variables and compressed these with PCA to compute a more robust and less correlated overall indicator. For instance, Nicolli and Vona extract principal components (PCs) and subsequently, create three sub-indices) for renewable energy generation, renewable energy certificates (RECs), and R&D credits.[67] In a similar vein, Galeotti et al. sum the different simulated indicators they create with the OECD's EPS to effectively capture the 'diversification of the environmental policy portfolio.'[68] Thereafter, they use PCA to reconstruct 'emissions-based' indicators, which helps reduce the correlated variables to smaller latent PCs.[69]

Even though the aforementioned transformations represent important contributions to the literature, there remains much space to further develop this body of research and analysis. As a main consequence of this lack of development, substantial disparities remain throughout the empirical literature.[70] Thus, we argue that researchers should focus efforts on transforming existing indicators such as the OECD's EPS through machine-learning, deep-learning, and pattern discovery. This will increase the veracity of these indicators and provide better support to empirical models. Furthermore, these methods can also help to provide real-time policy feedback, which is a subject we tackle in the final section of this chapter.

Policy Feedback

Automated Policy feedback is a fervent and burgeoning field since this emerging research area could have significant impacts on climate policy, green growth, and governance for the environment. A related concept is 'anticipatory governance' that enables policymakers to quickly tweak policies based on rapid feedback.[71] These feedbacks can also link between domains: firms and government, economy and the environment, and investors and entrepreneurs, who are all critical to the success of an environmental policy with respect to the economy.

67. Nicolli and Vona. 'Evolution of renewable energy policy.'

68. Galeotti, et al., 'Environmental policy performance.'

69. Ibid.

70. Brunel and Levinson, 'Measuring the stringency;' Galeotti, et al., 'Environmental policy performance.'

71. Stefano Maffei, Francesco Leoni, and Beatrice Villari, 'Data-driven anticipatory governance. Emerging scenarios in data for policy practices,' *Policy Design and Practice* 3, no. 2 (May 2020): 123–34. https://doi.org/10.1080/25741292.2020.1763896

Emerging methods are very promising along these lines. For example, Kong, Feng, and Yang demonstrate how governments can be provided with real-time policy and monitoring feedback for environmental regulations.[72] Such tools have likewise been deployed to report on energy security and energy sustainability.[73] As a corollary, simulation could allow careful calibration at the local level that often suffers from the simultaneity problem because federal environmental policies impact smaller jurisdictions in multifarious ways. The scenarios can be repeated hundreds of times and provide predictions of different policy interventions.[74] In this manner, policymakers might compare the different results and 'collaboratively distinguish the best solutions for tackling the situation under investigation.'[75] Open-source tools such as Rapidminer, KNIME, and WEKA can provide solutions here. Additionally, although some simulations have indeed been carried out for climate change policies such as the integrated assessment models, these have not fully materialised through machine-aided techniques yet. Hence, there is much room for future research in this area.

The Climate Policy Competitiveness Index

As mentioned above, green growth, innovation, and climate policy form a confluence of important subject areas that can be adequately addressed with climate policy indicators. However, high-dimensionality, auto-correlation, or lack of variation within such indicators have impeded their more effective development and usage. In this subsection, to demonstrate the application of indicator construction and transformation, we build three composite indexes. The 'off-the-shelf' indicators we use to build our composite indicator are the following:

72. Yuan Kong, Chao Feng, and Jun Yang, 'How does China manage its energy market? A perspective of policy evolution,' *Energy Policy* 147 (December 2020): 111898. https://doi.org/10.1016/j.enpol.2020.111898

73. Ibid.; Kapil Narula and B. Sudhakara Reddy, 'Three blind men and an elephant: The case of energy indices to measure energy security and energy sustainability,' *Energy* 80 (February 2015): 148–58. https://doi.org/10.1016/j.energy.2014.11.055

74. Aggeliki Androutsopoulou and Yannis Charalabidis, 'A framework for evidence based policy making combining big data, dynamic modelling and machine intelligence,' in *Proceedings of the 11th International Conference on Theory and Practice of Electronic Governance,* Galway, 2018 (Galway: Association for Computing Machinery), 575–83.

75. Ibid., 580.

- The climate change performance index (CCPI).[76]
- The World Economic Forum's competitiveness index (WEF).[77]
- The World Bank's ease of doing business index (EDB).[78]
- The UNFCCC cooperation index.[79]

We develop three separate composite indicators using the above: (1) a green growth investment potential indicator (GGPI) with the CCPI, EDB, and WEF; (2) a revised cooperation index (CI) with the UNFCCC CI's six variables; and (3) a climate stability indicator (CSI). These combine the variables that are included in the four indexes above, averaging the standardised component variables. To visualise the results in PCA space, we derive the first two principal components of each data matrix. FIGURES 6, 7, and 8 illustrate the first principal components representing the maximum variance directions of data. These components account for the variance dispersed through the various indices.

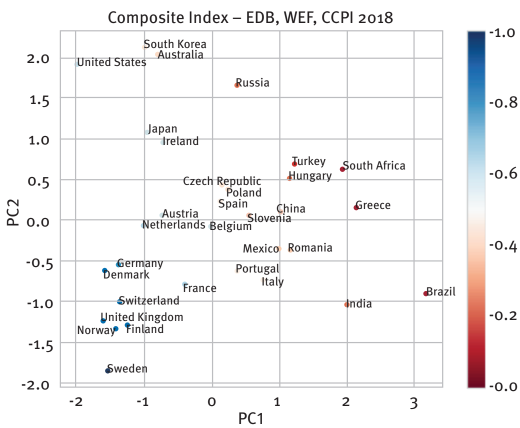

FIGURE 6. Green Growth Investment Potential (GGIP) Indicator

Source: Prepared by authors.

76. Burck, Marten, and Bals, *Climate Change Performance Index.*

77. Klaus Schwab, ed, *The Global Competitiveness Report 2019* (Cologny: World Economic Forum, 2019).

78. 'Ease of Doing Business Score and Ease of Doing Business Ranking,' World Bank, accessed May 24, 2022. http://bitly.ws/rIxt

79. Bättig, Brander, and Imboden, 'Measuring countries' cooperation,'

The GGIP composite indicator (WEF, EDB, CCPI) shows that Sweden, the U.K, Norway, Finland, and Denmark are the best climate investment countries in 2018. The worst countries for climate investment based on this indicator are Iran, Algeria, Saudi Arabia, Argentina, and Egypt.

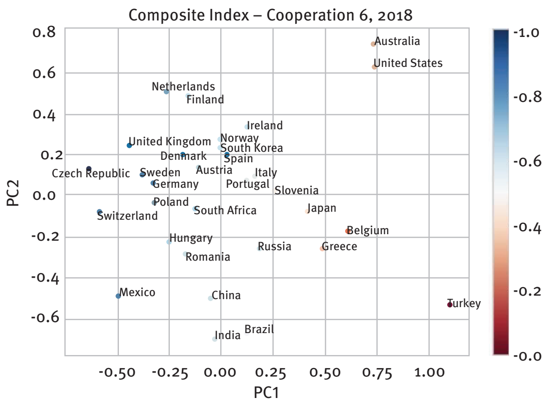

FIGURE 7. Revised UNFCCC Cooperation Indicator.

Source: Prepared by authors.

The revised UNFCCC-CI demonstrates that the Czech Republic, Switzerland, and Mexico are the most cooperative countries regarding climate change policy. The least cooperative, based on our composite indicator, are the United States, Belgium, and Turkey for 2018.

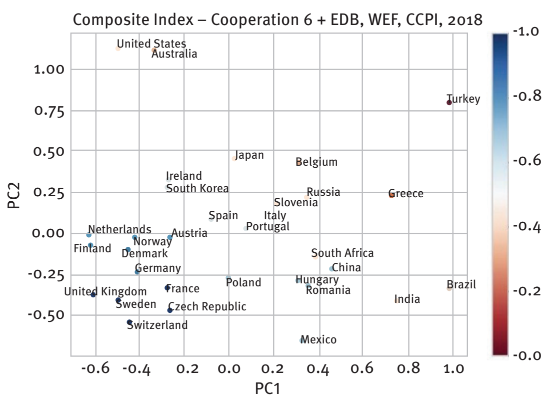

FIGURE 8. Climate Policy Stability Indicator

Source: Prepared by authors.

The Climate Policy Stability Indicator combines all of those listed above and demonstrates where the most stable climate investments can be made, at the country level. Sweden and the U.K. have the most stable environments for climate change policy, whilst also cooperating highly with the UNFCCC process. BRICS countries fall to the bottom of this indicator, which does not bode well for meeting the global objectives of the Paris Agreement.

Let us summarise the composite indicators we have created and briefly discussed. Our main purpose is not to introduce a new index, but to deploy some of the methods and tools discussed in this paper to transform these 'off-the-shelf' indicators above. Our three indicators, in short, provide a snapshot of green growth competitiveness at the country level. They suggest what the most competitive countries vis-a-vis climate change policies are and who is winning the 'green race.'[80] The indicators are not constructed for empirical application but rather to provide an example of how the considerations discussed throughout this paper, coupled with some transformation methods, may be effectively employed by future researchers. We expect that future research will greatly expand upon these methods.

6.4. Discussion

In the previous section, we discussed the transformation of climate policy indicators and presented our examples. We created three separate indicators for some countries in 2018. While this serves as an example, this line of research could be developed much further in the future. In this section, we address other important tools which might equip future researchers to undertake these important tasks. In this train of thought, we highlight many of the existing tools to help researchers construct, transform, and apply climate policy indicators.

Tools and Methods for Future Research and Analysis

There are a number of automated data collection techniques that can help enhance climate policy indicators and enable researchers in both developing

80. Fankhauser, et al., 'Who will win?'

and developed countries to create and transform climate policy indicators. These are often free to use (e.g., open-source) and include, but are not limited to Scrappy, Apify SDK, Cheerio, PySpider, UiPath, Rapidminer, KNIME and WEKA, TraMineR, Grafter, and OpenRefine.

t-distributed Stochastic Neighbor Embedding (t-SNE)

Graphical display of high-dimensional data has become important to pattern discovery and machine learning. A main method along these lines called t-distributed stochastic neighbor embedding, i.e., 't-SNE,' allows for the transformation of data that has many input variables. It has proven to be highly effective in producing a graphical display of high-dimensional data.[81] Like PCA, which is discussed and applied above, t-SNE effectively reduces high-dimensional data. However, in contrast to PCA, t-SNE preserves rather than maximises variance. To maximise the variance in the underlying data, especially after visualisation, it is helpful to show what would otherwise be difficult when detecting differences in climate policy across countries and over time (e.g., with PCA). In this sense, preserving the variance, as in t-SNE, is more reliable for further empirical analysis because it represents the underlying data more exactly.

Support Vector Machines (SVMs) and Neural Networks

Another deep-learning tool is support vector machines (SVMs). It could help classify and, in turn, re-classify the hundreds of climate policies found around the world. In this vein, SVMs excel in regressing data in high dimensions. This would enable quicker identification of troublesome and inconsistent climate policies that show limited benefits or are otherwise incapable of instantiating substantive changes on the ground.

Yet, while SVMs are considered easier to implement and are also able to model data that are not linearly separable, neural nets are typically harder to configure and debug due to the high number of hyperparameters required for fine-tuning. Similar to SVMs, neural networks, which are 'opaque function approximators' that perform successive computations on signals through a

81. Laurens van der Maaten and Geoffrey Hinton, 'Visualizing data using t-SNE,' *Journal of Machine Learning Research* 9, no. 11 (November 2008): 2579–2605. http://bitly.ws/rIxK biologically inspired architecture of layers and nodes, can also be important tools here. Elsewhere, Gründler and Krieger have leveraged SVM to create a democracy index covering over 50 years and over a hundred countries.[82] This might be extended to create a similar index for climate policy stringency across countries and over time.

One of the many recent applications of neural networks is in natural language processing (NLP) where patterns in textual data such as Twitter streams can be used to infer public sentiment.[83] Another benefit, in contrast to SVMs, is that neural nets can be updated online, which could enable real-time inferences. Such tools might be particularly critical for 'anticipatory' climate governance; in other words, to enable swifter identification and analysis of climate policies concerning the economy. Such semi-automated techniques could also be quite useful to refine and re-calibrate climate proxies as countries alter their policy strategies because of political changes. Or they could be used to gauge public sentiment on emerging climate policies.

6.5. Conclusion

In this chapter, we explored the issue of climate policy indicators, their inherent complexity, design, transformation, and empirical application. While a number of climate policy indicators exist, there remain many underlying problems with these. In addition, as green growth includes not only climate and environmental policy but also green competitiveness and industrial policy concerns,[84] transformation and construction of composite indicators, as we have shown, is incredibly important. These problems can enable rapid and accurate assessment of policy, and climate policy impacts on the environment and the

82. Klaus Gründler and Tommy Krieger, 'Democracy and growth: Evidence from a machine learning indicator,' *European Journal of Political Economy* 45 (December 2016): 85–107. https://doi.org/10.1016/j.ejpoleco.2016.05.005

83. Ana Reyes-Menendez, José Ramón Saura, and Cesar Alvarez-Alonso, 'Understanding# WorldEnvironmentDay user opinions in Twitter: A topic-based sentiment analysis approach,' *International Journal of Environmental Research and Public Health* 15, no. 11 (November 2018): 2537. https://doi.org/10.3390/ijerph15112537

84. René Kemp and Babette Never, 'Green transition, industrial policy, and economic development,' *Oxford Review of Economic Policy* 33, no. 1 (January 2017): 66–84. https://doi.org/10.1093/oxrep/grw037 economy. Plus, as a main consequence of the relative lack of development in climate policy indicators, policymakers are unable to readily assess the impacts of climate policy on the economy, which is a salient issue, especially in the era of widespread green growth policies. We have proposed to follow recent success using PCA to transform existing indicators. Going one step further, we have suggested deploying new machine learning, pattern discovery, and deep learning techniques. We then introduced our indicators, which constitutes only a starting point for future research.

The techniques discussed in this chapter are no panacea. Great caution is warranted when employing these methods. While human biases are likely to be reduced, they will remain. This is why we provided a detailed discussion on the topical issues impacting climate policy transformation. Even though much hope is pinned on machine learning, pattern discovery, and deep learning, ultimately researchers have to make important, well-reasoned, appropriate, and logical research decisions. If done correctly, however, the impact of these indicators can be significant, especially considering the massive funding now devoted to green growth. Beyond the responsibility for accurate and robust research, therefore, researchers must also be cognizant that climate policy indicators will, on their own, have highly meaningful impacts on the future of the global environment.

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7. Analysing Energy Systems Integration: A Socio-Technical Approach and a System Architecture Methodology

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7.1. Introduction

One possible pathway to drive the energy transition flexibly and cost-effectively is energy systems integration (ESI), also known as sector coupling, of electricity, gas, and heat. ESI aims to capture and exploit interactions and diversity across multiple energy vectors by connecting energy systems physically and virtually across infrastructures and markets. ESI is perceived as a possible solution as it

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provides the required system flexibility by diversifying input and output energy streams. This solution also allows a peak in demand or production to be shifted from one system to another by conversion between vectors. This would create new interactions and interfaces between the different components of the energy system resulting in emergent properties such as flexibility. Moreover, ESI is expected to have an impact on the current energy system architecture with changes in the planning and operations paradigm, the market structure, and the regulatory framework.[5]

This chapter presents a methodological framework to identify and analyse those interactions across energy systems and understand the possible architecture of the future integrated energy system. The framework is based on a system-of-systems (SOS) modelling approach that represents the future integrated energy system architecture. It includes structural and functional interlinkages across systems and stakeholders while reducing complexity through abstraction. In this vein, focusing on ESI as a case study, this chapter aims to answer the following research questions:

- How to identify and analyse interactions across socio-technical systems?
- How to identify the structure of current and possible future socio-technical networks?

This chapter is structured as follows. First, section 2 discusses ESI from a socio-technical transitions perspective. Next, section 3 describes the methodology and the underpinning conceptual framework. Afterward, section 4 explains the framework application. Finally, section 5 summarises the contributions made here and discusses future work horizons.

5. Mark O'Malley, et al., *Energy Systems Integration: Defining and Describing the Value Proposition* (Golden: International Institute for Energy Systems Integration, 2016). http://dx.doi.org/10.2172/1257674; Richard Hanna, et al., *Unlocking the potential of Energy Systems Integration* (London: Energy Futures Lab, 2018). http://bitly.ws/qsBs; Tooraj Jamasb and Manuel Llorca, 'Energy Systems Integration: Economics of a New Paradigm.' Economics of Energy and Environmental Policy,' *The Energy Journal* 8, no. 2 (April 2019): 7–28. http://dx.doi.org/10.5547/2160-5890.8.2.tjam

7.2. A Multi-System Perspective for Energy Systems Integration

This section explores relevant concepts from the transitions literature and discusses ESI from a socio-technical transitions perspective. In the scope of the socio-technical transition literature, integration has been identified as one of the multi-regime interactions that could occur within or across socio-technical systems. The concept of multi-regime interactions extends from the multi-level perspective (MLP) theory, moving to a multi-system perspective (MSP) that highlights the fact that interactions between multi-regimes across systems, rather than within systems, are of main interest. This perspective is applied to ESI, where interactions occur between the multi-regimes (i.e., generation, networks, and consumption) of its different integrated systems (i.e., electricity, gas, and heat). In this train of thought, a SoS conceptualisation of ESI is suggested and a method to operationalise this understanding is later presented below.

The Multi-System Perspective

The energy system is considered socio-technical and is composed of actors and institutions in addition to technological artefacts and knowledge interacting to provide energy services for society.[6] This system is undergoing a transition to achieve the energy policy trilemma objectives of delivering decarbonisation, maintaining a secure and reliable energy supply, and providing acceptable and affordable energy.[7] A key theory presented in the literature to understand the dynamics of sustainability transitions is the MLP, which distinguishes between three levels. First, the niche-innovations level is where radical novelties emerge in protected spaces. The second level is the socio-technical regime and constitutes the institutional structuring of existing systems. The third level regards the socio-technical landscape where exogenous developments that affect niche and regime activity take place. According to the MLP, transitions happen upon

6. Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955–67. https://doi.org/10.1016/j.respol.2012.02.013

7. Kathleen Araújo, 'The emerging field of energy transitions: progress, challenges, and opportunities,' *Energy Research & Social Science* 1 (March 2014): 112–21. https://doi.org/10.1016/j.erss.2014.03.002.

interactions between processes at the three levels. Typically, niche innovations pick up momentum internally through learning processes while changes at the landscape level create pressure on the regime. At some point, the regime gets destabilised creating an opportunity for niche innovations.[8]

Different types and timings of interactions between the multiple levels lead to diverse types of transition pathways, namely: transformation, technological substitution, de-alignment and re-alignment, and reconfiguration.[9] This latter happens when, for instance, innovation is initially adopted to solve local regime problems, but leads to an adjustment in the system architecture.[10] It stems from the concept of architectural innovations that alter the architecture of a system without changing its components by reconfiguring an established system to link existing components in a different way.[11] However, although reconfigurations and architectural changes are of interest in the scope of ESI, the MLP, as initially described, focuses on breakthroughs of singular innovations and the transition pathways only describe the interactions between the different levels of the MLP.

An extended version of the MLP accounts for interactions between multi-regimes and multi-niches. For example, multiple regimes exist and interact in the mobility system such as auto-mobility, bus, rail, and cycling.[12] Similarly, in the electricity sector, multiple regimes typically include generation, networks, and consumption.[13] In this case, the transition pathway becomes a whole system

8. Frank W. Geels, *Technological Transitions and System Innovations: A Co-Evolutionary and Socio-Technical Analysis* (Cheltenham: Edward Elgar Publishing Limited, 2005).

9. Frank W. Geels and Johan Schot, 'Typology of sociotechnical transition pathways,' *Research Policy* 36, no. 3 (April 2007): 399–417. https://doi.org/10.1016/j.respol.2007.01.003

10. George Papachristos, Aristotelis Sofianos, and Emmanuel Adamides, 'System interactions in socio-technical transitions: Extending the multi-level perspective,' *Environmental Innovation and Societal Transitions* 7 (June 2013): 53–69. https://doi.org/10.1016/j.eist.2013.03.002

11. Rebecca M. Henderson and Kim B. Clark, 'Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms,' *Administrative Science Quarterly* 35, no. 1 (March 1990): 9–30. https://doi.org/10.2307/2393549

12. Frank W. Geels, 'Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016),' *Energy Research & Social Science* 46 (December 2018): 86–102. https://doi.org/10.1016/j.erss.2018.07.008

13. Andrew McMeekin, Frank W. Geels, and Mike Hodson, 'Mapping the winds of whole system reconfiguration: Analysing low-carbon transformations across production, distribution and consumption in the UK electricity system (1990–2016),' *Research Policy* 49, no. 5 (June 2019): 1216–31. https://doi.org/10.1016/j.respol.2018.12.007.

reconfiguration due to multiple change mechanisms.[14] Thereby, a new whole system architecture is expected as a result of reconfiguration since linkages between subsystems are changing.[15]

The MSP builds on the multi-regime interactions, but it is distinguished by focusing on interactions between multiple regimes across systems rather than multiple regimes within the same system.[16] For instance, in the context of ESI, beyond looking at the interactions within the multiple regimes of the electricity system (generation, networks, and consumption), emphasis should be placed on the interactions across the different energy systems (electricity, gas, and heat) each of which has their multiple regimes within. This can be expanded to other utility sectors such as water and telecom.[17] It is therefore essential to clearly define the boundaries of the systems under study to identify those internal and external ones.[18]

In a review of the MSP, Rosenbloom mentions that the focus of the MSP is on identifying three aspects.[19] First, the functional and structural interlinkages between the systems. Second, the system interaction patterns and their implications for sustainability transitions. Third, are the emerging interfaces where interactions take place. Identifying interfaces is particularly important as it helps understand how the system architecture could be shaped upon a transition and how system boundaries may be accordingly redefined.[20]

By the same token, the author points out four types of multi-regime interactions:

- Competition: It is where regimes compete in delivering similar functions.

14. Geels, 'Low-carbon transition.'

15. McMeekin, Geels, and Hodson, 'Mapping the winds.'

16. Daniel Rosenbloom, 'Engaging with multi-system interactions in sustainability transitions: A comment on the transitions research agenda,' *Environmental Innovation and Societal Transitions* 34 (March 2020): 336–40. https://doi.org/10.1016/j.eist.2019.10.003

17. Kornelia Konrad, Bernhard Truffer, and Jan-Peter Voß, 'Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors,' *Journal of Cleaner Production* 16, no. 11 (July 2008): 1190–1202. https://doi.org/10.1016/j.jclepro.2007.08.014

18. Papachristos, Sofianos, and Adamides, 'System interactions.'

19. Rosenbloom, 'Engaging with multi-system.'

20. Ibid.

- Symbiosis: It refers to where regimes cooperate in delivering a societal function
- Integration: It implies where regimes become integrated to form a new entity for delivering a societal function.
- Spill-over: It is where elements from one regime are taken up within another (i.e., transfer of rules).

In conclusion, system interactions are characterised by the MSP as diverse because systems tend to share a range of different connections, layered stretching across regime and niche levels at multiple geographic scales. These evolve with system boundaries and objectives changing over time.[21]

Conceptualising Energy Systems Integration

The MSP is applied to understand the dynamics between multiple regimes across socio-technical systems. ESI involves multiple energy systems, namely: electricity, gas, and heat. The systems are linked by coupling components such as combined heat and power (CHP), power-to-x (P2X), and heat pumps (HPs). These technologies enable energy vector conversion or electrification of end-use sectors. These are examples of niche innovations that create new linkages between regimes.[22] Each of the energy systems has multiple regimes responsible for generation, networks, and consumption. Interactions occur between multiple regimes across different systems. For instance, CHP couples the electricity and heat systems at the generation level, both being fed by the same energy source. On the other hand, P2X couples the different energy systems at the networks level. In turn, HPs can relate energy systems at both networks and consumption levels, depending on their scale.

ESI originates from a holistic approach that considers the whole energy system (WES) comprising multiple energy vectors, the energy supply chain span from generation to end-use, and the system environment embracing multiple perspectives and objectives of different energy actors. This is similar to the MSP

21. Ibid.

22. Geels, 'Low-carbon transition.'

characterisation of system interactions, which are diverse, layered, and evolving as described earlier and reflected in the methodological framework proposed below. System interactions involved in ESI clearly fall under the integration type defined earlier. Integration of socio-technical regimes involves coupling previously separated regimes to form a new entity, which does not necessarily mean that parent systems would disappear.[23] This chapter conceptualises this new entity for the case of ESI as a SOS. This latter is defined as an integration of independent systems that act jointly towards a common goal, through synergies, to collectively offer emergent functionality that cannot be provided by constituent systems (CSS) alone. A SOS is characterised by operational and managerial independence, geographical distribution, evolutionary development, and emergence.[24] The SOS features apply to ESI where different utility companies are independently responsible for operating, managing, and developing the CSS. These latter are naturally geographically dispersed and emergent behaviour that cannot be delivered by individual components separately as a result of interaction between the CSS.[25]

Integration can take place at the actors and institutional level or take a hard form with technological integration.[26] Both forms of integration are expected in ESI, which will involve a whole system reconfiguration bringing about different system architectures. At the technological level, ESI will create new interactions and interdependencies between the different energy systems beyond traditional boundaries, making it more complex to manage the WES. Moreover, interactions lead to emergent behaviour that would affect the system performance and it should be anticipated and captured. Thus, new planning

23. Ron Raven and Geert Verbong, 'Multi-Regime Interactions in The Dutch Energy Sector: The Case of Combined Heat and Power Technologies in the Netherlands 1970-2000,' *Technology Analysis & Strategic Management* 19, no. 4 (2007): 491–507. https://doi.org/10.1080/09537320701403441

24. Claus Nielsen Ballegaard, et al., 'Systems of Systems Engineering: Basic Concepts, Model-Based Techniques, and Research Directions,' *ACM Computing Survey* 48, no. 2 (November 2015): 1–41. https://doi.org/10.1145/2794381

25. Saurabh Mittal, et al., 'A system-of-systems approach for integrated energy systems modeling and simulation,' paper presented at *the Society for Modeling & Simulation International Summer Simulation Multi-Conference*, Chicago, USA, July 26–29, 2015. http://bitly.ws/qtqe

26. Raven and Verbong, 'Multi-Regime Interactions.'

and operational paradigms need to be designed to account for the complexity involved and the emerging behaviour. At the markets and institutional level, ESI will bring together multiple actors with different objectives and motivations. In this vein, new opportunities to develop ESI will foster partnerships between separate energy businesses, each of which has an independent market structure and regulatory framework. In addition, new actors could emerge with new business models posited to take advantage of ESI. This will lead to a change in the market structure and the governance framework, which again mean a new energy system architecture.

A number of other relevant studies can be found in the sustainability transitions literature. For example, CHP is deemed as a case study of a technology that would create multi-regime interactions between distinct systems (electricity and gas) to demonstrate that transitions would possibly cross traditional regime boundaries.[27] Another study delves into the interactions between the different energy systems (electricity, heat, transport) in the case of electrification, stressing the relationships between the actors implied.[28] Lastly, another research suggested exploring future system changes through different possible system architectures, focusing merely on the electricity system, though.[29]

7.3. A System-of-Systems Architecture Methodology

To operationalise the MSP in the context of ESI and understand the interactions across the integrated energy systems, a SOS architecture methodology is proposed here. The methodology was initially developed to facilitate the sustainability assessment of integrated energy systems by modelling the whole system as a SoS and analysing its system architecture. The methodology yields

27. Ibid.

28. Daniel Rosenbloom, 'A clash of socio-technical systems: Exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario,' *Energy Research & Social Science* 49 (March 2019): 219–32. https://doi.org/10.1016/j.erss.2018.10.015

29. Kristina Hojčková, Björn Sandén, and Helena Ahlborg, 'Three electricity futures: Monitoring the emergence of alternative system architectures,' *Futures* 98 (April 2018): 72–89. https://doi.org/10.1016/j.futures.2017.12.004

appropriate criteria and indicators for evaluating the effectiveness of ESI as a pathway to achieving the energy transition objectives. This is done first by identifying the system requirements representing different stakeholders' needs and objectives and then mapping them with the relevant system functionalities or capabilities that fulfil those requirements.

Due to the integrated and complex nature of the system under study, the system needs to be broken down into its different components to study the interfaces and interdependencies between them. The modelling process highlights the interactions between the different energy systems at different levels and the system environment involving multiple stakeholders. In doing so, abstraction at different levels is employed to capture emergent behaviour and reduce complexity. Moreover, the possible structure and relations are manifested in a system architecture model. Thus, this methodology is proposed to understand the interactions across socio-technical systems and the possible future structure of socio-technical networks.

The first aim of the methodology is to develop a conceptual model of the WES with appropriate evaluation principles. This means that the model should be multi-dimensional (i.e., representing different perspectives of multiple stakeholders), multi-vectoral (i.e., covering multiple energy vectors), and systemic (i.e., spanning the energy supply chain from generation to end-use through networks). Likewise, the model should be future-oriented to adapt to possible structural changes in the energy system and systematically replicable for different situations. Finally, the model should lead to the evaluation of the system but the applicability of this depends mainly on data availability. This is supported by the conceptual framework shown in FIGURE 9.

As shown above, the modelling and analysis are carried out using systems engineering methods, namely model-based systems engineering (MBSE), architectural frameworks, and requirements analysis.[30] Similarly, the SOS architecture methodology is used as a structured approach to develop or represent the potential future conditions of a system. Furthermore, a system architecture

30. Nielsen Ballegaard, et al., 'Systems of Systems Engineering.'

includes principles and guidelines governing the structure, functions, and interactions between its components and with its environment, and how it will meet its requirements. Besides, 'system requirements' refer to the functions and capabilities that the system needs to fulfil or acquire and relate mainly to the needs of stakeholders. This approach enables the system to be broken into a number of interacting perspectives and helps translate system requirements into possible solutions and visualise the potential impact. This approach also highlights interfaces between sub-systems, components, and actors involved.[31] Using this approach allows for a socio-technical evaluation emphasising not only interactions between systems but also the relations between the whole system and its stakeholders. Thereby, this approach delivers on the requirement for the model to be multi-dimensional and futuristic.

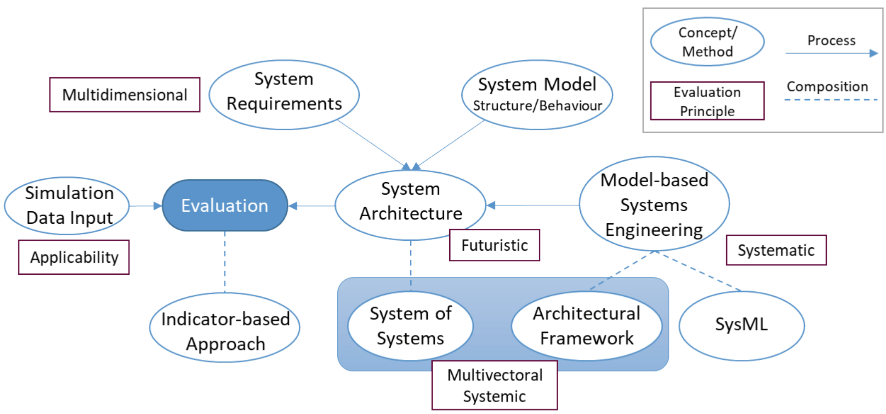

FIGURE 9. Conceptual Framework

Source: Prepared by authors.

By the same token, the system is modelled as a sos. Such an approach applies to large scale interdisciplinary problems that span multiple distributed systems.[32] It also allows the system to be decomposed into its different constituent systems

31. Energy Systems Catapult, *Systems thinking in the energy system: A primer to a complex world* (Birmingham: Energy Systems Catapult, 2018). http://bitly.ws/qvgP

32. Ibid.

(i.e., electricity, gas, and heat) and system elements (i.e., generation, networks, and consumption) stressing the interdependencies between them. A SOS approach supports a diverse and holistic understanding of the evolving systems and a focus on the boundaries and interactions between the different systems.[33] This satisfies the requirement for the model to be multi-vectoral and systemic.

Additionally, MBSE techniques are used to develop the conceptual model and represent the system architecture. MBSE is the formalised application of modelling to support system design, architecture, analysis, and evaluation. MBSE is supported by the systems modelling language (SysML), which is a graphical modelling language for designing and analysing complex systems.[34] SysML diagrams include structural and behavioural diagrams, in addition to requirements and parametric diagrams. The modelling is guided by a framework that considers the system views required to describe a system architecture systematically.

7.4. Framework Application

The architectural framework employed for this analysis is an adapted version of the framework 'system-of-systems approach to context-based requirements engineering' (SoS-ACRE).[35] The main feature of this architectural framework is it decomposes the system under study into different levels as for the SOS architecture. System views are divided into four system levels, namely: the Context, SOS, CS, and whole system levels. At each level, several views are developed to show the system structure, composition, stakeholders, requirements, and measures of effectiveness, using SysML diagrams. Another significant characteristic of this framework is it shows the interactions between the different CSs contexts and the ones between CSs and the SOS as a whole.

33. Erik Pruyt and Wil Thissen, 'Transition of the European Electricity System and System of Systems Concepts,' paper presented at *2007 IEEE International Conference on System of Systems Engineering*, San Antonio, USA, April 16–18, 2007. http://doi.org/10.1109/SYSOSE.2007.4304305

34. Ana Luisa Ramos, José Vasconcelos Ferreira, and Jaume Barceló, 'Model-based systems engineering: An emerging approach for modern systems,' *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 42, no. 1 (January 2012): 101–11. http://doi.org/10.1109/TSMCC.2011.2106495

35. COMPASS. "D21.1 – Report on Guidelines for SoS Requirements". COMPASS Project; 2012.

After modelling the system, appropriate evaluation criteria are derived from system requirements at different levels.. Indicators are finally assigned considering the indicative parameters to measure levels of fulfilment. This process also entails making choices on benchmarking and grouping indicators, and these depend on two main factors: evaluation and data availability. Finally, the conceptual system model is coupled with a simulation model representing the same system topology and conditions to quantify the performance and relationships, and consequently, the indicators for evaluation.

In this train of thought, scenario analysis is conducted to evaluate and compare the performance of the system with different configurations and under different conditions of energy supply and demand. This has been applied to case studies based in the Findhorn village and the North of Tyne region in the UK.[36] The case studies imply several scenarios to deliver heat with different network configurations (electricity, heat, and gas) and coupling technologies (CHP, P2X, and HPs). Each of these constitutes a CS. The conceptual system model is developed for all scenarios as described by the architectural framework. This enables the creation of diagrams that show:

- The SOS structure and composition in terms of CSs (i.e., electricity, gas, heat, and coupling technologies).
- The CSs composition regarding system elements (i.e., generation, networks, and individual technologies).
- The systems stakeholder groups involved (i.e., local government, local community, network operators, end-users, and prosumers).
- System requirements reflecting the non-functional relationships between stakeholders and the SOS (energy trilemma objectives).
- System requirements reflecting the functional relationships among the CSs and with the SOS (e.g., delivering energy, transforming energy, and providing grid services, etc.)

36. Ali El Hadi Berjawi, et al., 'Whole Energy Systems Evaluation: A Methodological Framework and Case Study,' in *Whole Energy Systems*, eds. Vahid Vahidinasab and Behnam Mohammadi-Ivatloo (Cham: Springer, 2022), 41–82.

- The mapping of the system's functions, components, requirements, and indicators.

As a result, the framework proposed here provides a method to encompass stakeholders' perspectives in evaluating the effectiveness of a socio-technical pathway that involves multi-systems interactions towards achieving the transition objectives. The evaluation is conducted using metrics that allow for a reduced representation of the complex system architecture, including structural, and functional interlinkages.

7.5. Conclusion and Future Work

In summary, this chapter makes several contributions. First, it discusses a socio-technical transitions analysis of energy systems integration (ESI) through the multi-system perspective (MSP). Second, it justifies a system-of-systems (SOS) conceptualisation of ESI in line with the MSP in order to understand multi-system interactions. Third, it presents a structured methodological framework to identify and analyse multi-system interactions implied in ESI and to evaluate the potential future system architecture. Reflecting on those contributions, multiple streams for future research work are discussed below. These streams include generalisability to other socio-technical systems, coupling with quantitative simulation modelling, and understanding the co-evolutionary dynamics between the physical reconfiguration and the market reconfiguration.

This chapter presents the case of integrated electricity, gas, and heat systems to illustrate the interactions across socio-technical systems. In terms of generalisability to other socio-technical systems beyond energy (e.g., food, water, mobility, and telecom), the proposed SOS conceptualisation is expected to still apply to a case of integration. Accordingly, since the proposed methodology is context-based, it can be used to identify possible structural and functional interlinkages across systems and to evaluate potential future system architectures. However, patterns of change could turn out to be different due to the different physical and institutional properties that different systems exhibit. Therefore, more empirical evidence is still needed to support the understanding of the patterns of change entailed in multi-systems transitions including integrated energy systems.

In this regard, some studies have called for coupling sustainability transition frameworks with quantitative simulation models to understand future transition pathways.[37] On the other hand, among the challenges identified for future systems engineering practise, there is a need for methods that can both incorporate assessments for higher-level goals such as sustainability for SOSS and involve stakeholders in the assessments.[38] In this context, the proposed methodological framework contributes to both areas of research. This is because, first, it acts as a bridge between the MSP framework and the simulation models for integrated energy systems. Likewise, it enables a whole system socio-technical evaluation that implies multiple stakeholders' perspectives and multiple technological levels. These contributions should be further enhanced by developing a functional specification guideline describing the formal coupling of the conceptual system model and the quantitative simulation models.

Finally, considering ESI as a pathway for the energy transition implies that both social and technological changes are expected to unfold to achieve the transition objectives, including those for physical infrastructures, market structures, and consumer behaviours.[39] While the focus of this chapter has been on the physical (technical) system architecture, this can be a basis to expand the analysis to the market system architecture using the same methodological approach. This raises a question for future work on the co-evolutionary dynamics of change between the physical system reconfiguration induced by ESI and the consequent, or prerequisite, market reconfiguration required to implement ESI.

37. George Papachristos, 'Towards multi-system sociotechnical transitions: why simulate,' *Technology Analysis and Strategic Management* 26, no. 9 (August 2014): 1037–55. https://doi.org/10.1080/09537325.2014.944148; Danie Rosenbloom, 'Pathways: An emerging concept for the theory and governance of low-carbon transitions,' *Global Environmental Change* 43 (March 2017): 37–50. https://doi.org/10.1016/j.gloenvcha.2016.12.011

38. Wim J. C. Verhagen, Josip Stjepandić, and Nel Wognum, 'Future perspectives in systems engineering,' In *Systems Engineering in Research and Industrial Practice: Foundations, Developments and Challenges*, eds. Josip Stjepandić, Nel Wognum, and Wim J. C. Verhagen (Cham: Springer, 2019), 403–20. https://doi.org/10.1007/978-3-030-33312-6

39. Bruno Turnheim, et al. 'Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges,' *Global Environmental Change* 35 (November 2015): 239–53. https://doi.org/10.1016/j.gloenvcha.2015.08.010

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8. Policy Metrics for Coherent and Socially Inclusive Urban Transformation in Mobility and Energy

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8.1. Introduction

Rationale

Cities occupy only a small portion of the Earth's surface but are home to more than half of the world's population. Thus, these are the major contributors to global greenhouse gas emissions from energy use and highly prone to the risks and effects of climate change.[3] Accordingly, cities have an important role in the

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3. Michael Acuto, Susan Parnell, and Karen C. Seto, 'Building a global urban science,' *Nature Sustainability* 1 (January 2018): 2–4. https://doi.org/10.1038/s41893-017-0013-9; Ahmed Sodiq, et al., 'Towards modern sustainable cities: Review of sustainability principles and trends,' *Journal of Cleaner Production* 227 (August 2019): 972–1001. https://doi.org/10.1016/j.jclepro.2019.04.106; United Nations Department of Economic and Social Affairs, *World Urbanization Prospects: The 2018 Revision* (New York: United Nations, 2019). http://bitly.ws/qwTG; United Nations Industrial Development Organization, *Sustainable Cities: Hubs of Innovation, Low Carbon Industrialization and Climate Action* (Vienna: UNIDO, 2016). http://bitly.ws/qwS3 decarbonisation of society, in conformation to the Paris Agreement's aim of net-zero carbon emissions by the middle of the XXI century.[4] Particularly, this concerns carbon-intensive sectors such as transportation and energy.[5]

Mobility and energy have always been connected at the supply side (through fuels and resources), while the process of decarbonisation is likely to result in stronger links/interactions between both.[6] Urban energy use will be partly supplied through local generation of electricity from e.g., solar photovoltaics (PV) and make use of storage facilities and smart grid technology to balance irregular supply and demand.[7] Meanwhile, urban mobility will shift from motorised passenger vehicles to electric counterparts that are locally recharged. Electric vehicles (EVs) battery capacity can be used to shift demand patterns (e.g., during the night time or while charging at home) and as temporary storage facilities (i.e., batteries to even provide energy for non-driving purposes during peak-demand hours). According to some engineers, early simulations and (federally funded) experimentation, these intertwining developments are commonly recognised as an efficient solution to meet the decarbonisation and sustainability challenges[8]

4. 'The Sustainable Development Goals Report 2020,' United Nations Statistics Division, accessed April 4, 2022. https://unstats.un.org/sdgs/report/2020/

5. Daniel M. Kammen and Deborah A. Sunter, 'City-integrated renewable energy for urban sustainability,' *Science* 352, no. 6288 (May 2016): 922–28. https://doi.org/10.1126/science.aad9302

6. Weert Canzler, et al., 'From "living lab" to strategic action field: Bringing together energy, mobility, and Information Technology in Germany,' *Energy Research & Social Science* 27 (May 2017): 25–35. https://doi.org/10.1016/j.erss.2017.02.003; Gaofeng Gu and Tao Feng, 'Heterogeneous choice of home renewable energy equipment conditioning on the choice of electric vehicles,' *Renewable Energy* 154 (July 2020): 394–403. https://doi.org/10.1016/j.renene.2020.03.007; Michela Longo, Federica Foiadelli, and Wahiba Yaïci, 'Electric vehicles integrated with renewable energy sources for sustainable mobility,' in *New Trends in Electrical Vehicle Powertrains*, eds. Luis Romeral Martinez and Miguel Delgado Prieto, 203–23 (London: IntechOpen, 2019). https://doi.org/10.5772/intechopen.76788; Massimiliano Manfren, Paola Caputo, and Gaia Costa, 'Paradigm shift in urban energy systems through distributed generation: Methods and models,' *Applied Energy* 88, no. 4 (April 2011): 1032–48. https://doi.org/10.1016/j.apenergy.2010.10.018; Marianne Ryghaug and Tomas Moe Skjølsvold, *Pilot Society and the Energy Transition: The Co-shaping of Innovation, Participation and Politics (1st ed.)* (Cham: Palgrave Pivot, 2021). https://doi.org/10.1007/978-3-030-61184-2.

7. Phil Johnstone, et al., 'Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom,' *Energy Research & Social Science* 59 (January 2020): 101287. https://doi.org/10.1016/j.erss.2019.101287; Ryghaug and Skjølsvold, *Pilot Society.*

8. Canzler, et al., 'From "living lab" to strategic;' Gu and Feng, 'Heterogeneous choice;' Longo, Foiadelli, and Yaïci, 'Electric vehicles.'

and are strongly driven by national and European policy targets and measures.[9] It is also suggested to be an opportunity to engage traditional consumers more actively in energy-reduction debates and sustainability thinking.[10] For many, the symbolic qualities of EVs help make issues of mobility needs and energy scarcity concrete through, for instance, drivers becoming more aware of their driving and (re)fuelling habits in the light of their energy bill at home.[11] In some cases, this amplifies an interest in other decarbonisation opportunities (e.g., improving home energy efficiency or local energy production).[12]

The process of decarbonisation increases not only the local interconnection of the mobility and energy domains but also the risk of socio-spatial inequalities. After all, access to sustainable mobility and energy deliberately depends on the spatial properties of the places where people live. How can sustainable mobility, which is primarily aimed at shifting from motorised forms of mobility towards active (e.g., walking or cycling) and public modes of transport, also be ensured for people living in remote or poorly connected neighbourhoods with few local services?[13] The potential of sustainable energy production, which will be partly achieved through the local generation of electricity or heat, depends on local natural resource endowments/scarcity (e.g., hours of sunshine, opportunities

9. Longo, Foiadelli, and Yaïci, 'Electric vehicles;' Detlef P. van Vuuren, et al., *The implications of the Paris Climate Agreement for the Dutch climate policy objectives* (The Hague: PBL Netherlands Environmental Assessment Agency, 2017). http://bitly.ws/qw6r. The development and use of information and communication technology (ICT) and digitalisation are essential for realising the envisaged usage scenarios (within mobility/vehicle-to-grid settings as a passage to the development of distributed generation and smart grid), new roles and actor constellations (e.g. prosumers, energy cooperatives and increasing opportunities of ICT in the smart energy field), and business models (especially for energy trading within urban microgrids) that shape the intersectoral field (see Canzler, et al., 'From "living lab" to strategic;' Di Silvestre et al., 'How Decarbonization, Digitalization and Decentralization are changing key power infrastructures,' *Renewable and Sustainable Energy Reviews* 93 (October 2018): 483–98. https://doi.org/10.1016/j.rser.2018.05.068; Ryghaug and Skjølsvold, *Pilot Society.*)

10. Sanya Carley and David M Konisky, 'The justice and equity implications of the clean energy transition,' *Nature Energy* 5 (August 2020): 569–77. https://doi.org/10.1038/s41560-020-0641-6; Gu and Feng, 'Heterogeneous choice;' Ryghaug and Skjølsvold, *Pilot Society*.

11. Ryghaug and Skjølsvold, *Pilot Society*.

12. Ibid.; Carley and Konisky, 'The justice and equity.'

13. Erling Holden, Geoffrey Gilpin, and David Banister, 'Sustainable mobility at thirty,' *Sustainability* 11, no. 7 (April 2019): 1965. https://doi.org/10.3390/su11071965; Håkan Johansson, et al., 'A need for new methods in the paradigm shift from mobility to sustainable accessibility,' *Transportation Research Procedia* 14 (2016): 412–21. https://doi.org/10.1016/j.trpro.2016.05.093

for using geothermic, aqua-thermic, or anthropogenic heat sources). However, it also relies on physical space to install PV panels: people in flats with common roofs may have much fewer opportunities for installation than people with detached houses.[14] The interaction between mobility and energy transitions may even aggravate the growing inequalities. For instance, dwellers in terraced houses have more roof space to install PV panels, which provide sustainable energy onsite and allow them to drive their privately owned EVs at lower costs. On the other hand, those who live in rented high-rise apartment blocks on the outskirts lack such opportunities despite having more mobility and energy needs.

Problem Statement

Despite the great urgency for a rapid sustainability transformation of urban areas, current policy, and planning approaches to target urban challenges and meet different (inter)national goals are based on different ambitions and understandings of how cities operate and have led to fragmented approaches with suboptimal consequences for the larger urban context.[15] Policy processes are generally structured along organisational silos that result in policies that might be optimal for a certain sector but often undermine the effectiveness of others and are poorly integrated with (long-term) policy targets.[16] Sector-specific policies for mobility and energy, given the strong links between the two, may promote conflicting developments, which reduce the effectiveness of both transformations. For example, the need for a functioning all-electric energy system at home may necessitate

14. Teis Hansen and Lars Coenen, 'The geography of sustainability transitions: review, synthesis and reflections on an emergent research field,' *Environmental Innovation and Societal Transitions* 17 (December 2015): 92–109. https://doi.org/10.1016/j.eist.2014.11.001; Kammen and Sunter, 'City-integrated renewable energy.'

15. Jonas Bylund, 'Joint programming for urban transformations: the making of the JPI Urban Europe Strategic Research and Innovation Agenda,' *Urban Transformations* 2 (September 2020): 10. https://doi.org/10.1186/s42854-020-00012-y; Urban Europe, *Joint Call for Proposals for Research and Innovation Projects: Urban Transformation Capacities* (European Union: Urban Europe, 2020). http://bitly.ws/qxcj

16. Marc Dijk, et al., 'Policies tackling the "web of constraints" on resource efficient practices: The case of mobility,' *Sustainability: Science, Practice and Policy* 15, no. 1 (October 2019): 62–81. https://doi.org/10.1080/15487733.2019.1663992; Urban Europe, *Joint Call for Proposals*; Paula Kivimaa and Florian Kern, 'Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions,' *Research Policy* 45, no. 1 (February 2016): 205-17. https://doi.org/10.1016/j.respol.2015.09.008; Martin Larbi, *Green Urbanism in Contemporary Cities: A Socio-technical Transition Analysis, PhD diss.* University of Adelaide, 2019. https://hdl.handle.net/2440/120462 the ownership of EVs (as batteries for the intermittent self-generated electricity from PV panels), and thereby, it hinders a shift to car alternatives. On the other hand, there might be potential for synergistic developments such as achieving zero-carbon/emission, reliable services in both mobility and energy domains, or the shift to affordable EV sharing services. Whereas the integration of mobility and land-use policies has been on the research agenda already for many years,[17] the interference between mobility and energy policies has not been studied yet, and hence, how they can be made more coherent remains unclear.

Current approaches targeting sustainability challenges of urban mobility and energy systems do not only tend to stay within sectoral silos but also easily neglect socio-spatial inequalities of the transformation. Growing socio-spatial inequalities in terms of access to (sustainable) mobility and energy across various neighbourhoods create the real risk of mobility- and energy poverties. They are also greatly influenced by the spatial properties of the places in which people find themselves.[18] In the light of sustainability transformation, there is a need to make sure the transformation is also fair in a social sense.[19] Insights on the social impacts of mobility and energy transformations are crucial and therefore needed by policymakers and planners.

On account of the current predominance of policies that are sector-specific and do not take socio-spatial inequalities into account, there is a need for coherent and just policies or policy mixes. In this vein, we should (i) maximise synergies and minimise trade-offs in the effectiveness of sustainable urban mobility and energy transformations, and (ii) minimise socio-spatial inequalities that could result from both transformations. To support the development of such policies, there is a need for *ex-ante* evaluation and assessment of their

17. See Dominic Stead, 'Transport and land-use planning policy: really joined up?' *International Social Science Journal* 55 (June 2003): 333–47; David Banister, 'Viewpoint: Assessing the reality—Transport and land use planning to achieve sustainability,' *Journal of Transport and Land Use* 5, no. 3 (December 2012): 1–14. https://doi.org/10.5198/jtlu.v5i3.388

18. Neil Simcock and Caroline Mullen, 'Energy demand for everyday mobility and domestic life: Exploring the justice implications,' *Energy Research & Social Science* 18 (August 2016): 1–6. https://doi.org/10.1016/j.erss.2016.05.019

19. Susana Borrás and Jackob Edler, 'The roles of the state in the governance of socio-technical systems' transformation,' *Research Policy* 49, no. 5 (June 2020): 103971. https://doi.org/10.1016/j.respol.2020.103971 impacts on trade-offs and inequalities in the interconnected transformations, including relevant indicators. These indicators should both change over a longer period (i.e., a few decades) and provide insights into the socio-spatial heterogeneity, as shown in FIGURES 10 and 11.

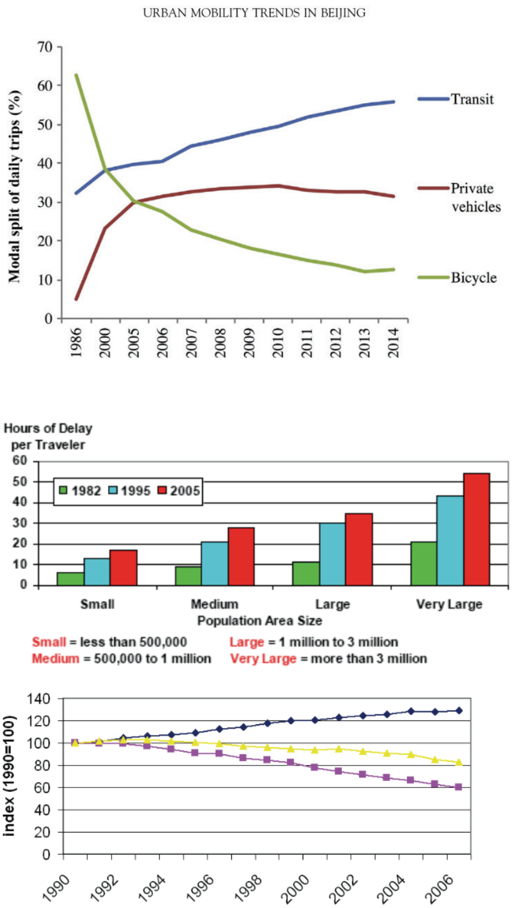

FIGURE 10. Examples of Time-Series of Possible Transformation Indicators (Left) and Impact Indicators (Right)

Source: Gao et al. and Dijk.[20]

20. Yuan Gao, et al., 'Transport and Mobility Trends in Beijing and Shanghai: Implications for Urban Passenger Transport Energy Transitions Worldwide,' in *Urban Energy Transition: Renewable Strategies for Cities and Regions (2nd ed.)*, ed. Peter Droege, (Amsterdam: Elsevier Ltd., 2018), 205–23. https://doi.org/10.1016/b978-0-08-102074-6.00025-5; Marc Dijk, *Innovation in Car Mobility: Coevolution of*

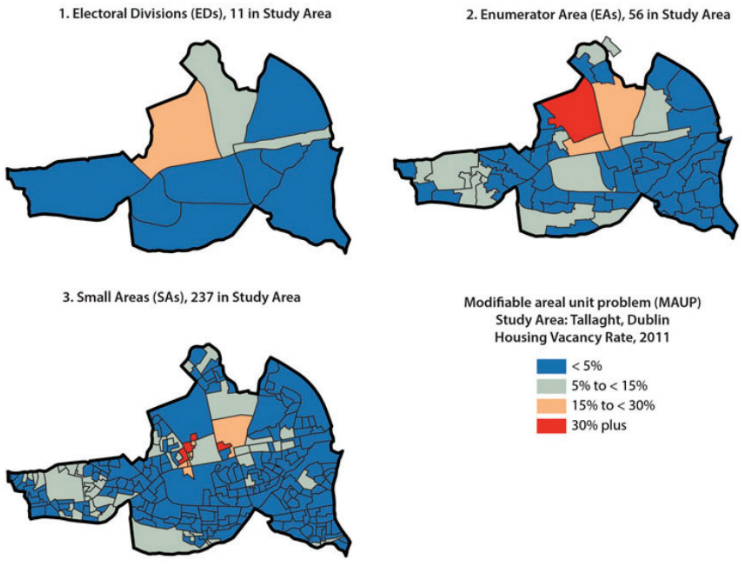

FIGURE 11. An Example of an Indicator (Housing Vacancy Rate as of 2011) at Statistical Geographies that Are Nested in the County Town of Tallaght in Dublin, Ireland

Source: Kitchin, Lauriault, and McArdle.[21]

Within the challenging policymaking context that is heavily constrained by time, budget, and span of control, these metrics for urban transformation ought to be comprehensive enough to capture the interdependencies and key environmental and socioeconomic impacts of mobility and energy transformations. Yet, they should not be too complex (i.e., they should not have too many indicators and not be too methodologically rigorous).

We hereby propose a methodological approach to developing a neighbourhood-level dashboard with a 'light' set of actionable indicators. Our purpose is to provide a much-needed simple assessment tool to address tensions and synergies in the interconnected urban mobility and energy transformations.

Demand and Supply under Sustainability Pressures. PhD diss. (Maastricht University, 2010). https://doi.org/10.26481/dis.20100923md

21. Rob Kitchin, Tracey P. Lauriault, and Gavin McArdle, 'Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards,' *Regional Studies, Regional Science* 2, no. 1 (January 2015): 6–28. https://doi.org/10.1080/21681376.2014.983149

Likewise, we seek to focalise the interactions and potential effects of a policy package for said transformations. Additionally, we aim to incorporate the consideration of just urban transformation. Along these lines, the proposal is structured and organised into several sections within this chapter as follows. Section 8.2 discusses the literature reviews of urban transformation, urban assessment , and policy for transformation. In this light, the identification of knowledge gaps in the mobility–energy transformation nexus flags the need for metrics to understand and score the reciprocal sustainability impacts of the interconnected urban transformations at the neighbourhood level. Section 8.3 starts to sketch the contours of a manageable set of relevant indicators that should result in an indicator dashboard. The dashboard comprises some generic categories, which can be tailored to fit local specificities. It is intended to serve as a simple assessment tool that makes aggregated information on the cross-system interactions and sustainability implications of the interconnected urban transformations available in a meaningful way for transformation policy. Ideally, indicators are scored using both longitudinal and spatially explicit data to offer a more complete understanding of the mobility-energy nexus in sustainability transformation and bring to light the much-needed consideration of socio-spatial inequality. Lastly, Section 8.4 discusses the merits/potential of the approach for urban mobility policy and draws some conclusions.

8.2. Literature Review

Urban Transformation

Rapid decarbonisation towards carbon-neutrality by 2050 requires a transformation of urban systems in the coming three decades. In the urban context, we refer to transformations as fundamental and structural changes in urban practises that involve both material arrangements (e.g., technologies and infrastructures) and nonmaterial ones (e.g., conventions, norms, competencies, and cultures).[22] This generally involves nonlinear, complex, and long-term process-

22. Harriet Bulkeley, et al., eds. *Cities and Low Carbon Transitions (1st ed.)* (Abingdon: Routledge, 2011); Niki Frantzeskaki, et al., 'Urban Sustainability Transitions: The Dynamics and Opportunities of es of innovation, experimentation, upscaling, and institutional restructuring. In addition, it engages a wide range of actors who are not only on the receiving ends of urban processes but also engage in decision-making.[23]

Cities are large and growing sociotechnical ensembles and should thus be analysed as such.[24] Analyses of urban transformation have been a limited share in studies of socio-technical sustainability transformation in the past decades[25] but they have been recently increasing and seen as interesting avenues for a variety of research directions.[26] Still, more attention needs to be paid to local and spatial specificities from which transformations emerge within an urban context and unfold similarly/differently across locations, scales, and developmental stages.[27]

The past decades' advancement in the studies of socio-technical changes introduced a variety of heuristic devices to help researchers make sense of voluminous, multidimensional, and cross-disciplinary data. Such advances also allowed understanding approaches that are needed for a better understanding of transformation processes and pathways whilst making meaningful

Sustainability Transitions in Cities,' in *Urban Sustainability Transitions (1st ed.)*, eds. Niki Frantzeskaki, et al. (New York: Routledge, 2017), 1–22. https://doi.org/10.4324/9781315228389-1

23. Niki Frantzeskaki, et al., 'Urban Sustainability Transitions;' Thomas Lützkendorf and Maria Balouktsi, 'Assessing a sustainable urban development: Typology of indicators and sources of information,' *Procedia Environmental Sciences* 38 (2017): 546–53. https://doi.org/10.1016/j.proenv.2017.03.122; Bruno Turnheim, Paula Kivimaa, and Frans Berkhout, 'Beyond experiments,' in *Innovating Climate Governance: Moving Beyond Experiments*, eds. Bruno Turnheim, Paula Kivimaa, and Frans Berkhout, (Cambridge: Cambridge University Press, 2018), 1–26. https://doi.org/10.1017/9781108277679.002

24. Anique Hommels, 'Studying Obduracy in the City: Toward a Productive Fusion between Technology Studies and Urban Studies,' *Science, Technology, & Human Values* 30, no. 3 (July 2005): 323–51. https://doi.org/10.1177/0162243904271759

25. Jochen Markard, Rob Raven, and Bernhard Truffer, 'Sustainability transitions: An emerging field of research and its prospects,' *Research Policy* 41, no. 6 (July 2012): 955-67. https://doi.org/10.1016/j.respol.2012.02.013

26. Frantzeskaki, et al., 'Urban Sustainability Transitions;' Jonathan Köhler, et al., 'An agenda for sustainability transitions research: State of the art and future directions,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 1–32. https://doi.org/10.1016/j.eist.2019.01.004; Ivan Savin and Jeroen van den Bergh, 'Main topics in EIST during its first decade: A computational-linguistic analysis,' *Environmental Innovation and Societal Transitions*, 41 (December 2021): 10–17. https://doi.org/10.1016/j.eist.2021.06.006

27. Frantzeskaki, et al., 'Urban Sustainability Transitions;' Frank W. Geels, et al., 'The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014),' *Research Policy* 45, no. 4 (May 2016): 896-913. https://doi.org/10.1016/j.respol.2016.01.015; Köhler, et al., 'An agenda for sustainability.'

comparisons and preventing data mis-gathering and misinformation.[28] For instance, the use of a conceptual framework that is rooted in innovation and evolutionary theories such as the multi-level perspective (MLP) has been prominent in the field due to its ability to explain long-term and far-reaching system change.[29] However, it has also criticised for poor insights into the local, spatial specificities of transformations.[30] At the urban level, the niche–regime dichotomy seems less productive because actors and practises are too entangled to be affiliated to only one of the two, and hence a more sensitive lens is needed.

This criticism has engendered the pursuit of a deeper local understanding of sociotechnical transformations through the lens of social practise theories (SPTs), which emerged from studies of sustainable consumption[31] and are increasingly applied in social science and energy research.[32] Unlike MLP, SPTs decentre technology and put the routines of people at the core. The theories refer to social practises as the routinised way people do things, such as how people travel, eat, shower, and heat their homes, etc. More recent elaborations on the basic three-element model of SPTs, i.e., 'meanings, materialities, and competences,'[33] have proven to be useful for analysing system change as transforming practises.

28. Benjamin K. Sovacool and David J. Hess, 'Ordering theories: Typologies and conceptual frameworks for sociotechnical change,' *Social Studies of Science* 47, no. 5 (June 2017): 703–50. https://doi.org/10.1177/0306312717709363

29. Köhler, et al., 'An agenda for sustainability;' Mohammadreza Zolfagharian, et al., 'Studying transitions: Past, present, and future,' *Research Policy* 48, no. 9 (November 2019): 103788. https://doi.org/10.1016/j.respol.2019.04.012

30. Hansen and Coenen, 'The geography of sustainability;' Mike Hodson and Simon Marvin, 'Urbanism in the anthropocene: Ecological urbanism or premium ecological enclaves?' *City* 14, no. 3 (June 2010): 298–313. https://doi.org/10.1080/13604813.2010.482277; James T. Murphy, 'Human geography and sociotechnical transition studies: Promising intersections,' *Environmental Innovation and Societal Transitions* 17 (December 2015): 73–91. https://doi.org/10.1016/j.eist.2015.03.002

31. Filippo Corsini, et al., 'The advent of practice theories in research on sustainable consumption: Past, current and future directions of the field,' *Sustainability* 11, no. 2 (January 2019): 341. https://doi.org/10.3390/su11020341; Elizabeth Shove and Alan Warde, *Inconspicuous consumption: the sociology of consumption and the environment* (Lancaster: Lancaster University, 1998). http://bitly.ws/qwUF; Zolfagharian, et al., 'Studying transitions.'

32. Elisabeth M. C. Svennevik, Marc Dijk, and Peter Arnfalk, 'How do new mobility practices emerge? A comparative analysis of car-sharing in cities in Norway, Sweden and the Netherlands,' *Energy Research & Social Science* 82 (December 2021): 102305. https://doi.org/10.1016/j.erss.2021.102305

33. Elizabeth Shove, Mika Pantzar, and Matt Watson, *The Dynamics of Social Practice: Everyday Life and How it Changes* (London: SAGE Publications Ltd, 2012). https://doi.org/10.4135/9781446250655

Attention to local specificities has been demonstrated by recent applications of social-practise-based frameworks to unpacking transformations in different places such as Barnes Hofmeister and Keitsch's case of urban cycling, Dijk, Hommels, and Stoffers's case of urban car mobility and cycling, and Svennevik, Dijk, and Arnfalk's and Svennevik, Julsrud, and Farstad's cases of shared mobility.[34] These studies have examined certain new practise (such as car-sharing) in relation to established mobility practises. Moreover, they have addressed others such as housing, working, and shopping. In other words, they have conceptualised urban living as a patchwork of entangled practises as illustrated in FIGURE 12.

We expand Svennevik, Dijk, and Arnfalk's conceptual model, which primarily focuses on the urban mobility practises model, to include both mobility and energy practises' nexus (e.g., how people routinely travel, heat/cool their houses, and (re)fuel their vehicles, etc.) As shown in FIGURE 12, passenger mobility and household energy practises involve others on the users/travellers' side, but also grid operator and urban governance, among others, in relation to each other through partially shared infrastructure and partly interrelated meanings and competencies. As earlier studies have shown, such practises transform regarding each other and other (neighbouring) urban practises (e.g., working, housing, land-use planning, and parking operation in other cities, etc.). Although these earlier studies have offered new conceptualisations and ways of explaining urban transformation, they do not provide insight into the impacts of transformation in terms of environmental and social indicators. We turn to such literature subsequently in next section.

34. See Tobias Barnes Hofmeister and Martina Keitsch, 'Framing complexity in design through theories of social practice and structuration: A comparative case study of urban cycling,' *Proceedings of the Future Focused Thinking - DRS Conference*, eds. Paul Lloyd and Erick Bohemia, June 27–30, 2016, Brighton: Design Research Society. https://doi.org/10.21606/drs.2016.47; Dijk, Hommels, and Stoffers, 'Transformation of urban mobility practices in Maastricht (1950-1980): Co-evolution of cycling and car mobility,' presented at *Cycling Research Board Annual Meeting 2020, Eindhoven, October 26–28, 2020.*; Svennevik, Dijk, and Arnfalk, 'How do new mobility practices emerge;' Elisabeth M. C. Svennevik, Tom Erik Julsrud, and Eivind Farstad, 'From novelty to normality: Reproducing car-sharing practices in transitions to sustainable mobility,' *Sustainability*: *Science, Practice and Policy* 16, no. 1 (October 2020): 169–83. https://doi.org/10.1080/15487733.2020.1799624

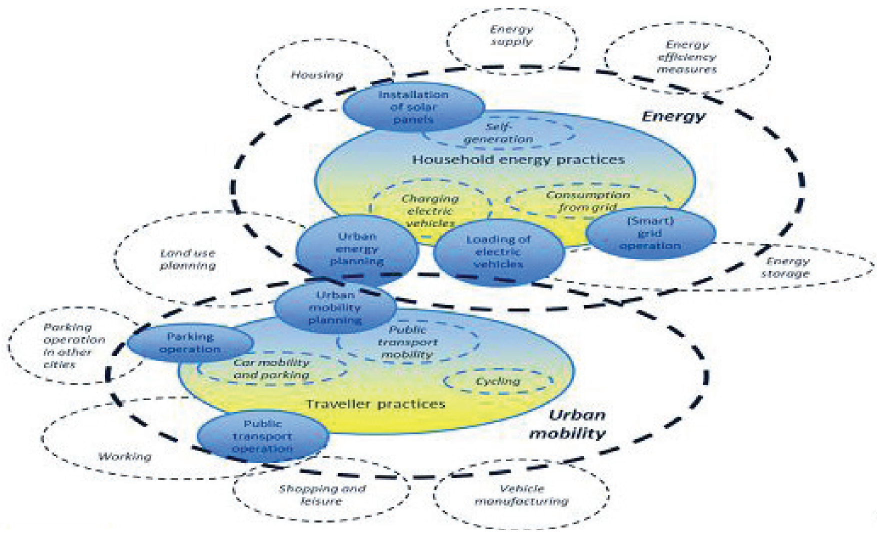

FIGURE 12. Urban Living Conceptualised as a Patchwork of Entangled Practises

Source: Prepared by authors based on the cases from Barnes Hofmeister and Keitsch; Dijk, Hommels, and Stoffers; Svennevik, Dijk, and Arnfalk; and Svennevik, Julsrud, and Farstad.[35]

Urban Assessment

Owing to the rise of sustainable development (SD) and urban managerialism, cities around the world have been routinely generating suites of indicators. They help not only systematically monitor and evaluate their progress and performance but also guide visions and strategies, support decision-making, and policy formulation, and inform urban governance.[36] Research on sustainability assessment (SA) for the urban context, which has been growing and receiving a strong interest across a wide spectrum of studies and cities in the past decade, tends to revolve around identifying and measuring many dozens of indicators

35. Svennevik, Julsrud, and Farstad, 'From novelty to normality.'

36. Matthew Cohen, 'A Systematic Review of Urban Sustainability Assessment Literature,' *Sustainability* 9, no. 11 (November 2017): 2048. https://doi.org/10.3390/su9112048; Rob Kitchin, Tracey P. Lauriault, and Gavin McArdle, 'Indicators, Benchmarking and Urban Informatics,' in *Understanding Spatial Media*, eds. Rob Kitchin, Tracey P. Lauriault, and Matthew W. Wilson (London: SAGE Publications Ltd., 2017), 119–26. https://doi.org/10.4135/9781526425850.n11 that are difficult for practitioners to employ.[37] The often-followed three-pillar approach (or triple bottom line) can lead to an oversimplification of such a complex problem as urban governance. This is because it impairs our ability to understand the interdependence across the sustainability pillars and is unable to capture all aspects of complex concepts such as SD or complex systems such as a city.[38] Analysing urban systems and improving their performance with respect to the sustainability pillars have largely relied on pertinent tools and methods from the fields of ecological economics, industrial ecology, and operations research. However, these involve simulation models with a high level of computational complexity and extensive data requirement.[39]

Policymakers, planners, and city managers are heavily constrained by time, budget, resources, and span of control (i.e., division of authority between local and national governments). At the same time, they are limited in technical knowledge and experience with respect to defining performance indicators and retrieval, collection, preparation, and interpretation of data.[40] They want to get a snapshot of how the city is performing in different areas but do not necessarily have the capacity and interest to comprehend technical or methodological details of indicator suites, which, despite their multitude, are typically developed for specific use purposes and thus, difficult to derive

37. Cohen, 'A Systematic Review;' Stanislav E. Shmelev and Irina A. Shmeleva, 'Global urban sustainability assessment: A multidimensional approach,' *Sustainable Development* 26, no. 6 (October 2018): 904–20. https://doi.org/10.1002/sd.1887; Pramit Verma and Akhilesh S. Raghubanshi, 'Urban sustainability indicators: Challenges and opportunities,' *Ecological Indicators* 93 (October 2018): 282–91. https://doi.org/10.1016/j.ecolind.2018.05.007

38. Cohen, 'A Systematic Review;' Kathryn M. Davidson, et al., 'Assessing urban sustainability from a social democratic perspective: A thematic approach,' *Local Environment* 17, no. 1 (November 2011): 57–73. https://doi.org/10.1080/13549839.2011.631990; Alexandros Gasparatos, Mohamed El-Haram, and Malcolm Horner, 'A critical review of reductionist approaches for assessing the progress towards sustainability,' *Environmental Impact Assessment Review* 28, no. 4–5 (May–June 2008): 286–311. https://doi.org/10.1016/j.eiar.2007.09.002

39. Shmelev and Shmeleva, 'Global urban sustainability assessment.'

40. Astrid Gühnemann, et al., *Monitoring and evaluation: Assessing the impact of measures and evaluating mobility planning processes* (Brussels: European Platform on Sustainable Urban Mobility Plans, 2016). http://bitly.ws/qwQy; Aapo Huovila, Peter Bosch, and Miimu Airaksinen, 'Comparative analysis of standardized indicators for Smart sustainable cities: What indicators and standards to use and when?' *Cities* 89 (June 2019): 141–53. https://doi.org/10.1016/j.cities.2019.01.029; Samuel Stehle and Rob Kitchin, 'Real-time and archival data visualisation techniques in city dashboards,' *International Journal of Geographical Information Science* 34, no. 2 (June 2019): 344–66. https://doi.org/10.1080/13658816.2019.1594823 actionable generalisations.[41] In seeking to reduce the complexity of urban systems, treating a city as a sum of simplified, one-dimensional indicators decontextualises it from the wider set of relations that frame its development and the interconnections and interdependencies among them.[42] Benchmarking indicators for cross-city comparison assumes a normative standard by which cities should be assessed or judged rather than acknowledging the varying characteristics that determine how development goals are prioritised and how different strategies are applied to achieve sustainability in different cities.[43]

In theory, enhancing the efficiency and effectiveness of policymaking relies on the application of systemic evaluative rationality to public policy problems and *ex-ante* assessment based on empirical data, of which increasing diversity, availability, and openness in the last decade may create new opportunities.[44] In practise, policymakers hardly can do so. Although academic literature has currently provided limited insight on new data developments in policy practise, a review shows that the new types of big data are not replacing the usage of traditional ones, namely: surveys and statistics.[45] It suggests the dominance of traditional data, i.e., in descending order, survey data, statistical data, and geographical information system (GIS) data, for urban mobility policy assessment. Likewise, literature anticipates the continuation of their importance and

41. Pekka Halla, Romano Wyss, and Claudia R. Binder, 'Conceptualizing Urban Systems for Sustainability Assessment: Four Powerful Metaphors,' in *Sustainability Assessment of Urban Systems*, eds. Claudia R. Binder, Romano Wyss, and Emanuele Massaro (Cambridge: Cambridge University Press, 2020), 241–60. https://doi.org/10.1017/9781108574334.012; Huovila, Bosch, and Airaksinen, 'Comparative analysis;' Stehle and Kitchin, 'Real-time.'

42. Kitchin, Lauriault, and McArdle, 'Indicators, Benchmarking, Urban.'

43. Ainhoa Gonzalez, et al., 'Community of practice approach to developing urban sustainability indicators,' *Journal of Environmental Assessment Policy and Management* 13, no. 4 (December 2011): 591–617. https://doi.org/10.1142/s1464333211004024; Kitchin, Lauriault, and McArdle, 'Indicators, Benchmarking, Urban.'

44. Michael Howlett and Sarah Giest, 'The policy-making process,' in *Routledge Handbook of Public Policy (1st ed.)*, eds. Eduardo Araral, et al. (London: Routledge, 2012), 17–28. https://doi.org/10.4324/9780203097571-8; Xu Liu and Marc Dijk, 'The role of data in sustainability assessment of urban mobility policies,' *Data & Policy* 4 (January 2022): e2. https://doi.org/10.1017/dap.2021.32; Organisation for Economic Cooperation and Development, OECD, *Better Policies for Sustainable Development 2016: A New Framework for Policy Coherence* (Paris: OECD Publishing, 2016). https://doi.org/10.1787/9789264256996-en

45. Liu and Dijk, 'role of data in sustainability.'

relevance in said context despite the surging attention to and availability of open, location-based big data.

In spite of the greater availability of (open) data, sustainability monitoring studies have concluded that more indicators do not necessarily deliver more actionable understanding. On the contrary, these have proposed embracing the principle of decision relevance ('why to measure') in designing monitoring schemes ('less is more').[46] The selection of tools and indicators for urban assessment has room to benefit from an explicit conceptualisation of the complex assessment problem. This conceptualisation helps deliver a coverage of necessary aspects of sustainability, especially those ones that have been hitherto under-appreciated/addressed, and signals whether the interplay of said aspects supports or compromises the ability of the system to sustain itself in the long run in a transparent, unbiased, unarbitrary, conscious, and reflexive fashion.[47]

Transformation Policy

Concerning policy, studies of sustainability transformation have called for a broad mix of research and innovation policies with particular attention being paid to societal experimentation. Scholars have proposed frameworks that align such experiments with long-term policy objectives often accompanied by long-term targets and plans to achieve them, which can be supported by strategic visioning and foresight processes.[48]

Molas-Gallart et al. propose a formative approach to the evaluation of what is called transformative innovation policies (TIPs).[49] TIPs are generally policy mixes that seek to enable a transformation. Their evaluation approach is a

46. Todd S. Rosenstock, et al., 'When less is more: Innovations for tracking progress toward global targets,' *Current Opinion in Environmental Sustainability* 26–27 (June 2017): 54–61. https://doi.org/10.1016/j.cosust.2017.02.010

47. Jasper Großkurth, *Regional Sustainability: Tools for Integrated Governance. PhD diss.* (Maastricht University, 2008). https://doi.org/10.26481/dis.20081209jg; Halla, Wyss, and Binder, 'Conceptualizing Urban Systems.'

48. See Derk Loorbach, *Transition Management: New Mode of Governance for Sustainable Development* (Utrech: International Books, 2007). https://hdl.handle.net/1765/10200

49. Jordi Molas-Gallart, et al., 'A Formative Approach to the Evaluation of Transformative Innovation Policy,' *Research Evaluation* 30, no. 4 (October 2021): 431–42. https://doi.org/10.1093/reseval/rvab016 generic and complex 'sociotechnical transformation' framework that includes the description of the situation to be transformed, the desired goals, and the steps linking them.[50] The intermediate steps consist of 'supporting individual and organisational learning' through a process of 'reflexive monitoring and evaluation' of policy interventions.[51] It includes the expected relations between the resources invested in intervention and their effects and the assumptions under which they expect such effects.[52] Molas-Gallart et al.'s approach is well-thought-out from a learning perspective. A disadvantage is that the strong emphasis on learning processes and *ex-post* and *ex-ante* policy assessment is at odds with the current logic of the public sector. The 'projectification of policy practise'[53] has only constrained learning processes and there is hardly any capacity for policy assessment at lower levels of government. Therefore, there is a need for simpler tools that do support the transformation process but do not depend on a cultural shift towards 'reflexive monitoring and evaluation.'

We aim to develop a 'transformation dashboard' for specific domains (i.e., transport and energy) and geographic scope (i.e., urban level). Such a dashboard can be helpful when urban governments have only adopted the aim to shift to low-carbon transport and energy practises. It could be an element in Molas-Gallart et al.'s evaluation approach but, again, it does not assume a particular evaluation and learning approach.

Our concern is that the dashboard does reflect the systemic character of the policy aim. Yet, our approach does not include the formulation and evaluation of specific policy interventions and associated learning processes. We seek to depict the overall status of the transformation process and, accordingly, help make policies in transport and energy more coherent and ensure a fair distribution of transformation across the city.

50. Molas-Gallart, et al., 'A Formative Approach.'

51. Ibid.

52. Ibid.

53. Damian Hodgson, et al., eds. *The Projectification of the Public Sector (1st ed.)* (New York: Routledge, 2019). https://doi.org/10.4324/9781315098586

8.3. Metrics for Urban Transformation

What indicators can give an insight into how urban passenger mobility and energy practises transform over a few decades? Objective indicators from both sides of the urban mobility–energy transformation nexus include, but are not limited to, sharing personal car trips or kilometres driven versus that of other mobility modes, ownership, and use of internal combustion engine vehicles. They also imply the electric counterpart and share of dwellings with local renewable energy generation (e.g., home-installed, or community-based PV panels). In the quest for such indicators, the interference between mobility and energy systems should be viewed as a hypothesis that needs further investigation rather than strict guidance for the search. The increasing interference and its potential to transform the urban landscape is plausible in principle and evinces the growing need and opportunities to align both sides of the nexus (e.g., smart loading of EVs). Nevertheless, the realisation of such interference may still be limited in certain cities or countries and thus, it might not be sufficiently significant when expressed as objective indicators.

Sociotechnical transformation pathways that unfold over a few decades can be mapped through time series of such indicators (see examples in FIGURE 10), either retrospectively or prospectively (i.e., as scenarios). While the use of longitudinal data resonates well with the temporal nature of social changes and is common in this field of research, it should also be complemented by cross-sectional elaborations of complexities and interrelationships between specific variables and sub-elements/systems that are associated with the transformation at hand.[54] In other words, transformative pathways ought to be formulated in terms of endogenous enactment and ideally embrace both characterisation of the overall course of development (global/outside-in) and depiction of immediate action processes that create short-run developmental episodes (local/inside-out).[55]

54. Zolfagharian, et al., 'Studying transitions.'

55. Geels, et al., 'The enactment of socio-technical.'

As noted, the reviewed studies of urban transformations lack the indication of the sustainability levels of said transformations, and therefore, we propose an indicator dashboard that can be employed as a simple *ex-ante* or *ex-post* policy support tool. Our suggested approach to indicator-based urban assessment lies in the integration of several mobility and energy aspects of urban living, how they lead to sustainability impacts, and how they reflect fundamental change over time in the whole urban system.

Sustainability is a normative yet subjective and ambiguous concept.[56] It concerns cross-system interactions that are complex, dynamic, and interdependent and subject to contextuality, contingency, value judgement, and interpretation.[57] The key challenge of indicator-based SA thus entails the dilemma of being general enough to ground it in the core features of sustainability whilst specific enough to describe the context- and place-specificities at hand.[58] Therefore, we propose an indicator dashboard with some generic categories that can be tailored to fit local specificities.

To select indicators for a particular locality, we recommend employing both analysis of written sources such as policy reports, databases, statistical yearbooks, and local media in combination with interviews. Clearly, this assumes the availability of reliable data at a sufficient level of spatiotemporal resolution. It also requires interaction with urban policymakers, planners, and practitioners, etc., who have first-hand insights into local policy and sustainability priorities. When indicators have been selected, various data sources, for example, a combination of survey data and big data (e.g., real-time traffic, a global positioning system (GPS), mobile phone, and social media data) can be used to score the indicators.

56. Angus Morrison-Saunders, et al., 'Towards sustainability assessment follow-up,' *Environmental Impact Assessment Review* 45 (February 2014): 38–45. https://doi.org/10.1016/j.eiar.2013.12.001; Verma and Raghubanshi, 'Urban sustainability indicators.'

57. Paul M. Weaver and Jan Rotmans, 'Integrated sustainability assessment: What is it, why do it and how?' *International Journal of Innovation and Sustainable Development* 1, no. 4 (May 2007): 284–303. https://doi.org/10.1504/ijisd.2006.013732

58. Großkurth, *Regional Sustainability.*

We propose that the dashboard is utilised 'not just as a tool for *ex post facto* research, but to also guide sustainability visions and strategies for sustainable urban development.'[59] The rapid evolution of soft computing techniques and availability of computational resources for urban systems research increasingly require engineering and scientific disciplines. This is to work with political decision-makers within a complex setting in which multiple and conflicting objectives, preferences, and value systems must be addressed in noncontentious and noncontroversial manners.[60]

Grounded in complexity and multiplicity, the multi-criteria analysis (MCA) resonates with the nature of urban systems[61] and forms the underlying frame of the dashboard. The principle of MCA lies in evaluating certain subjects against a set of predefined criteria without necessarily enforcing the translation of their results into a common scale depending on the perspective of sustainability and the degree of compensability between the criteria.[62] Similarly, techniques such as the analytic hierarchy process (AHP) incorporate both quantitative and qualitative aspects of a problem and systematically derive their relative importance by means of pairwise comparisons. Thereby, AHP can be used for transparent accounting and comprehension of different values, trade-offs, and priorities.[63]

Selection, development, and interpretation of indicators in relation to the overall understanding of the complex system at hand can be facilitated with a theme/issue-based framework. Its flexible structure allows for the addition of cross-cutting (sub)themes and articulates linkages between the indicators,

59. Cohen, 'A Systematic Review': 10.

60. Catherine D. Gamper and Catrinel Turcanu, 'Multi-criteria analysis: A tool for going beyond monetization?' In *The Tools of Policy Formulation: Actors, Capacities, Venues and Effects*, eds. Andrew J. Jordan and John R. Turnpenny (Cheltenham: Edward Elgar Publishing, 2015), 121–41. https://doi.org/10.4337/9781783477043.00017; Gasparatos, El-Haram, and Horner, 'A critical review,' 286–311; Manfren and Costa, 'Paradigm shift in urban.'

61. Stanislav E. Shmelev and Irina A. Shmeleva, 'Methods and indicators for urban sustainability assessment,' in *Sustainable Cities Reimagined (1st ed.)*, ed. Stanislav E Shmelev (Abingdon: Routledge, 2020), 1–25. https://doi.org/10.4324/9780429287725-1; Shmelev and Shmeleva, 'Global urban sustainability assessment.'

62. Gamper and Turcanu, 'Multi-criteria analysis;' Gasparatos, El-Haram, and Horner, 'A critical review.'

63. Michela Nardo, et al., *Tools for Composite Indicators Building* (Ispra: European Communities, 2005). http://bitly.ws/qxn8 their relevance to policy aims and processes, and the overarching goal of integrated urban sustainability.[64] Employing this framework to organise the practise-informed transformation indicators around key themes diverges from the conventional three-pillar framework, which can improve the manageability of the urban assessment process and is widely used by national and local governments. Still, it oversimplifies the fundamentally co-dependent reality of urban systems, in which assessment elements interact with one another in a nested hierarchy and do not always conveniently fit in one sustainability pillar, and do not necessarily reflect the experience and perceptions of residents and users of urban space.[65] Put it simple, the three sustainability pillars may serve as 'blind-spot checkers' that checks the balance of the selected indicators in the light of the three pillars of sustainability rather than the starting point for selecting indicators.

Possible indicators to include in the dashboard encompass those that are commonly associated with impacts of urban living on the environment such as air quality and resource consumption. The former can be represented by the atmospheric concentration of common urban air pollutants (such as coarse and fine particulate matters, soot, ozone, and nitrogen dioxide), the record of violation of air quality standards, and the presence of plans and measures of safeguarding air quality.[66] The resource consumption can be spoken of as tangible resources (e.g., energy, biodiversity, and land), of which depletion of non-renewable kinds should be limited and smart(er) uses of the renewable substitutes ought to be enhanced. In addition, said consumption might be

64. Jiangu Wu and Tong Wu, 'Sustainability Indicators and Indices: An Overview,' in *Handbook of Sustainable Management*, eds. Christian N. Madu and Chu-Hua Kuei (Singapore: Imperial College Press, 2012), 65–86. https://doi.org/10.1142/8164

65. Davidson, et al., 'Assessing urban sustainability;' Wu and Wu, 'Sustainability Indicators and Indices.'

66. Dominique Gillis, Ivana Semanjski, and Dirk Lauwers, 'How to monitor sustainable mobility in cities? Literature review in the frame of creating a set of sustainable mobility indicators,' *Sustainability* 8, no. 1 (December 2015): 29. https://doi.org/10.3390/su8010029; Todd Litman, *Well Measured: Developing Indicators for Sustainable and Livable Transport Planning* (Victoria: Victoria Transport Policy Institute, 2021). https://www.vtpi.org/wellmeas.pdf; Peter-Paul Pichler, et al., 'Reducing urban greenhouse gas footprints,' *Scientific Reports* 7 (November 2017): 14659. https://doi.org/10.1038/s41598-017-15303-x; World Business Council for Sustainable Development, WBCSD, 'Methodology and Indicator Calculation Method for Sustainable Urban Mobility,' Eltis. October 10, 2017. http://bitly.ws/qw62; World Health Organization, WHO. 'Ambient (outdoor) air pollution,' September 22, 2021. http://bitly.ws/qw5J regarded in the light of intangible resources (e.g., respect for local traditions and the sense of community).[67]

Built on a more integrative interpretation of urban sustainability, the dashboard also encompasses indicators that have implications for quality of life, social equity, and environmental justice. For example, accessibility and affordability address individuals' capability to access basic and developmental needs (i.e., education, healthcare, transportation, housing, recreation of individuals, capital, transfer of knowledge, and career opportunities).[68] In mobility terms, these indicators address several elements of urban transport planning (e.g., connectivity of roads and paths, land use patterns, and availability of mobility options/substitutes) and can be used to anticipate inclusive urban living, especially for low-income, disadvantaged, and (mobility-)impaired individuals.[69] The emerging consideration of justness in low-carbon transformations also induces the novel interpretation of these indicators in terms of the access to affordable and reliable energy and decarbonisation opportunities (e.g., adoption of low-carbon and energy-efficient technologies and participation in energy-related decision-making processes). The latter are evidently uneven across socioeconomic and demographic groups.[70]

Urban forms, geography, socioeconomic conditions, and urbanisation dynamics influence energy needs, availability of energy resources, burdens, and access to low-carbon and energy-efficient alternatives. It is important to note that these aspects do not only vary from one city to another but also from one neighbourhood to another within the same city.[71] Integrating geographically explicit data instead of solely treating a city as an internally homogeneous entity enables the identification of disproportionate burdens and unequal access

67. Litman, *Well Measured*; Sodiq, et al., 'Towards modern sustainable cities.'

68. Didem Dizdaroğlu, 'The role of indicator-based sustainability assessment in policy and the decision-making process: A review and outlook,' *Sustainability* 9, no. 6 (June 2017): 1018. https://doi.org/10.3390/su9061018; Sodiq, et al., 'Towards modern sustainable cities.'

69. Sodiq, et al., 'Towards modern sustainable cities;' Litman, *Well Measured*.

70. Carley and Konisky, 'The justice and equity.'

71. Carley and Konisky, 'The justice and equity;' Kammen and Sunter, 'City-integrated renewable energy,' 922–28.

to resources and decarbonisation opportunities. This also sheds understanding of how these distributional consequences of sustainability transformation effect other aspects of urban living at large.[72]

Driven by the inadequate consideration of social justice in the mainstream urban sustainability discourses,[73] our indicator dashboard explicitly specifies 'distribution across neighbourhoods' as a separate and crosscutting subtheme (see FIGURE 13). Each of the selected indicators should be spatialised across the city's census wards (or statistical sectors, e.g., neighbourhoods, districts, boroughs, and postcodes, etc.) as exemplified in FIGURE 11. These are viable scales at which interactions within urban systems and between several aspects of urban sustainability and the socio-spatial manifestation of sustainability transformation can be meaningfully captured and assessed. This is investigated by some of the recent socio-spatial correlation studies on agglomeration externalities in terms of accessibility versus air pollution and clean technology privilege in terms of EV diffusion.[74] In this line, a general-purpose GIS software such as *ArcGIS Pro* comprises key functions and easily referenced web-based services that enable the analyses of multiple categories of spatially explicit data from different time frames. This software can be used to develop a comprehensive understanding of urban sustainability in relation to real-world composition, configuration, and patterns.[75]

72. Carley and Konisky, 'The justice and equity;' Lu Huang, Jianguo Wu, and Lijao Yan, 'Defining and measuring urban sustainability: A review of indicators,' *Landscape Ecology* 30 (May 2015): 1175–93. https://doi.org/10.1007/s10980-015-0208-2

73. Vanesa Castán Broto and Linda Westman, 'Just sustainabilities and local action: Evidence from 400 flagship initiatives,' *Local Environment* 22, no. 5 (November 2016): 635–50. https://doi.org/10.1080/13549839.2016.1248379

74. See Nicola da Schio, Kobe Boussauw, and Joren Sansen, 'Accessibility versus air pollution: A geography of externalities in the Brussels agglomeration,' *Cities* 84 (January 2019): 178–89. https://doi.org/10.1016/j.cities.2018.08.006; Jean León Boucher and Walter Mérida, 'Inflated lives and a clean tech privilege in Washington State: Policy amidst spatialized affluence,' *Energy Research & Social Science* 85 (March 2022): 102418. https://doi.org/10.1016/j.erss.2021.102418

75. David J. Maguire, 'ArcGIS: General-Purpose GIS Software,' in *Encyclopedia of GIS*, eds. Shashi Shekhar, Hui Xiong, and Xun Zhou (Cham: Springer, 2017). https://doi.org/10.1007/978-3-319-17885-1_68

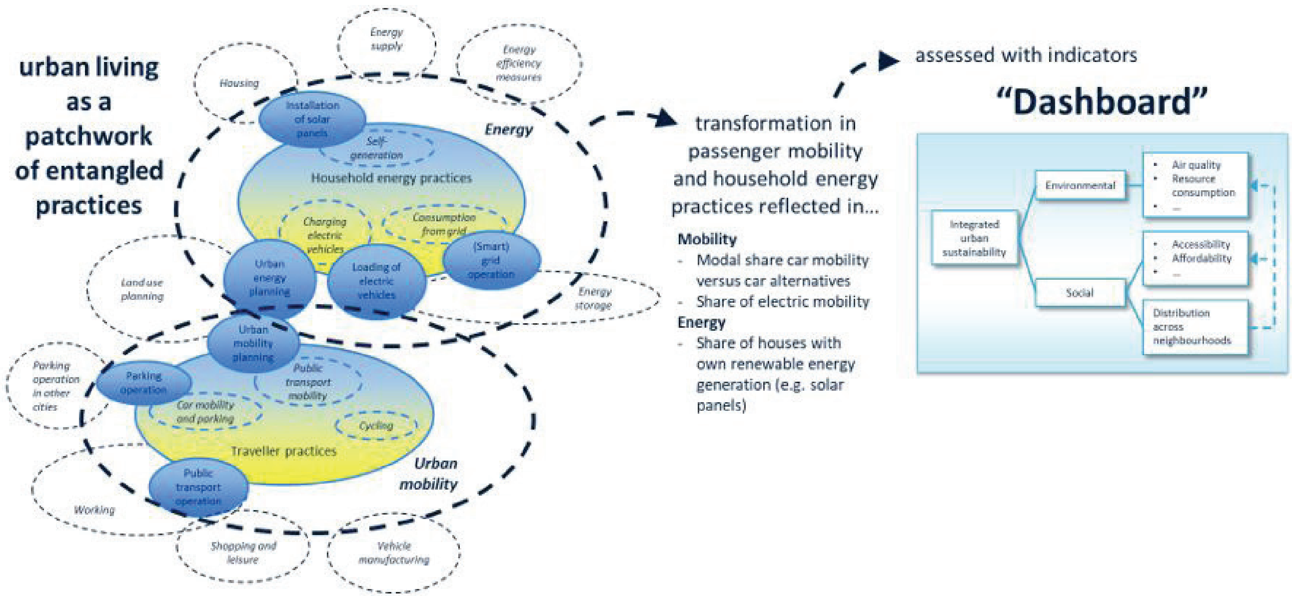

FIGURE 13. Urban Living Conceptualised as a Patchwork of Entangled Practises with Attention to Transformation in Passenger Mobility and Household Energy Practises and Assessed with an Indicator Dashboard

Source: Prepared by authors.

8.4. Conclusions and Discussion

Current approaches targeting environmental challenges not only tend to stay within sectoral silos but also easily neglect socio-spatial inequalities of the transformation like the risk of mobility and energy poverty and growing inequalities in access to mobility and energy across the various neighbourhoods. The traditionally separated mobility and energy fields have been increasingly interconnected through the pressing global and urban sustainability challenges that necessitate simultaneous decarbonisation of transport and energy systems. An emerging point of interest is how these transformations can be shaped inclusively. We have posited an indicator dashboard for urban transformations encompassing key interactions at the mobility–energy nexus that can support urban practitioners in their governance challenges of managing the interconnected transformations whilst safeguarding their fairness. We propose to apply a limited number (e.g., about ten) of indicators to reflect both the transformation process and its impacts. As a digestible coverage of sustainability aspects on both sides of the nexus, the contextualised indicator dashboard illuminates the effects of the complex cross-system interactions in relation to the overarching goal of integrated urban sustainability in a useful way for policymakers. The longitudinal mapping of the urban transformation pathways, which is potentially useful for supporting policy visions and planning, is accompanied by socio-spatial cross-sectional insights to generate a more complete understanding of the transformation.

Sustainability-related problems can never be addressed adequately from a single perspective.[76] Stakeholders' participation is principal to the goal-setting step of indicator development, which is much less of a research focus and presently lacks integration of citizen- and expert-led approaches due to ambiguity in the definition of sustainability.[77] In practise, this step of indicator development can be enhanced through co-creation with local actors. Widely promoted as the principal mechanism for realising societal transformations in pursuit of

76. Weaver and Rotmans, 'Integrated sustainability assessment.'

77. Verma and Raghubanshi, 'Urban sustainability indicators.'

various sustainability goals, cocreation encompasses acknowledging the importance of the local level. This entails accommodating meaningful collaboration and transparency, moderating actor groups and interests, and pursuing inclusiveness based on consideration of realistically available resources and respect for existing initiatives.[78] The co-creation approach links scholarly research to socio-political perceptions and requirements, the gap between which poses a major challenge for urban governance research.[79]

Although this chapter is predominantly research-driven, the next step of developing our proposed dashboard should take place at the policy-research interface and discuss a particular local context through processes of co-creation.[80] Realising sustainability transformation in real-world contexts involves dealing with a collection of competing goals and strategies. These hamper both the achievement of one another and the progress of the transformations and thus, require a balanced approach to enable the cocreated decisions whilst advancing the transformation processes.[81] Urban planners, local authorities, and other key stakeholders can benefit from understanding their scope of influence and the outcomes of their possibilities of action in relation to positive progress in the area to which each indicator is assigned, provided that the indicators are tailored to the local conditions and contextual knowledge at hand.[82]

The dashboard, whose indicators should be aligned to policy goals and vice versa, informs the synergistic and contradictory effects of decision-making

78. Sigrun Kabisch, et al., 'New urban transitions towards sustainability: Addressing SDG challenges (research and implementation tasks and topics from the perspective of the Scientific Advisory Board (SAB) of the Joint Programming Initiative (JPI) Urban Europe),' *Sustainability* 11, no. 8 (April 2019): 2242. https://doi.org/10.3390/su11082242

79. Nuno F. da Cruz, Philipp Rode, and Michael McQuarrie, 'New urban governance: A review of current themes and future priorities,' *Journal of Urban Affairs* 41, no. 1 (August 2018): 1–19. https://doi.org/10.1080/07352166.2018.1499416

80. Niki Frantzeskaki and Nadja Kabisch, 'Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany,' *Environmental Science & Policy* 62 (August 2016): 90–98. https://doi.org/10.1016/j.envsci.2016.01.010; Emma Puerari, et al., 'Co-creation dynamics in Urban Living Labs,' *Sustainability* 10, no. 6 (June 2018): 1893. https://doi.org/10.3390/su10061893

81. Kabisch, et al., 'New urban transitions;' Paula Kivimaa, et al., 'Passing the baton: How intermediaries advance sustainability transitions in different phases,' *Environmental Innovation and Societal Transitions* 31 (June 2019): 110–25. https://doi.org/10.1016/j.eist.2019.01.001

82. Lützkendorf and Balouktsi, 'Assessing a sustainable urban.'

for the enveloping socio-technical systems that can leverage transformative change in urban development practises.[83] It can provide policymakers and planners with insight into the impacts of mobility and energy transformations to effectively evaluate and adjust policies, plans, urban structures, and societal functions. When applying the dashboard in such policy discussion, a consequence table can be developed (see TABLE 12).

TABLE 12. Quantitative Consequences

Criteria → ↓ Means	C1	C2	C3	C4
M1	+		–	
M2	+	+		
M3	–			+
M4		+	+	
M5		+/–	–	
M6			+	+

Source: Taken from Enserink et al.[84]

The table above focuses decision-makers on the evaluation and comparison of attributes based on the proxies for the things that matter. Likewise, it transparently informs needed information base, potential trade-offs, uncertainties, and relative priorities.[85] This sort of decision-sketching/support tool could be populated with either qualitative or quantitative estimates of expected

83. Alexander P. N. van der Jagt, et al. 'Nature-based innovation systems,' *Environmental Innovation and Societal Transitions* 35 (June 2020): 202–16. https://doi.org/10.1016/j.eist.2019.09.005; Arnim Wiek and Claudia Binder, 'Solution spaces for decision-making—A sustainability assessment tool for city-regions,' *Environmental Impact Assessment Review* 25, no. 6 (August 2005): 589–608. https://doi.org/10.1016/j.eiar.2004.09.009

84. Bert Enserink, et al., *Policy Analysis of Multi-Actor Systems* (The Hague: Lemma, 2010).

85. Lee Failing, Robin Gregory, and Michael Harstone, 'Integrating science and local knowledge in environmental risk management: A decision-focused approach,' *Ecological Economics* 64, no. 1 (October 2007): 47–60. https://doi.org/10.1016/j.ecolecon.2007.03.010; Robin Gregory, et al., *Structured Decision Making: A Practical Guide to Environmental Management Choices (1st ed.)* (Chichester: Blackwell Publishing Ltd., 2012).

consequences or impact to help make coherent and internally consistent judgements and to insulate against the pitfalls of unaided decision-making.[86]

Our metrics have a significant parallel with Keirstead and Leach's approach to urban sustainability indicators (USIs).[87] It recognises urban services (e.g., transport and energy) as integral to multiple aspects of urban life and sustainability agenda and the use of such services as a derived demand, based on which the different influences of energy-consuming activities (e.g., household number and car ownership), the resource requirement to meet such demand (e.g., consumption of petrol, natural gas and electricity resources), and the resultant impacts of consumption (e.g., fuel poverty and carbon dioxide emissions) on the overall urban sustainability goals can be distinguished.[88] Such a framework could help policymakers select useful indicators and avoid irrelevant ones, identify parts of the service chain that needs high-quality data, relate the indicators to specific areas of policy responsibility, and identify causal links between metrics. Development and assessment of indicators in relation to policy aims and available high-quality data can be followed by a number of niche-expansion strategies. Examples of these are: replicating the experiment to build experience, promoting policies that are complementary to the niche, and maintaining the networks that have arisen around the niche. These ideas might inspire innovation researchers' work on the diffusion of new technologies (e.g., green electricity tariff or ecolabelling scheme or solar energy systems) to further develop sustainability endeavours.[89]

While indicator selection methodology is heavily focused in both this chapter and the past decade's research on the application of USIs, attention should also be given to understudied aspects such as reporting findings and sustaining

86. Liibeth A. Acosta, et al., 'Using scenarios and models to inform decision making in policy design and implementation,' in *The Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services*, eds. Simon Ferrier, et al. (Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2016), 35–82.

87. James Keirstead and Matt Leach, 'Bridging the gaps between theory and practice: a service niche approach to urban sustainability indicators,' *Sustainable Development* 16, no. 5 (October 2007): 329–40. https://doi.org/10.1002/sd.349

88. Ibid.

89. Ibid.

the indicator framework. Equally important is to address the emerging aspect of the application and universal applicability/acceptability of findings in actual situations that lead to challenges lying in the numerous governments' administrative machinery and will to implement them.[90] Finally, whilst still lacking, a comparison between case studies is encouraged to test the SA tool's robustness at highlighting the disparity in political (in)stability, availability of infrastructure, and local resources or lack thereof, urban challenges, priorities, practises, and institutions. Accordingly, such comparative exercises could promote urban sustainability in different regions across the world.[91]

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9. Mapping Research Systems in Kenya, Tanzania, and Rwanda and their Relation with the Sustainable Development Goals

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9.1. Introduction

Scientific research is a critical ingredient to develop knowledge-based economies where knowledge drives productivity, social wellbeing, and the achievement of socio-economic needs. Without scientific capacity, the skills and capabilities available in a country are constrained, and therefore, the ability to absorb, adapt, and develop new ideas and technologies is limited. However, in lower-income contexts like Kenya (KE), Rwanda (RW), and Tanzania (TZ), the organisation of the economy is often unfavourable to the application of science and technology in production. Hence, it is frequently argued that it is too difficult to demonstrate how research will lead to benefits and that it wastes

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resources that could be used in other types of interventions (e.g., to reduce poverty). Given the budget constraint, it is critical to better understand which areas of research should be prioritised in order to improve the socio-economic impact of research investments in these contexts.

In this chapter, we investigate the strengths and weaknesses of the research systems in KE, RW, and TZ versus the main challenges they face. Our central assumption is that a misalignment between the investment in research areas and the socio-economic challenges may reduce the effectiveness of the investments in research to address those goals.[3] Our main objective is to understand the extent to which the research priorities in these countries are aligned with their major socio-economic challenges. In this vein, we intend to bring prioritisation and directionality to the debate about science policy investment.

In what follows, we will first focus on the background of our analysis. Then we will describe the data and methodology used. Afterward, we will discuss the results obtained. Finally, we will put forward some conclusions.

9.2. Background

Total research output per capita in low-income countries is small when compared to high-income countries. Since spending on science and technology is low and, invariably, a fraction of what is promised by governments in these contexts,[4] the majority of research in these countries is still based on international collaboration and funding from foreign donors.[5]

Foreign understanding of problems, priorities, and criteria for funding often influence research in low-income countries. Thereby, since these latter have scarce resources to support their research programmes, it is important to better

3. We use the term 'societal needs' (or goals) in a broad way, capturing all explicit or implicit demands for new knowledge to address specific of general challenges/goals from nutrition to environmental sustainability.

4. Linda Nordling, 'The African science decade that wasn't,' *Research Professional News*, December 19, 2019. http://bitly.ws/qAw6

5. Joanna Chataway, et al., 'Science Granting Councils in Sub-Saharan Africa: Trends and tensions,' *Science and Public Policy* 46, no. 4 (March 2019): 620–31. https://doi.org/10.1093/scipol/scz007; United Nations Education, Scientific and Cultural Organisation, UNESCO, *Science Report: Towards 2030* (Paris: UNESCO Publishing, 2015).

understand if international funders are supporting research that is aligned with recipient countries' main socio-economic challenges or not. If they are, research collaboration networks that promote this alignment could be a relevant instrument to improve research capabilities and address socio-economic challenges along with domestic investment. If they are not, it can be argued that international research funding organisations may need to rethink how they structure and organise their research funding programmes and priorities.

Similar questions about the relation between research priorities and societal needs have been raised by several scholars, mostly focusing on high-income research-intensive countries. In this train of thought, science policy and innovation scholars have long debated whether it is more beneficial for societies to allow science and scientists to define their priorities or to steer science to address societal needs in the light of the stark inequalities investment in research contribute maintaining.[6]

Based on recent investigations of high-income countries' research and knowledge investment,[7] Wallace and Rafols suggest adopting the term 'research portfolio' to characterise the distribution of countries' research activities aimed at advancing knowledge to address socio-economic needs and challenges.[8] Recent evidence indicates that research portfolios are driven by different incentives, which may privilege certain research areas with respect to others,[9] in ways that privilege parts of the society that may be less in need of scientific advances (but have higher purchasing power). The distribution of research portfolios can be

6. Vannevar Bush, *Science: The Endless Frontier* (Washington: American Council of Learned Societies, 1945); Michael Polanyi, John Ziman, and Steve Fuller, 'The Republic of Science: Its Political and Economic Theory,' *Minerva* 1, no. 1 (1962): 54–73. https://www.jstor.org/stable/41821153; Michael Gibbons, et al., *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies* (London: Sage, 1994); Richard R. Nelson, 'The Moon and the Ghetto revisited,' *Science and Public Policy* 38, no. 9 (November 2011): 681–90. https://doi.org/10.1093/scipol/38.9.681; Richard R. Nelson, 'On the uneven evolution of human know-how,' *Research Policy* 32, no. 3 (June 2003): 909–22. https://doi.org/10.1016/S0048-7333(02)00093-8

7. Federal RePorter, 'Federal ExPorter,' March 6, 2020. http://bitly.ws/qD44; National Institutes of Health, 'RePort: Research Portfolio Online Reporting Tools,' accessed May 3, 2022. https://report.nih.gov

8. Matthew Wallace and Ismael Rafols, 'Research Portfolio Analysis in Science Policy: Moving from Financial Returns to Societal Benefits,' *Minerva*, *53*, no. 2 (June 2015): 89–115. https://doi.org/10.1007/s11024-015-9271-8

9. Ibid.

explained by a number of factors. Scientific and technological paradigms define limited spaces of prioritisation, which depends on past and current development in science and technology.[10] Path dependencies related to sunk costs, externalities, and accumulation of knowledge also contribute to defining future priorities.[11] The distribution of resources available to invest in research, and the 'power to make investment decisions'[12] contribute to defining whose priorities are more relevant. The 'lack of voice'[13] of those who are most in need and would benefit most from improvements in 'socio-economic needs'[14] reduces the likelihood for research investments to prioritise the needs of the most marginalised. Lastly, the 'research community'[15] has its incentives dictated by career paths and evaluation. Despite the fact that they are generated, it is important to systematically investigate if there is a misalignment between research priorities and societal demands.[16]

Evidence has been collected mainly in the area of health research while studying the relation between the prioritisation of research investment and disease burden.[17] These studies seem to find that the largest chunks of health

10. Giovanni Dosi, 'Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change,' *Research Policy* 11, no. 3 (June 1982): 147–62. https://doi.org/10.1016/0048-7333(82)90016-6; Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).

11. Robin Cowan and Philip Gunby, 'Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies,' *The Economic Journal* 106, no. 436 (May 1996): 521–42. https://doi.org/10.2307/2235561; Richard R. Nelson and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge: The Belknap Press of Harvard University Press, 1982).

12. Joanna Chataway, Joyce Tait, and David Wield, 'Understanding company R&D strategies in agro-biotechnology: trajectories and blind spots,' *Research Policy* 33, no. 6–7 (September 2004): 1041–57. https://doi.org/10.1016/j.respol.2004.04.004

13. Albert O. Hirschman, *Exit, Voice, and Loyalty: Responses to Decline in Firms, Organizations, and States* (Cambridge: Harvard University Press, 1972).

14. Laurens Klerkx and Cees Leeuwis, 'Institutionalizing end-user demand steering in agricultural R&D: Farmer levy funding of R&D in The Netherlands,' *Research Policy* 37, no. 3 (April 2008): 460–72. https://doi.org/10.1016/j.respol.2007.11.007

15. Barry Bozeman and Daniel Sarewitz, 'Public values and public failure in US science policy,' *Science and Public Policy* 32, no. 2 (April 2005): 119–36. doi:10.3152/147154305781779588

16. Elizabeth C. McNie, 'Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature,' *Environmental Science & Policy* 10, no. 1 (February 2007): 17–38. https://doi.org/10.1016/j.envsci.2006.10.004; Daniel Sarewitz and Roger A. Pielke Jr., 'The neglected heart of science policy: reconciling supply of and demand for science,' *Environmental Science & Policy* 10, no. 1 (February 2007): 5–16. https://doi.org/10.1016/j.envsci.2006.10.001

17. Hugo Confraria and Lili Wang, 'Medical research versus disease burden in Africa,' *Research Policy* 49, no. 3 (April 2020): 103916. https://doi.org/10.1016/j.respol.2019.103916; James A. Evans, Jae-Mhan Shim, research are not directed toward diseases that impose the highest-burden on people's life. For example, Cassi et al. focus on the prioritisation in policy. They show that societal concerns in relation to obesity, as perceived by policymakers, do not match very well with prioritisation in research on obesity.[18]

There is scarce research that investigates research priorities beyond high-income countries and health. One of the few examples is Ciarli and Rafols's study.[19] It uses data on publications about rice to investigate if country publication profiles are correlated to the main societal needs related to rice production. They find some obvious alignments, but also some worrying misalignments driven by the factors listed above. For instance, countries with a higher per capita caloric intake from rice and higher rates of malnutrition, do not invest more in research related to human consumption.[20] It is mainly exporters that invest more than other countries in topics related to human nutrition. In this chapter, we move beyond specific sectors such as health and agriculture and examine the entire research portfolio. For simplicity, we focused on three East African countries that score differently with respect to several indicators of science, technology, and innovation, and employed the SDGs as proxies for societal needs.

9.3. Data and Methods

We used Web of Science (WOS) and Scopus publication data as a proxy for scientific output and the Sustainable Development Goals (SDGs) as a proxy for socio-economic challenges. We downloaded bibliometric data (full record except for references) for all publications with at least one author from one of

and John P. A. Ioannidis, 'Attention to Local Health Burden and the Global Disparity of Health Research,' PLOS One 9, no. 4 (April 2014): e90147. https://doi.org/10.1371/journal.pone.0090147; Alfredo Yegros-Yegros, et al., 'Exploring why global health needs are unmet by research efforts: the potential influences of geography, industry and publication incentives,' *Heal Research Policy and Systems* 18 (May 2020): 47. https://doi.org/10.1186/s12961-020-00560-6

18. Lorenzo Cassi, et al., 'Improving fitness: Mapping research priorities against societal needs on obesity,' *Journal of Informetrics* 11, no. 4 (November 2017): 1095–1113. https://doi.org/10.1016/j.joi.2017.09.010

19. Tommaso Ciarli and Israel Rafols, 'The relation between research priorities and societal demands: The case of rice' *Research Policy* 48, no. 4 (May 2019): 949–67. https://doi.org/10.1016/j.respol.2018.10.027

20. Ibid.

the three countries (KE, RW, and TZ) between 1990 and 2017. This included 49,651 documents from WOS and 51,055 documents from Scopus.[21] Then we merged the two datasets by creating identifiers using DOIs, titles, publication year, and journal names. When the same publication existed in both datasets, we tried to save the fields with more or better information. The final dataset included 49,046 publications for which an abstract is available, including articles, reviews, conference proceedings, books, and book chapters.

Regarding SDGs data, the aim was to measure the relative salience of a societal challenge with respect to other societal challenges in a given country to compare it with relative research specialisation. To measure a proxy for socio-economic challenges, we collected all the UN SDG indicators for all periods available and we checked those indicators having data availability for KE, RW, and TZ between 2012 and 2017. After compiling a set of indicators with complete data (see Appendix A TABLE 13), we run a principal component analysis per SDG to obtain a single index. In this light, we followed the next steps:

For the selected indicators, we did a linear transformation, by converting each indicator/country into a score between 1 (best) and 0 (worst):

$$N_{ct} = \frac{Worst_t - x_{ct}}{Worst_t - Best_t}$$

Next, we reversed some variables for consistency (see Appendix A TABLE 13), forcing higher values to represent better results. For each variable, we then calculated the relative distance of each indicator/country to the frontier of that indicator (top5% - percentile 95) and we changed all values below zero to zero. After this transformation, higher values represented the worst results concerning the SDG targets (higher challenges relative to countries at the frontier).

Subsequently, we calculated Z-scores for each relative distance to the frontier (top5%). Ulteriorly, we computed a principal component analysis (PCA)[22] for each SDG with more than one indicator available. Also, we forced the PCA

21. We also downloaded Dimensions data but since abstracts were unavailable, we could not use it.

22. J. Edward Jackson, *A Use's Guide to Principal Components, Wiley Series in Probability and Statistics*. (Hoboken: John Wiley & Sons, Inc., 1991).

to estimate only one component per SDG. Later, we predicted the scores of all SDGs for all countries and we normalised the results between 0 and 1 (1 = Worst country; 0 = Best country). Finally, we transformed the normalised scores into percentages to make them comparable with publication shares.

Analysis

In the first part of our analysis, we studied the national and international research collaboration networks of research institutions in KE, RW, and TZ and the relevance of each research organisation in the overall research network. We used co-authorship as a proxy for research collaboration.

Then, we used 'overlay maps'[23] to graphically examine how research priorities have changed through time in each of the three countries across different topics. We created maps by using semantic similarity between publications (VOSviewer topic modelling algorithm) to identify the main research topics. In doing so, we also employed WOS categories to measure the relative research specialisation in given topics of KE, RW, and TZ in relation to the world research specialisation.[24] As a result of this exercise, we sought to have a better understanding of the dynamics of research in KE, RW, and TZ, strengths, weaknesses, and future opportunities.

In the second part of our analysis, we followed Ciarli and Rafols to study the relation between revealed research priorities and socio-economic demands.[25] We examined the extent to which the distribution of investment in research across societal challenges (calculated by the share of publications associated with a SDG) is related to the salience of the socio-economic challenges (SDG scores). In order to do this, we first had to allocate each publication to SDGs. To do so, we defined a topic/keyword query for each SDG that would allow us to retrieve all publications related to that SDG (research priorities). Once we defined

23. Ismael Rafols, Alan L. Porter, and Loet Leydesdorff, 'Science Overlay Maps: A NewTool for Research Policy and Library Management,' *Journal of the American Society for Information Science and Technology* 61, no. 9 (September 2010): 1871–87. https://doi.org/10.1002/asi.21368

24. Beka Balassa, 'Trade Liberalisation and "Revealed" Comparative Advantage,' *The Manchester School* 33, no. 2 (May 1965): 99–123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x

25. See Ciarli and Rafols, 'The relation between research, 949–67.

the term/keywords per SDG, we searched all publication titles and abstracts and allocated to a SDG all publications that contained at least one term of the relevant query. To define the query, we followed the next steps:

- We searched the UN SDG website and Wikipedia for SDG descriptions and we used topic modelling (NLP) to extract the most relevant and frequent terms used in each SDG.
- We combined our list of terms with lists of keywords defined in earlier research[26] and we asked several experts on STI and development to revise the queries.[27]
- After defining a robust set of terms per SDG, we went back to our dataset of publications authored by at least one researcher in KE, RW, and TZ to retrieve those containing keywords associated with each SDG per country.[28]

Finally, we graphically analysed the relative salience of each SDG for the three countries' societal needs as measured by the salience of the SDG indicator relative to the best performer. Plus, we examined the relative specialisation in each of the 17 topics related to SDGs research priorities).

In order to map the role that different funding organisations may play in shaping research priorities, we analysed which funding institutions supported research in KE, RW, and TZ in a given SDG. To do so, we used the acknowledgement paratext of scientific publications in WOS where authors acknowledge the financial support from the funding agencies.[29] Thus, we focused only on

26. Colombian Administrative Department of Science, Technology, and Innovation, Colciencias, *Libro Verde: Política Nacional de Ciencia e Innovación para el Desarrollo Sostenible* (Bogotá: Panamericana Formas e Impresos, 2018). http://bitly.ws/qDpZ

27. 'About,' African Centre for Technology Studies, accessed May 4, 2022. https://acts-net.org/ksi/index.php/about

28. The same publication can be associated to multiple countries and SDGs. We used the full-counting method.

29. Confraria and Wang, 'Medical research,' 103916; Rodrigo Costas and Thed N. Leeuwen, 'Approaching the "reward triangle": General analysis of the presence of funding acknowledgments and "peer interactive communication" in scientific publications,' *Journal of the American Society for Information Science and Technology* 63 (June 2012): 1647–61. https://doi.org/10.1002/asi.22692; Nicola Grassano, et al., 'Funding publications from 2009 to 2017 because wos only provides systematic information from the funding text of acknowledgements for publications since August 2008. Next, we utilised OpenRefine[30] and manual searching methods to group different name variations for the same funding institution mentioned in the acknowledgements section of our sample of publications. After that, we analysed only those sponsoring research in KE, RW, and TZ with more than 10 publications (appearing more than 0.03% of times) between 2009 and 2017. We ended up with 178 funding institutions associated with at least one publication in our dataset. Besides calculating the number of publications with acknowledgements to a specific funding institution by SDG and country, we also classified each funding institution into six group types following the G-finder classification.[31] These groups were: 1) Kenyan public funding; 2) Rwandan public funding; 3) Tanzanian public funding; 4) public funding not based in KE, RW, and TZ (including multilateral funders such as World Health Organisation and United Nations); 5) philanthropic funding; and 6) corporate funding.

9.4. Results

Publication Trends in Kenya, Rwanda, and Tanzania

The scientific output of researchers in Africa has increased considerably in recent years,[32] but it is still between two and three percent of the world's share.[33] Relying on wos data only,[34] FIGURE 14 plots the number of total publications per capita for KE, RW, and TZ between 1990 and 2017. We found that the increase in publications from 2005 to 2006 has also been accompanied by a rise in research

Data from Publication Acknowledgments: Coverage, Uses, and Limitations,' *Journal of the Association for Information Science and Technology* 68, no. 4 (April 2017): 999–1017. https://doi.org/10.1002/asi.23737

30. We used the text facet cluster function to list all affiliations and then we grouped affiliations based on three different keying algorithms (fingerprint, n-gram and metaphone3).

31. Policy Cures Research, 'G-FINDER: tracking funding for global health R&D,' last modified March 24, 2022. https://gfinder.policycuresresearch.org/PublicSearchTool/

32. Hugo Confraria, Jaco Blanckenberg, and Charl Swart, 'The characteristics of highly cited researchers in Africa,' *Research Evaluation* 27, no. 3 (July 2018): 222–37. https://doi.org/10.1093/reseval/rvy017

33. UNESCO, *Science Report: Towards 2030*.

34. The shares of publications with an author from a specific African country are similar in both datasets (66% for Kenya, 32% for Tanzania, and 5% for Rwanda).

productivity (number of publications per population). Likewise, Kenyan scientific productivity has followed the African average, whereas researchers in Rwanda and Tanzania have produced around half the African average publications per capita in the last 5 years of the analysis.

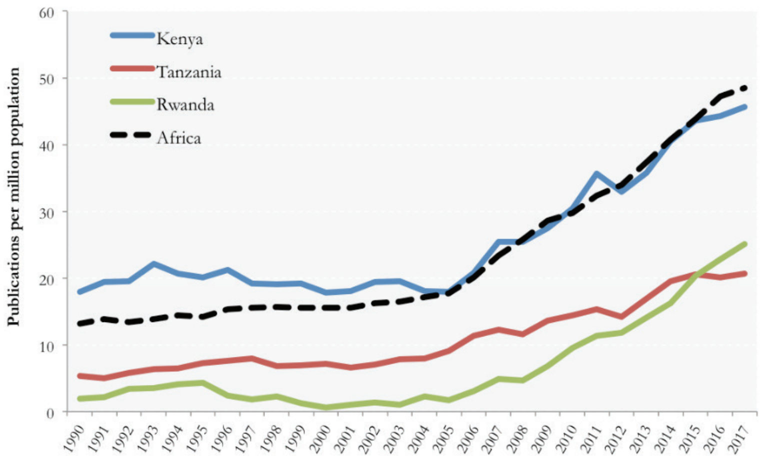

FIGURE 14. Trends in Scientific Productivity – KE, RW, and TZ versus Africa Average.

Source: WOS.

Research Networks in Kenya, Rwanda, and Tanzania

To identify the main actors and the main linkages of the research systems in KE, RW, and TZ, we built several networks of institutional research co-authorships in these countries. FIGURES 19, 20, and 21 (see Appendix B) show our construction of a network graph with 20 institutions that produced more publications at WOS. Each node represents one research organisation in one of the three countries. The size of the node indicates the number of publications. Edges plot the co-authorship between organisations. An edge means that there are at least two publications authored by researchers in each of the organisations represented by the connected nodes. The thickness of the edges represents the number of co-authored publications.

In FIGURE 19 (see Appendix B), we analysed the top-10 collaborators (national or international) of each Kenyan institution identified before. We found that the University of Nairobi has a central position in the Kenyan research network since it is a top-10 collaborator of most other Kenyan institutions. Kenya Medical Research Institute (KEMRI) also has a central position in the network, but it has a very high intensity of collaboration with foreign institutions, especially in the US and UK. The other Kenyan research organisations in this graph (top publishers) also seem to collaborate more often with foreign institutions than with Kenyan ones. For example, among the top-10 collaborators of the 'African Population and Health Centre,' only one is from Kenya (i.e., the University of Nairobi).

In FIGURE 20 (see Appendix B), we did the same analysis for the two Rwandan main research organisations. We found that the University of Rwanda and Rwanda Biomedical Centre are the main collaborators of each other and that Harvard University is the second top collaborator of both organisations. It is also clear that most of the collaborators are specialised in health-related areas like the National Institutes of Health (NIH, USA) or the Swiss Tropical and Public Health Institute.

FIGURE 21 (see Appendix B) maps the main co-authorship networks for Tanzanian top research organisations. As for the previous countries, the main collaborators of Tanzanian research organisations are also foreign organisations (US and UK mostly). The University of London, NIH (USA), and London School of Hygiene and Tropical Medicine (LSHTM) have gatekeeping positions because they all are top collaborators of at least three Tanzanian institutions within the system. We did not identify any KE or RW institution that is the main collaborator of any Tanzanian institution.

In sum, we could see a high level of collaboration between KE, RW, and TZ research organisations and foreign institutions, but a low level of collaboration between Kenyan, Rwandan, and Tanzanian research organisations.

Research Specialisation in Kenya, Rwanda, and Tanzania

In this section, we investigate which scientific areas and topics Kenyan, Rwandan, and Tanzanian researchers have prioritised between 1990 and 2017. In FIGURE 15, we combined WOS and Scopus publications data and we use VOSviewer NLP algorithms to analyse the main topics present in the abstracts of all publications identified.[35] We identified topics by co-word similarity after filtering the main terms from all publications' titles and abstracts,[36] terms forming a topic if they appear together (in the same publication) in more than an average pair.

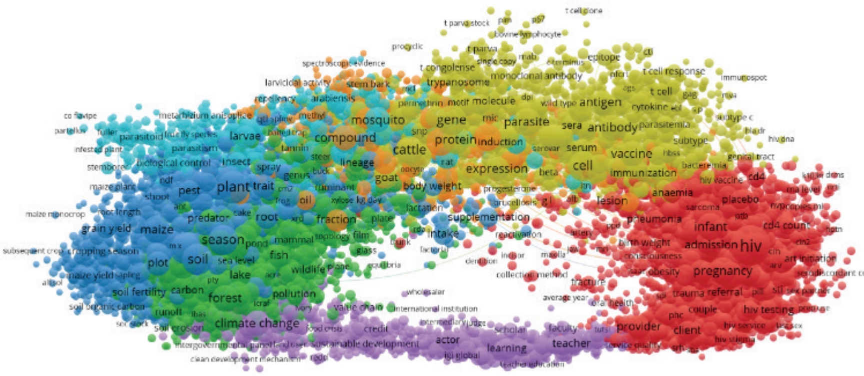

FIGURE 15. Map of Topics More Frequent in Research Done by Researchers from KE, RW, and TZ between 1990 and 2017[37]

Source: WOS and Scopus.

Most topics in KE, RW, and TZ reported in FIGURE 15 seem to be related to health issues (e.g., pregnancy, HIV, vaccine, gene, and parasitoid), agriculture (e.g., maize, pest, and grain yield), environmental sciences (e.g., pollution, wildlife, and forest), and social sciences (e.g., learning, teacher, and sustainable development). Using VOS viewer clustering algorithm, we grouped these topics in seven clusters of terms related to different areas: 1 – Clinical medicine/HIV/pregnancy (red); 2 – Environmental sciences (green); 3 – Agriculture (dark

35. Nees Jan van Eck, et al., 'A comparison of two techniques for bibliometric mapping: Multidimensional scaling and VOS,' *Journal of the American Society for Information Science and Technology* 61, no. 12 (December 2010): 2405–16. https://doi.org/10.1002/asi.21421; Ludo Waltman, Nees Jan van Eck, and Ed C.M. Noyons, 'A unified approach to mapping and clustering of bibliometric networks,' *Journal of Informetrics* 4, no. 4 (October 2010): 629–35. https://doi.org/10.1016/j.joi.2010.07.002

36. Relevant terms are those that appear frequently across all publications, but do not appear in too many publications. This is because terms that appear in all publications are paired with all other terms and therefore, they are not useful to distinguish between more or less frequent pairs of terms.

37. The proximity of terms and clusters created based on the co-occurrence of terms in abstracts using the VoSviewer algorithm.

blue); 4 – Human and animal diseases (yellow); 5 – Social sciences/sustainability (purple); 6 – Malaria /parasites (light blue); 7 – Biomedicine (orange). It is important to note that clusters 4 and 7 were not easily classifiable because they include terms from many different fields.

Since the above analysis on research specialisation is limited to publications co-authored by researchers in KE, RW, and TZ, we could not establish if these patterns of specialisation are peculiar to East African countries or follow a global pattern in research. On the other hand, in order to understand if there are any areas of research that are totally missing from the research map of KE, RW, and TZ, in FIGURE 22 (see Appendix C) we compared the research specialisation of the three countries with the global specialisation in the 251 WOS categories.[38] We divided the relative specialisation of KE, RW, and TZ in a given category (the share over total publications in the country) with the relative specialisation in the world publications (the share over total publications in the world).

Research on WOS categories such as tropical medicine, parasitology, infectious diseases, and agronomy in KE, RW, and TZ is above the share of research devoted to those categories internationally. Their research specialisation in infectious, parasitic, and vector diseases is probably due to the high disease burden that Eastern African countries face in these diseases in relation to the rest of the world.[39] In contrast, WOS categories related to engineering, physics, and 'high-tech' receive extremely low attention in research in all three countries, with respect to their relative importance internationally. Some of the 50 'neglected' research areas include industrial engineering, neuroimaging, cell and tissue engineering, automation and control systems, and biomedical engineering.

Relation between Investment in Research Areas and Socio-economic Challenges (SDGs)

The next question is whether such strong and narrow specialisation in health and agriculture is connected to the relative importance of the SDGs that may benefit from such research in KE, RW, and TZ. In this section, we discuss the

38. Because we need to use WOS categories, this analysis is focused on publications from WOS.

39. Confraria and Wang, 'Medical research.'

extent to which the research produced by researchers in these countries is associated with topics related to the SDGs. We first built a list of terms that relate to each SDG. Using them, we created a query of keywords/terms per SDG to search for publications containing those terms in all the abstracts of our dataset of publications.

Having analysed the research priorities in KE, RW, and TZ across SDGs, we needed a measure of relatively more problematic SDGs for the three countries to study the relationship between the research priorities and socio-economic demands (as measured by SDGs). For each SDG we devised an index between 0 (the country is among the best performers in the world (top5%) and 1 (the country is the worst performer in the world). One of the major findings is that the countries are top performers in SDG13 – Climate action. This is mainly due to their low CO_2 emissions per capita compared to the rest of the world. Another important result is that SDG9 – Industry, infrastructure, and innovation is the one where the three countries are performing worst. This SDG includes indicators such as the quality of overall infrastructure and internet use by the population. Finally, despite differences between KE, RW, and TZ, their relative position in SDGs 1 – No poverty, 2 – Zero hunger – and 6 – Clean water and sanitation is also low.

Having a measure of the revealed research priorities and the relative burden posed by each SDG, we could study the extent to which the distribution of investment across research topics associated with specific SDGs is related to the major socio-economic challenges (SDGs) in KE, RW, and TZ. The distribution of investment in research was calculated by the number of publications associated with a specific SDG divided by the total number of publications in a country/period. The distribution of socio-economic challenges was calculated by the share of a SDG challenge index score in the total amount of scores in a country/period. FIGURES 16, 17, and 18 plot the relative research prioritisation across all SDGs on the right, and the relative SDG burden on the left.

Our major finding is that, overall, the distribution of SDGs burdens faced in the three countries is more uniform than their research specialisation would suggest. The high prioritisation of SDG 3 (i.e., Good health and well-being) across all countries, would suggest that the perception of the SDG3 burden is significantly higher than for the other SDGs. Instead, the burden faced by the three countries, according to international SDGs benchmark indicators seem to be mostly in SDG1 – poverty (Rwanda), SDG2 – Zero hunger (Rwanda), SDG6 – Clean water and sanitation (all three countries), SDG9 – Industry, infrastructure and innovation (all three countries) or SDG14 – Life below water (KE and TZ). This apparent misalignment between the focus of research and the challenges faced by countries in terms of SDG indicators may undermine the development of (research) capabilities to study the contextual conditions to best achieve the SDGs targets in which countries perform worst.

Research Funding

We discussed that the research agenda of countries such as KE, RW, and TZ may be influenced by foreign donors and funders. Given the highly skewed specialisation towards one specific SDG, it is important to understand who the major funders are across SDGs and if such prioritisation is related to how countries are performing on the different SDGs. In order to understand who is funding the research related to specific SDGs, we used the funding acknowledgements paratext of all publications with at least one author from the countries in question between 2009 and 2017.

FIGURE 23 (see Appendix D) shows that 32% of the publications with Kenyan authors have had at least one foreign public funder (foreign government or multilateral funder, not located in KE, RW, or TZ). The second biggest funder group is philanthropic institutions (e.g., Bill and Melinda Gates Foundation and Wellcome Trust) and only 4% of the publications have had a Kenyan funder mentioned in the funding acknowledgements. It is important to emphasise that these acknowledgements' data has limitations; thereby, for 42% of the publications, we could not identify any funder. This can be because there are publications that do not receive institutional research funding or because the author forgot or decided not to include research funding acknowledgements. There are also 1866 Kenyan publications (around 10%) that report a funder in the acknowledgements but which we could not identify. Also, we found that funding from corporations is less than 2%. Lastly, the SDG with more relative funding is SDG 3 (i.e., Health and well-being).

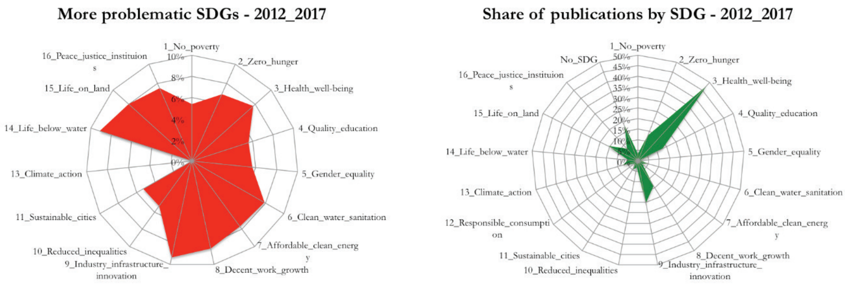

FIGURE 16. Kenya Main Societal Challenges versus SDG Research Production 2012 – 2017

Source: WOS, Scopus, and UN.

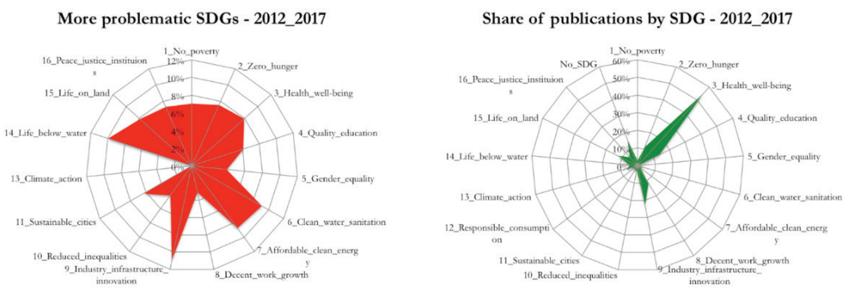

FIGURE 17. Tanzania Main Societal Challenges versus SDG Research Production 2012 – 2017

Source: WOS, Scopus, and UN.

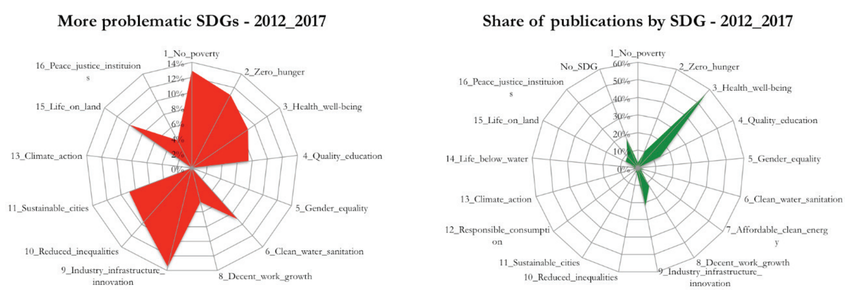

FIGURE 18. Rwanda Main Societal Challenges versus SDG Research Production 2012 – 2017

Source: WOS, Scopus, and UN.

FIGURE 24. (Appendix D) shows similar results for publications produced by Rwandan researchers. Findings indicate that 29% of the research there is funded by foreign public funders, 7% by philanthropic institutions, 3% by Rwandan institutions, and 1% by corporations. We could not identify funders in 243 publications (11%) and 48% of the publications have no funding reference.

As for Tanzania, the distribution is very similar (see Appendix D FIGURE 25). We found that 33% of the research there is funded by foreign public funders, 11% by philanthropic institutions, 3% by Tanzanian institutions, and 1% by corporations. We could not identify funders in 1171 publications (11%) and 40% of the publications have no funding reference.

We also took a closer look at the main funders supporting research in specific SDGS. TABLE 14 (see Appendix E) reports the top-20 funders in KE by SDG between 2009 and 2017. Some key findings are that NIH is the major research funder across all SDGS; Wellcome Trust and Gates Foundation funded more than 10% of all publication in SDG3; the EU funded more than 9% of the publications in SDG 13, 14, 15; DFID funded 2.5% of the publications; and there is a low representation of national funders.

TABLE 15 (see Appendix E) reports the top-20 funders in Rwanda by SDG during the same period. Here since the number of publications analysed is smaller than in the Kenyan case, the percentages of funders' shares in some SDGS are prone to small changes. Still, the major findings are that: NIH, which is the major research funder across almost all SDGS; the Swedish government (e.g., SIDA) and the Dutch government (e.g., NOW and NUFFIC), which are important funders in some SDGS; finally, there is a low share for national funders (<2% of total).

TABLE 16 (see Appendix E) shows the top-20 funders in Tanzania by SDG between 2009 and 2017. It evidences that NIH is the major research funder in all SDGS; Gates foundation, EU, and Wellcome Trust are again important funders; MRC (the UK or ZA) are important in SGD 3 and 5; lastly, low share for national funders (<2% of total).

Overall, our analysis of the research funding landscape shows a strong dependence of the research systems in KE, RW, and TZ on external research funding (public non-African and philanthropic organisations). It is guided towards different SDGs, but the largest emphasis of external funders is on health-related research (SDG3 – Health and well-being).

9.5. Discussion and Conclusions

In this chapter, we analysed the research systems in Kenya, Rwanda, and Tanzania in order to understand to what extent the research priorities in these countries are aligned with their main socio-economic challenges. The challenges faced by these countries are various and interrelated, ranging from poverty to hunger, health, education, innovation, and jobs. In order to make sense of such complexity, we estimated how these countries perform against benchmark countries with respect to the global challenges defined in the SDGs indicators. To measure research priorities, we delved into the research specialisation of KE, RW, and TZ in topics related to each SDG by allocating publications from the Web of Science (WOS) and Scopus to SDGs using a query developed using SDGs descriptions.

On one hand, we found that in the three countries there is a high research prioritisation in SDG3 (Good health and well-being). Also, results revealed that there is very little research capacity in engineering and physical sciences, poverty, hunger, or life below water, which seems at least as challenging as health across the three countries. On the other hand, we concluded that the distribution of socio-economic challenges is more uniform than their research specialisation would suggest. These findings show that the SDGs' research areas, which receive the most funding (mainly from foreign funders) and whose researchers publish most in international journals, are not necessarily the research areas where the countries do worst with respect to SDGs indicators. Such misalignment between the investment in research areas and the socio-economic challenges may reduce the effectiveness of the investments in research to address those challenges.

In line with previous studies, we also saw a high dependence in KE, RW, and TZ on international research collaboration and international (public and philanthropic) research funding that is mostly centred on health research-related areas. Some of the biggest funders include the NIH (all institutes combined), Wellcome Trust, Bill and Melinda Gates Foundation, and European Union (i.e., EU, ERC, and EC).

Our analysis has limitations, and the results must be interpreted with caution since scientific publications in WOS and Scopus are imperfect estimates of research efforts in a specific SDG and country. Both WOS and Scopus underrepresent journals from lower-income regions[40] and may give a biased picture of the research prioritisation in these countries.[41] This is even though they are reliable databases that are vastly used for bibliometric studies. Second, SDG indicators are limited estimates of socio-economic challenges since we used composite indexes and many relevant indicators for certain SDGs are not available in lower-income regions. Third, the research priorities were approximated by the number of publications per SDG divided by the total number of publications in a country. This did not allow comparing with the world relative distribution, as this would require whole access to WOS and Scopus since socio-economic challenges are measured in relation to the world frontier in a specific SDG. Both indicators are shares but they have different benchmarks. Finally, the marginal impact of increasing research investments in areas related to a certain SDG on the improvement of that SDG may not be the same for all SDGs. For instance, local studies on health (SDG3) may lead to significant improvements in the health outcomes of a country (although we do not find evidence of this), whereas more local research on poverty (SDG1) may not lead to similar marginal improvements. Future research should look carefully at this issue and also consider spill-overs between SDGs and positive and negative interactions among them, and how these may guide research prioritisation and building of research capabilities to address different challenges. Furthermore, since many of the publications that we identified have multiple authors, it would be important to understand the roles of Kenyan, Tanzanian, and Rwandan researchers in these collaborations.

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41. Ismael Rafols, Ciarli Tommaso, and Diego Chavarro. 'Under-Reporting Research Relevant to Local Needs in the Global South. Database Biases in the Representation of Knowledge on Rice,' paper presented at *15th International Conference on Scientometrics and Informetrics*. Istanbul, Turkey, June 29 – July 3, 2015. http://bitly.ws/qAwM

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Appendix A

TABLE 13. Variables Used for Approach 2

SDG	Description	Reversed
1_No_poverty	Poverty headcount ratio at $1.90/day (%)	
2_Zero_hunger	Cereal yield (t/ha)	Yes
	Prevalence of stunting, under - 5s (%)	
	Prevalence of wasting, under - 5s (%)	
3_Health_well - being	Adolescent fertility (births per 1,000)	
	HIV prevalence (per 1,000)	
	Life Expectancy at birth (years)	Yes
	Maternal mortality (per 100,000 live births)	
	Death rate from NCDs (per 100,000)	
	Neonatal mortality (per 1000 live births)	
	Subjective wellbeing (0-10)	Yes
	Incidence of tuberculosis (per 100,000)	
	Traffic deaths (per 100,000)	
	Under 5 mortality (per 1000 live births)	
	UHC Tracer Index (0-100)	Yes
	Infants who receive 2 WHO vaccines (%)	
4_Quality_education	Net primary school enrolment rate (%)	Yes
	Mean years of schooling (years)	Yes
5_Gender_equality	Unmet demand for contraceptives (%)	
	Female labour force participation (% male)	Yes
	Women in national parliaments (%)	Yes
6_Clean_water_ sanitation	Population using at least basic sanitation services (%)	Yes
	Population using at least basic drinking water services (%)	Yes

SDG	Description	Reversed
7_Affordable_clean_ energy	Access to clean fuels (%)	Yes
	CO2 from fuels and electricity (MtCO2/TWh)	
	Access to electricity (%)	Yes
8_Decent_work_ growth	Access to bank account or mobile - money (% adult pop.)	Yes
	Unemployment rate (%)	
9_Industry_ infrastructure_ innovation	Quality of overall infrastructure (1 - 7)	Yes
	Internet use (%)	Yes
	Mobile broadband subscriptions (per 100)	Yes
10_Reduced_ inequalities	GINI index	
11_Sustainable_ cities	Improved water source, piped (%)	Yes
	Annual mean levels of fine particulate matter in cities (population weighted)	
	Satisfaction with public transport (%)	Yes
13_Climate_action	CO2 emissions from energy (tCO2/capita)	
14_Life_below_water	Ocean Health Index - Biodiversity (0-100)	Yes
	Ocean Health Index - Clean waters (0-100)	Yes
	Ocean Health Index - Fisheries (0-100)	Yes
	Fish caught by trawling (%)	
15_Life_on_land	Freshwater sites, mean protected area (%)	Yes
	Terrestrial sites, mean protected area (%)	Yes
	Red List Index of species survival (0-1)	Yes
16_Peace_justice_ instituions	Corruption Perception Index (0-100)	Yes
	Government efficiency (1-7)	Yes
	Property rights (1-7)	Yes
	Feel safe walking at night (%)	Yes

Source: Prepared by authors.

Appendix B

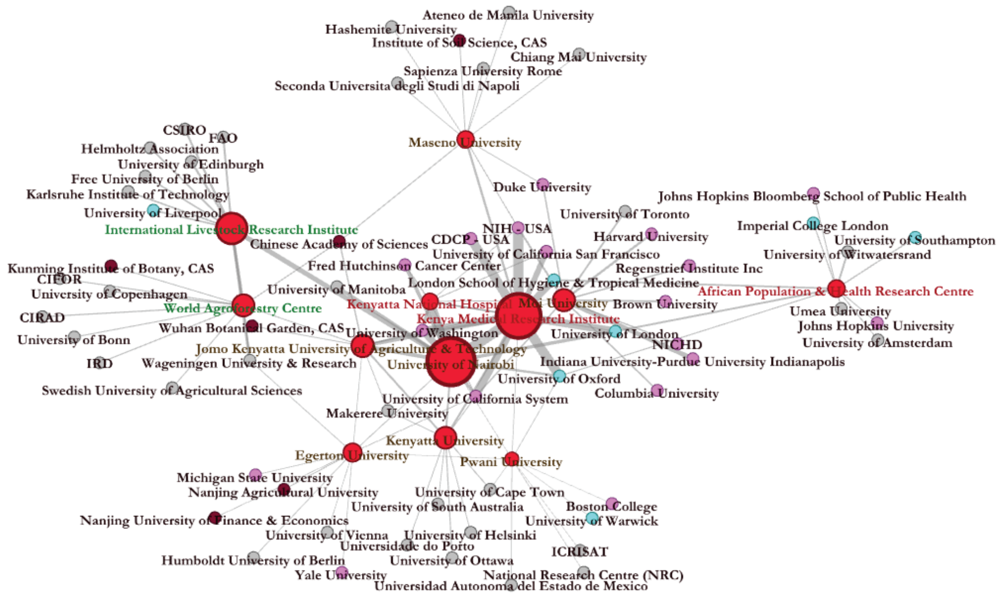

FIGURE 19. Collaboration Research Networks between Kenyan Institutions and Other Institutions (Top 10 Collaborators) in All Fields[42]

Source: WOS.

42. Node colours: Kenya (red), USA (pink), UK (light blue), China (brown); node size: number of publications (min=115, max=2116); edge size: number of collaborations (top10 for each Kenyan institution); labels: academic (brown), research institute (green), health institute (red), and government (blue).

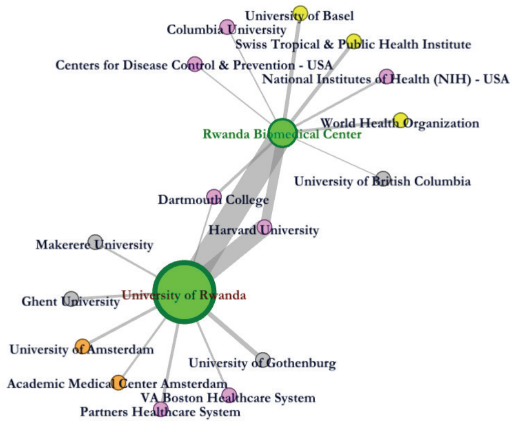

FIGURE 20. Collaboration Research Networks between Rwandan Institutions and Other Institutions (Top 10 Collaborators) in All Fields[43]

Source: WOS.

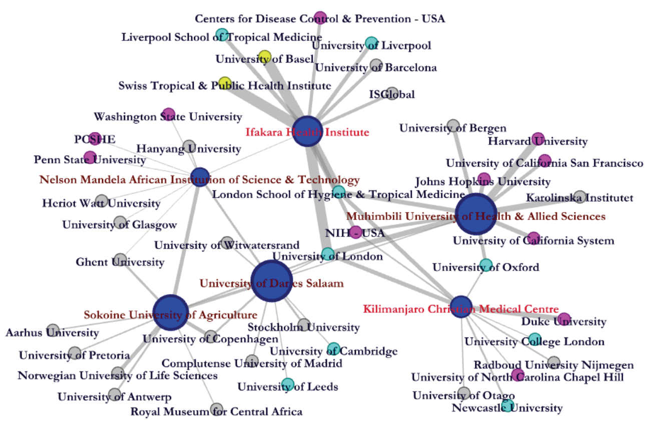

FIGURE 21. Collaboration Research Networks between Tanzanian Institutions and Other Institutions (Top 10 Collaborators) in All Fields[44]

Source: WOS.

43. Node colours: Rwanda (green), USA (pink), Netherlands (orange), Switzerland (yellow); node size: number of publications (min=146, max=579); edge size: number of collaborations (top10 for each Rwandan institution); labels: academic (brown), research institute (green), health institute (red), government (blue).

44. Node colours: Tanzania (blue), USA (pink), Switzerland (yellow), UK (light blue); node size: number of publications (min=205, max=934); edge size: number of collaborations (top10 for each Tanzanian institution); labels: academic (brown), research institute (green), health institute (red), government (blue).

Appendix C

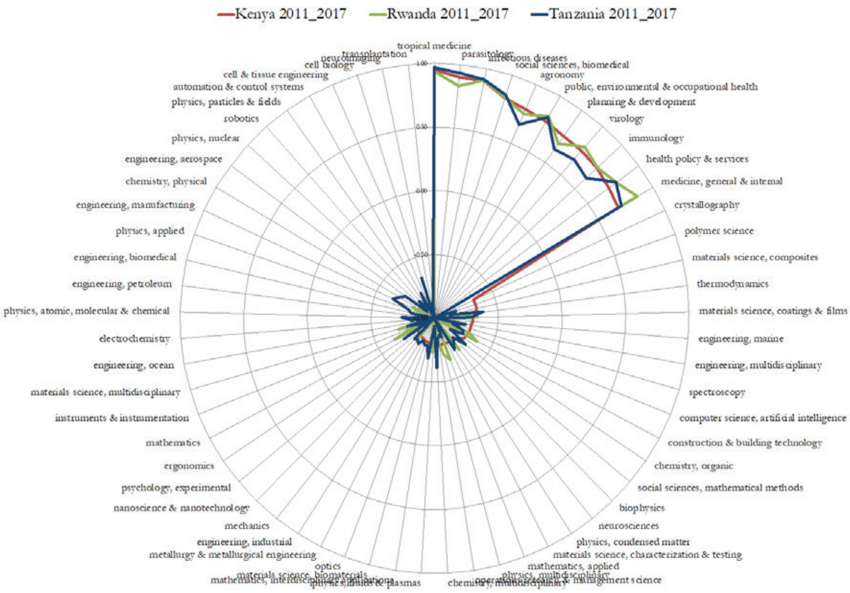

FIGURE 22. Research Specialisation in KE, RW, and TZ Compared to the World (wos)[45] [46]

Source: wos.

45. Normalised relative comparative advantages were calculated between 2011 and 2017.

46. From the original 251 areas, we excluded humanities-related areas and ended up analysing 223 areas. The only areas displayed in this graph are the ones of high specialisation (>0.6) and low specialisation (<0.6) for the three countries.

Appendix D

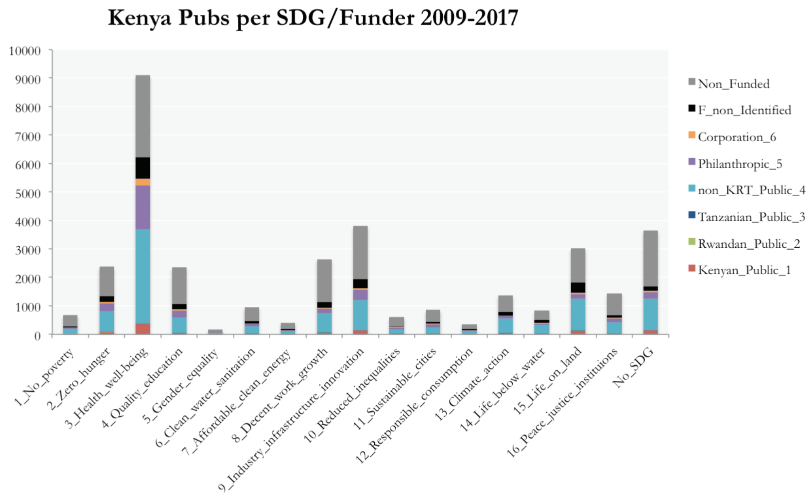

FIGURE 23. Share of Publications Associated with a SDG per Funding Type – Kenya

Source: WOS and Scopus.

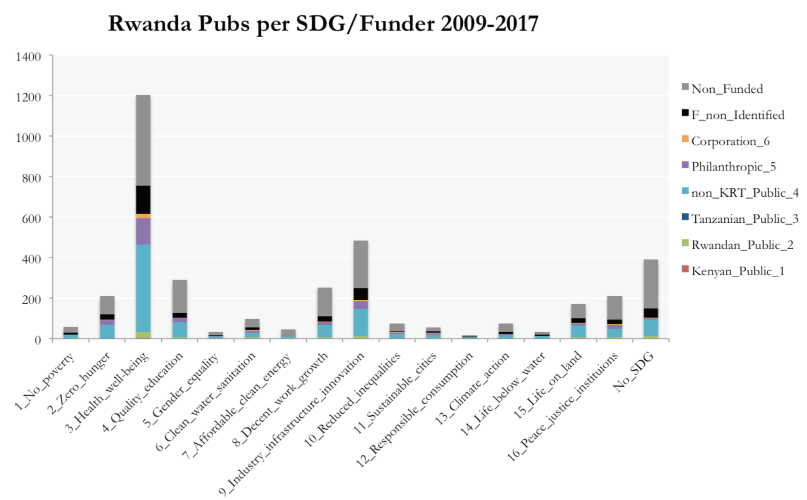

FIGURE 24. Share of Publications Associated with a SDG per Funding Type – Rwanda

Source: WOS and Scopus.

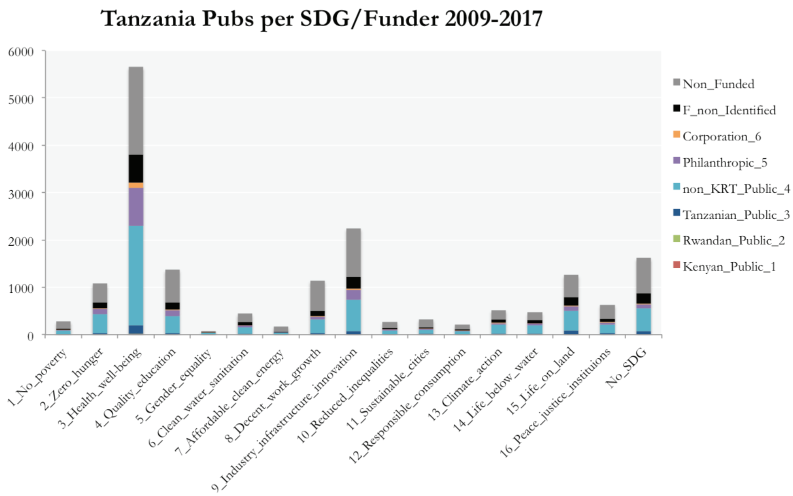

FIGURE 25. Share of Publications Associated with a SDG per Funding Type – Tanzania

Source: WOS and Scopus.

Appendix E

TABLE 14. Top 20 Funders (Share) per SDG – Kenya. 2009 – 2017

	1_No_poverty	2_Zero_hunger	3_Health_well - being	4_Quality_education	5_Gender_equality	6_Clean_water_sanitation	7_Affordable_clean_energy	8_Decent_work_growth	9_Industry_infr_innovation	10_Reduced_inequalities	11_Sustainable_cities	12_Responsible_consumption	13_Climate_action	14_Life_below_water	15_Life_on_land	16_Peace_justice_instituions	No_SDG	Total
NIH_4	10%	13%	26%	14%	16%	9%	11%	9%	12%	17%	12%	10%	13%	17%	11%	15%	11%	3296
Wellcome_ Trust_5	5%	6%	12%	7%	5%	3%	2%	3%	5%	9%	12%	1%	1%	2%	1%	6%	2%	1280
Gates_ Foundation_5	4%	6%	10%	5%	8%	5%	3%	3%	5%	7%	6%	3%	3%	1%	2%	5%	3%	1139
EU_4	4%	6%	5%	2%	4%	5%	8%	6%	5%	5%	4%	7%	11%	9%	9%	3%	4%	950
USAID_4	4%	5%	6%	3%	5%	3%	3%	4%	4%	5%	2%	2%	3%	3%	3%	4%	2%	754
DEU_Gov_4	2%	3%	2%	1%	0%	3%	1%	2%	3%	2%	2%	9%	4%	2%	4%	0%	6%	623
MRC_4	1%	3%	6%	3%	2%	2%	1%	1%	2%	5%	2%	1%	0%	1%	0%	2%	1%	581
NSF_4	2%	2%	2%	1%	0%	2%	2%	2%	2%	2%	2%	1%	6%	3%	6%	2%	4%	580
DFID_4	5%	3%	4%	2%	7%	2%	2%	3%	3%	4%	4%	2%	4%	2%	3%	4%	1%	488
CDC_4	0%	2%	4%	2%	1%	1%	1%	0%	1%	1%	3%	0%	0%	0%	0%	2%	1%	402
CGIAR_4	3%	5%	1%	1%	2%	2%	9%	3%	3%	2%	1%	3%	7%	3%	5%	1%	1%	371
SWE_Gov_4	3%	3%	2%	1%	2%	2%	3%	1%	1%	2%	7%	2%	2%	2%	2%	1%	1%	356
KEMRI_1	1%	2%	3%	1%	1%	1%	0%	0%	1%	2%	2%	0%	0%	1%	0%	2%	0%	293
WHO_4	1%	1%	2%	1%	4%	1%	1%	1%	2%	2%	1%	0%	0%	0%	0%	2%	1%	237
CFAR_4	0%	1%	2%	1%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	217
PEPFAR_4	0%	0%	2%	1%	2%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	1%	0%	216
BEL_Gov_4	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%	2%	2%	2%	0%	1%	201
NNSFC_CN_4	0%	0%	0%	0%	0%	1%	1%	1%	1%	0%	0%	2%	2%	0%	1%	0%	3%	193
NLD_Gov_4	0%	1%	1%	1%	1%	2%	1%	1%	1%	0%	0%	1%	2%	2%	2%	1%	1%	187
BBSRC_4	1%	1%	1%	0%	4%	0%	1%	1%	1%	1%	0%	2%	1%	0%	1%	0%	1%	185
Total	681	2371	9097	2348	168	947	391	2638	3796	597	859	356	1364	830	3018	1437	3644	19339

Source: WOS and Scopus

TABLE 15. Top 20 Funders (Share) per SDG – Rwanda. 2009 – 2017

	1_No_poverty	2_Zero_hunger	3_Health_well - being	4_Quality_education	5_Gender_equality	6_Clean_water_sanitation	7_Affordable_clean_energy	8_Decent_work_growth	9_Industry_infr_innovation	10_Reduced_inequalities	11_Sustainable_cities	12_Responsible_ consumption	13_Climate_action	14_Life_below_water	15_Life_on_land	16_Peace_justice_ instituions	No_SDG	Total
NIH_4	17%	9%	19%	9%	12%	2%	6%	5%	10%	20%	9%	11%	4%	15%	4%	12%	7%	265
Gates_ Foundation_5	0%	9%	7%	6%	3%	8%	0%	2%	4%	8%	5%	0%	5%	0%	0%	7%	0%	85
EU_4	0%	2%	5%	1%	3%	2%	0%	1%	3%	5%	9%	6%	1%	0%	2%	1%	2%	78
USAID_4	2%	5%	5%	3%	0%	1%	0%	2%	4%	3%	0%	0%	0%	0%	2%	0%	1%	76
SWE_Gov_4	3%	3%	3%	3%	18%	4%	4%	2%	2%	7%	9%	0%	5%	3%	3%	4%	5%	72
NLD_Gov_4	3%	5%	4%	3%	0%	6%	0%	6%	3%	1%	4%	17%	7%	3%	12%	2%	1%	72
BEL_Gov_4	2%	3%	3%	2%	3%	0%	0%	2%	2%	0%	2%	0%	1%	0%	1%	2%	2%	54
Univ_Rwanda_2	3%	0%	1%	1%	3%	7%	9%	3%	2%	1%	5%	6%	3%	9%	5%	1%	3%	46
EDCTP_4	0%	0%	3%	1%	3%	0%	0%	0%	0%	3%	0%	0%	0%	12%	0%	2%	0%	43
MRC_4	2%	2%	3%	2%	0%	1%	0%	0%	2%	11%	0%	0%	0%	0%	0%	1%	0%	41
Wellcome_ Trust_5	2%	3%	3%	1%	0%	2%	0%	1%	2%	5%	7%	0%	1%	0%	1%	1%	0%	40
NSF_4	0%	1%	1%	1%	0%	0%	0%	0%	2%	3%	2%	0%	0%	3%	2%	1%	4%	37
WHO_4	2%	1%	3%	1%	3%	2%	0%	2%	1%	3%	4%	0%	0%	0%	0%	1%	0%	37
CFAR_4	3%	2%	3%	0%	0%	0%	0%	0%	2%	0%	0%	0%	0%	3%	0%	3%	0%	35
DorisDuke_ Found_5	0%	1%	3%	2%	0%	2%	0%	3%	3%	1%	0%	0%	0%	0%	0%	3%	0%	35
DFID_4	0%	3%	2%	1%	0%	1%	0%	0%	2%	4%	4%	0%	0%	0%	0%	1%	0%	34
Harvard_4	3%	2%	2%	2%	3%	1%	2%	2%	3%	1%	0%	0%	0%	0%	0%	4%	0%	32
CDC_4	0%	1%	2%	2%	3%	0%	0%	1%	1%	0%	5%	0%	0%	0%	0%	0%	0%	31
NNSFC_CN_4	0%	1%	0%	0%	0%	5%	0%	1%	2%	1%	0%	0%	4%	0%	5%	0%	3%	27
RWA_Gov_2	0%	1%	2%	2%	3%	0%	0%	1%	1%	0%	5%	0%	1%	0%	1%	1%	0%	27
Total	59	211	1203	290	34	98	47	252	485	74	55	18	75	34	172	211	392	2157

Source: WOS and Scopus.

TABLE 16. Top 20 Funders (Share) per SDG – Tanzania. 2009 – 2017

Funder/SDG	1_No_poverty	2_Zero_hunger	3_Health_well - being	4_Quality_education	5_Gender_equality	6_Clean_water_sanitation	7_Affordable_clean_energy	8_Decent_work_growth	9_Industry_infr_innovation	10_Reduced_inequalities	11_Sustainable_cities	12_Responsible_consumption	13_Climate_action	14_Life_below_water	15_Life_on_land	16_Peace_justice_instituions	No_SDG	Total
NIH_4	11%	20%	25%	13%	33%	12%	6%	11%	13%	15%	13%	10%	12%	14%	12%	14%	11%	1843
Gates_ Foundation_5	5%	8%	9%	5%	0%	7%	3%	4%	5%	4%	3%	4%	2%	1%	1%	4%	3%	623
EU_4	5%	5%	7%	5%	4%	6%	2%	5%	5%	4%	4%	7%	7%	8%	7%	3%	4%	578
Wellcome_ Trust_5	1%	3%	7%	3%	1%	2%	1%	1%	3%	5%	6%	0%	2%	3%	2%	2%	2%	460
MRC_4	2%	3%	7%	3%	18%	1%	1%	2%	3%	4%	2%	1%	1%	0%	1%	2%	1%	396
SWE_Gov_4	4%	3%	3%	2%	11%	4%	5%	3%	2%	4%	2%	6%	4%	7%	3%	4%	4%	327
USAID_4	3%	4%	4%	3%	5%	2%	1%	3%	3%	1%	1%	3%	2%	1%	1%	2%	1%	304
NSF_4	1%	2%	2%	1%	0%	3%	1%	1%	2%	1%	2%	0%	4%	3%	4%	2%	4%	277
DFID_4	3%	2%	3%	2%	10%	2%	3%	2%	3%	5%	4%	2%	3%	2%	2%	3%	1%	246
DNK_Gov_4	1%	2%	2%	2%	0%	3%	0%	1%	2%	2%	3%	0%	1%	2%	1%	1%	1%	187
DEU_Gov_4	1%	3%	1%	1%	1%	2%	1%	2%	2%	3%	3%	4%	3%	2%	2%	2%	2%	176
NOR_Gov_4	2%	1%	2%	1%	0%	0%	2%	1%	2%	2%	2%	3%	2%	2%	2%	1%	2%	164
BEL_Gov_4	1%	1%	1%	1%	0%	3%	0%	1%	1%	0%	2%	2%	3%	2%	2%	0%	3%	152
WHO_4	0%	1%	2%	2%	1%	1%	0%	1%	1%	2%	1%	2%	0%	1%	0%	1%	0%	140
TZA_Gov_3	1%	1%	2%	1%	3%	0%	1%	1%	1%	1%	1%	0%	1%	0%	2%	2%	1%	135
NLD_Gov_4	1%	2%	1%	1%	0%	3%	1%	1%	1%	1%	1%	1%	3%	4%	2%	1%	1%	129
PEPFAR_4	1%	1%	2%	1%	1%	0%	0%	0%	1%	1%	0%	1%	0%	0%	0%	2%	0%	116
EDCTP_4	1%	1%	2%	1%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	114
CDC_4	0%	1%	2%	1%	1%	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%	2%	0%	109
Univ_Dar_es_ Salaam_3	1%	1%	0%	0%	0%	1%	2%	1%	1%	1%	1%	1%	2%	2%	3%	1%	2%	100
Total	281	1078	5654	1376	73	442	177	1144	2249	269	328	210	520	470	1262	633	1618	10187

Source: WOS and Scopus.

10. Towards A Set Of Transformation Measurements Within A Community From An Organisational Change And Transformational Learning Perspective

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10.1. Introduction

Traditionally, when society demands actions to achieve sustainable development goals, governments respond in a centralised way, aligning activities to influence public and private policies to attack major social problems such as extreme poverty, social inclusion, ecological sustainability, and governance for peace and

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security.[5] However, these top-down initiatives have not shown the expected results because they are usually implemented for fixed periods, using limited resources. Real impacts remain feasible only for some people in communities, ample and sustainable initiatives being inaccessible to the majority of communities.

Since communities have been excluded from the design of initiatives that aim to improve their quality of life, these have started to propel local transformation projects where members get involved in activities and implement strategies. Thus, communities have designed small-scale experiments (niches) and developed them in collaboration with public allies such as universities and the State and the private sector, among others. It is expected that within small-scale community initiatives, sustainability transformations can be fostered, looking for new ways to address challenges, these latter eventually resulting in changes in the main systems (i.e., the regime).[6] Still, transformational initiatives within communities remain insufficient to meet a large number of challenges.[7]

To respond to challenges and amplify the results and impacts, there is a need to understand what happens within the niche while promoting transformation initiatives. The management literature indicates that successful niche building takes place in areas where transformations at organisational and individual levels occur. Particularly, literature that studies transformational change in organisations contends that it is possible to interpret those processes that support transformations in communities. Likewise, it allows identifying elements of those factors needed to induce long-term niche changes. This literature also analyses learning processes that happen when transformational processes are

5. Juvancir da Silva, et al., 'Sustainable development assessment from a capitals perspective: Analytical structure and indicator selection criteria,' *Journal of Environmental Management* 260 (April 2020): 110147. https://doi.org/10.1016/j.jenvman.2020.110147

6. Nigel Forrest and Arnim Wiek, 'Success factors and strategies for sustainability transitions of small-scale communities – Evidence from a cross-case analysis,' *Environmental Innovation and Societal Transitions* 17 (December 2015): 22–40. https://doi.org/10.1016/j.eist.2015.05.005

7. Robert W. Kates, William R. Travis, and Thomas J. Wilbanks, 'Transformational adaptation when incremental adaptations to climate change are insufficient,' *Proceedings of the National Academy of Sciences* 109, no. 19 (April 2012), 7156–61. https://doi.org/10.1073/pnas.1115521109; Karen O'Brien, 'Global environmental change II: From adaptation to deliberate transformation,' *Progress in Human Geography* 36, no. 5 (October 2012): 667–76. https://doi.org/10.1177%2F0309132511425767 implemented. Finally, it sheds light on how learning works as a catalyst for the relationship between organisational and individual levels.

The literature indicates that in a context where transformational processes are implemented at organisational and individual levels while learning happens, it is feasible to support long-term transitions. In this regard, there are calls to deepen the existing models and methods to study and understand the transformations[8] and to identify what kinds of processes can be socially and organisationally transformational.[9] This chapter aims to fill this gap by contributing with a novel conceptualisation of transformational change at the niche level. Thus, the next section tackles how organisational transformational change is connected to individual transformative learning, and based on this conceptual connection, it develops a set of measures to follow changes. Later, the subsequent section presents a case study where the set of measures was used as a method to understand and follow up advances regarding transformational processes. Finally, a reflection on the implemented processes and the achieved results is posed.

With these contributions, actors involved in initiatives related to niche building might improve their understanding of processes underlying transformations and have a tool to evidence advances towards long-term niche changes. The analysis presented here stems from a reflection process on the results that a transformative initiative has produced in the city of Girón, Santander, Colombia.

10.2. Organisational Transformational Change and Individual Transformative Learning

Strategic niche management literature refers to transformational change as a turn in the way organisation members perceive their roles, responsibilities,

8. Matias Ramirez, et al., *Mobilizing the Transformative Power of the Research System for Achieving the Sustainable Development Goals* (Brighton: University of Sussex, 2019). https://dx.doi.org/10.2139/ssrn.3497623

9. Paul Mapfumo, et al., 'Pathways to transformational change in the face of climate impacts: an analytical framework,' *Climate and Development* 9, no. 5 (June 2015): 439–51. https://doi.org/10.1080/17565529.2015.1040365 and relationships.[10] Said transformation involves a major shift in characteristic features and functions resulting in a fundamentally new system or process.[11] Besides, it implies reshaping the culture and redesigning elements of the organisation. Therefore, the target of transformation should be the entire organisation, the total system, not individual members.[12] This is because when context changes, including norms, rules, or culture, individual behaviour is modified and adapts to the new pattern.[13]

Concerning measurement, Mapfumo et al. pinpoint that 'asking whether a transformational change has occurred in the context of a particular project cannot be answered with a categorical "yes" or "no."'[14] Regarding the cases the authors reviewed, such a question transcends that dualism because of these cases' key attributes.[15] Hence, when developing measures to verify organisational transformations, it is crucial to identify characteristics underlying transformations at the niche level that can be evidenced. In doing so there is a possible follow-up on them.

Behind successful organisational transformation processes, there are processes that foster individual transformational learning as well.[16] As a transformative change in an organisation develops, context changes; as a result, members go through an internal process where their perspectives and frames of reference also change. Thus, individuals experience a process of critical reflection on their assumptions, attitudes, and beliefs that, accordingly, lead to a transformation of their behaviours, practises, and skills. Brooks contends that, by combining critical reflection with action, organisations obtain a powerful catalyst for change and build the foundation of learning, which is known as

10. Gregory M. Henderson, 'Transformative Learning as a Condition for Transformational Change in Organizations,' *Human Resource Development Review* 1, no. 2 (June 2002): 186–214. https://doi.org/10.1177%2F15384302001002004

11. Mapfumo, et al., 'Pathways to transformational change.'

12. W. Warner Burke, *Organization Change: Theory and Practice* (Thousand Oaks: Sage Publications, 2018).

13. Ibid.

14. Mapfumo, et al., 'Pathways to transformational change,' 447.

15. Ibid.

16. Henderson, 'Transformative Learning.'

action learning.[17] Evidence shows that building change on action learning increases the chances for organisational transformation successfully to occur.[18] Transformational processes develop through cycles that evolve in parallel, receiving influence and influencing others (see FIGURE 26).

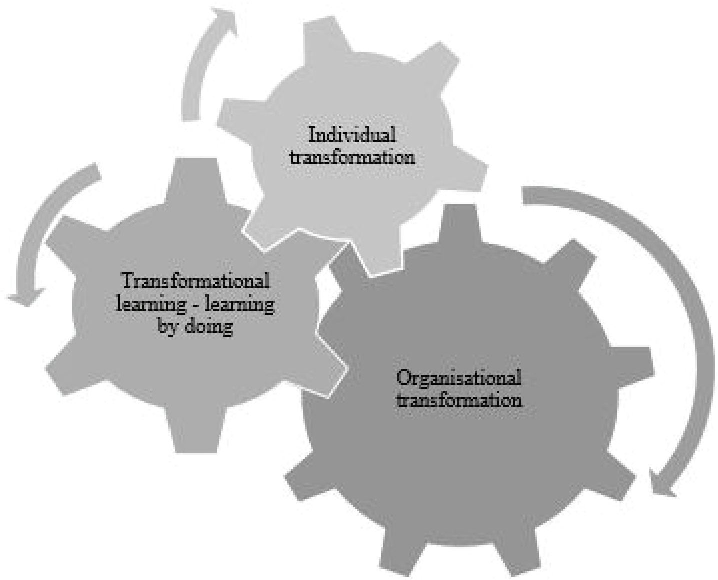

FIGURE 26. Processes Involved in Organisational Transformational Change

Source: Prepared by authors based on Mapfumo et al.; Henderson; Brooks.[19]

With a transformative learning perspective, it is possible to understand individual change and how learning is linked to the organisational one. Individual change does not depend on contextual variables but rather on a personal process where perspectives and frames of reference are transformed through critical reflection, as mentioned before. However, for organisational change to

17. Ann K. Brooks, 'Critical Reflection as a Response to Organizational Disruption,' *Advances in Developing Human Resources* 1, no. 3 (August 1999): 66–79. https://doi.org/10.1177%2F152342239900100308; Ann K. Brooks, 'Building learning organizations: The individual-culture interaction,' *Human Resource Development Quarterly* 3, no. 4 (Winter 1992): 323–35. https://doi.org/10.1002/hrdq.3920030403

18. Henderson, 'Transformative Learning.'

19. Ibid.; Brooks, 'Critical Reflection as a Response;' Mapfumo, et al., 'Pathways to transformational change.'

take place, critical reflection and action should be connected through practise at a group level. Regarding this point, Marquardt indicates that action learning is achieved through processes or programmes involving small groups of people solving real problems.[20] This happens while they focus on what they are learning and how their learning can benefit each group member and the organisation as a whole.[21] FIGURE 27 shows the relationship between organisational and individual transformation and transformational learning generated from these two.

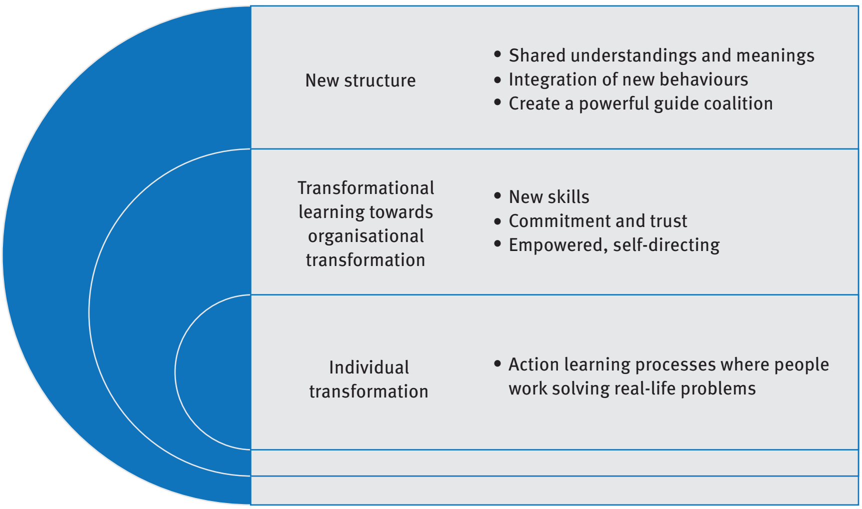

FIGURE 27. Organisational Transformational Elements

Source: Prepared by authors based on Burke; Nevis, Lancourt, and Vasallo; Kotter; Beckhard and Pritchard; Argyris and Schon; Freire; and Marquardt.[22]

20. M. J. Marquardt, *Action Learning in Action: Transforming Problems and People for World-Class Organizational Learning* (Palo Alto: Davies-Black Pub., 1999).

21. Ibid.

22. Burke, *Organization Change*; Edwin C. Nevis, Joan E. Lancourt, and Helen G. Vassallo, *Intentional revolutions: A Seven-Point Strategy for Transforming Organizations* (San Francisco: Jossey-Bass Inc Pub., 1996); John P. Kotter, *Leading change*, rev. ed. (Boston: Harvard Business Press, 2012); John P. Kotter, 'Leading change: Why transformation efforts fail,' *The Magazine* (May-June 1995). http://bitly.ws/qGxL; Richard A. Beckhard and Wendy Pritchard, *Changing The Essence: The Art Of Creating and Leading Fundamental Change in Organizations* (San Francisco: Jossey Bass Publishers, 1992); Chris Argyris and Donald A. Schon, *Organizational learning II. Theory, Method, and Practice* (Reading: Addison-Wesley, 1996); Paulo Freire, *Pedagogy of the Oppressed*, rev. ed. (New York: Bloomsbury Publishing, 2018); Marquardt, Action Learning in Action.

Based on comprehension of organisational change and transformational learning and how these relate to each other for achieving organisational transformation, FIGURE 27 introduces a summary of key elements. TABLE 17 describes each of these elements.

TABLE 17. Description of Organisational Transformational Change Elements

Elements of the transformed organisation	
'New structure' (Burke).	The organisation changes its culture and designs new elements for its structure.
'Shared understandings and meanings' (Nevis, Lancourt, and Vassallo).	The organisation institutionalises new comprehensions of reality.
'Integration of new behaviours' (Nevis, Lancourt, and Vassallo).	The organisation develops new ways to act or conduct, different from what it is used to do.
'Create a powerful guide coalition' (Kotter)	Develop a network of allies that support activities within the organisation.
Elements of the transformed individual	
'New skills' (Beckhard and Pritchard)	Members develop abilities to do new things for themselves.
'Commitment and trust' (Argyris and Schon)	Members show higher levels of commitment to work for goals and higher levels of trust among them and to the process.
'Empowered, self-directing' (Freire)	Members show confidence when doing things and determine what to do.
Transformational learning towards organisational transformation	
'Action learning processes where people work solving real-life problems' (Marquardt)	Learning-by-doing

Source: Prepared by authors based on Burke; Nevis, Lancourt, and Vasallo; Kotter; Beckhard and Pritchard; Argyris and Schon; Freire; and Marquardt.[23]

23. Ibid.

10.3. The Endogenous Community Development Plan of Ciudadela Nuevo Girón: An Initiative for Transformational Change

In this section, we describe a case study that accounts for an application of the framework related to organisational transformation. This initiative, which started in 2014 and is still underway, has gathered academic and religious institutions and civil and private organisations together to act vis-a-vis the problems experienced by a vulnerable community, namely: *Ciudadela Nuevo Girón* located in the northeast part of Colombia. This community has more than 8,000 inhabitants (1,760 families) most of them living in a neighbourhood divided into seven geographical sectors called 'sectors,' from 1 to 7 (e.g., Sector 1).

Since *Ciudadela Nuevo Girón* struggles with serious problems like poverty, poor health, drug addiction, violence, and prostitution, among others, the initiative aims to foster social and individual transformations while boosting community welfare. After several years of work and reflection on the activities and elements that emerged from the process, researchers have concluded that the achievements evidenced up to now correspond to what the theories about organisational transformational change indicate.

This case study seeks to find social transformations in the foregoing community. To do so, this project is led by members of the community, researchers form *Universidad Autónoma de Bucaramanga* (UNAB), and representatives from the catholic religious community of Dominican Sisters of the Presentation (RCDSP). Plus, throughout time, eight different organisations have joined the team: four regional universities, two national NGOs, the community's school, the municipality's government, and a newly created community's NGO. In total, 11 groups are working together in a single initiative towards quality life's improvement in this community.

Originally, the objective of the project was to design a community development model based on the empowerment of the community's internal capacities. This initial process used a participatory action research methodology (PAR) and allowed the co-designing of an 'endogenous community development model' (MDCE) seeking improvements in the community's quality of life. To achieve the expected results, leaders and representatives of the community, as well as researchers from UNAB and members of the RCDSP, have worked together on the co-design. Finally, thanks to the MDCE implementation, the community transforms itself into a more resilient community organisation. Configured as a network of actors that works for the alleviation of social problems, this community creates conditions where entrepreneurial activities can be fostered and general wellbeing can be strengthened.

The MDCE is a model that aims to improve the quality of life of the community inhabitants. This is because it empowers them to associate with external actors including alliances with government, academe, and the private sector. It also encourages them to organise and develop processes to face community issues related to health, education, income generation, and social infrastructure, ensuring active and effective participation. Under the framework of the model, actors enhance their knowledge about how they should take community actions in these areas and how to build communal capabilities to work together to achieve goals. Specifically, actors are enabled to conduct legal and public policy management; organise themselves in a democratic, inclusive, solidary, and egalitarian way; intervene in the management of social programmes for their benefit; and achieve associativity as an instrument to generate alliances with actors present in the territory. Accordingly, the MDCE calls on individuals to exercise and defend citizens' rights and create their own community culture.

Through the development of activities in this project, results have shown a strengthening of the community action, an increase in the number of alliances, and evidence of individual transformations. In 2019, eight new organisations joined the initiative: four regional universities, two national NGOs, and the community's school. In 2020, when the pandemic stopped all on-site participation of allies, community members remained together working and looking for ways to continue the initiative. Among others, up to this moment, the MDCE has revealed the following impacts regarding organisational and individual transformations:

1) Leadership training for more than 20 women who represent the seven sectors of *Ciudadela Nuevo Girón*, at least two per sector. Also, 15 additional women got trained in community organisation management.

2) Configuration of a social network that involves about 120 women, men, and children.
3) Constitution of four teams made up of community members who have assumed responsibility for actions related to the management of community health, education, income generation, and social infrastructure.
4) The creation of a community foundation (NGO) where the associates are members and leaders of *Ciudadela Nuevo Girón*.
5) Community members' change of expectations regarding benefits that could result from the project. Usually, these communities are used to receiving donations or subsidies from external actors (e.g., municipalities, private companies, and NGOs) without having to work to obtain them. In this project, the community is committed to hard work. This has been materialised through 250 meetings once a week without interruption (even during pandemic times).
6) Community's finding of a common focus by which to work on improving quality of life in *Nuevo Girón*. This emphasis has produced individual changes and has empowered people, allowing them to have a motivation to work with others. Women working on the project have nurtured a feeling of autonomy and self-confidence. It is interesting to note that now their partners or husbands encourage them to take part in the project even though at the beginning these men severely opposed their participation.

Nonetheless, the foregoing processes and results have not been straightforward. Actors have gone through many cycles that include reflection processes in meetings, which has shown an improved participants' understanding of their individual transformations and the visible achievements that working together has brought to the community. Likewise, reflection has concluded that characteristics from the literature regarding transformed organisations and individuals are clearly reified in the community processes and individuals. Lastly, while the community is transformed, the niche is strengthened and shielded, attracting important external actors to work with the group and increasing legitimacy.

10.4. Organisational Transformation and Individual Transformation in Ciudadela Nuevo Girón

The processes developed within *Ciudadela Nuevo Girón* and the results obtained regarding transformations at the community and individual levels have been evidenced by all actors involved in the project. TABLE 18 shows such evidence, which, as mentioned before, derives from a reflective process that meets the characteristics of transformed organisations and individuals indicated in the literature.

TABLE 18. Evidence Obtained from Ciudadela Nuevo Girón that Shows Organisational Change Elements

		Evidence from Ciudadela Nuevo Girón
Characteristics of the transformed organisation	The new structure (Burke)	The community learns how to self-organise around community problems creating new groups of representatives to work on the MDCE areas.
	Shared understandings and meanings (Nevis, Lancourt, and Vassallo)	The community understands that they are responsible for their future and that welfare expectations would not solve the community problems in the long run.
	Integration of new behaviours (Nevis, Lancourt, and Vassallo)	The community organises activities for the neighbourhood to strengthen its values and identity.
	Create a powerful guide coalition (Kotter)	A new set of alliances between academic, religious, NGOs, and the community to support transformations within Ciudadela Nuevo Girón.
Characteristics of the transformed individual	New skills (Beckhard and Pritchard)	Women and men start new small businesses.
	Commitment and trust (Argyris and Schon)	Individual permanent work to implement the MDCE. More than 5 years of continuous and uninterrupted work.
	Empowered, self-directing (Freire)	Women and men assume leadership and responsibility for the development of community activities.

		Evidence from Ciudadela Nuevo Girón
Transformational learning towards organisational transformation	Action learning processes where people work solving real-life problems (Marquardt)	Community representatives co-designing activities with the academic, religious, and NGOs towards the implementation of MDCE. In these spaces, there are reflection processes to correct problems and strengthen successful processes.

Source: Prepared by authors based on Burke; Nevis, Lancourt, and Vasallo; Kotter; Beckhard and Pritchard; Argyris and Schon; Freire; and Marquardt.[24]

10.5. Towards a Set of Measures to Evidence Organisational Transformational Change

Through reflection, the researchers have been able to understand how the MDCE implementation has advanced and evolved through time as well as to evidence those processes developed at the community and individual levels to achieve results. Also, the reflection process has worked for all allied institutional members as a mechanism that facilitated understanding of how transformations occurred.

Concerning the literature introduced in this paper, it is possible to conclude that theoretical findings align with what the project members and community actors have lived and learned while working on the project in *Ciudadela Nueva Girón*. In fact, based on these findings, during the pandemic in 2020, the project's actors designed a set of qualitative measurements to gather more specific elements about transition processes and subsequent transformations. The measurement set classifies indicators into two levels: organisational and individual. Its instrument is a Likert-scale questionnaire that enables participants to evidence perceptions about community and individual elements (see TABLE 19).

24. Ibid.

TABLE 19. Organisational Transformational Change Measurement Set

Community-level questions (Likert scale 1-7)	**Elements of the transformed organisation**
Has the community organised itself into new structures that allow it to work better to achieve development goals?	New structure
Does the community understand that they must work together to achieve the proposed development objectives?	Shared understandings and meanings
Has the community been able to organise activities in the context of the initiative that they thought they were not capable of developing before?	Integration of new behaviours
Has the community developed permanent alliances with external organisations or institutions to work for the development of common objectives?	Create a powerful guide coalition
Individual-level questions (Likert scale 1-7)	**Elements of the transformed individual**
Do you consider that you have learned new skills that you did not have some time before?	New skills
Do you feel a greater commitment to working for the community to contribute to the achievement of the objectives? Do you trust those with whom you are working for the development of the proposed objectives?	Commitment and trust
Do you think you are capable of becoming a leader in your community or a manager of the activities that support the development of objectives?	Empowered, self-directing
Transformational learning towards organisational transformation	
Do you consider that the initiative provides spaces where we can work with others to solve the problems we are experiencing? Are there spaces where we can revise what we have done to improve them?	Action learning processes where people work solving real-life problems

Source: The project's actors based on Burke; Nevis, Lancourt, and Vasallo; Kotter; Beckhard and Pritchard; Argyris and Schon; Freire; and Marquardt.[25]

This set of measures is designed in a way that allows second-order learning assessment among the project's participants, which is a factor that adds

25. Ibid.

to the sustainability of this transformation initiative. For future projects, these measurements can be tested within niches where transformation processes are developed and used with organisations and individuals involved in transformations.

10.6. Conclusion

This chapter aimed to study transformative responses at the community level to understand the social and individual processes that occur within it, the community studied being based in Girón, Santander, Colombia. Normally, community transformative initiatives are promoted centrally with less than encouraging results. In the case described here, a perspective of action developed by a community working together with several different institutions has proven to be more effective and achieve lasting results. This is because it has implied activities to foster transformative change at organisational and individual levels.

To do this, the organisational transformational change framework has been drawn on to understand how transformations within organisations develop and evolve. At the same time, the transformative learning framework has been applied to make sense of how individual responses support organisational changes. The analysis of these two conceptual frameworks has triggered reflective processes on the activities implemented. In this train of thought, an array of measurements including measures at the organisational and individual levels are suggested as a way to evidence transformations, which, in the long run, might serve as a tool to see processes of niche building and shielding.

In conclusion, while transformation processes have occurred at the community level, niches can be built and shielded and constitute a network of allies that work to solve real-life problems. For this reason, the application of organisational and individual transformations frameworks and the monitoring of initiatives and projects that use them are relevant if society wants to find working paths to those big challenges that it faces.

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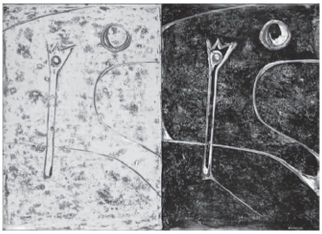

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This book provides a fresh and comprehensive understanding of the most significant methodological advances in the study of transformative change through policy decision-making; this latter being commonly influenced by metrics and evaluation processes. In this vein, the book presents methodological approaches to the study of sustainable transitions by suggesting that these metrics and evaluation processes can play a new role. It contends that using these approaches in the implementation of policy programmes, projects, and interventions can offer a further reflexive perspective, which helps transformations to take place and enhance metrics' transformative potential.