Knowledge co-production for social and ecological transition

Reaching sustainability co-benefits through interdisciplinary partnership research

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Table

Foreword

This report analyses a multitude of successful projects to accelerate the ecological and social transition through research in partnership with social actors.

However, this report constitutes only a preliminary work in progress based on a synthesis of the literature. It will be supplemented by a series of more systematic interviews with project leaders and a theoretical framework on participatory methods.

All comments and suggestions are welcome, in order to complete the list of projects and initiatives, fill in the gaps, broaden the debate, etc. Do not hesitate to send comments to the address tom.dedeurwaerdere@uclouvain.be.

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1 Introduction: accelerating social and ecological transition

Over the last half century, advances in science and technology, and growth in international trade have stimulated economic growth and improved living conditions of people around the globe. At the same time, the worrisome consequences of a development model based on ever more intense use of scarce natural resources have become more and more apparent. As shown for instance in 2009 in a seminal article in the journal *Nature*, major limits for remaining within a safe operating space on Earth have already been surpassed. This is the case for climate change, biodiversity extinction and the global nitrogen cycle (Rockström et al., 2009). Others, such as the access to fresh water or the availability of productive land, are reaching their limit. In turn, the surpassing of these limits is fuelling new conflicts over access to resources and exacerbates existing inequalities. As a result, the Earths' resources and the use of ecosystem's services are more and more unequally distributed.

In response to the persistent ecological and social crisis, social actors from business, civil society and policy have developed new strategies to operate within the Earth's limited resources and to mitigate the negative social impacts of environmental harm. Nevertheless, many of these strategies only focus on measures to attenuate specific negative environmental consequences, such as economic incentives for more sustainable product development or technological improvements in energy efficiency. What is missing are integrated approaches that address the need for society-wide transformations, while considering possible synergies and co-benefits with broader social demands for improved human well-being in basic spheres of human activity such as mobility, healthy nutrition, or meaningful work. As a result, even if sector-specific strategies are also part of the solution, in the end they only have a limited effect on overcoming the current crisis and fail to motivate large parts of the population to effectively embark on the proposed ecological and social transition pathways.

For instance, what are the benefits of a decarbonisation of mobility through a shift to electric cars, even with appropriate distributive measures for low-income groups, if overall car use continues to increase? What is the real benefit of this policy, if dependence on private car use further exacerbates the encroachment on public space and urban green in already densely occupied urban environments? Or what is the impact on biodiversity of the creation of protected areas in developed and emergent economies, if the latter massively import biomass for energy or livestock feed that put a high pressure on tropical rainforests and available land for local farmers? Similarly, what are the societal benefits of introducing new business model such as the circular economy or the sharing economy if these models fail to deliver quality jobs, in terms of social security and decent wages, or to respect basic privacy and consumer protection rights in the digital environment?

What these examples illustrate is that without addressing the interdependencies between environmental, economic and social demands for improvement in human well-being, there are few prospects for overcoming the current crisis. Contemporary sustainability research shows at least three reasons for this.

First, the ecological transition will require broad lifestyle changes, whether it be in food production and consumption, mobility or building. Change in behaviour in these sectors of activity is motivated by a broad variety of social and individual well-being dimensions, most of them unrelated to ecological issues. For instance, as shown by scholars of the slow food movement, food habits are in first instance related to social values such as family bonds, personal creativity and subsistence (Ehrenfeld, 2008).

The transformation of lifestyles will therefore also need to create, restore or at least preserve opportunities for satisfying these broader social demands.

Second, the transition needs to address the many distributional issues of access to well-being benefits from nature and ecosystem services. For instance, ecosystems provide many community-wide services and values, beyond their direct contribution to agricultural products, energy or carbon capture. These community-wide services can be related to use values such as water purification within a watershed and pollination services, or they can be related to non-use values such as cultural heritage. Therefore, different social groups are impacted in different ways when ecosystem services and values are under pressure, with important distributional consequences when implementing societal transition towards more sustainable use patterns (Spangenberg et la., 2014).

Third, as shown for instance by comparative research on large-scale sustainability transitions, the adoption of an integrated approach creates more enduring motivations for support by various social groups that are impacted by the transitions. Indeed, successfully addressing the broader social demands for social and individual well-being creates new opportunities for many actors, instead of only offering the perspective of mitigating the adverse social and ecological aspects of the current crisis (Du Plessis, 2012).

The move towards an operational framework for implementing an integrated approach of environmental, economic and social sustainability is at the heart of new policy frameworks that emerged over the last three decades. Most prominently, the United Nations General Assembly embarked, at the turn of the century, on a process to redefine its sustainability objectives. The global effort first started with the historic United Nations Millennium Declaration in 2000, with a strong focus on the lives of the world's poorest people, and gradually evolved into the 17 goals for sustainable development adopted by all United Nations Member States in 2015 to provide for a "shared blueprint for peace and prosperity for people and the planet, now and into the future" (UN, 2015).

The integrated framework aims to offer an answer to the current social and ecological crisis and provide a roadmap for knowledge mobilisation to accelerate the social and ecological transition. This urgently needed operationalisation of the concept of sustainable development does however raise new challenges for the role of science within society. Indeed, much contemporary science does not provide appropriate guidance to navigate the current crisis, as it is disciplinary in nature, highly specialized and conducted in isolation from societal debates over value related sustainability choices. As underlined by sustainability scholars, to understand integrated sustainability issues, and to design solutions, new modes of organizing research are needed that cross disciplinary boundaries, clarify the underling values-based choices, and mobilize both expertise from academic researchers and social actors engaged in transition pathways.

To introduce these new challenges, and the new practices of knowledge co-production in support of the social and ecological transition, this section first highlights the core ideas of the integrated approach to sustainability. Next it presents the new challenges for science and the opportunities offered by the emerging transdisciplinary science-society research partnerships.

1.1 Towards an integrated sustainability approach: the United Nations agenda 2030

Supported today by the work of the Division for Sustainable Development Goals of the United Nations, the sustainable development goals are a clear statement of the need to shift from the practice of sustainable development as growth within limits to a roadmap for action promoting synergies among environmental, economic and social sustainability outcomes (see figure 1.1). Although inevitably trade-offs and compromises will continue to exist, the overall goal is to promote activities where more synergies than trade-offs can be found, with the view to maintaining or restoring the Earths' basic life supporting processes and addressing key aspects of social and individual human development (Kroll et al., 2019).

For instance, one area with high potential for joined environmental and social benefits is the transformation of cities through shifting from private car mobility to public transport and prolific bicycle mobility and walking. This shift does not only leads to major health benefits, but also generates new possibilities for the creation of public spaces and urban greening (Kroll et al., 2019, p. 8). In addition, urban transition processes are also an opportunity to addressing nonquantifiable dimensions of human development such as culture or the creation social bonds (UCLG, 2018; Mackie et al., 2018).

Several multi-lateral international organisations established programmes of work for joint action on ecological and social sustainability. For example, the International Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), with 135 member countries and a secretariat supported by the United National Environment Program (UNEP), developed a guide for expert assessments of biodiversity and ecosystems services emphasizing the shift towards social sustainability dimensions of biodiversity policy. In particular, the guide goes beyond a vision of biodiversity as an environmental issue only. More specifically, it proposes to assesses the contribution of biodiversity to human well-being through assessing three interrelated components: the value of nature itself, nature's contribution to people and quality of life.

Social targets

SDG1 No poverty
SDG3 Good health and well-being
SDG4 Quality education
SDG5 Gender equality

Ecological targets

SDG 13 Climate action
SDG 14 Life below water
SDG 15 Life on land
SDG 16 Clean water and sanitation

Overarching justice and social inclusiveness goals

SDG 10 Reduced inequalities
SDG 16 Peace, justice and strong institutions
SDG 17 Partnerships for the goals

& Transforming society wide systems for reaching the social, ecological and inclusiveness goals

SDG 2, 7, 8, 9, 11 12 : food systems, cities, work, etc.

Figure 1.1. Sustainable Development Goals (SDGs) (classification based on the framework developed in UN2019b, p. 21-24) (source: SDG images from sdgs.un.org).

This renewed impetus, at the international level, for jointly addressing social and environmental sustainability goals inspired a wealth of new initiatives by governments, business and civil society throughout the world. Some well-known examples include positive energy regions or positive energy districts in cities and rural areas; combined interventions for sustainable forestry, sustainable farming, and purification of drinking water and air; or the formulation of healthy and planet friendly diets.

For example, in Austria, the Climate and Energy fund established 105 Climate and Energy Model Regions, based on the successful case of a seminal policy initiative in Murau (Späth, 2012). This Austrian alpine mountain district promoted action around a vision of a transition to zero fossil fuels in the district, while using this transition to save the region from economic decay through involving the population in new initiatives around sustainable mobility, housing and tourism.

Another interesting example is the city of Munich, which implemented nature-based solutions for purifying the cities' drinking water, while at the same time providing incentives for a transition to sustainable food and timber production in the surrounding countryside (Meiffren & Pointreau, 2009). In particular, the metropolitan region of Munich created in 1991 a 6000-ha protected land in the water catchment area for its drinking water, through converting 2250 ha of this land to organic farmland. In this context, the city provided technical and financial support to farmers that converted to organic production practices and mobilized all the actors of the food supply to market the new produce, among others through food delivery to the canteens of the municipal schools and nurseries. For the local authorities, the cost of these various programs still was substantially less then investing in new chemical water treatments plants.

As these and other examples show, producing joint environmental and social outcomes implies active investment in collective action across sectors of activity that are usually disjointed, even if long-term win-win outcomes can be expected. Therefore, producing synergies and co-benefits among sustainability goals involves negotiation of many trade-offs and active public policies for redistribution, the outcomes of which will need to be carefully assessed, as illustrated in table 1.1. In this context, several organisations are developing innovative tools to analyse the interlinkages, trade-offs, and synergies among the environmental and social sustainability goals. The positive message from these analyses is that in many areas the number of positive synergies exceed the number of negative trade-offs between the sustainable development dimensions. The more complete message is that in all areas negative trade-offs exist and only through appropriate design and implementation overall positive outcomes can be expected (Kroll et al., 2019).

Table 1.1. Co-benefits and trade-offs between Sustainable Development Goals: the example of energy efficiency policies for climate action (SDG13).

Accelerating energy efficiency and switch to low carbon energy (SDG13)		SDG1 No poverty	SDG3 Good health and well-being
	Industry (Efficiency of production processes)	Financial savings in industry leading to sustainable economic growth	More clean water (reduced energy demand reduces water use in energy production)

		Negative impact on workers in fossil fuel industry in the absence of policies for re-training of workers	
13 CLIMATE ACTION	**Building** (Isolation, low carbon heating systems, LED lighting, clean stoves)	Reduced energy bills through energy efficiency measures *Costs to the poor of new equipment, in the absence of social distributional measures*	Reduced asthma & allergies from indoor pollution through housing renovation
13 CLIMATE ACTION	**Transport** (Electrification, biofuels, infrastructure for cycling/walking, public transport)	*Costs, if electricity prices go up without social distributional measures*	Reducing ambient air pollution and increasing physical activity *Less clean water (if biofuels come from water-intensive feedstock)*

Legend: data in the table compiled from IPCC, 2018, pp. 481-483 (see IPCC, 2018 for the references to the supporting research); in green, co-benefits; in red, trade-offs to be removed.

The importance of considering both co-benefits and possible negative trade-offs when designing transition pathways can be illustrated by the detailed analysis of possible synergy with sustainability goal 13 (Climate Action) in the work of the Intergovernmental Panel on Climate change (IPCC). For instance, in the 2018 special report on global warming of 1.5°C, the authors analyse various actions to limit global warming to 1.5°C (IPCC, 2018). Pathways for limiting global warming to 1.5°C show robust positive synergies between SDG 3 (health), SDG 7 (energy) and SDG 12 (responsible consumption and production). However, if poorly implemented, so-called Carbon Dioxide Removal options (for instance through shift to bioenergy, carbon capture and storage technologies, or reforestation) could lead to negative trade-offs. Indeed, evidence indicates that these options may also impose significant constraints upon poor and vulnerable communities. Crops for bioenergy may increase irrigation needs and exacerbate water stress. Further, via increased food prices and competition for arable land, land appropriation and dispossession, the shift to bioenergy might have disproportionate negative impacts upon rural poor and indigenous populations (IPCC, 2018, p. 462).

Overall, the integrated perspective on sustainability contained in the Sustainable Development Goals, which defines the so-called Agenda 2030, offers a more credible and readily operational framework to address sustainability issues. The United Nations initiative provides a pilot example of a framework with true transformative potential, which has led to the further development of many variations of operational criteria and indicators ever since (see for instance, OECD, 2017). The latter is clearly endorsed by Gro Harlem Brundtland, former Prime Minister of Norway and the chairperson of the Commission that released in 1987 the so-called Brundtland report, which popularized the term sustainable development. In her foreword to the 2019 Global Sustainable Development report, she clearly states that "sustainable development is the only way that we can avert environmental and social disaster". According to Brundtland, "we will only secure a prosperous, peaceful and liveable planet if we harness economic growth and development to social solidarity across and between generations". For her, "the adoption of the Sustainable Development Goals in 2015 was a key moment in defining that agenda and building a consensus for urgent, inclusive action". According to her, "the true transformative potential of the 2030 Agenda can be realized through a systemic approach that helps identify and manage trade-offs while maximizing co-benefits among the various sustainability goals" (UN, 2019b, p. xvi).

1.2 Beyond disciplines: creating transdisciplinary science-society research partnerships

Achieving society-wide transition processes to bring about the expected synergies and co-benefits among the sustainability goals cannot be left to chance. The pursuit of far-reaching societal transformations requires deliberate planning, monitoring and interactive knowledge gathering in the implementation phases. In this context, the Global Sustainable Development Report underlines the role that science must play in providing the evidence to overcome the current social, economic and political impasses, and to enable creative and transformative solutions. As stated in the report, typically, researchers use transdisciplinary approaches, characterised by bringing together scientific, lay, practical and indigenous knowledge, as well as fundamentally different world views in a multi-dimensional and highly interactive research framework (UN, 2019b, p. 120).

The move towards mobilizing transdisciplinary partnership science in support of the sustainable development goals seems a promising way forward to overcome the failure of conventional disciplinary science to address the complexity and value-laden nature of integrated economic, environmental and social transformation pathways. Indeed, as also stated in the 2018 IPCC special report on global warming of 1.5°C, the inclusive and systemic approach to sustainability is an endeavour fraught with discussions over moral values and social norms. The approach entails deliberation and negotiation over goals and strategies, along with collaborative learning and information sharing in highly uncertain and adaptive implementation processes (IPCC, 2018, p. 459).

Scientists, for whom professional independence and rigour are defining principles, can be wary about such engagement which is necessary value-laden and must deal with inherent uncertainties of complex systems, which cannot be overcome through more experimentation or through gathering more scientific evidence. In some cases, the disciplinary and value neutral approach might still provide sufficiently good approximations. However, for most society-wide ecological and social transition processes this is not the case, and a mono-dimensional and expert-led problem framing has shown to present several shortcomings. For instance, as shown in various studies, the disciplinary and value neutral approach does not allow to identify the most desirable co-benefits and trade-offs among the sustainability dimensions, tends to crowd out more socially inclusive problem definitions, obscure contested values, and reinforce power asymmetries (Bosomworth et al., 2017; Lawrence & Haasnoot, 2017; Lin at al. 2017; Singh et al., 2017).

Scientists, often driven by pressure to produce quick results or to satisfy pre-defined research goals, may continue to rely on disciplinary framing and be very cautious about entering into partnerships with social actors. Some may avoid working with powerful State actors or corporations, while others may avoid engaging with the rich body of local knowledge because of misconceptions about its value in comparison with academic knowledge. However, as also clearly stated in the Global Sustainable Development Report, this need not – indeed must not – be the case. Scientific research on value-laden and highly uncertain problems can uphold both the highest standards of scientific rigour, and consider social norms and objectives, as well as people's and communities' aspirations and preferences. As the subsequent chapters will illustrate, there are many inspiring examples of scientific knowledge produced through integrated and partnership-based approaches that produce urgently needed and highly credible scientific evidence on drivers of sustainability transitions, the design of desirable and feasible future scenarios and the conditions for increasing societal systems' adaptive capacity for moving in the direction of desirable future states.

A highly relevant example of the productivity of a multi-dimensional and social partnership-based approach to research is the "one health" approach called for by the World Health Organisation (WHO) and actively promoted by many international initiatives (Woods & Bresalier, 2014; Schneider et al., 2019; IPBES, 2020). The aim of one health research is to prevent and mitigate diseases that originate at the interface between humans, animals, and ecosystems. One health research requires integrating knowledge from many stakeholders, such as herders, health officials, human and veterinary doctors, scientists, and others (Zinsstag et al., 2011).

A well-documented case in the field of transdisciplinary research is the successful one health research for supporting a vaccination campaign of nomadic pastoralists in Chad in the mid 1990ies (Bergmann et al., 2012, pp. 192-201). Through stakeholder workshops, the project team co-designed health surveys and ethnological research with the nomads, the traditional healers, the local health department and veterinarian services. By means of a set of repeated pilot projects in the community, the project led to design health service delivery services that were effectively used by the nomads. One example of the outcomes of the one health approach was the development of mobile health services that addressed both the health of the humans and the animals of the herds.

More recently, in the context of the 2019 COVID-19 outbreak, one health research is playing an increasingly important role to prevent future zoonotic diseases. In this context, anthropologists, epidemiologists, and veterinarians aim to contribute to future prevention and prediction of pandemics by collaborating with Indigenous Peoples and Local Communities living in remote regions, to learn about wildlife trade and the role of livestock as intermediary hosts of potentially zoonotic infectious diseases from wildlife (Kelly, 2017; Gaddy, 2020; Harrison et al., 2020; Aguirre et al., 2021).

As can be seen from the above, the integration of the environmental, economic and social dimensions of sustainability does not only require a multi-dimensional approach that transcends disciplinary boundaries but also a multi-actor partnership approach to scientific research. The latter is needed to assess the human well-being implications of the current ecological and social crisis, to help to shape desirable co-benefits among multiple sustainability goals and to understand context specific drivers to upscale the ongoing transformations.

In a report for the office of the Swiss Prime Minister, Peter Messerli and Sabin Bieri aptly summarize the new science and policy fields that result from combining the multi-dimensional integrated systems approach to sustainability and multi-actor partnership deliberation (Messerli & Bieri, 2018; UN, 2019b, p. 112). As shown in figure 1.2, which is inspired from their analysis, sustainability challenges produce problem situations that are both scientifically complex and socially complex. The origin of scientific complexity in sustainability research resides in the multi-dimensional characters of the problems, leading to demanding knowledge integration efforts amongst different perspectives and complex interaction patterns. The origin of social complexity resides in a high degree of heterogeneous social values that play a role in assessing the desirable social outcomes. Problems that are both scientifically and socially complex define three typical situations where transdisciplinary partnership research is especially useful, which are complex, complicated and wicked problem situations (see figure 1.2). These three situations open a new space for science-society knowledge co-production that is both distinct from the conventional disciplinary science – in the lower left quadrant – and the situation of "chaos" where there is no space for agreement or for overcoming ignorance – in the upper right quadrant.

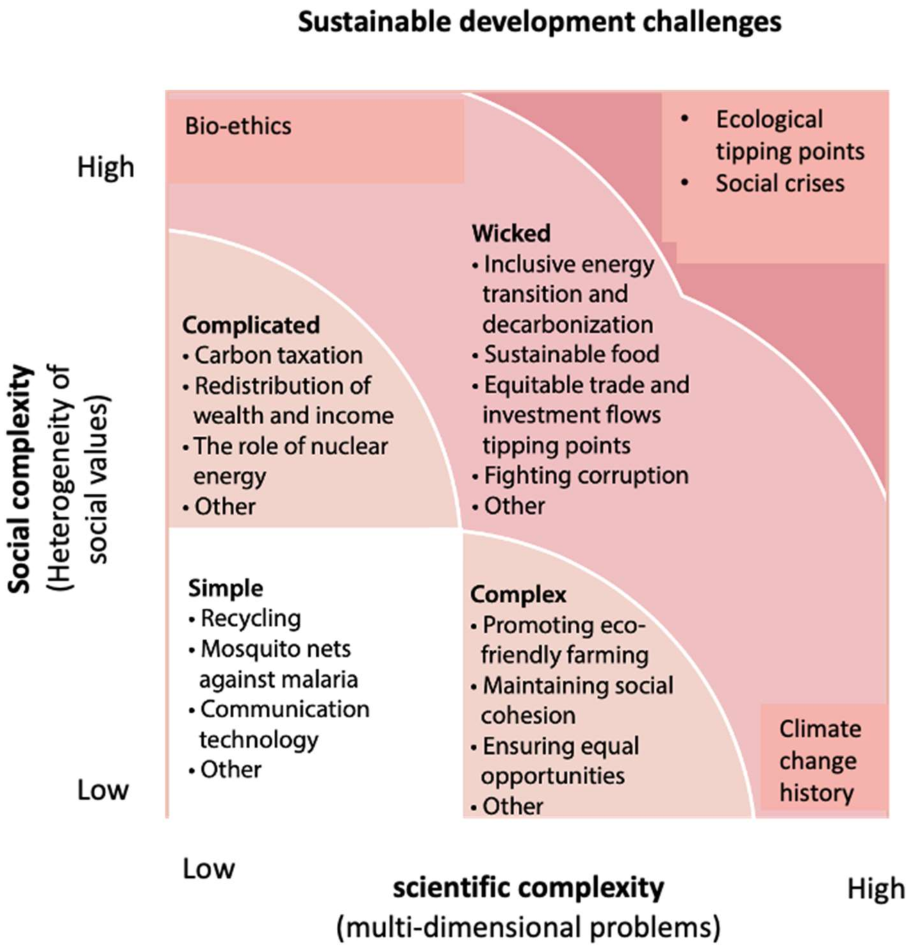

Figure 1.2. The scope of transdisciplinary research: complicated, wicked, and complex problems. (Source: figure by the author (adapted and modified from United Nations, 2019b, p. 112)).

In the original analysis by Messerli and Bieri, the authors strongly emphasized the possible sources of scientific uncertainty in sustainability research. In the broader context of the contribution of scientific research to social and ecological transition, such a focus might however be misleading. Indeed, such uncertainty is not specific to sustainability research, even though strong interdependencies amongst sustainability goals might lead to highly unpredictable problem situations. Moreover, when aiming at understanding the natural and social world, science probably provides the most certain source of knowledge we can reasonably obtain, within the limits of measurement error as defined within the scientific language and according to the standards of each research community in specific fields of inquiry (see Putnam, 1981).

The main specific source of scientific complexity for understanding society-wide transition processes concerns the need to mobilize scientific knowledge on very different problem dimensions and from very different problem perspectives. The latter requires to create a dialogue among different methodologies, types of evidence and vocabularies to frame a certain problem. Indeed, in integrated sustainability problems, even though we can have credible knowledge sources in sub-fields of specialisation and practice, multiple sources of knowledge need to be combined across language communities from different disciplines and across scientific and social actors' expertise. Depending on the problem at hand, the impact of this multi-dimensionality can range from "low" to "hight" (horizontal axis in the figure).

In practice this new space of multi-dimensional and partnership-based science continues to co-exist with the conventional disciplinary approaches. On the one hand, transdisciplinary partnership science is well positioned to provide knowledge on system-wide features such as the conditions for increasing the adaptive capacity of socio-ecological systems, the elaboration of plausible future scenarios or the evaluation of integrated sustainability policies. The conventional disciplinary approaches, on the other hand, are well positioned to understand the fine-grained mechanics of sub-components of the system, to produce predictions in laboratory conditions, or to improve the design of technical artefacts among others.

In sum, the multi-dimensional integrated approach to environmental, economic and social sustainability can be supported by these ongoing innovations in transdisciplinary partnership research. Indeed, to improve integrated sustainability, a new set of questions are raised that require understanding of system-wide properties such as the adaptive capacities of societal systems as a whole or the building of common frameworks to understand the links between the knowledge produced by very diverse social actors. Responding to this challenge, scholars from various fields have developed over the last decade innovative transdisciplinary research methods, whose goal is to embrace system-wide knowledge as a key for facilitating the governance of effective collaborations beyond disciplinary, sectoral, and societal boundaries (Pohl & Hirsch Hadorn, 2007; Bergmann et al., 2012; Seidl et al., 2013; Scholz & Steiner, 2015).

Transdisciplinary approaches in science mobilize various sources of knowledge, including disciplinary expertise and technical know-how from practitioners, but within a framework that addresses system-wide questions that disciplinary and technical approaches cannot address. These approaches have in common that they focus on knowledge co-production among scientists and non-academic stakeholders from business, government, and the civil society. In this context, the scientists need to become a partner in the ongoing social learning processes in given societal transition pathways, which involves a collaborative process of mutual learning on societal values and active sharing of information on unforeseen and unpredictable complex systems outcomes.

Over the last three decades, a large body of transdisciplinary research projects has been generated to provide scientific knowledge to support these transition processes. In this context, a vast literature on community-based, interactive, and participatory scientific research approaches, as well as new insights on the conditions for mutual understanding and collaborative learning in partnership research have been generated from transdisciplinary research projects. The next chapters will address these various methods and insights in more depth, with a specific focus on the way that these efforts contribute to advancing our understanding of social and ecological transition. However, before exploring this new terrain in more depth, a better understanding of the integrated perspective on sustainability that motivates the move towards transdisciplinary sustainability research is warranted. The next chapter therefore first reviews the interrelated social, economic and environmental sustainability issues that need to be addressed in key society-wide transition pathways. Further, this chapter will illustrate how co-benefits and synergies among sustainability goals can be envisioned in various specific contexts of social and ecological transition.

2 The research challenge: transforming society-wide sectors of activity

The Sustainable Development Goals are one among a series of new approaches that better integrate the environmental, social, economic and institutional dimensions of sustainability. United Nations member countries widely adopted the framework and elaborated national level indicators for monitoring progress. Although necessary evolving and incomplete, they nevertheless show the way forward to overcome a narrowly unidimensional environmental or technical approach to the urgent actions to be taken to overcome the current ecological and social crisis.

As reminded in the 2019 Global Sustainability report and illustrated in figure 2.2 below, the Goals are characterized by three core elements (UN, 2019b, p. 21):

1) balancing the economic, environmental and social dimensions of sustainable development,
2) leaving no one behind, and
3) ensuring the basic requirements for the well-being of future generations.

However, based on the latest data, all those elements are at risk of not being realized. Indeed, despite hopeful progress on important targets such as reducing child mortality and full enrolment in primary schools, and positive trends in progress on child malnutrition and social protection among other, at the current rate of progress many goals are unlikely to be attained by 2030. More worrisome, however, are a set of targets for which recent trends are not even in the right direction but that are of particular importance, as they make it also harder to reach other goals and targets. Four long-term negative trends, more specifically, fall in that category: rising social inequalities, climate change, biodiversity loss and the increasing amount of waste from human activity. Critically, recent analysis suggests that some trends presage a move towards crossing negative tipping points, which would lead to dramatic and difficult to reverse changes on time scales meaningful for society.

First in line of these worrying trends is the global rise in inequality. Although the rise in private wealth of the top 1% incomes remains below the levels reached in the early 20th century, the rise in wealth inequality has nonetheless been very large in the United States to levels unseen since 1940, with a rise of the top 1% wealth from owning 22% of all the private wealth in 1980 to 39% in 2014. The increase in top-wealth shares was also real but more moderate in countries like France or the UK, in part due to the dampening effect of the rising housing wealth of the middle class and a lower level of income inequality than in the United States (Alvaredo, 2018, p. 12).

Overall, nevertheless, inequality has been rising, even though at a different speed across countries. As illustrated in figure 2.1, in Europe on average the top 10% earners received 37% of the national income in 2016, as compared to 32% in the 1980; in China 41% in 2016, compared to 28% in 1980; and in the US 47% of the national income, compared to 34% in 1980 (Alvarerdo, 2018, p. 6). The dramatic rise in the United States is largely due to massive educational inequalities and a tax system that grew less progressive. From a broad historical perspective, this increase in inequality marks the end of a post second world war more egalitarian regime.

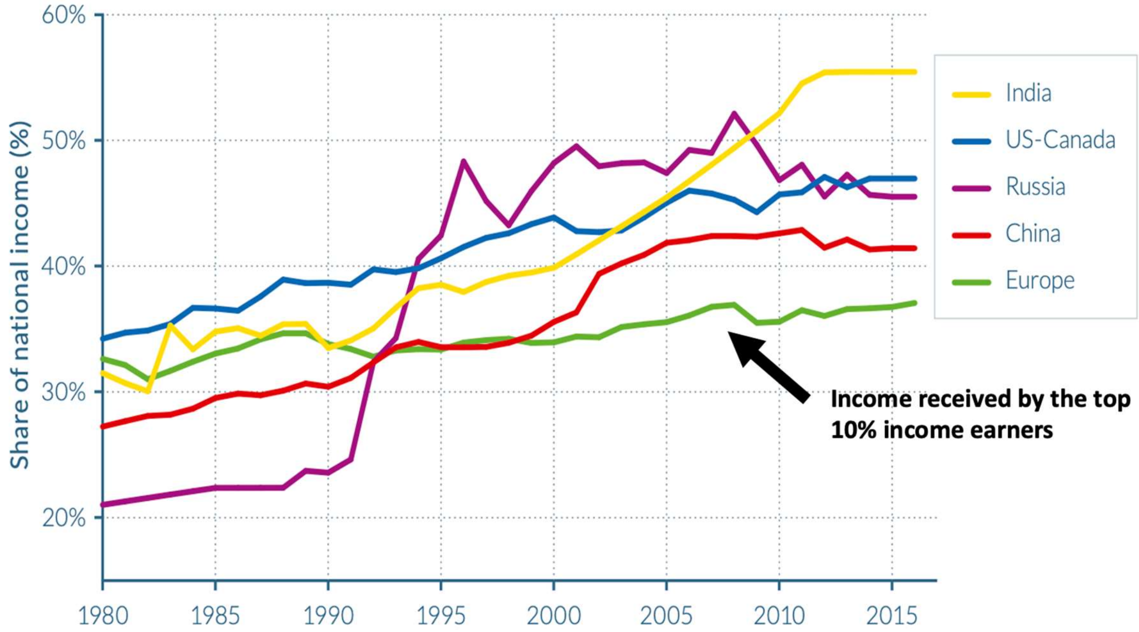

Figure 2.1. Top 10% income shares across the world, 1980-2016. Rising inequality almost everywhere but at different speeds. For example: in 2016, 47% of national income was received by the top 10% in US-Canada, compared to 34% in 1980 (Source: Alvaredo et al., 2018, p. 24)

The first major consequence of this trend are the very large transfers of public to private wealth in nearly all countries. While combined public and private national wealth has substantially increased, public wealth is now negative or close to zero in rich countries, in part due to rising public depth. This arguably limits government ability to regulate the economy, redistribute income and mitigate rising inequality through promoting access to higher education and skilled labour.

Greater inequality also directly impacts the scope of action for combatting the major environmental crises (UN, 2019b, p. 17) or global pandemics such as the COVID-19 outbreak. Those at the upper end of the income distribution may be able to shift the environmental costs of their lifestyles and consumption decisions to those at the lower end. Such shifts occur at the global scale in the case of climate change: the top 10% of emitters contribute to about 45% of global CO2 emissions, while the bottom 50% emitters contribute to 13% of the global emissions. Top 10% emitters live on all contents, with one third of them from emerging countries (Chancel & Piketty, 2015). Similar unequal patterns are also apparent at national and subnational levels, which is to a large extent related to higher average individual CO2 emission from transport, energy use and consumption level by higher income categories (Chancel & Piketty, 2015, p. 21).

This so-called "burden shifting" is also a major driver of biodiversity decline. In his book "Just Conservation", Adrian Martin provides a wealth of evidence of what he calls the unequal ecological exchange: in many countries, those who consume the most of a resource can be the one who suffer the less from its exploitation (Martin, 2017, p. 84). This is especially the case for high income countries that actively invest in protecting their remaining natural resources. Forests are a clear example of this, with many higher income countries being major consumers of both hardwood and soft-wood timbers from developing countries, while at the same time protecting and increasing the area of their domestic woodlands. Threatened species are another example: some of the countries who place the most pressure on biodiversity by importing products that require land-use that destroys the habitat of endangered species suffer the fewest threats to domestic biodiversity. For instance, as a detailed analysis of threats to the 25.000 threatened species of the IUCN red list shows, the USA, Japan, and Europe are world-wide the main importers of biodiversity threatening products, while achieving a high level of protection of biodiversity domestically (Lenzen et al., 2012).

Further, ecological inequalities also further aggravate the social inequalities. For instance, those at the bottom of the income distribution are also more at risk of facing the consequences of degraded environments, extreme weather events due to climate change and biodiversity loss. The 2019 Global Environmental Outlook noted that the livelihoods of more than 70 per cent of the world's poor are natural resources based (UN, 2019a), with for instance 350 million people living in forests, including 60 million indigenous people (Reid et al., 2005). Similarly, high income countries shift the burden of toxic chemicals and waste from consumption products to poorer communities at home (Bullard & Wright, 1990; Vornovytsky & Boyce, 2010) or to low- and middle-income countries (Bernhardt, 2016), often with major health consequences due to pollution exposure (Chatham-Stephens et al., 2013).

As will be illustrated in the various case studies in this chapter, tackling the increasing income and wealth inequality requires simultaneous action on several interrelated sustainability goals. Research consistently shows that public investments in basic education and access to health services are essential, along with mechanisms that ensure that people at the bottom of the income distribution have access to well-paying jobs (Alvaredo, 2018, p. 15). In addition, research has shown that tax progressivity is a highly effective tool to combat inequality. Tax progressivity is also a major condition of success of effective environmental taxation measures, as shown by successful examples in the Nordic countries (Hammar et al., 2013; Roth & Laan, 2020). Overall, meta-analyses of the interactions among the sustainability goals show a robust positive impact of combined actions on education, health, and quality jobs, leading to progress in most of the other goals (Kroll et al., 2019).

Reversing the trend of growing social inequalities is made more complex by the large-scale social transformations required to reverse the three other persistent negative trends identified in the 2019 Global Sustainable Development Report, which are the increase in greenhouse gas emissions, biodiversity decline and rising waste production. For instance, even a temperature rise limited to 1,5°C above pre-industrial levels could put pressure on people exposed to heat waves, create coastal flooding and reduce agriculture yields in many areas of the world. Nevertheless, based on current policies and pledges under the Paris Agreement, human-caused global warming is estimated to exceed 1,5°C above pre-industrial levels by the end of this century (IPCC, 2018, p. 95). Further, globally pollinators of 75% of the crops are being threatened and local varieties and breeds of domesticated plants and animals are disappearing, which poses a serious risk to global food security (Potts et al., 2016). In 2016, around 60 per cent of electronic waste ended up in landfills, where elements like mercury and lead can leak into soil and groundwater (Baldé et al., 2017). In 2010 alone, 8 million tons of plastic were dumped into the ocean, with major economic impacts on the fishing and the shipping industry (Geyer et al., 2017).

As can be seen from this brief overview of some of the well-known features of the current social and ecological crises, any progress on the sustainability goals will require to address multiple goals at once and organize society-wide changes in areas of food, transport and consumption practices among others. Narrow sectoral approaches seem more manageable and do play a role in preventing damage in the short term. However, they are only likely to deliver real benefits if they are embedded in an integrated approaches that provides guidance for system wide changes. Such integrated approaches will require to mobilize the knowledge and social innovations of citizens, social actors, policy makers and researchers in new kinds of science-society research partnerships. As this book aims to show, innovative science-society research partnerships are the basis to provide evidence-based insights on plausible and desirable futures and to improve the adaptive capacities of societies to reach the desired end-goals.

This chapter introduces the integrated problem framing that motivates the design of the science-society partnerships discussed in the sub-sequent chapers of the book. To this purpose, the chapter is structured along the main society-wide sectors of activity that are the backbone, or the so-called "entry points", of the knowledge-based transformations framework of the 2019 Global Sustainability Report. This framework is illustrated in figure 2.2., which is a stylized summary of the more complete approach presented in the report (UN, 2019b, p. 24). The strength of this framework is to consider the transformation of life-supporting sectors of activity in the context of a safe and just planetary operating space, and a set of overarching social justice goals. The upper part of figure 2.2 shows the safe and just space, with the ecological targets to the right (the so-called "nature" goals) and the basic human well-being and capability targets to the left (the so-called "people" goals). The lower part adds the overarching social justice goals: peace, justice, and strong institutions (Sustainable Development Goal 16), reduced inequalities (SDG 10) and partnerships for the goals (SDG 17).

Finally, the middle part of the figure adds the transformation of various basic life-supporting activities, which contribute to human sustainability objectives on their own but at the same time need to be connected to the people, nature and overarching social justice goals. The life-supporting activities that will be analysed in more depth are: (1) agriculture and food, (2) mobility and housing, (3) production and consumption of manufactured goods, (4) meaningful and decent work, and (5) energy production and consumption.

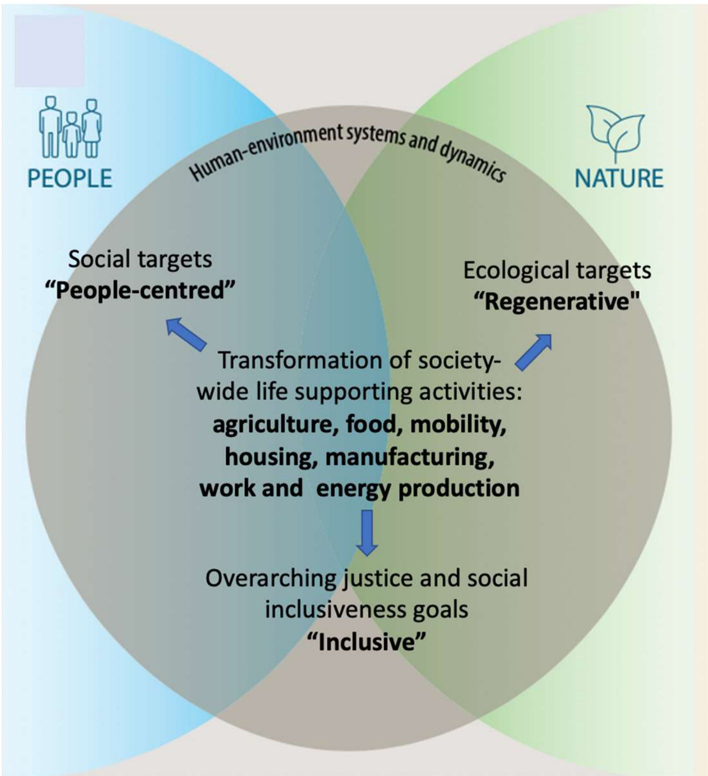

Figure 2.2. Society-wide transformations at the cross-roads of sustainability objectives.

- Regenerative human development designates development within the planetary limits/boundaries, now and for future generations.
- The social targets are the basic human well-being and capabilities.
- The overarching social justice goals reflect the “leaving no one behind” objective of the UN sustainable development framework

For the list of sustainable development goals corresponding to each of these three aspects, see figure 1.1 (source: figure by the author; source of the two background logos “nature” and “people”, UN 2019b, p. 24., Box 1-8).

Each of these society-wide transformations are characterized by various degrees of scientific and social complexity. Innovative science partnership and highly participative research methods will be needed to gain a better understanding of the various drivers of change in these complex systems and of the system-wide features that foster societal transformation. These partnerships and methods are the subject of chapters 3 and 4. As announced, this chapter first introduces the multi-dimensional and integrated approach to sustainability transitions and highlights some of the challenges for understanding opportunities and pathways of change in highly pluralistic and heterogeneous multi-actor processes.

2.1 Agriculture and food

Food and agricultural systems play a key role in many important features of sustainable human development. Agricultural production systems are not only at the basis of the food chains but also provide important services such as the management of agroecological landscapes, energy provision, on-farm food processing and recreation, and are related to local cultural identities. Food systems, in addition to providing nutrition and generating employment through the food supply chain, potentially contribute to a diversity of key human values such as cultivating family and community bonds around shared meals and creating opportunities for personal creativity.

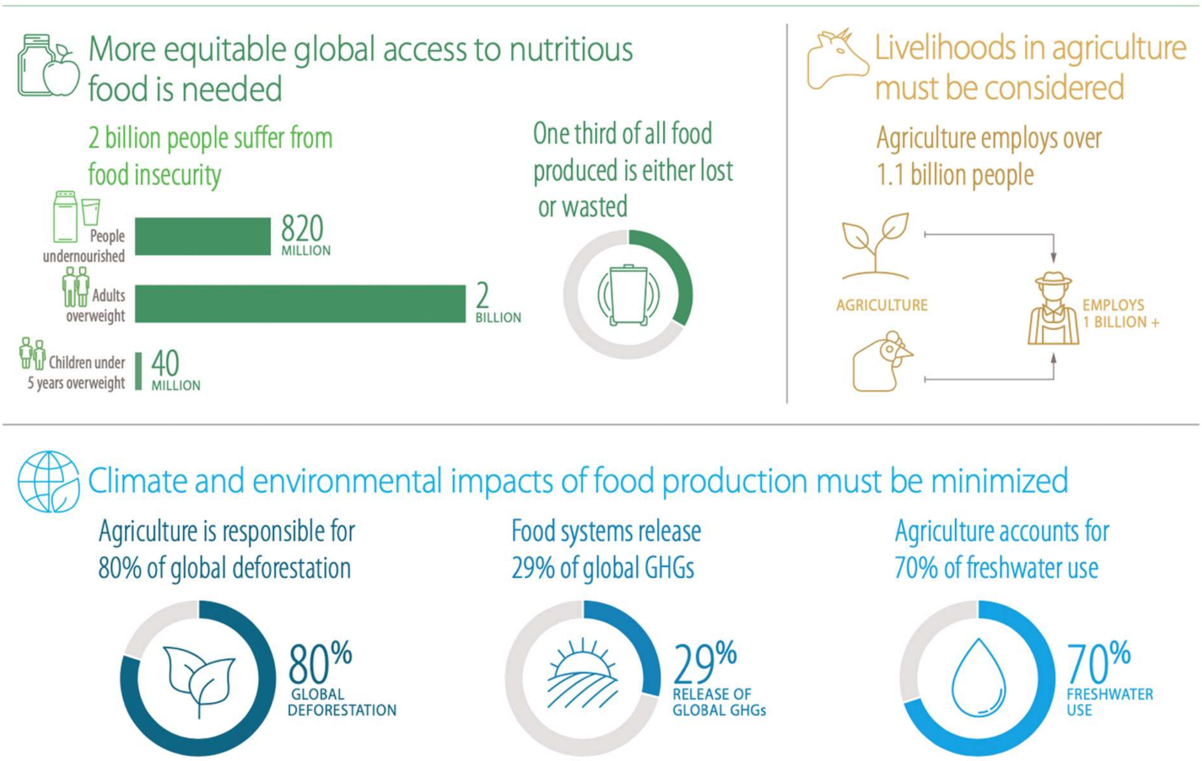

Figure 2.3. Stylised facts of the sustainability impact of agriculture and food systems (source: UN, 2019b. p65).

At the same time food and agricultural systems have become increasingly interconnected with some of the grand challenges of the current social and ecological crisis, with multiple ramifications into environmental and global justice issues. Because these challenges are so highly interconnected with the other sustainable development goals, UN Secretary-General Antonio Guterres has declared in October 2019, when announcing the preparation of the 2021 Food Systems Summit, that "Transforming food systems is crucial for delivering all the Sustainable Development Goals". Figure 2.3 illustrates that food and agricultural systems play a crucial role in some of the grand challenges of today. As can be seen from the various challenges, the current food and agricultural system act as an important barrier to improve upon various sustainable goals, mainly related to health, environment, and employment.

Available scientific evidence can help to identify entry point to address these challenges. The non-profit "EAT Global Science Forum", created by the Stockholm Resilience Centre, the UK Wellcome Trust and the Stordaelen Foundation, teamed up with the renowned British medical journal "The Lancet" to summarize the key actions points for a healthy diet within sustainable food systems. As in similar science-based efforts, the experts identify three major areas of action, with have a high impact on environmental sustainability, while contributing to improving human health: (1) change in diets, (2) improving the sustainability of agricultural production practices and (3) reducing food waste (Willett et al., 2019).

The dietary advice and the proposed changes in production practices are an important entry point to food system transformation, especially as it provides a baseline for formulating the key policy targets. However, this expert-based science advice, even from the leading sustainability scholars that were mobilized to form the EAT-Lancet commission, is unlikely to be able to address the many context-specific interactions among the sustainability goals that characterize the food system transformation. In addition, the many social and cultural values involved in food consumption practices, and the overcoming of vast inequalities in access to diversified nutrition, raise important value related challenges that go beyond the sectoral fixes of dietary habits and technical production choices.

As underlined in the lively international debate on food transitions, managing the many trade-offs and generating co-benefits among the sustainable development goals requires an integrated approach to system wide transformations, which addresses the need to create highly adaptive and context specific transformation pathways (Parsons & Hawkes, 2018, Nordic Council of Ministers, 2020). For instance, the report on the "Affordability of the EAT-Lancet reference diet" underscores that achieving a nutritious, environmentally sustainable diet will require to address society-wide issues, such as the way the food supply chains operate and how much people are paid for their work (Hirvonen et al., 2020). Moreover, in relation to dietary choices, there is strong evidence that specific food environments – which are those places where we make decisions about food, such as supermarkets or collective meal contexts on the workplace or at school – are critical to shaping our food choices (Swinburn, 2013; Graça, 2019).

An interesting example of integrating multiple sustainable development goals in transition pathways is the transition to organic agriculture organized by the city of Munich, already discussed in the introduction (Meiffren & Pointreau, 2009). Confronted with every higher cost of water sanitation, the city chose for investing in protecting forest and agricultural land in the region of the Mangfall valley, where most of the city water comes from. As explained above, this strategy implied the creation of a protected zone of 6000 hectares, including 2250 hectares of agricultural land that needed to be converted to organic agriculture. This conversion to more environmentally practices was not limited to a focus on the farmers' production methods but included intervention in all levels of the commercialisation chain of the organic products, from retail to marketing. Amongst others the municipality organized supply to nurseries and canteens, and awareness raising for sustainable food production through a partnership with organic producers' associations.

A second successful example, further down the chain, is the well-documented historical case of the food transition in North Karelia, Finland (Puska et al., 2009). In the early 1970ies, North Karelia was one of the poorest regions in Finland and confronted to the highest known level of hart diseases in the industrialized world, mainly due to the high intake of animal fats in the local diet. In collaboration with local associations, the government has set up a community intervention program that combined ex-ante and ex-post surveys, media campaigns, leadership training, and initiatives by retailors and school canteens that has led to a successful shift to more health diets, as illustrated in figure 2.4.

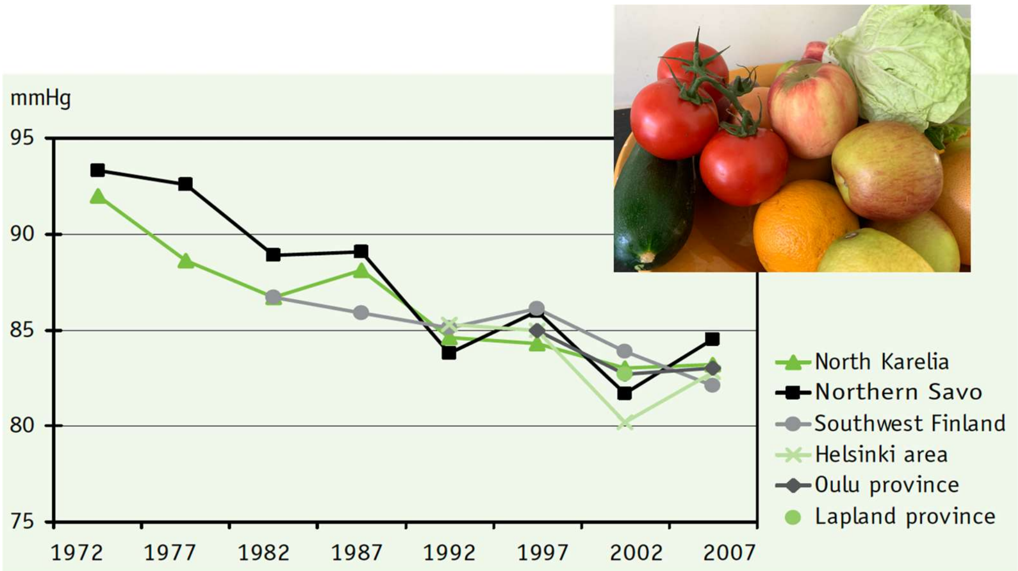

Figure 2.4. Example of achievements in the North Karelia project (Finland). Evolution of blood pressure (diastolic) in men aged 30-59 years in North Karelia, showing one of the highest heart disease rates in the industrial world in the early 1970ies. According to NIH (UK), high blood pressure (diastolic) is 90mmHg or higher (www.nhs.uk) (source: graph from Puska et al., 2009, photo by the author).

Scientists alone cannot identify the most effective and socially desirable entry points to tackle these multi-dimensional challenges. Indeed, the place to intervene in a food system may vary from context to context. Moreover, addressing the multiple challenges in an integrated manner is likely to lead to multiple co-existing food futures. Therefore, seen these plural pathways, transition models will need to integrate the perspectives of various social groups on the desirable outcomes.

To identify useful entry points for strategic action governments at local, national, and supra-national level have organized so-called future scenario and future visioning workshops. These transdisciplinary research workshops combine the best available scientific evidence on the challenges, with stakeholder knowledge on context specific opportunities and constraints (see also table 3.12 and accompanying discussion below). The resulting strategies do not offer universal or ready to use blueprints for action. Nevertheless, they capture the type of co-benefits that can be generated and trade-offs that can be managed in integrated transition pathways in specific contexts. As such, they offer an initial understanding of important connections and interactions between parts of food systems and how these systemic relations can be used to foster change.

Table 2.1 illustrates some of the co-benefits and trade-offs of different integrated transition pathways co-constructed by scientists and stakeholders in such large-scale future visioning processes in the Scandinavian or so-called Nordic countries. The table provides a snapshot of a set of co-benefits and trade-offs, developed in the context of developed economies and at national scale. Similar processes have been organized both in developing, emergent and other developed economies at local, national, and supra-national scale.

Table 2.1. Multi-dimensional food transition pathways in the Scandinavian countries

Identified places to intervene in the system	Co-benefits	Examples
Thriving countryside with local food networks and agro-ecological tourism	• Community building • Social bonds • Decent work	Iceland increase in rural population (1)
Lower saturated fat intake (replacing animal fats by nuts, olive oil for instance) **and more leguminous crops** in the diet	• Health • Environment	WHO 2018 healthy diet guidelines (2)
Promoting typical recipes with sustainably sourced products in the **food culture**	• Community building • Social bonds	Village cooking workshops, Nordic chefs (3)
New **business opportunities** around plant based and sustainably produced food	• Decent work • Competitive export markets	Nordic food lab (4)

Combining interventions in integrated food transition pathways

SDG INTERACTIONS (Co-benefits and Trade-offs) addressed

Legend. Generating multiple co-benefits and transforming trade-offs in integrated food transition pathways. Data compiled from reports from transdisciplinary partnership research in future visioning workshops (Nordic Council of Ministers, 2020; Wood et al., 2020). Some of the co-benefits also require transforming trade-offs, such as through support to transition from old to new business opportunities or helping groups with less skills to transition to new diets. References to the table (1) Iceland magazine, 2018; (2) WHO, 2018; (3) Nordic Council of Ministers, 2008 (4) Frøst, 2019.

The transformation of food systems further potentially has major positive implications for rural landscapes. As seen in integrated scenario planning and multi-stakeholder visioning of future sustainable pathways, co-benefits can be generated between various sustainable development goals in these landscapes. Although each pathway is highly context specific, common strategies in this perspective are the strengthening of rural identities and rural economies around local and sustainable food cultures, transforming diets, supporting low-income groups through training and capacity building, and regeneration of ecosystem services involved in life supporting processes such as water purification and pollination.

This kind of transdisciplinary agenda setting exercise is an important first step towards an integrated and collaborative approach of transition pathways. The specific methodologies of these scenario and visioning tools will be discussed in more details in chapter 3, along with a set of other science-society partnership research methods related to adaptive modelling, social and technological innovation, and policy evaluation among others. At the present stage, the discussion of the integrated approach to the social, environmental and economic sustainability transitions in food and agriculture systems aimed to highlight the following features:

1) Managing the many trade-offs and generating co-benefits among the sustainable development goals requires an integrated approach to system wide transformations, beyond sectoral fixes of dietary habits of consumers and technical production choices in agriculture.

2) The framing of transition pathways with multiple and value laden dimensions cannot be done in a scientifically sound way by relying on scientific evidence alone. Instead, processes for integrating available scientific knowledge, and knowledge from social actors on opportunities and constraints are needed to identify the most relevant problem dimensions and opportunities for change in the specific context.

2.2 Mobility and housing

The second society-wide transformation related to basic human needs concerns the improvement of means of transport and housing. Transforming these two sectors has direct major impacts on nearly all human well-being and planetary sustainability goals, especially seen the potential for transforming contemporary urban and peri-urban living environments. The many positive aspects of urban life, such as employment, opportunities for education and access to health care encourage rural to urban migration and urban sprawl (Bai et al., 2012). Cities are also home to leading businesses, cultural activities and civic institutions (Pineo and Rydin, 2018). Through good planning and design, city residents can also have access to public transport; urban green in parks, squares, and boulevard; and infrastructure for providing houses with energy, water, and wastewater treatment.

This concentration of opportunity and services can be very beneficial for the inhabitants' well-being. Yet, for centuries, the dense living and working conditions of cities also has many adverse impacts. Cities throughout the world are struggling with problems of air pollution, congested traffic, waste management and low-quality housing in poorer neighbourhoods.

The data compiled in the 2019 Global Sustainable Development Report shows the scale of the challenge. As can be seen in figure 2.5, urban and peri-urban development has far-reaching impacts on carbon emissions, land use, and use of materials and energy. For instance, in 2019 cities were responsible for 75% of all carbon emissions and 66% of energy use, a large part coming from transportation needs and heating of houses in peri-urban areas (Jones and Kammen, 2014). If development continues in the business-as-usual scenario, by 2050 the cities of the world will consume 90 billion ton of raw material, such as sand, gravel, iron, ore, coal and wood, mainly for further expanding the built environment of houses, offices and infrastructure (UN, 2018). And while cities cover only 2 per cent of the Earth's surface, they use much wider areas of land for satisfying their needs. For instance, the area covered by the water needs of cities, including drinking water and water for irrigation in food production, accounts for 41 per cent of the Earth's terrestrial surface (UN, 2015).

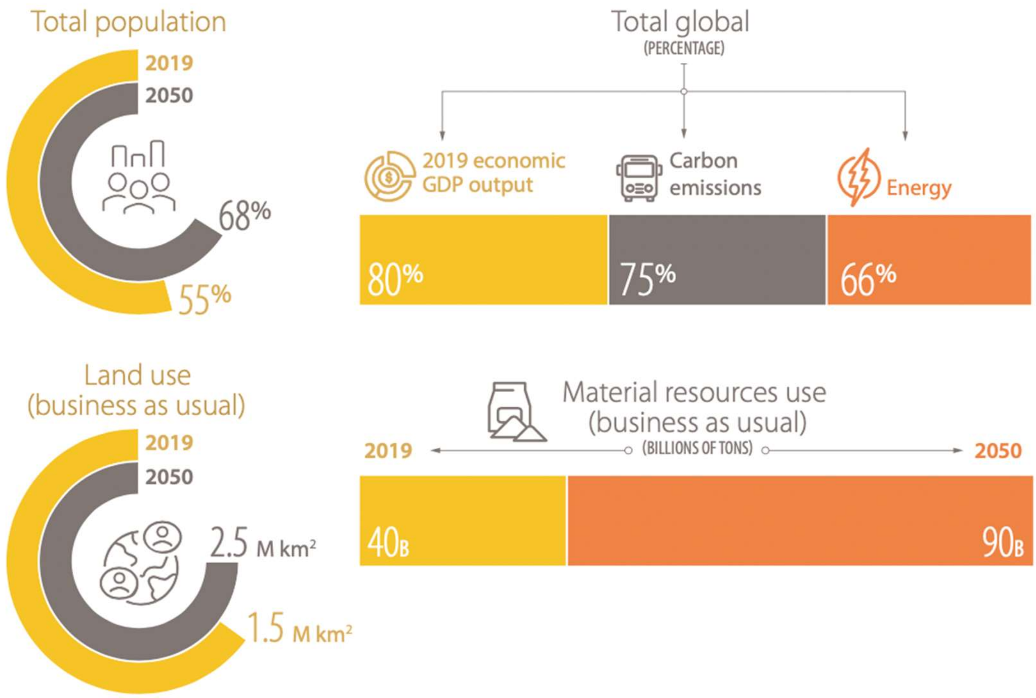

Figure 2.5. Stylised facts of the sustainability impact of cities (source: Un, 2019b. Page 84)

The difficulties in solving these environmental issues of city life are further amplified by the consequence of the growing inequalities world-wide. There is often a wide income difference between the well-off and the urban poor, which provide low-cost services for maintaining the basic city' services. These vulnerable and poor people often live in areas with inadequate infrastructure and poor housing, face difficulties to access public transport and public services, and are exposed to high levels of pollution and urban heat stress (UN, 2019b, p. 85).

A critical means of decoupling urban growth from increased environmental degradation, while contributing to improved social equity, is the development of an advanced public transport system and attractive active mobility through walking and biking, as illustrated in figure 2.6 (UN, 2019b, p. 91). Private cars are responsible for 60 per cent of transport-related emissions and an important source of pollution and traffic fatalities. However, despite the accumulation of scientific reports on sustainable mobility, urban planners and social actors still implement or support counter-effective measures, such as the increase in road capacity in peri-urban areas and the development of employment intensive workplaces in the periphery of cities, despite the availability of better-connected workplaces in more centrally located areas (Tennøy et al., 2016). Another well-documented ineffective policy is the development of bicycle paths without integrating this infrastructure policy in a broader active mobility policy including bike parking, calming of car traffic and neighbourhood safety (see Pucher & Buehler, 2008; see the "Future Street" project discussed in section 3.2.2).

As highlighted by a study of the relationships of transportation planners to scientific expertise in three Scandinavian cities, when the researchers fail to be involved with the communities of practice, planners turn to what others have done before them when confronted with scientific uncertainties or are more likely to be influenced by lobbying. In contrast, a context specific and pluralistic approach requires a more adaptive and interactive planning policy informed by real-world opportunities and constraints in the specific planning context (Tennøy et al., 2016, p. 28).

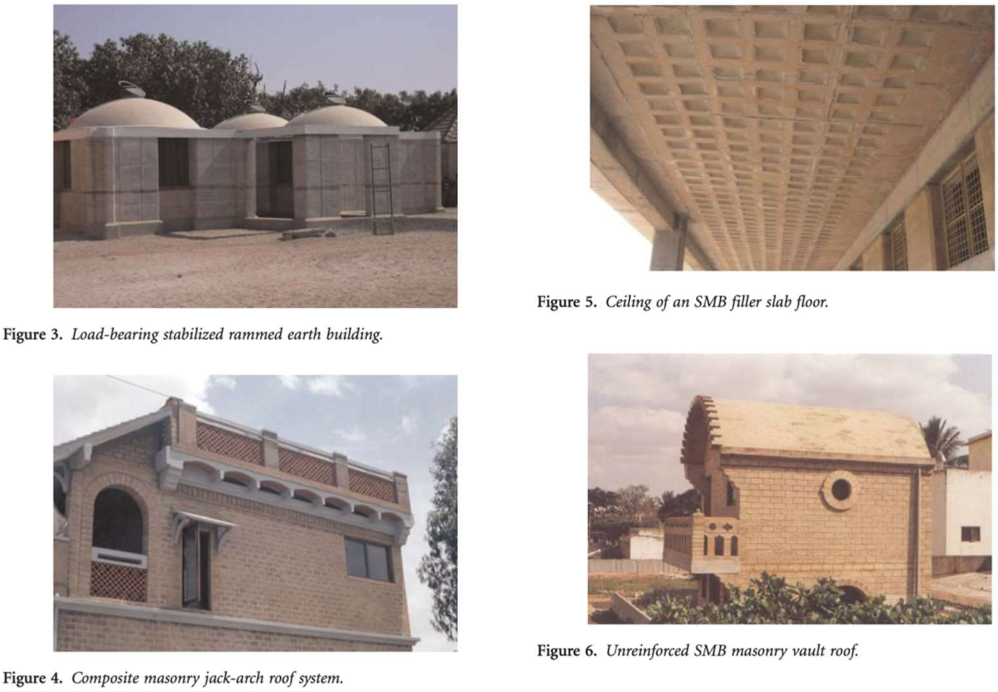

Figure 3. *Load-bearing stabilized rammed earth building.*

Figure 5. *Ceiling of an SMB filler slab floor.*

Figure 4. *Composite masonry jack-arch roof system.*

Figure 6. *Unreinforced SMB masonry vault roof.*

Figure 2.7. Building with rammed earth and stabilized mud blocks (source: Venkatarama, 2009, p. 178)

The built infrastructure in cities is a second area with major impacts on urban sustainable development. In the developed countries, there is an urgent need to renovate the existing housing stock, especially for improving heating efficiency, while shifting to materials with lower CO2 footprint, such as plant-based insulation material and roundwood (see figure 2.7). In the developing and emerging countries, there are huge opportunities to expand the use of low-energy materials that have been historically used and improved such as rammed earth or stabilized mud blocks (Venkatarama, 2009, p. 177). Nevertheless, as in the case of transport planning, such improvements are only likely to be successful in the long run if these advances are integrated in a holistic development approach that also addresses community building, overall settling planning and poverty reduction. For instance, in the case of the upgrading of informal urban settlements, financial considerations often predominate over the social aspects, leading to wrong assessment of changing needs in terms of family sizes and infrastructure services (Marais & Ntema, 2013, p. 92).

Despite the promising trends illustrated in the case of city transport and built infrastructure, the main trends however are still massively towards increased use of private cars, continuing urban sprawl, higher levels of urban pollution and resource intensive city development. Unidimensional technical fixes such as fuel efficiency of cars or energy renovation of houses are an essential step forward, but many of the benefits are eroded through the lack of integration with the other dimensions.

As seen above, to further disseminate the best practices of multi-dimensional sustainable urban development, a much deeper knowledge integration will be needed between social actors, urban planners and scientists. A good example of a transdisciplinary research effort in that direction is the Mobiles Baden-Württemberg project, which provided an integrated sustainability assessment of three mobility transition scenarios in the German region of Baden-Württemberg, which is home to major car companies such as Mercedes-Benz and Porsche (Blanck et al., 2017). Regional stakeholders from business, civil society and local government, along with academic scientists and mobility experts, were involved in all the steps of the future visioning exercise, from scenario selection to data gathering, identification of interventions in the system and implementation planning. As illustrated in table 2.2, the "new mobility culture" scenario, which had the best sustainability outcome, links the mobility transformation to co-benefits in the creation of public spaces, improved mobility connections for poorer neighbourhoods and civic participation, while addressing trade-offs with job losses in fossil fuel driven mobility sectors.

Table 2.2. Multi-dimensional mobility transition pathway in Baden-Württemberg

Identified places to intervene in the system	Co-benefits	Examples
Quality of public space (traffic calming, street as public space)	• Community building • Social bonds	Sustainable Streets Plan, New York (3)
Coherent network of intermodality (walking, biking, public transport, car)	• Health • Environment • Addressing inequalities	Nørrebro Green Cycleroute in Copenhagen (2)
Promoting **participation** of biking/walking associations in governance	• Democratic governance	Membership of the Danish Cycling Federation in various governance (1)
New **job opportunities** (renewable energy infrastructure for electric mobility, tourism in car-free city centers)	• Decent work • Competitive export markets	Jobs in renewable energy infrastructure in Germany (4)

Combining interventions in integrated mobility transition pathways

SDG INTERACTIONS (Co-benefits and Trade-offs) addressed

Legend. The 'New mobility culture scenario" co-constructed by scientists and stakeholders for the specific contexts of the region of Baden-Württemberg. The pathway addresses sustainable mobility, while generating multiple co-benefits and addressing important trade-offs. Data in the two first columns compiled from Blanck et al., 2017. References to the table: (1) Levels, 2019; (2) City of Copenhagen, 2017, p. 28; (3) Pineda & Vogel, 2014; Bondam, 2019 (4) Lehr et al., 2015 (source: table by the author).

Transportation and built infrastructure are of course only one of the core issues that need to be addressed to create more sustainable cities. Other important issues are urban greening, flood prevention and waste management. In each of these cases, social actors, scientists and policy makers, seen the strong interdependencies among the sustainable development goals, need to address the transformation of entire economic sectors that play a role in the provision of key services, the fostering of socio-economic equity and the transition to less-resource and energy intensive solutions.

2.3 Production and consumption of manufactured goods

As can be seen from the analysis of society-wide changes in rural and urban life-supporting activities, the present unsustainable choices often arise from not having fully appreciated the interlinkages across multiple sustainable development goals. The various life-supporting processes that are embedded in rural and urban environments, such as transportation, housing or food, are providing benefits – or conversely eroding possible benefits – with combined effects on social, environmental and economic sustainability dimensions. As illustrated above, these combined effects that provide a many opportunities for generating co-benefits between the sustainable development goals and for transforming the trade-offs.

The third category of society-wide transformations with a broad impact on a diversity of sustainability goals is the production and consumption of manufactured goods. Indeed, the principles and mechanisms for organising the production, consumption and distribution of goods have a direct impact on important sustainable development goals such as equal opportunities for men and women, fairness in resource consumption and affordable access to basic amenities such as energy and water for all.

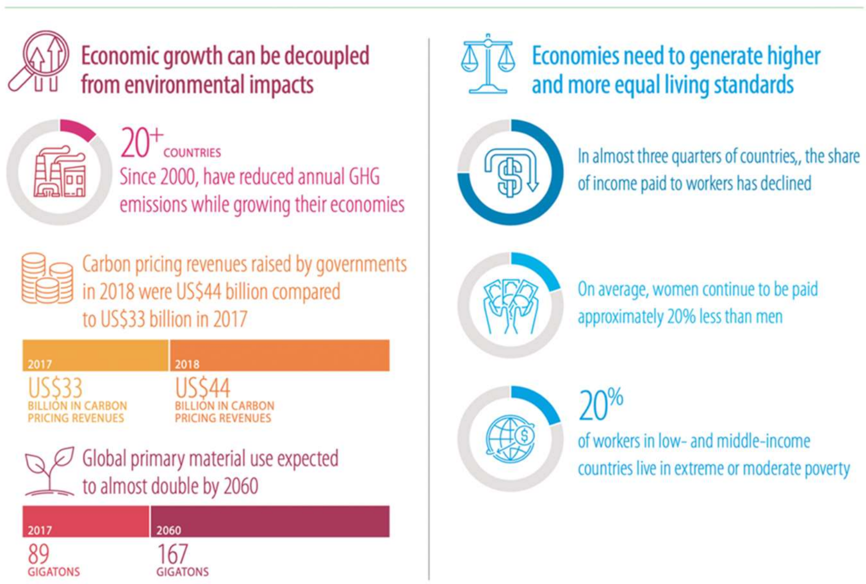

Figure 2.8. Stylised facts of sustainability impact of activities generating economic growth, such as the production and consumption of manufactured goods (source: UN, 2019b, p. 51)

The current modes of organisation of production and consumption, based on the dominant economic models of advanced and emergent industrialized countries, have contributed to advances in human well-being but in a highly unequal and unsustainable way, as illustrated in figure 2.8. For instance, data indicate that women spend about three times as many hours in unpaid work as men and face barriers in the labour market with lower wages and lower labour force participation (UN, 2019b, p. 16). Over the last five decades, as discussed above there has been an unprecedented growth in income inequalities, with only 10% of the world-wide increase in wealth and income flowing to the lowest 25%

of the income categories. Moreover, the middle classes in OECD countries only observed very sluggish income growth in the same period as compared to the top 10% earners (Alvaredo et al., 2018).

Further, overall resource consumption for industrial products and manufactured consumption goods is highly unequal. For high-income countries, the per capita use of materials to fuel private consumption is 60 per cent higher than for upper-middle-income countries and 13 times higher than that of low-income countries (UN, 2019a). This unequal resource consumption is related to overall energy consumption per capita but also to massive use of CO2 intensive materials in the industry such as steal, concrete and plastic (Falk et al., 2020). Resource consumption at those levels is clearly not viable. Instead, to provide the same level of opportunities and human well-being in all countries, for the present and future generations, there is an urgent need to reorganise consumption and production globally towards longer lasting and recycled goods with a smaller environmental footprint (Sheth et al., 2011).

The private sector, seen its considerable power and financial assets that sometimes exceed those of single countries (Deva, 2006), potentially can play an important role in the reorganisation of production and consumption processes. Indeed, private sector transformation towards sustainability can have significant beneficial impacts on all these dimensions. Nevertheless, it might also come with costs for affected workers and communities in resource intensive sectors, if not carefully planned. As highlighted in the Global Sustainability Report, a socially just and environmentally sustainable transition of private sector organisations towards sustainable production and consumption will require a combination of measures that includes mechanisms for job re-skilling, sustainable investment and sustainable finance, compliance with social and environmental regulations and an alignment of fiscal incentives with the sustainability goals (UN, 2019b, pp. 55-60).

However, in practice, the call for the transformation of the systems of production and consumption remains often limited to the adoption of eco-efficiency measures in production processes, with the view to respond to new regulatory constraints or to offer sustainable products for a limited number of niche markets. A good example is the concept of the circular economy that has been widely popularized by the business community. A review of indicators effectively used in measuring the sustainability of the circular economy shows that most of the indicators concern the economic feasibility of the circular economy (Kirstensen & Mosgaard, 2020). Although this is a necessary condition for the successful operation of circular economy businesses, this approach makes it difficult to assess if the transition is also beneficial to the environment, work conditions and various other human well-being goals (Korhonen et al., 2018, p. 40). Moreover, in this economic feasibility perspective, if the use of raw materials is cheaper than the use of recycled materials, and if repair and remanufacturing activities are more expensive than production of new products, companies will have few incentives to adopt the circular economy model. Further, it remains difficult to monitor if the transformation to increased circularity – especially for electronic products with potential high toxicity – is not realized through outsourcing remanufacturing and recycling to countries with less favourable labour conditions.

Figure 2.9. Les Petits Riens, a social enterprise for re-use of cloths in Brussels, Belgium. The company re-invests its surplus in social activities for the urban poor (source: 6th International Research Conference on Social Enterprise).

The Mc Arthur foundation has a longstanding engagement with the circular economy. According to their research, the major flaw in the business driven approach to the circular economy is the focus on the product specifications, without addressing the full production and consumption chain in an integrated manner (Webster, 2017). Indeed, some of the main potential contributions of the concept is to involve consumers in more sustainable consumption patterns by limiting the consumption of resource intensive products, to provide more transparency on the global supply chains and to increase citizen participation in transition processes. Therefore, to create positive co-benefits among the various sustainable development goals, the circular economy should address both the cost gains of increased eco-efficiency, the environmental aspects of both production and consumption behaviour and the social aspects of the circular economy, for instance through re-skilling of labour in resource intensive industrial sectors (see table 2.3).

The emergence of brands in the textile sector for the repair, recycling and upcycling of textile products in social economy enterprises or in regional innovation networks is a good example of such an integrated approach. For instance, social economy projects such as "IKOS" in Bordeaux, France, and "Les Petits Riens" in Brussels, Belgium (see figure 2.9), support an integrated business environment that promote ethical fashion, reuse of textile fabric, citizen autonomy and synergies with other regional economic actors (Perilleux et al., 2016; Real and Lizarralde, 2017; Tyl & Baldaccino, 2019). Similar integrated projects have been supported by various umbrella initiatives, such as the Mc Arthur foundation in the US, the EU Interreg project RESHAPE or the Sharing city project in Seoul, South Korea. In all these cases, the development of circular economy businesses included both product innovations, transformation of consumption behaviour and workers' skill development and training.

Table 2.3. Multi-dimensional sustainability objectives of selected circular economy businesses

Combining interventions in Integrated circular economy pathways

Identified places to intervene in the system	Co-benefits	Examples
Eco-efficiency of production and waste processing	• Climate change • Economic growth	Design of matresses so that they can be recycled into new matresses (1)
Citizen participation	• Community building	IKOS social enterprise ecosystem for repair and recycling in Bordeaux, France (2)
New **business models** connecting producers, consumers and users	• Industry innovation • Community building	Use of open innovation for a wood constructed modular sports hall (3)
New **job opportunities** in recycling and remanufacturing company networks	• Decent work • Competitive export markets	Model House Project promoted by the municipality of Nijmegen (4)

SDG INTERACTIONS (Co-benefits and Trade-offs) addressed

Legend. Data in the table compiled from discussions in UN2019b, reports of the Mc Arthur foundation, the EU Interreg project RESHAPE and the Sharing city project in Seoul, South Korea. References (1) Den Butter et al., 2018; (2) Tyl & Baldaccino, 2019; (3) Rovere et al., 2018; (4) Van Dijk & Keijzers, 2017. In addition to the realization of co-benefits, most of the initiatives also address the removal of some trade-offs, such as through training for new skills in transitioning away from resource intensive modes of production, or use of sustainable means of transportation and clean energy, if these are key inputs in the circular economy businesses.

The case of the circular economy illustrates the limits of a narrow product centred approach to the sustainability transition of production and consumption systems. This importance of a systems understanding of the interactions among the sustainability goals is not only important when addressing circular economy strategies, but it is also key in other pathways for transforming the organisation of production and consumption of manufactured goods. For example, the gradual phasing out of coal-fired electricity in Canada was only possible through a "just transition" perspective that explicitly addressed the securing of new jobs and community planning in the affected communities (Government of Canada, 2018). Another example is the establishment of criteria for sustainable foreign direct investment or sustainable finance, which requires all relevant information providers to come together to advance the definition of criteria and indicators. However, beyond the technical specifications, fostering sustainable investment requires to gather the public and private stakeholders to monitor the effective use of the criteria. Such monitoring can cover the use of the criteria in government rules for allocation of public money or in information provided by financial institutions to their clients.

In general, the systems perspective to sustainable production and consumption requires to integrate information from many actors and sub-systems, such as information on the global supply chain of materials, on environmental and social standards applied in the production process and information on consumer behaviour. As highlighted by the 2021 report of the United Nations Task Group on sustainable consumption and production, a systems approach requires to integrate data from social sciences, the humanities, and practical knowledge, beyond data from natural sciences (UN, 2021, pp.

90-91). Indeed, as stated in this report, to produce scientific knowledge on integrated transition pathways, there is a need to "ensure a multi-stakeholder participatory process to define knowledge needs, identify solutions and define a common agenda" (Ibid., p. 11). Further, data should be organized in a way that they can be discussed, evaluated, and further disseminated by practitioners (Ibid.).

2.4 Meaningful and decent work

Supporting the transformation to a less resource intensive and more equally distributed mode of production and consumption is an important responsibility for private sector companies, governments and citizens throughout the world. However, such a shift is also likely to have major impacts on economic growth overall, for instance through the downscaling of resource intensive sectors such as coal mining in Canada or industrial livestock farming in the Netherlands, and on the availability and access to quality employment for all.

Indeed, the large-scale transformation of the economy is likely to create new challenges for access to decent work, especially for the already socially excluded or vulnerable groups such as immigrant populations, women, indigenous people and people living in extreme poverty. Simultaneously, the rapid growth in information technology has been reducing the number and quality of jobs across the various professions over the last three decades (Brynjolfsson & McAfee, 2014; Standing, 2014). The enduring consequences of the 2008 financial crisis and the 2019 Covid-19 outbreak further adds to the uncertainties of the future evolution of the labour market.

The enduring negative trend on access for all to quality employment and the recent economic crises call for coordinated action to achieve more just and sustainable outcomes. At the same time, new opportunities from the globalization of trade, the diffusion of new technologies, and the internationalization of knowledge production and exchange of ideas also offer opportunities for reshaping the world of work in more sustainable directions.

The work of the International Labour Organisation on the concept of "decent work" provides an appropriate entry point for analysing the possible positive synergies with various other social sustainability goals. In the 2008 Declaration on Social Justice for a Fair Globalization, the ILO members defined decent work based on four pillars, consisting of opportunities for work that (1) are productive and deliver a fair income, (2) provide security in the workplace and social protection for families, (3) generate better prospects for personal development and social integration and (4) protect freedom of people to express their concerns, organize and participate in the decisions that affect their lives (ILO, 2008).

Scholars of psychology of work show that when people can satisfy their striving to engage in creative and constructive work – whether it be productive work or care work, both inside and outside the market-based workforce – they are more likely to experience individual well-being and to contribute to the welfare of their communities (Bluestein et al., 2019, p. 22). The broad research agenda of psychology of work shows that fair remuneration and social protection is a basic condition for reaching that goal. However, decent work also requires looking at a broader set of issues (Bluestein et al., 2019). For instance, there is a need to balancing market work and care work, especially in a context of increasing need for care work, not only for children and the elderly but also for employment and work-place health related issues. Further, employers should seek new means of including the voices of the growing amount of flexible and contract-based workers in the social dialogue, especially to meet the human needs of relationships and identity. Besides, overall empowerment of marginalized and minoritized social groups is essential to advancing these various human rights in the work life.

Despite increasing initiatives to support this agenda for decent work by governments and social movements throughout the world (see for example the G20 Employment working group), reaching these goals still seem daunting. For instance, while the advent of light manufacturing jobs in textiles, clothing, pharmaceuticals, household goods and toy production among others has brought employment to women workers in developing countries, it has not led to higher wages or better working conditions (OECD, 2008). In addition, the lack of labour representation results in little social protection. In countries such as India, women represent 96% of workers not represented by Unions (ETI, 2003). Further, recently, the World Health Organisation recognized burnout as an important and growing concern caused by chronic workplace stress (WHO, 2020). Moreover, throughout the world, marginalized working groups continue to be exposed to toxic pollution related to the disposal, management and treatment of hazardous substances and wastes (UN, 2020).

For society to change the systemic imbalances in the provision of decent work, an integrated approach will be required towards developing new skills for environmentally sustainable production, the empowerment of marginalized groups to claim their rights for a socially just workplace, and to balance care work and market work in a socially inclusive way. The work on decent work and women's empowerment illustrates such an integrated approach to decent work, as illustrated in table 2.4 (UN Women, 2012). For instance, in Bangladesh, the government supported an integrated program for micro credit enhancing women's largely informal economic activity within and beyond the homes, along with family planning services organized by female community workers (Kabeer et al., 2011). In India, the National Rural Employment Guarantee Act organizes public work programmes that provide employment and social protection to the working-age poor, with an important gender dimension. The program sets equal wages for men and women, allows childcare facilities to be provided on worksites and includes women in the monitoring and the management of the scheme (Holmes & Jones, 2011). Another example, which is also one of the cases of transdisciplinary research discussed in chapter 3 (see section 3.3.2), is the case of the empowerment of migrant families in several cities in the United States and Canada, through integrated programs providing the learning of language skills, community building and improvement in the access to basic public services (Goodkind et al., 2011).

The decent work agenda shows the multidimensional and integrated nature of meaningful and decent work that satisfies the aspirations to human well-being and environmental justice. As underlined by the members of the International Labour Organisation, the four strategic objectives of the 2008 Declaration are "inseparable, interrelated and mutually supportive" (ILO, 2008) and need to be integrated in a broad perspective that considers non-market care work and the conditions for a decent life (Budowski & Schief, 2020). Nevertheless, often the implementation of the agenda is based on statistical data only and misses many qualitative features or highly information intensive issues in areas such as health and security, discrimination at work and non-monetary benefits. For instance, in research on the evaluation of employment policy, Michal Quinn Patton, drawing on his extensive experience in conducting program evaluation, shows that official statistics of employment programmes in the US lack statistical variation to account for the specific situations of vulnerable social groups (Patton, 2002).

Table 2.4. Combined interventions for gender equality in UN's decent work and women empowerment agenda

Combining interventions in integrated “decent work and women empowerment” transition pathways

Identified places to intervene in the system	Co-benefits	Examples
Gender-sensitive legal and **social protections**	• Reduced inequalities	Minimum wage for domestic service workers, South Africa (1)
Support to **women’s entrepreneurship**	• Industry • innovation and infrastructure	Women Entrepreneurship Development Programmes, for instance at the International Labour Organisation (2)
Equal caregiving roles and equal sharing of unpaid work between men and women	• Good health • Decent work • Gender equality	Parental leave schemes in the Scandinavian countries (3)
Involvement of women in social dialogue and monitoring and management of employment programmes	• Strong and fair institutions • Responsible production and consumption • Environmental benefits	United Kingdom surveys on women's’ comprehensive sustainability approaches (3)

SDG INTERACTIONS (Co-benefits and Trade-offs) addressed

Legend. References: (1) Hertz, 2005; (2) Un Women 2012; (3) OECD 2008

Therefore, even if some aspects of the implementation of the agenda can be readily assessed with conventional statistics, such as the extent of child labour or differences in earnings, understanding the level of progress will require the combination of governmental statistics, in-depth qualitative research and information coming from social actors, such as the social partners and women empowerment organisations. In addition, addressing the research needs of practitioners who support or implement decent work development programmes requires additional monitoring efforts using data that is rich in terms of context and that covers the multiple dimensions decent and meaningful work (Ramalingam, 2013).

2.5 Energy production and consumption

The above discussion of the transformation of life supporting activities in food, mobility and housing shows that sustainability cannot be achieved through a technical product or environmental level focus only. Further, social sustainability is a key condition for the transformation of the socio-economic systems for organizing production, consumption and distribution of goods, as can been seen from the discussion around the circular economy and decent work. In response, over the last two decades, policy officials and science experts increasingly strive to effectively recognize the pivotal role of the social sustainability dimensions in the planning and negotiation of social and ecological transition scenarios.

The discard of the social sustainability dimension in many solutions to ecological problems is in part related to a strong focus on more technical areas of concern, such as the role of the energy transition in combatting global warming. However, as shown by an analysis of the most effective energy transition initiatives, the social dimension is also decisive for the transition towards more sustainable energy production and consumption.

Indeed, lifestyle, behavioural and organisational changes provide the bulk of the opportunities to reduce CO_2 emissions. The 2019 “Exponential Roadmap” for scaling solutions to halve carbon emissions by 2030 provide a good illustration of this (Falk et al., 2020). The international consortium of experts, led by the Stockholm resilience centre, calculated the most plausible scenarios for limiting global warming, based on the scaling of existing solutions. In the scenario of an overall 27Gt decrease in CO_2 emissions by 2030, the technical improvements account for a 9Gt decrease. The latter are made possible through a shift away from fossil fuels for energy provision in all sectors of activity (a 6Gt decrease), while making the primary energy production itself more sustainable (a 3Gt decrease). However, the major decrease in CO_2 emissions comes from the kind of behavioural and organisational changes towards less resource inputs and more sustainable consumption patterns discussed in the previous sections, leading to a net 18Gt decrease. Similar international assessments point in the same direction.

Nevertheless, for realizing the 9Gt decrease from the technical improvements in the energy system itself, the social sustainability dimensions are also essential. For instance, in Germany, the share of renewable electricity rose from just 3.4% of gross electricity consumption in 1990 to exceed 10% by 2005 and reaching 42.1% in 2019 (Burger, 2020). A large part of the success is due to the combination of conventional centralized solutions based on large-scale infrastructures with decentralized and more participatory approaches. The latter included installation of solar panels by private persons and farmers, which accounted for over 40% of the financing of renewable power generation in 2016, and energy cooperatives (Yildiz, 2014; Kahla et al., 2017). In Norway, the sale of electric cars has overtaken those powered by petrol, diesel and hybrid engines, reaching a 54% market share of the sale of new cars in 2021. This transition shifting away from fossil fuel cars, even though highly dependent on tax cuts on electric and hybrid cars by the government, has only be made possible through broader societal measures such as free municipal parking, access to bus lanes, toll road exemptions on the way to work and preferential access to ferries (Rietmann & Lieven, 2019). In Portugal, wind energy production expanded to a 23% share in 2020, reducing the countries’ dependence on the import of fossil fuel and creating new jobs, while maintaining affordable prices for electricity (Vieria et al., 2019).

The energy system also faces strong global global social equity challenges. Indeed, even if energy efficiency has improved in most developed countries, these countries remain highly dependent on the import of goods that are produced with cheap and carbon intensive energy inputs such as coal (Rauner et al., 2020). Moreover, both conventional and renewable energy operations depend on the sourcing of raw materials from mining operations throughout the world, many of which are in conflict ridden countries or in countries with poor labour protection measures (Monteiro et al., 2019). Further, according to the data of the Global Sustainability Report, access to affordable energy is still lacking for a major part of the world population, many of which remain dependent on high polluting and unhealthy fossil fuel stoves (Un, 2019b, p. 77 and figure 2.10). Finally, unregulated development of new mining operations or renewable energy installations creates new threats for the protection of land with high biodiversity or livelihood value (Jefferson, 2018).

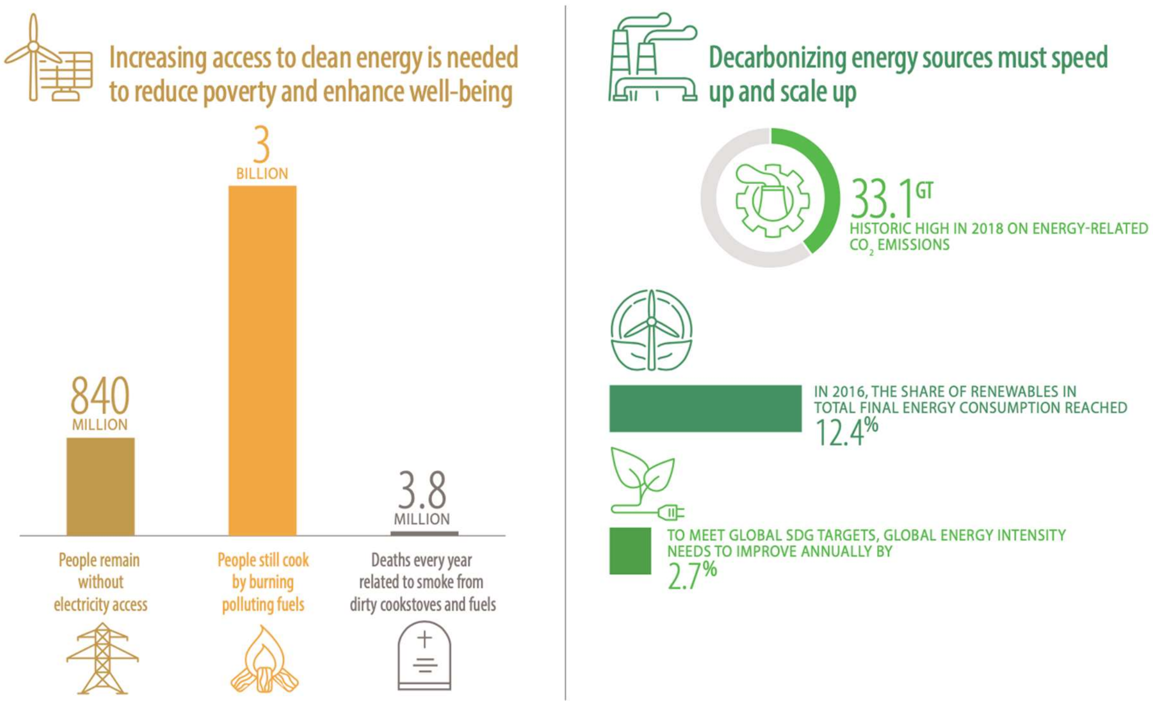

Figure 2.10. Stylised facts of the sustainability impact of energy production and consumption (source: UN, 2019b, p. 77)

Nowadays, multi-criteria assessments and scenario building tools allow to include social sustainability aspects in energy transition planning and social dialogue (Sierra et al., 2018). Yet, the evaluation of the social aspects is still neglected and the social sustainability assessment still an emergent topic, mostly lacking considerations of social equity or broader social well-being aspects (Chapman et al., 2016). Most energy assessments are based on cost-benefit analysis and aim to increase energy independence and affordability in the most cost-effective way. As a result, the adopted transition paths in most countries focus on tangible gains in CO2 emissions within the scope of possible cost-effective substitution possibilities, leading to scenarios for incremental adoption of renewables, instead of the large-scale and urgent energy transition that is called for.

A prominent example of a multi-dimensional integrated approach to energy transition is the case of the Vauban district in Freiburg, Germany, illustrated in figure 2.6 above. The energy used in this mixed-use district of some 5100 residents mainly comes from solar energy installed upon the private houses, a district heating grid that uses regional wood waste as fuel and a steam engine for cogeneration (Fritsche, 2002; Coates, 2013). Over 100 houses have a "plus-energy" standard, meaning that they produce more energy than they use, with surpluses sold back to the city grid. Social sustainability aspects are an important component of the project, with profits from the selling of energy surplus split between the households and city policies that impose small housing sites to keep the entry costs affordable. Part of this success is due to the collaboration between a high number of specialist professionals working in sustainability, the local authorities and international renowned research institutes such as the Institute for Social-Ecological Research (ISOE).

Another example of an integrated approach to the energy transition are the so-called "design for the base of the pyramid" sustainable energy projects. For instance, in Tanzania, the installation of local off-grid solar systems was combined with building a locally managed and owned biomass generator for peak electricity loads, using vegetable oil from local jatropha nuts (Chionidou, 2008). Similar initiatives of off-grid or micro-grid electricity provision have been promoted around the world. However, to be successful they should be designed around local needs and capacities, instead of the promotion of specific products or technologies (Wilson & Zarsky, 2009).

Table 2.5. Multi-dimensional interventions for the energy transition

Combining interventions in integrated renewable energy pathways

Identified places to intervene in the system	Co-benefits	Examples
Job creation through expanding **local renewable energy capacity**	• Decent work • Climate action	Portugals' wind energy policy (1)
Innovative investment models (citizen cooperatives, co-ownership, etc.)	• Social bonds • Community building • Climate action • Biodiversity	Freiburg Vauban district (2)
Transparency on the **social conditions of the sourcing of raw materials**	• Decent work conditions Justice and strong institutions • Responsible consumption and production	Policy for use of conflict minerals in research and development, University of Edingburgh (3)
Tax incentives and regulations	• Responsible consumption and production • Climate action	Norways' electric car policy (4)

SDG INTERACTIONS (Co-benefits and Trade-offs) addressed

Legend. (1) Vieira et al., 2019; (2) Coates, 2013; (3) Cooper, 2017; (4) Rietmann & Lieven, 2019. In addition to the co-benefits, various trade-offs with other sustainability goals need to be addressed, as also indicated in table 1.1. above, such as maintaining affordable prices to all and skill development for transition to less resource intensive modes of production and consumption.

Energy transition is often presented as a highly technical issue, mainly to be addressed through cost-benefit analysis and technological innovation. Some legitimate reasons for this are the presence of high upfront costs in many energy infrastructure decisions and the fact that many impacts are only visible in the very long-term or in other areas of the world. However, successful examples of energy transitions throughout the world show that technical and economic aspects alone are not sufficient to address the many interdependencies between the energy systems and the other sustainability goals.

To generate large-scale energy transitions, policy makers and social actors will need to explore the opportunities for generating co-benefits with other sustainability goals and to address the inevitable trade-offs, as illustrated in table 2.5 for the up-scaling of renewable energy. Notably, as shown for instance in scholarly reviews of available methodologies to integrate social sustainability in engineering design methods, such an effort will require a greater participation of "non-experts" to co-construct the framing of the social sustainability objectives and to integrate knowledge from the local context on constraints and opportunities for co-benefits (Sierra et al., 2018; Ceschin & Gaziulusoy, 2019).

3 Science-society research partnerships for understanding the drivers of change

Throughout human history science has played a key role in fostering progress in human well-being. Ancient knowledge of mathematics played a key role in developing public infrastructure for bringing drinking water into cities and organising complex irrigation systems in ancient civilisations from China, India to the Middle East and Europe (Swetz, 1979; Koutsoyiannis & Angelakis, 2003). In the 19th century, the control of many infectious diseases became possible with the pioneering work of Robert Koch and Louis Pasteur, and the introduction of the germ theory of disease at the end of the 19th century (Satcher, 1995). More recently, in 1970ies, the Consultative Group on International Agricultural Research set up a scientific crop breeding program with participating research centres throughout the world, which made a major contribution to the huge increase in crop yields of cereals such as rice, wheat and maize among others (Byerlee & Dubin, 2009).

In the process, science evolved from operating within small networks of well-connected individuals to large-scale collective endeavours. Especially after the second war, science went through a rapid transformation, evolving towards so-called “big science”, organized around social missions in nuclear physics, genomics and social science surveys among others. Along the way, issues arose that called for a great democratic scrutiny of the funding of large-scale science infrastructures and international consortia.

For instance, in the later 1930s, Enrico Fermi did some fundamental experiments in a little fishpond on the terrace outside the window of his lab. The pond provided the water that he needed for protecting his experiment with a nuclear chain reaction. Not long afterwards, Fermi was involved in a project on a massive industrial scale, whose outcome finally was the building of the nuclear bomb (Ravetz, 2006). In agronomic research, the scientists that had enthusiastically invented and promoted pesticides after the second world war now became involved in the debates around declining biodiversity and health risks, popularized in 1962 by Rachel Carson’s book the “silent spring” (Carson, 1962). As a result, value related questions became increasingly important in priority setting for science funding, both in basic and applied research.

The emergence of new research questions around multi-dimensional environmental, social and economic sustainability adds a layer of complexity to these emerging science-society issues and calls for a next stage in the evolution of contemporary science. Indeed, except for some specific research niches, post-war basic science research is characterized by a functional autonomy from society, led by independent scientists, and largely self-governing in its priorities, its procedures for information gathering and quality assurance of the produced knowledge. Even though science policy increasingly requires democratic accountability and proofs of societal relevance of this functionally autonomous, so-called “ivory tower” science, overall the design of scientific methods and research processes remain outside of the remit of the societal debates.

When social values are well established and consensual, researchers can capture the social sustainability dimensions and their interactions with the environmental and economic dimensions through conventional data gathering and analysis methods. However, when values are under intense debate, and evolving through individual and collective learning in situations of social change, researchers operating in the functionally autonomous world of academic science are unlikely to produce an appropriate understanding of the problem context. At best, social actors and policy makers will consider that the produced scientific knowledge is not socially relevant. However, when social values are evolving, scientists are also likely to fail identifying new real-world opportunities and credible pathways for change, or to capturing the diversity of legitimate perspectives on the problem situation.

As will be illustrated throughout this chapter, scholars in all disciplines from engineering, bio-medical sciences to economics, law and sociology have provided ample evidence of such failures. For instance, in the mid 1990ies, the inhabitants and social workers of a neighbourhood of New York city have built innovative research partnerships to overcome the failures of a highly contested study of asthma prevalence (Dedeurwaerdere, 2014, pp. 96-99). Previously, in 1992, researchers of the City University of New York Medical School, in collaboration with the New York City Department of Health, concluded that there did not appear to be an asthma problem in the neighbourhood, despite reporting of school absenteeism due to asthma and environmental pollution problems in the area. As noted by Corburn in his extensive field work on this case, form the outset residents “dismissed the study for failing to aggregate results by age, gender and ethnicity and, perhaps, most importantly, for only using hospitalization data from a local hospital which most neighbourhood residents rarely if ever visited” (Corburn, 2005, p. 119). By ignoring such crucial local knowledge, the study not only compiled very poor scientific evidence but, more importantly, further alienated the residents and social workers from the health professionals and scientific experts.

In response to the community concerns, El Puente, a local community organization, teamed up with CIET (Community Information and Epidemiological Technologies), a non-profit research organization specializing in community epidemiological research. This consortium organized three community wide surveys between 1995 and 1999 that culminated in radically different research results (Corburn, 2005, pp. 120-135). The community surveys showed, among others, that some sub-groups of the population that were nearly absent of the official national statistics on asthma at that time identified asthma as their main health concern, most prominently women over 45. Follow-up focus groups were able to relate this high prevalence to women’s employment in laundries, dry cleaners, beauty salons and sweatshop-like factories. As documented by Corburn, none of the major scientific results of this study could have been obtained by a traditional top-down, scientific principal investigator led study. The main reason is that to create trustful relations with the residents, the research team trained by El Puente and CIET had to be able to speak credibly about the broad range of health and social issues faced by the community and design the surveys based on an intimate knowledge of the local environmental concerns in the neighbourhood.

Scholars have reported similar failures to accounting for local context, to overcoming difficulties in data access or dealing with value controversies in many other areas. In response to these failures, researchers and policy makers have developed innovative methods over the last three decades, building upon earlier efforts in science-society partnership research initiated since the 1960ies in fields such as community health research, participatory technology assessment and social intervention research. Indeed, to address complex integrated social, environmental and economic sustainability challenges, building partnerships with social actors becomes an important asset in improving both the quality and the social relevance of scientific research. Often, however, such partnerships are only used to better translate independently generated ivory tower science to roadmaps of action or policy recommendations, often leading to mixed results when dealing with complex system wide problems. Nevertheless, as this chapter aims to show, for science to truly benefit from the additional knowledge gains from transdisciplinary partnership research, social actors should play a more direct role in the various steps of the research cycle.

Scholars who aim to develop an integrated approach to sustainability, connecting the social, environmental and economic sustainability dimensions, are confronted to a double challenge. First, as argued in the previous chapter, they need to understand the interactions among sustainability goals that can drive effective society-wide change processes, such as in food and mobility systems, or concerning the social organisation of work and economic production. This first challenge addresses the move from a technical focus on isolated problem dimensions to a multi-dimensional understanding of system-wide features of social transition. These system-wide features concern not only the understanding of the best possible alignment among various goals but also how to enhance the adaptive capacity of the system as a whole and how to foster social learning among the actors.

In practice, in many cases, the integrated approach to sustainability does not lead to identify one pathway but to a plurality of distinct pathways, which each envision different ways to create synergies and co-benefits among the interrelated sustainability goals. Therefore, in these cases, researchers on sustainability transitions are confronted to a second major challenge, which is to consider the social actor perspectives on the plurality of integrated pathways in a socially inclusive way.

For instance, in the transition to sustainable food systems, the development of local food networks, with possible co-benefits on social cohesion and dietary change, co-exists with a transition pathway that focuses on the transformation of global trade, through promoting increased transparency and developing standards for food products that are sourced regionally or internationally, with possible co-benefits on decent work and the environment. Similarly, in the energy transition in Germany, decentralized pathways with citizen cooperatives co-exist with the mobilisation of venture capital for large off-share infrastructure projects. Further, within the area of the organisation of meaningful and decent labour, there is a need for building new jobs in green, less resource intensive economic sectors, to compensate for the losses of jobs in other sectors. At the same time, scholars of degrowth insist upon the redistribution of work time, to account for a better balance between market work and care, with major co-benefits on mental health and gender equality.

Each of these pathways propose a way to building synergies and attenuating trade-offs among highly interrelated goals in the different specific sectors of transition. None of these pathways can be considered more optimal than another, as there is no external Archimedes point against which researchers might assess the improvements in absolute terms. They prioritize different combinations of sustainability goals, which at the end of the day all contribute, although in different manners, to improved human well-being and planetary health.

An appropriate understanding of the drivers of the ongoing transition dynamics and the prospects for improvement in a variety of possible pathways, requires a socially inclusive perspective on the pathways that are likely to produce tangible social benefits. Failing to do so might lead to neglect the full diversity of social possibilities of change, to fail to understand the reasons for social acceptability of change and might only support social learning among a limited number of change agents.

Therefore, the second challenge for developing an integrated approach to sustainability is to adopt a socially inclusive perspective on the various transition pathways. When the social actor perspectives on the transition pathways are very diverse and evolving, science-society partnerships can contribute to gather knowledge that is relevant for mapping these perspectives in a scientifically credible way. Indeed, in many cases, the social perspectives are still co-evolving with the available scientific knowledge, the implementation of ongoing initiatives and social learning among the stakeholders. In such cases, science-society partnerships can build a more inclusive understanding of the societal transition process and overcome some of the failures of ivory tower science to address society-wide transition challenges.

In sum, as also advocated by the seminal article on sustainability science by Kates et al. (2001), an integrated sustainability approach requires multi-dimensional and socially inclusive research approaches for understanding and advancing complex societal transition processes. One key aspect of sustainability science, therefore, is the involvement of social actors from outside academia and research institutions into the research process, with the view to integrate the best available knowledge, reconcile values and perspectives on various transition pathways, as well as creating ownership for problems and solution options (Lang et al., 2012).

While the field of transdisciplinary sustainability science has been growing, scholars generated a large body of literature on principles, quality criteria and successs factors. For this chapter, the analysis uses a well-recognized set of design principles, inspired from the synthesis of the literature produced by Lang et al. (2012) and the handbook on principles produced by the Swiss Academies of Arts and Sciences (Pohl & Hadorn, 2007). Reviewing over two decades of practice with transdisciplinary research practices throughout the world, these authors conceptualize the transdisciplinary research process as a sequence of three phases (see figure 3.1), including:

1) Collaborative problem identification and structuring: collaborative problem formulation and constitution of the research team
2) Interactive analysis: integrated scientific analysis and science-social actor knowledge co-production
3) Joint valorisation: joint interpretation of the research results, dissemination and societal valorisation

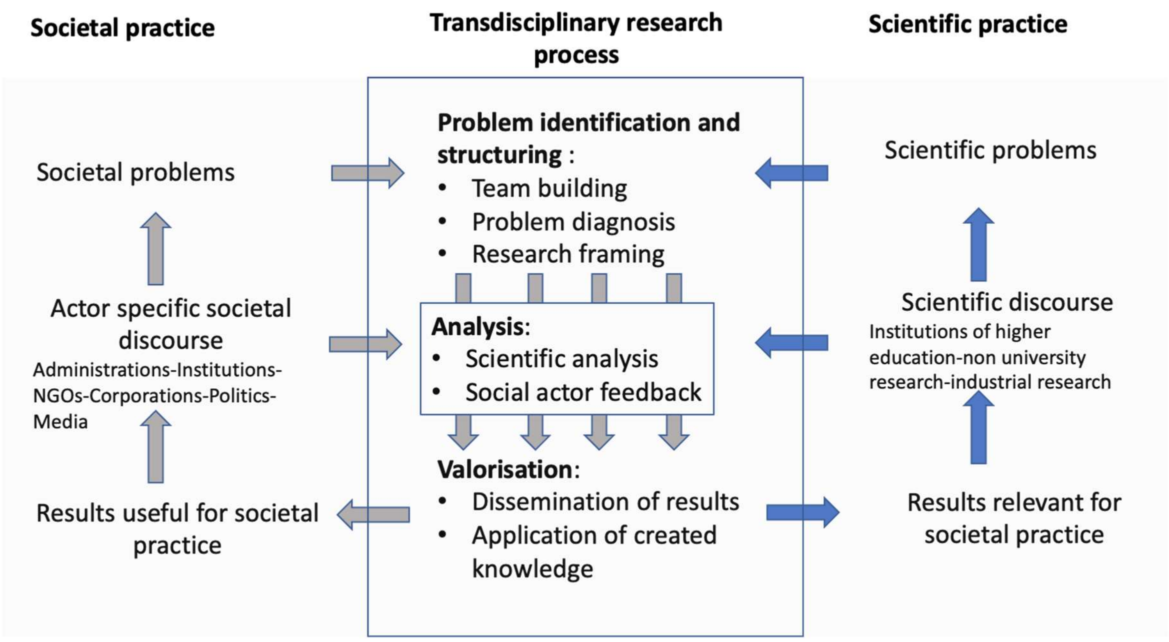

Figure 3.1. Transdisciplinary research process (source: figure by the author, adapted and modified from the overall scheme in Lang et al., 2012).

As also underlined by these authors, to enhance reciprocity and trust between the social actors and the researchers that are part of the research partnership, the various phases and their outcomes should already be thought of at the stage of the building of the collaborative team. Moreover, in many cases the research process allows for some iterations among these three phases, so that participants involved in one phase can learn from the outcomes from one of the other phases.

Despite the convergence on the understanding of the key components of transdisciplinary research, the scholarly literature remains rather fragmented and dispersed as to the choice of appropriate analytic methods for conducting transdisciplinary research. Indeed, many analytic methods from conventional disciplinary research remain insufficiently developed for addressing the scientific and social complexity of sustainability problems. Therefore, researchers need to adapt these methods with the view analyse multi-dimensional integrated sustainability questions in a science-society partnership research context. To contribute to this goal, this chapter reviews the various analytic methods for science-society research partnerships that have been developed over the last three decades and evaluates their accomplishments in improving our understanding of complex social and ecological transition processes.

To develop the envisioned integrated and socially inclusive approach to partnership research, the analytic methods need to be adjusted to the two major features of transdisciplinary sustainability research. First, they need to be able to consider multiple dimensions of sustainability, often studied within different research traditions with heterogeneous conceptual/methodological approaches. Second, they need to be highly interactive and context specific, so that the knowledge exchange during the various stages of the knowledge co-production process with the social actors can be organized in a sound and effective manner.

The choice of the appropriate analytic methods will further depend on the more specific goals of the research into a given sustainability issue. Therefore, to discuss the adaptation of the analytic methods to the needs of transdisciplinary research, this chapter is organized in a set of 4 clusters which each focus on a relatively similar set of drivers of sustainability transformations, within a multi-level approach to transition. These 4 clusters further build upon and extend the knowledge-based transformations framework of the 2019 Global Sustainability Report used in chapter 2. In this approach, societal transitions can be accelerated through an action at different levels, respectively (UN, 2019b):

1) technological innovation and intervention in bio-physical systems,
2) transformation socio-economic regimes,
3) transformation of governance mechanisms in implementing new regimes,
4) learning and building of mutual understanding on socio-cultural values.

Although most scholars recognize the importance of these four drivers of change in addressing major societal changes, they often fail to address the social, economic and environmental sustainability goals to be reached through these drivers in an integrated manner. The various sections of the chapter therefore discuss the challenges of a multi-dimensional approach of theses drivers, the benefits from the building of science-society partnerships and the choice of appropriate analytic methods for conducting transdisciplinary partnership research.

3.1 User and citizen co-design of technological drivers of change

Technological innovation on its own is neutral towards the achievement of sustainable objectives. At the same time, as witnessed for instance through the development of renewable energy, water sanitation or less polluting modes of transport, technological innovation has the potential to enable shifts away from business-as-usual scenarios and to contribute to sustainable development across many sectors of activity.

Design of new products and services is crucial to reduce the environmental impact. In this context, policy makers have promoted a broad set of tools to improve eco-efficiency and reduce environmental impacts, through promoting life-cycle assessments of new product development or environmental impact assessments of potentially polluting activities. However, although these measures are a necessary first step, the focus on sustainability features of the products and services is not on its own sufficient to obtain the radical improvements required to achieve sustainability (Ceschin & Gaziulusoy, 2016). For instance, innovations such as digital platforms for car sharing, LED lighting systems or less-energy-consuming water boilers have brought important cost benefits to consumers but without a proven shift in behaviour towards overall less resource intensive consumption patterns (Ceschin & Gaziulusoy, 2016). In other cases, emissions and waste reduction technologies in industrial production processes failed to engage the company shareholders or to mobilize the technical staff in developing new competences to implement the envisioned changes (Stindt et al., 2016).

How can sustainable product or service innovations be developed that address environmental challenges and at the same time increase user acceptance through producing co-benefits with social and economic sustainability dimensions? How can user-centred design of new technologies be developed for the factory floor, while generating effective participation of all the relevant actors in the re-organisation of production and supply chains? Further, how can the broad range of concerned societal stakeholders be associated to the design and dissemination of technologies that promote environmental, social and economic sustainability in an integrated manner?

In response to these challenges, researchers in engineering and bio-physical sciences, and social actors have developed a broad set of methods for user-centred research and technological innovation processes. Labelled in the literature through different terms such as “sustainable living labs”, “design for sustainability” or “product service system” innovations, these approaches share a focus on involving users and other relevant actors along value chains into technological design and innovation processes. This section introduces these user-centred research methods into technological innovation and discusses how these methods can be adapted to involve social actors at all or at specific stages of the research process, with the view to improve the system-wide sustainability outcomes in various sectors of activity.

3.1.1 A living lab for sustainable renovation in the historic city centre of Cahors, France

The research on energy refurbishment technologies in the historic city of Cahors in France aptly illustrates the contribution of user-centred research and innovation processes. As in many other cities, the development in recent decades of suburban areas has led to the depopulation of the city centre (Claude et al., 2017). In response, the municipality has established a living lab on new refurbishment technologies that are better adapted to the thermal renovation of old historic buildings, while enhancing the skills of local craftsmen (see figure 3.2). In doing so, the living lab aims to produce a set of co-benefits among the goals of sustainable building technologies, revitalizing the city centre to combat urban sprawl, the sourcing of bio-based materials and the conservation of valuable historic buildings.

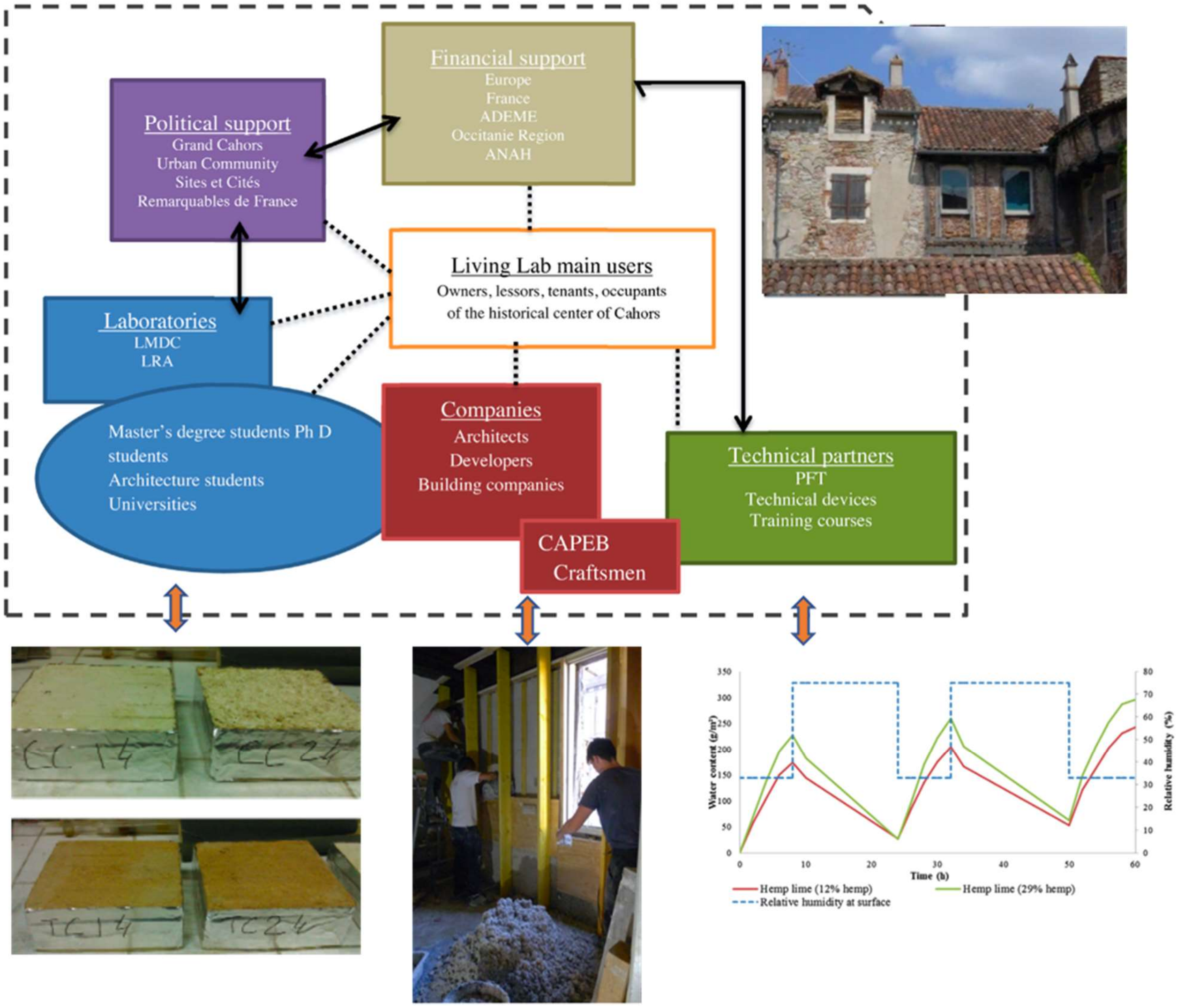

Figure 3.2. Overview of the main operators and their relationships in the Cahors living lab (source: figures from Claude et al., 2017).

However, the design of biomaterials and the choice of historical building techniques brings its share of complexity to this project, seen the many obstacles that may arise at every level of the chain of testing, producing, supplying and using of the new materials (Claude et al., 2017). For example, government programs for financial support of energy refurbishment are based on theoretical diagnosis of energy performance, which is not well adapted to the situation of old buildings. Moreover, the standard energy performance requirements can encourage renovators to favour solutions that are in contradiction with preserving the historical heritage, for instance by changing windows and doors, and may disturb the moisture regulating properties of the old materials. Further, despite being one of the green energies with high economic potential and the broad availability of these materials, the industry and the market for bio-based materials is still poorly coordinated and lacks overall recognition.

To address these issues, the Cahors living lab implements a user-centred research concept by involving local craftsmen, end-user, local authorities and material producers in the research process. In contrast with classical disciplinary and expert-based approaches, the participants to the living lab aim at developing sustainable technologies in a real-life context where political, ecological, socioeconomic and technological dimensions need to be integrated. According to comprehensive reviews of sustainable living labs (Liedtke et al., 2015; Dube et al., 2014), this process can be represented following the three main steps of the overall transdisciplinary research cycle discussed above (see figure 3.3): (1) joint ideation and planning, (2) user-centred and collaborative innovation processes, (3) dissemination and valorisation of scientific results.

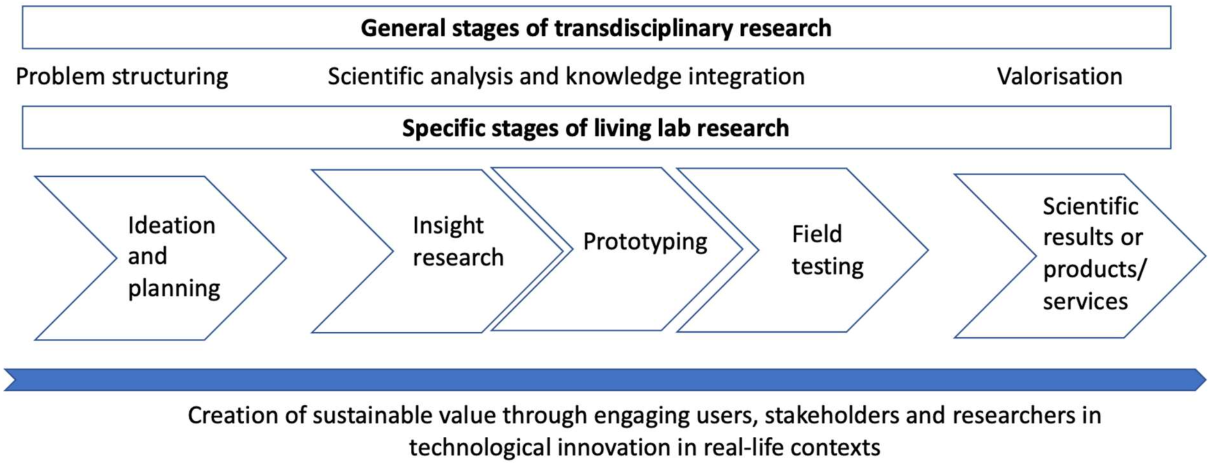

Figure 3.3. Overall process of a living lab, from problem structuring (left), analysis and knowledge integration (middle), to valorisation (right) (source: figure from the author, based on the analysis in Dube et al., 2014, p. 95 and Liedtke et al., 2015, p. 111)

a. Collaborative problem formulation and constitution of the research team

To involve the stakeholders in the definition of the research frame and the choice of the materials to be tested, the Cahors living organized a set of co-creation workshop during 2017-2018, in the context of the overall ENERPAT project (https://enerpatsudoe.fr/).

b. Integrated scientific analysis and science-social actor knowledge co-production

In the case of the Cahors living lab, the phase of insight research (see figure 3.3) was highly collaborative. Indeed, the real-life integration of the various sustainability dimensions requires to consider the climate and geographical conditions of the region, socio-economic and cultural factors, the shape and orientation of the building, embodied energy in the choice of the materials and energy, and moisture regulation efficiency (Claude et al., 2017). Thanks to the collaboration with craftsmen and empirical knowledge of vernacular techniques, mixes of earth and natural fibre were co-developed, and then tested in the laboratory to determine the desired properties. The archaeologist from the city council brought expert knowledge on the historical and socio-economic features of the buildings, while students of civil engineering made a study on the impact of the orientation of solar radiation on different walls.

Prototyping and field testing involved many iterations between laboratory and on-site measurements on the one hand and the on-site renovation activities on the other. The laboratory study of the biomaterials that were proposed by the craftsmen gave information for the preparation of the on-site materials. At the same time, various on-site experiments were performed (moisture measurements, testing the sealing of the doors, etc.) by researchers and students to improve the proposed refurbishment solutions.

c. Joint interpretation of the research results, dissemination, and societal valorisation

The results of the project were communicated through public events in 2018 and 2019 with various researchers and actors of the sustainable building sector. In addition to these events and the scientific publications from the project, the project team also mentions some other more indirect results that can impact the social practices. First, the project produced guidelines on various aspects of improving the energy efficiency of buildings in historic city centres. Second, for the federation of the craftsmen (CAPEB) and small building firms, the project allowed to upgrade the status and the recognition of their work. In particular, the project has shown that the craftsmen can contribute to solutions with many co-benefits for the environment, the creation of new social bonds in old city centres and conservation of historic patrimony. Nevertheless, seen the broader context of the building sector, where many refurbishment solutions are based on conventional solutions with non-renewable materials proposed by the industrialized building sector, a more systematic integration of the expertise and knowledge of the craftsmen in technological innovation processes remains a challenge to be addressed.

3.1.2 Towards multi-dimensional sustainability design approaches

Since the initial impetus in the 1990ies by early initiatives, such as the living lab initiated at the Massachusetts Institute for Technology in the United States (ENOL, 2019), researchers have developed a wide variety of user-centred methods for fostering social relevance and acceptance of technological innovation. Nevertheless, not all the user-centred methods are oriented towards advancing social, environmental and economic sustainability in an integrated manner.

In some cases, living labs use a narrow technical definition of environmental sustainability and focus for example on quantitative measures of energy efficiency only, without addressing the interaction with societal and economic features that might inhibit broader system-wide changes in energy provision and consumption (see for instance the University of Cape Town Lab mentioned in McGibbon et al., 2014; or the Lancaster University Campus Lab mentioned in Bates & Friday, 2017).

The narrow approach to living lab research can generate some very incomplete research results, sometimes with far-reaching consequences. One example of the challenge of integrating social dimensions within real-world analysis of the use of technologies is the recent diesel gate scandal in Europe. After the scandal came to light in 2015, showing wide-spread cheating with emissions standards by some prominent car companies, the European regulators continued to experience difficulties to build reliable test infrastructure for NOx emissions. In this case, the move from a failed laboratory testing system of car emissions to so-called Real Driving Emissions (RDE) test procedures in the EU clearly led to improvements. Nevertheless, the new procedures still fail to assess the real emissions based on drivers' real-world behaviour (see figure 3.4). Indeed, as shown by researchers at the European Joint Research Centre (JRC) in Italy, the emissions from real drivers' behaviour still exceed the emissions of the new Real Driving Emissions test, which is done on the road but in ideal driving conditions (Suarez-Bertoa et al., 2019; Suarez-Bertoa et al., 2020).

The lack of integration of user related information on driving behaviour in the testing of new technologies can put a doubt on test results of ecological innovations. For instance, in the case of plug-in hybrid cars, the plug-in feature is not always used by the car owners (Plötz et al., 2020). In this case, when plug-in hybrid innovations are implemented in heavy duty gasoline or diesel personal vehicles, without a related change in behaviour, the potential ecological benefit of the innovation is likely to be nullified.

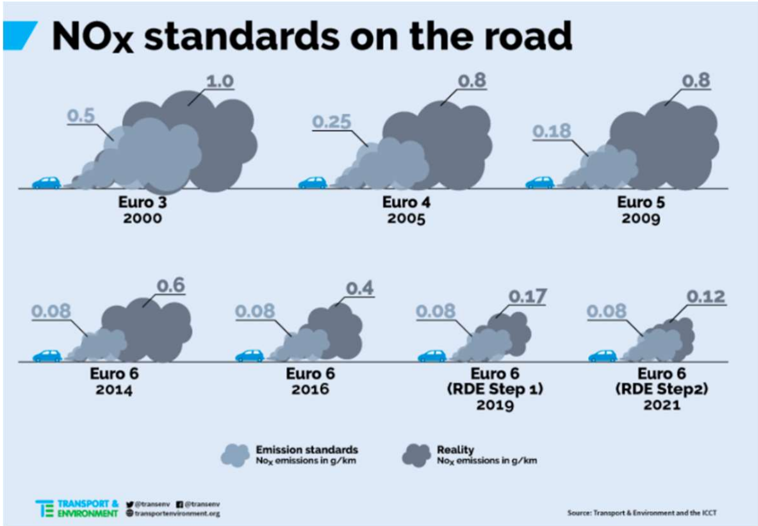

Figure 3.4. Real-world emissions (dark grey) compared to the standard on the road Real Driving Emissions (RDE) test (light grey) (source: Poliscanova, 2017, p. 26).

What is needed for making tangible and enduring contributions to sustainability, in contrast to these purely product focused improvements, is to address the social and psychological user aspects of new technologies and to build economically inclusive transition pathways that make the societal benefits of technological improvements available to the broadest possible user group.

The case of the sustainable building living lab in Cahors discussed above provides a good illustration of a research process that addresses these various dimensions:

(1) behavioural, educational and effectiveness aspects of environmental sustainability

- Through wide-spread collaboration with the local business actors, contribution to resource awareness in the building sector active in Cahors
- In-situ data collection on heating and airing with households participating to the research program, including participation to behavioural surveys
- Context specific analysis of environmental features of historical buildings/building techniques

(2) inclusive economic sustainability

- Promoting the recognition of small-scale entrepreneurship for historical and environmentally sustainable renovation
- Training of local craftsmen to new building techniques
- Promoting economic efficiency by technological innovation and testing of market-ready heating systems

(3) social sustainability

- Through networking citizens, stakeholders and building professionals, and strengthening of local community bonds
- Promoting inclusive health through building renovation (combatting moisture, in house pollution) accessible to all

The system-wide research approach of the living lab in Cahors is part of a broader effort to develop user-centred innovation research that covers the environmental, economic and social sustainability dimensions of technological innovation. First, in relation to environmental sustainability, the examples above clearly show the limits of purely product centred eco-design to foster system-wide ecological and social transition. In this context, engineering and design researchers, within the broad umbrella of the "Design for Sustainability" (DfS) approach, have shown the importance of behavioural and socio-psychological aspects of sustainable use of technologies. For instance, researchers have estimated that 78% of discarded products still function properly when replaced. This is due to various reasons, such as new trends in fashion, desire for societal status or changing needs of the users (Van Nes, 2003; Cooper, 2004, 2016). Further, for products that consume energy in use, the level of energy consumption is mainly determined by users' behaviour (Tang & Bhamra, 2009). In addition, user centred improvements are often counterbalanced by an overall increase in consumption levels.

Therefore, sustainable design approaches have increasingly investigated the way the broader production and consumption systems are organized in the various sectors of technological innovation. Known in the design literature as the design of "product service systems", these approaches highlight the importance of focusing on the broader network of actors who produce, deliver, and manage the services provided through the innovations (Mont, 2002).

Second, even if there is considerable potential for environmental improvements in the design for sustainability approaches, the latter are often insufficient on its own to create a socially inclusive innovation process. Indeed, many innovations are not applicable to all income groups or to low-income markets (Crul & Diehl, 2008, p. 129). In the latter contexts, researchers highlight the need to focus on specific issues that are different from the high-income markets, such as the desirability of the innovations by low-income groups, capacity building for effective use and affordability among others (Gomez Castillo et al., 2012, p. 129). In particular, the so-called "design for the base of the pyramid" approaches have shown the need to go beyond the targeting of the poor as potential consumers of sustainable product innovations. Instead, to reach more inclusive economic development, higher priority should be given to active involvement, such as value chains for sourcing products and/or services from those at the base of the pyramid, and empowering the poor as co-creators of new business opportunities (Simanis & Hart, 2008, p.128).

Third, in relation to improvement of social sustainability, such as strengthening of social bonds and improving public health issues, research on socio-technological transitions has amply shown the importance of addressing the interdependencies between technological and social improvements. In the case of the Cahors living lab, the focus on generating social co-benefits through the strengthening of community bonds, along with offering solutions for more healthy indoor environments of old buildings, played an important role in accelerating the acceptance of the proposed refurbishment solutions. More generally, techno-fixes that fail to address systemwide needs for improvement might shift the burden of finding affordable solutions to lower-income social groups (Ehrenfeld, 2008, p. 135).

Overall, as shown by various reviews of sustainable living labs (Ceschin & Gaziulusoy, 2016; McGrory et al., 2020), partnership research on technological innovation has gradually expanded its sustainability focus. The earlier approaches mainly dealt with environmental aspects. Moving on, social and economic sustainability aspects such as labour conditions, integration of marginalised people, social cohesion and the general quality of life have been increasingly integrated (Ceschin & Gaziulusoy, p. 145). In parallel, researchers have underlined the importance of co-producing knowledge with a broad variety of social actors. While the first approaches have been focusing predominantly on technical expertise, such as optimising eco-design or cradle to cradle solutions, subsequent developments have recognized the crucial importance of the role of the users' knowledge in generating long-lasting solution and a society-wide adoption of sustainability innovation.

Many of the methods used in sustainable living lab research and design for sustainability approaches are also used in conventional ivory tower science. However, when they are used in isolation and without the interactive features of the partnership research process, they are unlikely to provide the necessary knowledge to address multi-dimensional sustainability issues in society-wide transition processes. For instance, life cycle analysis is a popular method for product improvement in the industry, as it allows to identify resource efficiency potential along the entire production chain. This is highly attractive, as it allows to identify improvements in the production process where both environmental gains and increased cost-efficiency can be realized. Nevertheless, as clearly illustrated above in the case of the car industry, improvements in environmental impacts of production processes or features of end products are often annihilated by behavioural changes or piecemeal approaches to sustainability in the broader industrial innovation system.

In sum, the challenge is to integrate product related improvements with other sustainability dimensions, such as through an analysis of behavioural changes, psychological factors, business models, governance of innovation and inclusive economic development goals among others. Each research project obviously needs to zoom in on a subset of these features when building the research partnership. Depending on the most urgent challenges identified, researchers and social actors will therefore prioritize certain scientific and societal outcomes and organize the various phases of the knowledge co-production process accordingly. The latter will be illustrated in the remainder of this section, through three examples of successful living labs. These cases were selected for two reasons. First, they combined different research methods in the living lab, with the view to addressing the social, economic and environmental dimensions of a specific technological innovation process. Second, to reach that goal, these cases organize knowledge co-production activities in the various phases of the research process, as illustrated in table 3.1.

Table 3.1. Overview of the case studies discussed in section 3.1.2.

User and citizen co-design of technological drivers of change										
Project name	Topic of multi-dim (envt., social,econ.) sustainability research	Co-production			Scientif. outcome		Type of societal outcome			
		co-design	Joint anal.	Co-valorisation	New data	Integr. Learn	Multi-actor Collaboration	Strategy	Competences	Solutions
Food, agriculture and forestry										
CAPFLOR/SALSA, France	Farm autonomy, decent work and biodiversity protection	***	**	*	**	***	**		*	**
Urban/rural living environments										
Mistra SAMS, Sweden	Peri-urban mobility, community development, and combatting global warming	*	***	*	**	**	**	*		*

UnaLab, the Netherlands	Urban land use, urban heat, and biodiversity	*	*	***	**	*	**			

Legend. Scale for co-production: consultation only (*), joint research on some aspects (**), on nearly all aspects except some technical issues (***). Scale for scientific outcome/ societal outcome: mentioned in project publications (*), well documented (**), with in depth analysis (***).

a. Accompanying field testing of new seed varieties in Capflor and SALSA

The twin research projects Capflor (2011-2020) and SALSA (2013-2015) (Goutiers et al., 2016; Lacombe et al., 2017) by the French National Agricultural Research Institute (INRA) clearly show the benefits of partnership research to produce integrated knowledge across social, economic and environmental sustainability. The projects aim to promote fodder autonomy and less use of fertilisers on grasslands for feeding livestock, and accompany the field testing by farmers as illustrated in figure 3.5. As such the research address an increasing social demand for more sustainable grassland exploitation, which is illustrated by the recent controversy over the production methods of the famous Comté cheese. Comté is one of the most popular raw-milk cheeses in France. Research has shown that the increasing demand for the cheese has put pressure on the grasslands in the production regions, where overfertilization now has major impacts on the pollution of rivers and the landscape (Bettinelli, 2020). In this case, even if a transition towards more diversified and less fertiliser intensive grasslands would provide well established environmental and social benefits for the region, economic pressure remains a strong motive to adopt a fertilizer intensive system.

Figure 3.5. Field testing and group discussion among farmers are key to adapting seed mixes to the local conditions for developing grasslands that need less fertiliser and that promote biodiversity (source: Chambre d’agriculture du Tarn https://www.reussir.fr/lait/des-outils-daide-la-composition-dune-prairie).

The Capflor project started when a group of farmers were looking for a seed mix that would be more productive, biodiverse (for pollination services) and include legumes such as clover and alfalfa (for nitrogen fixation). Due to the absence of a tradition of using such complex mixed grasslands in France, they resorted to buying complex seed mixes from Switzerland, where researchers and farmers at Agroscope developed seed mixes through a user driven research platform with on the farm test fields. However, this attempt failed as the seeds were not adapted to the specific production area in France.

This failure is part of a set of more general problem with research into diverse seed systems. Diverse seed systems are an interesting option to reduce fertilizer use, while maintaining a good level of productivity. However, in contrast to the dominant grassland monocultures and simple associations of two or three seed varieties, there is no scientific way to develop a uniform seed package that is adapted to all kind of geographical areas. Technically, highly diverse seed mixes create interactions among the grassland varieties that produce very different dynamics in different geographical zones and climate conditions (Goutiers et al., 2016). Therefore, complex mixed grasslands beyond two or three seed varieties need to be adapted and tailor made for the different agronomic contexts.

Further, the farmers' knowledge and know-how of diverse grasslands management – which was widespread before the introduction of monocultures – has been lost over the last 50 years through the promotion of grassland monocultures and simple grass associations of two or three varieties by the State. As a result, market availability of seed mixes is also very restricted.

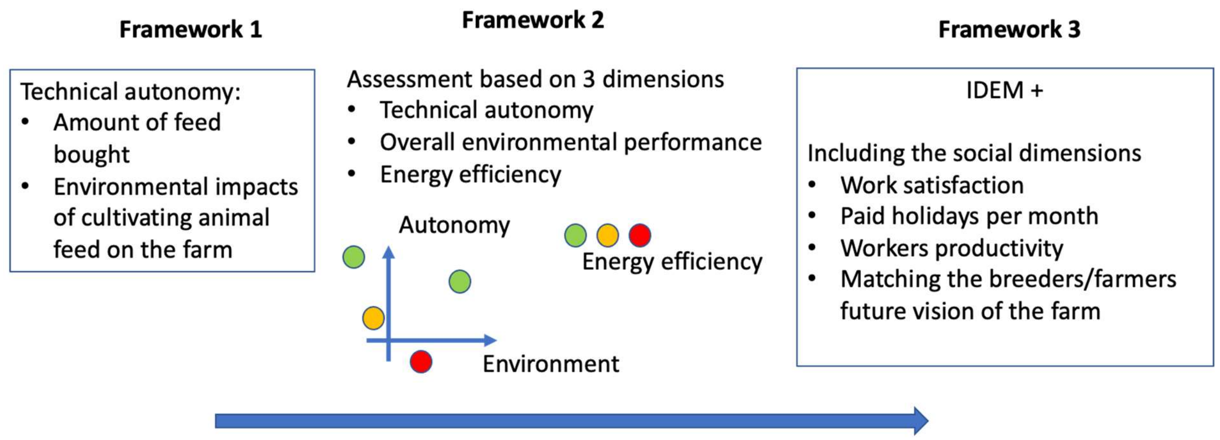

Figure 3.6. Evolution of the multi-criteria assessment tool from the beginning of the project (left column: F1) to the end of the project (right column: F3) (Source: figure by the author, based on table3 in Lacombe et al., 2017).

For supporting a transition towards diverse grassland management, a more integrated understanding is needed that is both technically informed, sensitive to the local context and that addresses broader social changes in market supply and social values. To this purpose the twin projects Capflor and SALSA organized a set of workshops among researchers, farmers and local organisation to identify the key decision-making criteria that should be used in designing a transition to a diversified grassland system that is both scientifically sound and socially legitimate:

Agronomic evaluation of
- The soil: balance between capacity for self-produced fodder and the size of the herd
- Feed: feed ratios for the herd
- Various mixes of grassland seeds (In the project Capflor more specifically)

Environmental assessment
- Biodiversity impact
- Pollution impact
- Soil conservation

Economic evaluation

- Energy efficiency
- Labour productivity

Social

- Work satisfaction
- Number of days of vacation
- Alignment with the farmers' narratives on desirable future of his farm

It is important to notice that, in contrast to conventional "ivory tower" theory development, the list of criteria was co-designed with the participating farmers. Moreover, the process was highly iterative between scientific test runs of the models and the science-practitioners' workshops: the model did evolve in an iterative manner from a more restricted technical sub-set in the first test runs of the model, to encompassing the social and economic features by the end of the project, as illustrated in figure 3.6.

The result of the entire process might be perplexing to researchers and policy makers used to expert led research processes. Indeed, the assessment does not provide an exhaustive view of all theoretically possible farm types, nor does it provide clear advice on the path to follow. Instead, the research process provided knowledge on the co-constructed list of criteria, which gradually evolved throughout the project. Moreover, there is no optimisation or "weighting" algorithm that would allow to converge towards the most desirable pathway. Instead, the project allows to map and collectively assess the social diversity of sometimes mutually exclusive pathways as they co-exist in the real-world farming landscape.

For instance, the project results highlight the positive aspects of the diversified grassland system with high biodiversity outcomes but does not discard other pathways such as grassland diversification with lower biodiversity outcomes, which provide an equally high level of fodder autonomy and work satisfaction. Indeed, one of the objectives of the project was to foster mutual learning among the farmers on the impacts of their farming choices, with the view to foster further experimentation to obtain social, environmental and economic improvements in each of the farming projects envisioned in the area.

In contrast to the failure of expert led advice, which fails to consider the local context – such as through the initial adoption of the Swiss seed mixes, the dynamics created by the twin Capflor/SALSA projects clearly produced both socially relevant and scientifically credible knowledge. Moreover, the project contributed to the increased uptake of more sustainable grassland management by the farmers in the area, as compared to other areas where no partnership research has been conducted. At present, in the project area of the Aveyron, more and more farmers are engaged in on-farm experiments of new seed mixes (Ribeiro, 2017, p. 34), and an increasing number of farmers have been shifting to diverse grasslands and fodder autonomy systems or showing interest in doing so (Apaba, 2014).

b. The use of behavioural surveys on sustainable mobility in Mistra SAMS

Digitalisation and electrification of mobility are likely to be key components of any energy efficient mobility future. Digitalisation enables more efficient transport logistics, the development of integrated booking systems among different modes of transport – better known as mobility-as-a-service (MAAS) – and social networking. Electrification, if based on renewable energy provision, can both lower the carbon footprint of cars and trucks, and lower air pollution.

As already highlighted in the previous chapters, transition towards more sustainable mobility will require more than just proposing a shift to electric cars and digital optimisation tools. To cite a well-known fact, the increase in fuel efficiency of cars over the last decades has largely been compensated by increase in car ownership and distances travelled. Nevertheless, existing research and development still has a bias towards technical dimensions and theoretical simulations of possible sustainability outcomes, while user perspectives and institutional dimensions are seldom explored in depth.

For instance, a survey of 2711 residents of Malmö in Sweden has shown that the purely technical accessibility criteria only capture part of the motivations for choosing between different mobility choices (Lättman et al., 2020). In particular, the survey shows that bicycle users rate their accessibility significantly higher than what technical accessibility criteria based on distance and travel time would predict. Obviously, such subjective well-being related criteria should be considered in research on technological innovation paths (Ryan & Pereira, 2021).

To overcome this research gap, the Mistra SAMS research projects in Stockholm, Sweden, has set up two living labs that combine the development of digital innovations with behavioural, environmental and economic analysis of sustainability choices. One living lab organizes a space for telework from a co-working space in Tullinge, south of Stockholm. This so-called telecommuting centre offers 14 workplaces plus conferencing facilities (for example telephone boots, meeting rooms) as illustrated in figure 3.7. The second living lab explores the use of smartphone applications to improve mobility choices.

Figure 3.7. Transdisciplinary research on digitally supported services for sustainable mobility at KTH Royal Institute of Technology: The MISTRA SAMS co-working space at Tullinge, Stockholm (source: photo by the author, November 2019).

The aim of the Tullinge living lab is to investigate the effects on travel behaviour in suburban areas of having a professional office space near the participants' homes (Bieser et al., 2021). The space started its operation in January 2019 and as of February 2020, 44 people regularly worked from there, mostly employees from an IT company with headquarters in the North of Stockholm. As the participants all live in proximity to the living lab, they save substantial commuting time on the days that they work from the living lab.

The project analysed the energy impact of teleworking at the hub, both directly at the hub and indirectly through transportation choices, and the behaviour of the participants, based on detailed time-use diaries kept for three weeks. The results show that, when working from the living lab, participants frequently use alternatives to the car, for instance walking and biking. The energy savings depend on the energy use at the hub, as compared to home working for instance. Therefore, the living labs allows to map a set of effective opportunities for energy saving through teleworking at a hub: providing energy-efficient transport options at the hub, such as bike sharing services; creating local destinations, such as local groceries or lunch places; and energy savings at the hub itself.

The second living lab of Mistra SAMS provided smartphone applications to inform users about the real costs of car driving, along with a set of economic incentives to change to other mobility options. The results were in line with previous studies that show that participants have very low insights into the costs of personal car ownership and usage. Moreover, most participants showed an active unwillingness to increase their knowledge of the costs, as a strategy to allow oneself the freedom and the convenience of the car (Sjöman et al., 2020, p. 13). These behavioural data suggest that what people value most about their cars, such as individually tailored departure locations to individual destinations, will be hard to replace by digital solutions offering multi-modality choices in transportation such as Mobility as a Service.

Nevertheless, the research also shows opportunities for matching the right services and policies to specific categories of travel needs. For example, very long journeys during summer holidays may be partially replaced by train if new mobility services at the place of destination can satisfy the mobility needs during the holidays. Further, beyond the opportunities of user-centred technological innovations, urban planning issues, like the localisation of housing, services and workplaces, will continue to play an important role in ensuring that biking and public transport are seen as real alternative options (Ibid., p. 15).

As mentioned on its project website, Mistra SAMS uses a deep transdisciplinary approach, which involves both interdisciplinary analysis and a close collaboration with users and practitioners. More specifically, as explained by the project coordinator Anna Kramers (personal interview, 3 October 2019), the choices of the technology to be tested and the specific research questions to be addressed in the living lab research were not all specified in advance at the start of the project. In a workshop with the 16 partners from academia, industry and the public sector, the project participants tried to understand what the living lab research would really contribute to the problems of Stockholm city. As observed by the participants, there were already so many co-working places, so how could this project impact on the ongoing transformation of work and workplace organisation in a positive way? In particular, the city of Stockholm liked the idea to analyse the impact on decreased car use in Stockholm by living lab participants, while the private company Ericsson was interested in testing their vision of a digitally networked society that will transform the way work is organised.

Based on these discussions, the participants agreed to set up a co-working for people who otherwise commute to distant office spaces and to analyse the impact on their use of car, public transport, cycling or walking. In a second step the proposal was sent to the main project stakeholders and transport officials for feedback and a second workshop was organized to integrate that material and decide upon the organisation of the living labs. An important question raised by the city of Stockholm was the inclusive nature of the proposed digitalisation of mobility and work solutions. Indeed, the co-working hub was situated in a well-off neighbourhood of Stockholm and the private company's first interest was to see how a sustainable business model can be developed around the new services. These inputs called for including a diversified public in the co-working space, both from the company and from free-lance workers in the neighbourhood. As stated by Tina Ringenson, reaching this goal was not especially easy, but through an active Facebook campaign and intense discussions with managers at Ericsson, a reasonably good composition was reached (personal interview, 19 September 2019). In a follow-up project that was awarded to Mistra SAMS (2021-2024) these questions will be further explored.

Overall, the feedback from the social actors throughout the project was important to further deepen the research question beyond the technological innovations only. This led Mistra SAMS to address a set of institutional and economic questions in the living lab research, such as the possible role of the public actor in organizing active mobility, the public transport options around the co-working hub and the possible impact of economic incentives on transport behaviour. Nevertheless, such broadening also comes with a cost. Indeed, seen the complexity of the many possible social, institutional and economic aspects, the project management has to select those aspects that are most relevant to the problems at hand, and the possible pathways and local opportunities for solving these problems. In the case of Mistra SAMS, the secret of the successful multi-dimensional approach seems to lie in the strong partnerships with some key societal partners, the systematic consultation of the partners before moving to the next step and the agile adaptation of the research tasks based on new inputs and insights from the research (Kramers & Akerman, 2019).

c. Use of visualisation tools in UnaLab

The Urban Natural Lab (UnaLab) addresses heat and water related problems in city environments through nature-based solutions. The project puts a strong focus on interactive co-creation with the city stakeholders and professional experts to implement selected nature-based solutions. Moreover, some of the projects offer interesting examples of collaborative design of dissemination outputs of a partnership research project, such as the Eindhoven UnaLab in the Netherlands.

More specifically, in the city of Eindhoven, the project addresses the problem of urban heat caused by the expansion of the built environment through urban sprawl and the lack of urban green in the city centre. In Northern Europe, temperature differences between city centres and rural areas in the summer can reach 3 to 10°C in densely built areas under clear and cloudless conditions (Van Hove et al., 2011, p. 4). This reality creates more intense heatwaves in urban areas and is expected to result in higher mortality, as observed for instance in several cities during the 2003 heatwave in France (Filleul et al., 2006).

The area between the Vestdijk Boulevard and the city centre of Eindhoven was chosen as one of the demonstration areas to experiment a range of different nature-based solutions addressing climate and water related challenges. The new design was created through a highly interactive planning and design process with the local stakeholders and citizens. The reconstructed Vestdijk Boulevard now only has one lane left for cars and one for buses. The trees and plants in the new green spaces have been selected to enhance the attractiveness and the biodiversity of the area and the soil capacity has been improved to increase the infiltration capacity. The introduction of more green spaces and less pavement also reduced the heat problem in the area.

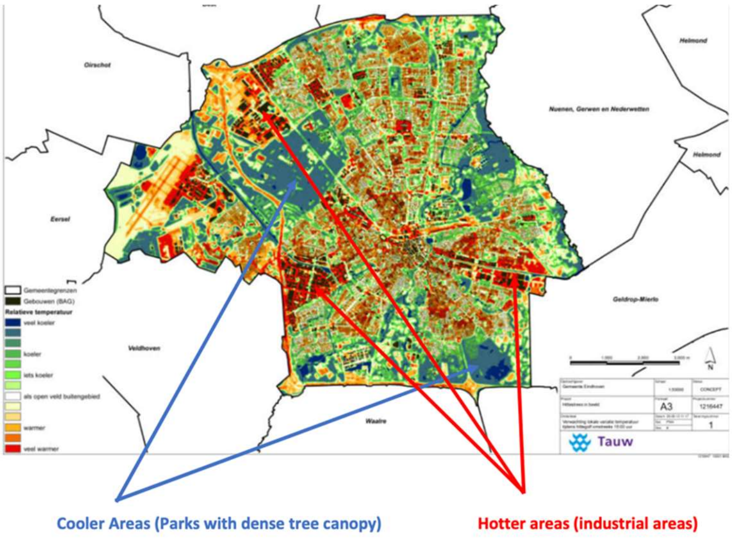

Figure 3.8. Interactive heat Stress map for Eindhoven (source: Bodilis, 2018, p. 39).

To evaluate these interventions, the project partners co-designed a heat map tool which visualizes the impacts of green infrastructure on the city as shown in figure 3.8. This heat map allows to show the contributions of new green infrastructures to cooling. In addition, the collected data was also integrated in the end of the project in a user-friendly interface that now serves as a capacity building tool for awareness raising and planning for the city officials. For reaching this outcome, the research partners needed to enhance the usability of the tool, so that users can easily simulate possible interventions in an efficient and attractive way. Through a set of interactive workshops for co-designing this project output, potential users raised a set of issues, such as the difficulty to understand the information displayed, the use of scales and colours and missing information to fully understand the role of greening in the city centre (Bodilis, 2018, p. 48). Further, important indicators for the city related to accessibility, biodiversity, water quality and air pollution were missing and were added to the maps. Overall, the resulting visual dashboard provides a visual support to various categories of end-users, following the establishment of the experimental nature-based solutions for combatting urban heat in the city centre.

Beyond the technical impacts on cooling of urban heat and flood management, important social and economic aspects were included in the on-line visualisation interface. On the technical level, the interface allows to simulate the heat impact of the introduction of blue spaces (very high) as compared to de-paving of roads for instance (quite low). On the socio-economic level, the interface shows simulation of change in housing prices around new large parks and the accessibility of inhabitants to urban green recreational areas. On this basis, in contrast to purely technical greening approaches, the interactive dissemination of the projects results provided also useful for a more integrated discussion on the outcomes of the cities' investment in green infrastructure, through including aspects such as inclusive well-being improvements and the combatting of urban sprawl.

3.1.3 Methods for user-centred technological innovation research

As argued above, researchers and social actors who aim to overcome the failures of "ivory tower" science to address multi-dimensional environmental, social, and economic sustainability issues are confronted to a double challenge. First, as amply illustrated in the discussion in chapter two of transitions in cross-cutting areas such as food, mobility or housing, there is a need to move from a technical focus on isolated problem dimensions to understanding system-wide features of social transition. Second, in doing so, researchers need to consider a plurality of pathways, which each envision different ways to create transitions that produce synergies and co-benefits among the most relevant sustainable development goals for the specific case at hand. Indeed, in many cases the systems approach does not lead to identify one optimal pathway but a plurality of pathways that fit both with the best available data and the diversity of social value orientations of the involved social actors.

What these two challenges show is that the development of science society partnership research over the last half century cannot be based on a rejection of conventional scientific methods but requires the integration of existing tools and methods in a new way of organizing the research process. Therefore, the failures of "ivory tower" science to address pluralistic and context specific transition pathways does not lead to a call for less science and less knowledge but to a call for more and better science, through enhancing the existing methods with new principles of collaboration and interactive knowledge gathering.

Through this process, both new research perspectives and social opportunities for synergies among the sustainability goals might emerge. Indeed, transdisciplinary user-centred research on new technologies is highly interactive, as the understanding of the transition pathways by the social actors evolve with the results of the scientific knowledge production. Moreover, researchers might revise their prior value assessments based on the ongoing dialogue with the social actors in the technological innovation pathways.

As science-society partnerships are still a relatively young and emerging branch of research, especially in the bio-physical sciences, research and social actors cannot yet rely on an established tradition of analytic methods that are most apt to be used in science-society partnership research. Nevertheless, a quick glance on the broad array of existing sustainable living labs and design for sustainability approaches shows that successful knowledge integration depends on the co-design of a multi-dimensional framework of analysis, which considers the problem framing of both the researchers and the social actors, and the organisation of a highly interactive and collaborative knowledge co-production processes.

Obviously, not all user centred research on technological innovation has proven successful, and many fields of research are still experimenting with methods to enhance their methods with the principles of collaboration and interactive knowledge gathering. For practical purposes, researchers and social actors can however find inspiration in some well-developed and successful sustainable living labs in various areas of transition.

To this purpose, table 3.2 shows some of the main methods that have been adapted and used in a successful way in partnership research on technological innovation in social and ecological transition process. This table defines success of the partnership research as a project that (1) produced integrated knowledge across the social, economic and environmental sustainability dimensions, (2) that was validated by the science and social actor participants and (3) that was disseminated both in scientific and social actor arenas. Other important goals, such as empowerment, problem solving or policy advice are clearly present in many of these cases. Often the latter are a key motivation for social actors and scientists to step into a partnership research agreement. Nevertheless, the use of a more restricted set of requirements for success allows to consider a broader set of partnership research in the analysis of available tools and methods.

Ideally, multiple methods for the various aspects of sustainability should be used at each of the three stages of the partnership research process: problem formulation (mainly in relation to synthesizing the prior art), analysis (multiple methods) and valorisation of the results (co-design of research outputs). Nevertheless, as illustrated in the overview of methods used in the various case studies above, research partners can often rely on prior studies and research results that already address some of these aspects in similar transition arenas. On the one hand, the researchers can rely on similar partnership research approaches in the given sector of social and ecological transition. On the other hand, social actors with experience in similar transition arenas can contribute to assess the relevance and feasibility of the methods for the case at hand. In the end, the appropriate mix of methods will depend on the mutual learning between the research partners and the specificities of the case at hand.

Table 3.2. Methods and fields of application of transdisciplinary partnership research into technological innovation processes

User and citizen co-design of technological drivers of change		
Food, agriculture and forestry		
Adding value to the food value chain in small-holder dairy farming, Kenya	LL	Restrepo et al., 2020
Housing and mobility in urban/rural living environments		
Citizen science in Manchester neighbourhoods with industrial pollution, United Kingdom	I-CS	Newman et al., 2020
Renovation of historic houses in inner city in Cahors, France (see text above: Cahors living lab)	LL	Claude et al., 2017
Green infrastructure in the inner city of Eindhoven to combat summer heat, the Netherlands (see text above: UnaLab)	LL	Bodilis, 2018
Green infrastructure in a city park to combat flooding in Tampere, Finland	LL	Särkilahti, 2019
Digital services for sustainable mobility solutions in Stockholm, Sweden (see texte above Mistra SAMS)	LL	Bieser et al., 2021; Sjöman et al., 2020
Production and consumption of manufactured goods		
Tiles for green roofs based on recycled plastic, Belgium	LL	Ragaert et al., 2020
Meaningful and decent work		
Seed selection for forage autonomy, France (see text above: CAPFLOR/SALSA)	LL	Goutiers et al., 2016; Lacombe, Couix et Hazard, 2017
Nuclear radiation around mines, Niger and Namibia	I-CS	Conde, 2014
Energy production and consumption		
Solar energy from a solar concentration technology demonstration facility in Palermo, Italy	LL	Di Bono et al., 2018

Legend. Successful research projects based on partnership research and a multi-dimensional approach to sustainability (collected from google scholar and selected collective volumes on transdisciplinary research). Projects are considered successful if they (1) produced integrated knowledge across the social, economic and environmental sustainability dimensions, (2) were validated by the science and social actor participants and (3) were disseminated both in scientific and social actor arenas. Methods LL: Living lab ; I-CS: Interdisciplinary and co-designed citizen science.

3.2 Participatory modelling and assessment of socio-economic drivers of change

As can be seen in the discussion of the technical levers of change, entrepreneurship and public investment play a key role in the dissemination or upscaling of technical solutions for transition. At the same time, entrepreneurship and investment activities are embedded in a broader framework of economic policy, planning and socio-economic decision making which can facilitate or inhibit social and ecological transition process. Strengthening this broader framework of socio-economic policies, with the view to avoiding undesirable outcomes and promoting desirable outcomes, is key to achieving the social transformations necessary for implementing the Sustainable Development Goals.

The 2019 expert-group that authored the 2019 Sustainable Development Report highlights various areas where socio-economic policies can play a key role as lever of change (UN, 2019b, pp. 32-34). Steering private entrepreneurship and domestic and foreign investment towards producing synergies among the various sustainable development goals is a powerful lever for achieving the necessary transformations. More specifically, policies that encourage trade in goods and services with fair prices, decent labour conditions and wages, and environmentally friendly production techniques can significantly boost progress towards the sustainable development goals (UN, 2019c). Further, private sector and non-profit actors can promote synergies among sustainable development goals through initiatives like social, environmental and corporate governance reporting or principles for responsible investing.

The community investment scheme established by the worker unions' sponsored investment fund "Fondaction" in Quebec is a good example of a successful sustainable investment fund. This fund not only invests in stock markets based on strict responsible investment rules but also finances deep-seated needs of local communities not addressed by mainstream finance, including poverty alleviation, community development and environmental regeneration (Strandberg and Plant, 2004; Lévesque, 2017). As of November 30, 2020, Fondaction managed assets of 2,61 billion US dollar thanks to retirement savings entrusted by more than 177.500 shareholders from the Quebec population. Fondaction invests these savings in more than 1200 Quebec SMEs engaged in the transition to sustainable development, directly or through specialized funds (www.fondaction.com).

Moreover, effective tax policies remain vital to generate the resources for public expenditures and investments, both domestically and abroad. Indeed, as highlighted in the 2019 Sustainable Development Report, international development cooperation remains vital to support many developing countries to invest in basic infrastructure, health, education and public goods, and to provide support to strengthening public administration and governance. In this context, assistance to economic infrastructure and services – the second largest category of official development assistance – has been growing in recent years, particularly in the energy sector (UN, 2019b, p. 33). Nevertheless, over the last decade, investments in renewable energy and other financial support with direct environmental benefits remained a relatively small part of the official development assistance, which still includes major investments in fossil fuel plants and fossil fuel subsidies to consumers (OECD 2017, p. 119 and 126; UN, 2019c, p. 41).

As shown by scholars both in economics and sustainability science, conventional disciplinary economic theorizing alone fails to provide an adequate framework for such multi-dimensional economic policy and decision making (Scrieciu, 2007; Salas-Molina, 2019). Two main reasons are highlighted in the literature. First, classic micro-economic theory models economic agents, such as consumers and firms, as rational decision makers who maximize an economic utility or profit function, subject to a budget or cost constraint (Salas-Molina, 2019). In practice, to produce easy to compute models, economic modelling considers one criterion of maximization, be it the firms' profit or the consumers' satisfaction gained from the consumption of goods or services measured through their utility function. However, as seen from the examples above, to produce the most socially desirable solutions to integrated sustainability problems, public and private entrepreneurs need considering more than one single criterion in the output variables of the model.

Second, in disciplinary economic models that do consider multiple-dimensions, these dimensions are often considered in quantitative terms only, while many social and socio-environmental sustainability dimensions are more appropriately captured by a qualitative research approach. This failure by the quantitative models to capture many of the real-world decision-making features is also recognized in current practice in interdisciplinary market research for instance, as quantitative research fails to capture the emotional and social-psychological features of consumer choice. In this context, firms massively use qualitative focus group meetings with prospective consumers to better understand the real-world multi-dimensional decision criteria of human agents.

In the context of economic theorizing, the limits of quantitative approaches have been extensively documented in the literature on social cost-benefit analysis (Nussbaum, 2000; Masur & Posner, 2011). Indeed, cost-benefit analysis adopts a quantitative approach to both the economic and social dimensions, for example through calculating a monetary equivalent for assessing the social values. This approach might give an idea of the efficiency of a policy measure at a certain moment in time and in each context. Nevertheless, the results of such an analysis cannot account for the broad scope of intangible social benefits that often drive sustainability transition in the long run, such as the formation of social bonds or the creation of more inclusive societies. Moreover, as argued in the general introduction to this section, to take into account the plurality of viewpoints on multiple socially desirable and efficiency improving pathways, researchers need to integrate the perspectives from social actors in the design of the socio-economic assessment.

In response to these well-known failures of disciplinary economics to address broader social and socio-environmental dimensions of sustainability transformations, scholars and entrepreneurs have developed a set of multi-disciplinary and interdisciplinary decision support tools. These decision support tools consider multiple criteria, both in a quantitative and qualitative manner, and, through an interactive knowledge gathering process, organize a dialogue on the value-laden choices among the plurality of socially desirable transition pathways. Within transdisciplinary research on socio-economic drivers of change, two research traditions in particular have been highly successful in enabling multi-actor and multi-disciplinary partnership research.

First, management science scholars, from within the interdisciplinary tradition of operations research, have developed multi-criteria analysis methods, based on the general idea of minimizing the sum of the deviations between achievements and goals set by decision makers (Salas-Molina, 2019). The development of this approach resulted in a wide diversity of methods, both in micro-economic and macro-economic decision making, which better reflect the socio-economic reality of social actors that need to consider multiple and conflicting criteria. As will illustrated below, these methods have been widely used in transdisciplinary partnership research, as the multi-criteria assessments methods increasingly introduced stakeholder contributions to the analysis.

A second research tradition further developed the quantitative modelling perspective by integrating the long-term and qualitative dimensions through the exploration of sub-models that represent desirable future scenarios or options for change. These participatory complex system models combine quantitative modelling with various constraints introduced in the modelling exercise through the consideration of specific value laden options and scenarios that are co-constructed with the social actors (Macharis et al., 2009). Participatory complex system models do not provide the same accuracy and rigorous control of all the variables as conventional disciplinary models, but they allow for a better understanding of the outcomes of envisioned action strategies and future scenarios in a scientifically sound and socially robust manner, as illustrated in table 3.3.

Table 3.3. Strengths and weaknesses of participatory complex system models (source: adapted from Schmetska & Gaube, 2020)

		Combined to	
	Participatory research	**Participatory complex system models**	**Predictive modelling**
Strengths	• Socially robust knowledge • Improved communication	• Scientific sound results for future scenario and envisioned strategy outcomes • Integration across social and natural sciences • Enables deliberation	• Rigorous control of the variables • Accuracy • Need for reduction
Weaknesses	• Doubts on accuracy and effectiveness	• Time consuming • Demanding	• Abstract
Expected achievement	• Dialogue	• Options for change • Interactive interface • New perspectives	• Systems thinking

This section draws upon these two thriving research traditions of multi-criteria assessment and participatory complex system modelling, with the view to present tools and methods that contribute to transdisciplinary partnership research on the socio-economic levers of sustainability transitions. More specifically, through examples of transition challenges in mobility systems, energy research and food systems, this section will illustrate the various ways in which these methods can be adapted to partnership research and provide a better understanding of the socio-economic dynamics in society-wide transition processes.

3.2.1 Sustainable mobility in Potsdam, Germany

The ClimPol research group at the Institute for Advanced Sustainability Studies in Potsdam, Germany, provides a good illustration of highly successful partnership research on mobility planning in an integrated sustainability perspective. The group develops this research in cooperation with international science partners, the federal government, the state of Brandenburg and local business and society partners. The team worked in 2015-2016 on a multi-criteria assessment of possible solutions to the widespread air pollution that recognizes the importance the social dimension of mobility transitions and can be used in combination with the more conventional technological and economic measures.

As aptly summarized on ClimPol website, air pollution is currently one of the most important environmental problems worldwide. According to the Global Burden of Disease study published in *The*

Lancet, 4,2 million premature deaths were caused by outdoor pollution in 2015 alone (Landrigan et al., 2018). Pollutants such as particulate matter with an aerodynamic diameter smaller than 2.5 µm (PM2.5), nitrogen oxides (NOx) and tropospheric ozone (O3) are a cause of cancer, respiratory and cardiovascular disease, and premature death (EEA, 2019). In addition, nitrogen oxides (NOx) and tropospheric ozone (O3) produce harmful damage to vegetation and fauna directly, as well as affecting the quality of water and soil.

Nevertheless, despite this wealth of scientific data, in 2019 in Europe alone most urban populations were exposed to levels of pollution that exceeded the World Health Organisation (WHO) guidelines (see table 3.4) and the yearly death toll almost equals the 2020 Covid-19 excess mortality, as shown in the latest available statistics for the year 2016 (see table 3.5).

Table 3.4. Urban air pollution in EU-28 (source: EEA, 2019, p. 7).

Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (minimum and maximum observed between 2015 and 2017)

Pollutant	EU reference value (a)	Urban population exposure (%)	WHO AQG (a)	Exposure estimate (%)
PM_{10}	Day (50)	13-19	Year (20)	42-52
$PM_{2.5}$	Year (25)	6-8	Year (10)	74-81
O_3	8-hour (120)	12-29	8-hour (100)	95-98
NO_2	Year (40)	7-8	Year (40)	7-8
BaP	Year (1)	17-20	Year (0.12) RL	83-90
SO_2	Day (125)	< 1	Day (20)	21-31

Key: < 5 % | 5-50 % | 50-75 % | > 75 %

Legend. Reference values in brackets in µg/m3, except BaP, which is in ng/m3. The colour code indicates the percentage of the population that is exposed to pollution above the thresholds, respectively for the EU reference values (column 2) and the stricter WHO reference values (column 4).

Table 3.5. One year mortality of fine particulate pollution and 2020 excess mortality due to COVID-19 compared (sources: (a) EEA, 2019, p. 8; (b) Eurostat, 2021).

	Premature deaths (EU-28) - year 2016 (a)		Excess mortality (EU-28) - year 2020 (b)
PM2,5	374,000	Covid-19	545,000
NO2	68,000		
O3	14,000		
Total	456,000		

At the same time, policies for combatting air pollution and climate change have a considerable potential for generating many co-benefits and synergies among sustainability goals (Diggelmann et al., 2010; Buehler et al., 2017). For instance, the research group on mobility and climate at ClimPol developed a holistic vision that clearly highlights such co-benefits and possibilities for attenuating trade-offs (Schmale et al., 2016, p. 73). As shown in the project, urban development focusing on expanding public transport and active mobility (cycling and walking) provide major health and social welfare benefits, while contributing to curbing air and noise pollution. A quantitative assessment of the extension of park and ride facilities outside the city centre – connecting with tram, buses and cycling lanes, see figure 3.9 – shows the high impact of such urban development measures both on emissions, greenhouse gasses and accessibility to affordable and efficient transport options.

Much research on transport and pollution is still conducted through expert led disciplinary science. As shown in a review of scholarly work by the ClimPol project team, most mobility planning decision-support tools are focusing on one issue, whether it be traffic planning, air quality plans or energy-related policies (Von Schneidemesser, 2017, p. 3). For instance, time efficiency surveys focus on individual route planning, which lead to put a heavy focus on time gains that can be made by various mobility choices, without considering measures to stop the circle of increasing travel speed, travel distances and energy consumption (BFS & ARE, 2017; Hoppe & Michl, 2017). Other studies use cost-benefit analysis, to compare the costs of mobility choices with various benefits in terms of satisfaction of individual mobility needs and pollution impacts but without considering the broader benefits on urban welfare or quality of life, which cannot be captured entirely in quantitative measures (Delhaye et al., 2017). As a result of these mono-dimensional analyses, the various impacts of mobility choices are analysed separately, leading to advice that fails to motivate social actors for system-wide mobility transitions.

Figure 3.9. (left) Well-connected park and ride facilities outside of Potsdam city centre; (right) Potsdam city centre (source: Oelschlager, 2019; Kutzner, 2015)

To support multi-dimensional decision making on mobility transitions, the research group on mobility and climate developed a multi-criteria assessment jointly with scientists, practitioners and decision makers, between 2015 and 2017 (Schmale et al., 2015; 2016). This assessment included environmental considerations, as well as considerations for road safety, eco-mobility and quality of life.

As stated by the project team, to successfully apply such a multi-criteria assessment to complex urban transport challenges, several types of knowledge need to be included. Practical knowledge was used to judge for example feasibility of local travel options, while discussions with social actors played a role in clarifying value choices related for instance to social equity in urban planning. Scientific knowledge contributed to the various quantitative and qualitative assessments of environmental, economic and social impacts. To integrate these various types of knowledge, knowledge co-production was organized at the various stages of problem framing, scientific analysis and valorisation of results. The objective of applying a multi-criteria assessment in the case of Potsdam was not to decide between several alternative measures but to support the municipality in linking the various measures to existing urban planning programs in various departments of the municipality.

a. Collaborative problem formulation and constitution of the research team

Initially, the city's « urban- and climate-friendly mobility » initiative identified over 75 specific measures that were in the planning or pre-implementation stage in 2013. With so many measures it was difficult to maintain an overview of the synergies, overlaps or counter-productivity of the measures and to assess the priorities within the limited city's budget.

In a first phase, the project team gathered roughly ten representatives from various departments of the municipality's administration, one person from the state province and one from the ministry of environment, as well as two natural scientists. This working group framed collaboratively the main research questions and decided upon the use of a multi-criteria analysis based on a scoring of the various measures, combined with group-based discussions for converging on the scores based on available scientific data and practitioners' knowledge.

b. Integrated scientific analysis and science-social actor knowledge co-production

All measures were assessed by a multi-criteria method that considered impacts on six categories: air quality, climate change, noise emissions, road safety, eco-mobility and quality of life (see figure 3.10). As the project worked with a list of measures that are already in the municipalities' planning stage, the consortium decided not to prioritize the measures based on financial cost of implementing the measures. As will be seen below, the economic considerations were introduced later in the project, through a discussion on changes to the municipalities' budget based on the project results, whereby finances were reallocated so that the highest priority measures were to be realized in the middle to near term.

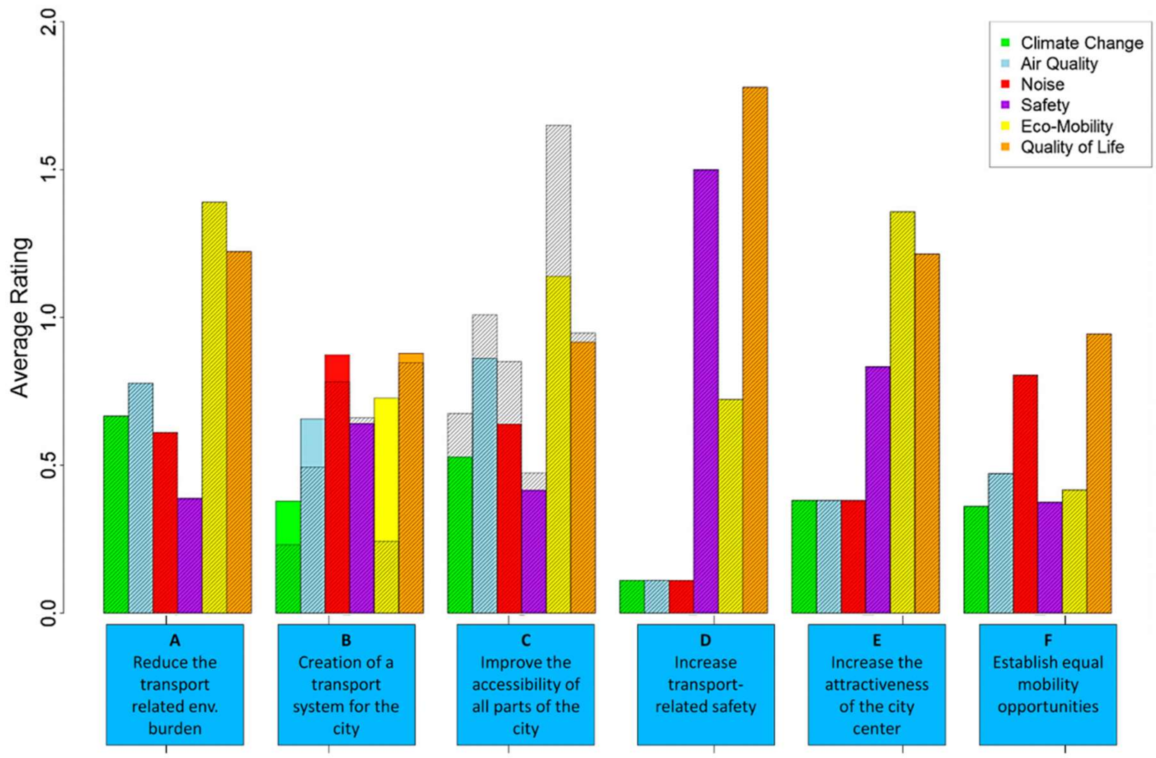

Figure 3.10. Participatory multi-criteria assessment of 6 transport scenarios in Potsdam, Germany (source: Schmale, 2015).

Based on the scoring of the list of specific measures, the results were averaged, and different weighting factors attributed to the categories. The latter were adjusted with the view to give greater weight to those categories responding to legal obligations and city targets. Subsequently, an average index value per measure was calculated, resulting in a ranking where measures with the highest synergies received higher priorities.

The integrated assessment was applied in a one-day workshop. Prior to the workshop, the team conducted research to select the criteria and gather the best available scientific data. At the workshop, breakout groups ranked the various measures. The resulting scores were statistically analysed by the scientists and presented to the participants in the various working groups. Further discussions, adjustments, plausibility checks and decisions on weighting of the various criteria were carried out within the plenary workshop meetings.

Table 3.6 presents the list of generic measures that are ranked as very high and high priority. The very high priority group included extension of park and ride facilities (connecting public transport with cycling and motorized traffic), enhancement of infrastructure for public transport and cycling, managing parking spaces in the city (to discourage driving), as well as the creation of a mobility agency. Most measures were assessed based on reference data and previous experience. In addition to this expert related data, more qualitative factors such as public acceptance and contextual features were included through group-based discussion among the participants. An example of such contextual information is the projected use of the park and ride facilities, which included the assumption by the municipality that their usage would be required and not wholly optional, mainly by measures for limiting the traffic flow into the city.

Table 3.6. Number of priority measures within the various types of measures, project outcome of the Potsdam multi-criteria assessment (source: Schmale, 2015).

Generic Measure Type	Number of Specific Measures of the Generic Type Included in the Priority Group
group 1 (very high priority)	
connecting public transport options with cycling and motorized traffic	5
public transport infrastructure	3
cycling infrastructure	2
parking	2
mobility management	1
integrated urban development	1
new or re-construction of street sections	1
group 2 (high priority)	
pedestrian friendly city	2
new or re-construction of street sections	2
new mobility options	2
service around cycling	1
parking	1
speed limits	1
public relations work	1
emission reduction for vehicles	1
connecting public transport options with cycling and motorized traffic	1
mobility management	1
higher quality of public transport	1

c. Joint interpretation of the research results, dissemination, and societal valorisation

The social valorisation of the research results was mainly related to the implementation of the priority measures within the city mobility plan. Based on the project results, the measures foreseen in the budget for the next six years were adjusted to follow the final project ranking.

The scientific impact of the project was two-fold. First the project further elaborated a method initially tested for integrated sustainability planning in Basel in 2003 (Stauffacher & Scholz, 2013), by more explicitly integrating urban welfare issues and a strong partnership with the local decision makers in the design of the process. Second, the project led to the formulation of a series of follow-up research questions around the implementation of several of the proposed measures.

Nevertheless, despite the projects' successful results, the project team mentions the urgent need of the further development of higher education and career opportunities in transdisciplinary approaches. Transdisciplinarity in transport planning is still a novel method and more projects are needed to reach a critical mass. More specifically, it remains a challenge to translate scientific knowledge on integrated approaches to context specific issues, such as tackling mobility related air quality and CO2 emissions at local and sub-national policy level (von Schneidemesser, Kutzner and Schmale, 20178). The main barrier identified by the ClimPol research is the gap between available high-level and aggregated scientific knowledge on mobility systems on the one hand and the information on sub-national and local-level impacts of air quality and climate change mitigation measures on the other. As concluded by the authors, effective on-the-ground sustainability transitions need to go hand in hand with production of knowledge at appropriate local and sub-national scale to inform these transitions.

3.2.2 Self-explaining people-friendly street design in Auckland, New-Zealand

The Future Streets project in Auckland, New Zealand, is a good illustration of the outcome of a series of transdisciplinary partnership research projects based on systems dynamics modelling and community surveying. The project is headed by a multi-stakeholder consortium from the regional transport planning authority (Auckland Transport), the New Zealand Transport Agency, local community leaders, various local transport consultancies and university researchers (Mackie et al., 2018). The various research projects that led to Future Streets were inspired by a pilot project on traffic calming in Point England, Auckland. The pilot project modified local streets by making them less formal, removing line marking, placing planting and artwork to slow motorists, and reinforce a sense of place, as illustrated in figure 3.11. Five years after this pilot project the annual social cost of traffic crashes in the intervention area had halved, with more pedestrians and cyclists using local streets (Mackie et al., 2018).

Figure 3.11. Pilot project on traffic calming through self-explanatory features and introduction of greening and indigenous artwork providing a sense of place (source: MacMillan and Mackie, 2016, fig. 3).

The idea of broadening this pilot project to a set of social interventions for redesigning the streets in the Mãngere neighbourhood in Auckland is the result of several years of collaborative research. The Mãngere area is an area with a large indigenous population. The area was selected because of the high number of fatal and serious car crashes in the neighbourhood. The choice of the various priority interventions in the area was based on intensive community consultation and the insights from a series of projects that were conducted from 2014 to 2016.

More specifically, in 2014 the project team ran a participatory dynamic system modelling with the view to assess the sustainability benefits of three different active mobility infrastructure projects (Macmillan et al., 2014):

a) Regional Cycle Networks: a project by the Auckland Regional Council to develop a mixed cycling infrastructure based on on-road marked lanes with no physical segregation, off-road shared footpaths and a small number of new shared bus and bicycle lanes
b) Arterial segregated bicycle lanes: creation of physically segregated cycling lanes on high-capacity urban roads
c) Self-explaining roads: traffic calming on the local roads through self-explaining features such as road narrowing, trees and art

Through careful selection and ongoing collaboration with the non-academic project partners in a socially inclusive way, the project team was able to generate a high level of uptake of the research results by the local communities. After the first participatory modelling exercise, various of the research questions were deepened both in follow-up research and in proposed social interventions such as the Future Streets project.

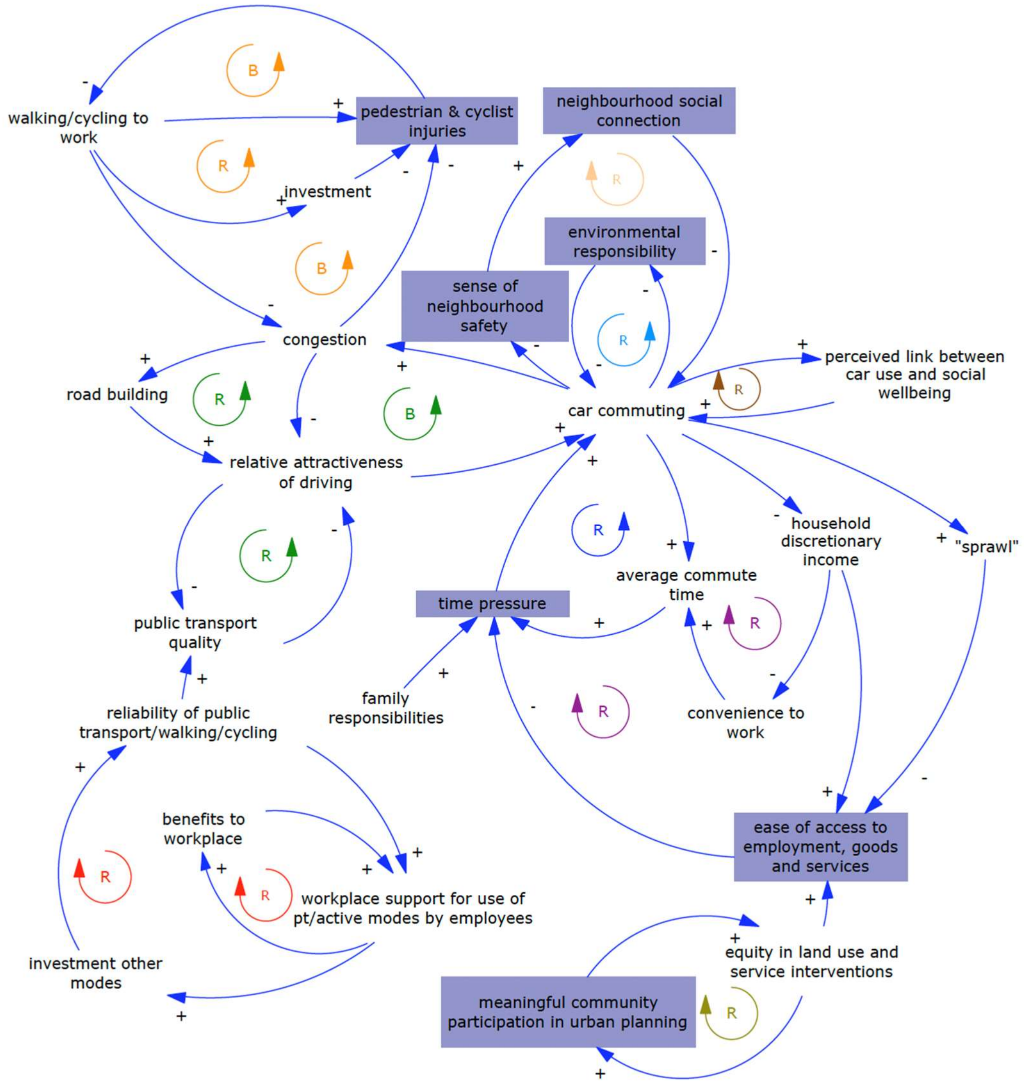

Figure 3.12. Causal loop diagram of the trip to work and wellbeing. Arrows with a positive sign (+) indicate a change in the variable at the arrow-tail in the same direction. Arrows with a negative sign (−) lead to an inverse change in the arrowhead variable ; R – Reinforcing loop, the result of which is an amplification of the initial pattern of behaviour ; B – Balancing loop, the result of which may be to dampen the initial pattern of behaviour or create oscillation (source: Macmillan and Mackie, 2016, fig.2.).

a. Collaborative problem formulation and constitution of the research team

For the initial participatory systems dynamics study in 2014, the research team created a stakeholder group of 16 people from public authorities, citizens from various social groups, researchers and representatives of indigenous communities from the Mãori and Pacific people (Macmillan et al., 2014).

The constitution of a representative, comprehensive stakeholder group, with connections to local and regional policy was considered a key condition of a successful participatory modelling process. Among others, the creation of a comprehensive stakeholder group allowed a continuous process of confidence building with the social actors.

b. Integrated scientific analysis and science-social actor knowledge co-production

In 2014, the project team created a detailed quantitative model of a sub-system of the overall dynamic system model, as illustrated in figure 3.13. The aim of the quantitative model was to understand the costs and the impacts of the three different active mobility infrastructure projects on bicycle mode share, cyclist injuries and air pollution, in a period running from 1991 through 2051 (2014). Interestingly, the combination of self-explanatory slow-traffic roads and arterial segregated cycling lanes produced by far the best cost-benefit ration in the simulation (Macmillan et al., 2014)

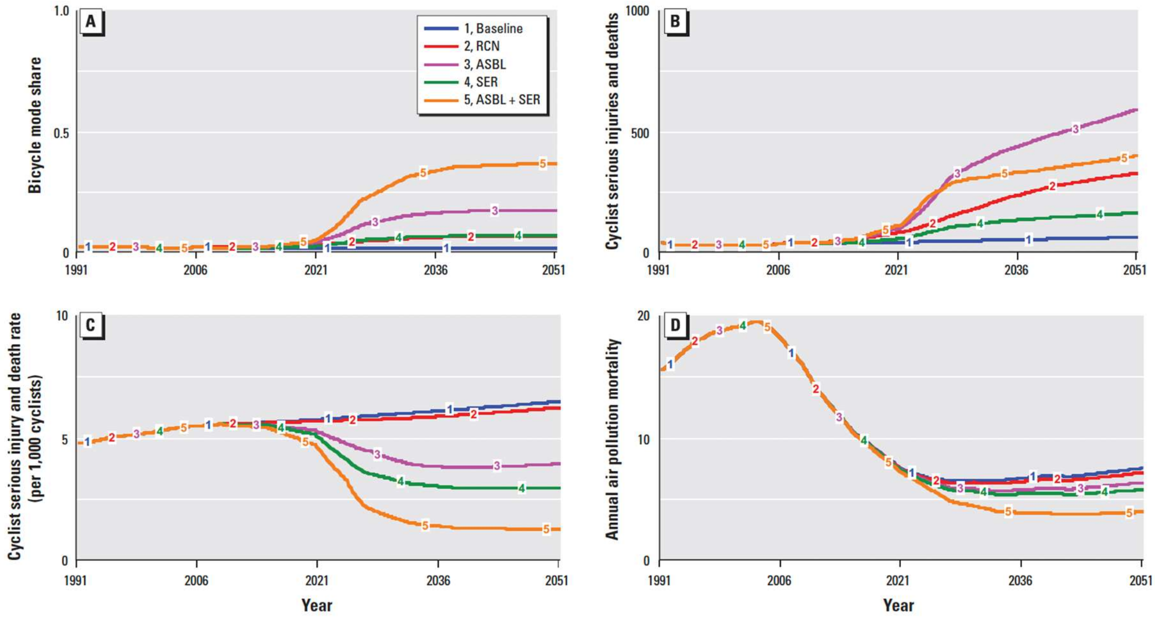

Figure 3.13. Modelling of 5 mobility scenarios for the street design, with outcomes for active mobility, safety and pollution: baseline ; RCN: information brochures on regional cycling networks; ASBL: arterial segregated bicycle lanes; SER: self-explanatory slow-traffic roads (source: MacMillan et al., 2014, p. 341).

Figure 3.12 represents the more complete dynamic system model that was elaborated in the 2016 follow-up project. The model results from a stepwise research process, based on semi-structured interviews, literature search and multi-stakeholder workshops, and was finally elaborated with the support of dedicated modelling software.

As can be seen from the figure, both economic, environmental and social sustainability dimensions are included in the understanding of the dynamics of the system. This model helped to build consensus around an integrative understanding of the socio-economic system and supported further research on different aspects of the integrated system that both have significant impacts and are highly relevant to the community.

More specifically, based on a vast number of community engagement meetings, the project identified various social well-being factors that were highly valued by the community, such as neighbourhood connections, a sense of neighbourhood safety and ease of access to employment, goods, and services (2016). In addition, the researchers also engaged with cultural values that are important to the indigenous communities of the neighbourhood. The latter led to road improvements that reflect the identity of Māngere people. Some of these improvements are coloured pathways that refer to shark oil traditionally used by Māori (Kōkowhai – yellow), use of endemic plant species in the plantings for slowing traffic and signposts for wayfinding to culturally relevant landmarks (Mackie et al., 2018).

c. Joint interpretation of the research results, dissemination, and societal valorisation

From a scientific point of view, both the 2014 initial participatory dynamic system model and the more elaborated 2016 model were highly innovative and lead to a series of follow-up research projects on various of the identified co-benefits between sustainability goals.

From a societal perspective, the Future Street project in the Mãngere area of Auckland is the most visible project outcome. In addition, the follow-up partnership research was directly based on the insights gained from the dynamic systems modelling, such as a project on quantitative and qualitative assessment of the multi-dimensional sustainable development impacts of the Future Streets project (Macmillan et al., 2020).

3.2.3 An integrated approach to sustainability in participatory modelling and assessment

To design economic levers that produce social, economic and environmental co-benefits, scholars and entrepreneurs have adapted a broad range of participatory modelling approaches, with the view to combine quantitative and qualitative research tools. As indicated in table 3.3 above, the key strength of conventional quantitative computational models used in socio-economic analysis is the accuracy of the produced results and the generic system results that can be compared across cases. However, many of the core social sustainability variables, such as strengthening of social bonds or work-life balance, cannot be captured in quantitative measures. Therefore, for navigating multi-dimensional transition outcomes, new approaches are needed that combine the strengths of the computational approach for modelling socio-economic systems, with the strengths of qualitative research approaches, such as surveys and participatory research processes.

The two sustainability mobility case studies analysed above illustrate two of the main computational modelling approaches that have been adapted for their use with mixed quantitative/qualitative data in socio-economic analysis. The first are participatory multi-criteria assessments and decision support models, illustrated through the Potsdam ClimPol project, and the second participatory dynamic system modelling, illustrated through the Future Streets project. As we will see in the short review of some other cases below, ideally one should combine both methods. Indeed, the multi-criteria models allow to better understand the appropriateness of various decisions options based on the desirable system outputs, while the dynamic system modelling allows to provide insights on the way that changes in the inputs to the system (the parameters of the local context, or of likely future trends and scenarios) modify the overall system dynamics. Obviously, computational models that provide new insights both on the decision options and the likely system dynamics can provide a more complete understanding of the system.

In many cases, however, such a combined approach is not feasible, and researchers will opt for one of the two computational approaches, based on the most salient research questions. Moreover, available knowledge from prior research and local expertise can also provide reliable insights both on the dynamics or the decision options to complete the research framework. In any case, whether the research team opts for an approach based on multi-criteria analysis or participatory system dynamics modelling, the major challenge for using the computational models is to integrate the more qualitative sustainability goals into the research process. Therefore, in each of the next sections, before discussing the use of these methods in the analysis of various society-wide transition processes, some general strategies are presented that researchers and social actors can use to combine the quantitative and qualitative aspects in participatory systems and multi-criteria computational modelling.

a. Integrating environmental, economic and social sustainability in participatory complex systems modelling

Ever since the publication in 1972 of the influential computational models of "The limits to Growth" by Dennis Meadows and her co-authors at MIT, computational modelling of system dynamics has been improved and has become a key tool for our understanding of the evolution of complex socio-economic systems. Grounded in organisational research and systems theory, system dynamics models typically analyse networks of cause-effect relations among the elements of a system and feedback loops that stabilize or amplify changes in the system through time. This simulation of system-wide effects of networks of causal relations and feedback processes makes system dynamics modelling well suited to exploring emergent system-level behaviour of integrated social-ecological systems and assessing the implications of management or policy interventions in these systems (Schlüter et al., 2019).

However, the use of computational models alone is not sufficient to understanding the dynamics in the multi-dimensional sustainability transition processes. Indeed, the recourse to formal approaches could also hamper the integration of social sustainability considerations into the understanding of the system dynamics. For instance, as highlighted by an analysis of various modelling techniques used in natural disaster risk management, the time spent on data collection for realistic bio-physical modelling, the calibration of the models to the bio-physical situation and the validation through real-world experiments often affects the time left for integrating social scientific knowledge into the computational modelling exercise (Hedelin et al., 2017).

The in-depth review by Maja Schlüter and her colleagues of dynamic modelling tools, and the comparison of dynamic modelling tools in the PhD thesis of Laura Basco Carrera, both identify the more recent development of participatory complex systems modelling as a promising alternative to the expert-led and bio-physical data driven simulation models (Schlüter et al., 2019; Basco Carrera, 2018). In particular, the approaches based on mediated modelling (van den Belt, 2004), group model building (Vennix, 1999) and companion modelling (Etienne, 2013) seem especially suited to integrate social sustainability concerns (Basco Carrera, 2018, p. 182). These approaches are based on co-development of system dynamics models by the social actors and the researchers, with several iterations allowing for joint learning on the system understanding and problem perception. For instance, in the case of companion modelling, research projects often combine computer simulations with role-playing games based on the same system dynamics model. As shown by scholars of companion modelling, combining the computational approach with the role-playing game facilitates learning among the researchers and the social actors in complex and often power-ridden problem situations (for an illustration in irrigation management, see for example Gurung et al., 2006).

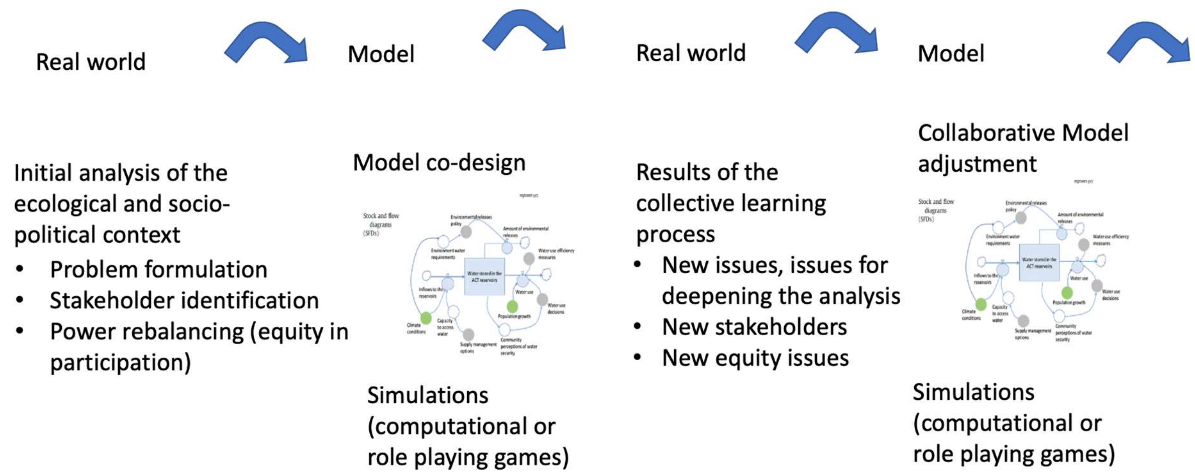

Figure 3.14. Iterative development of participatory system dynamics models (source: figure by the author, based on the discussion in Etienne, 2013, p. 24).

More generally, participatory systems dynamics modelling has shown to facilitate learning among social actors and to support the exploration of alternative development pathways. In practice, as the understanding of the social actors evolves during the participatory modelling process, researchers need to update and adjust the computational models in various rounds of model design. The first phase, the building of the model, requires input from a broad range of people and an initial understanding of the main causal interactions in the socio-ecological system. In the next phases, the computation of the model in a series of test runs allows to tackle the limitations and flaws of the initial intuitive mental models of social actors and researchers, used for capturing the dynamics of complex systems in the initial phases of the research (Videira et al., 2010). Therefore, as the theory and practice of participatory modelling built up over the years, researchers increasingly realized the importance of the ongoing commitment of the researchers and social actors throughout a series of iterations between computational modelling and participatory workshop discussions as illustrated in figure 3.14. and table 3.7.

One project that ranks quite high on ongoing commitment to co-production features is the NATCAP project in Belize, Central America. The NATCAP project provided data intensive real-world modelling of ecosystems health and fisheries revenue in Belize, a coastal state in Central America (Verutes et al., 2017; Arkema et al., 2019). A six-year collaboration (2010-2016) between the research consortium of NATCAP and the Coastal Zone Management Body allowed to build relationships, make scientific advances and strengthen local planning capacity. Through joint data gathering among scientists and various Coastal Advisory Committees, the project was able to identify sensitive habitats and explore alternative strategies to over-intensive coastal real estate development and aquaculture, with the view to safeguard the long-term sustainability and revenues of the coastal lobster fisheries. In particular, the project led to the 2016 management plan, considered visionary by many observers, which allowed to overcome conflicts among sectors competing for limited space such as oil exploration, aquaculture, fisheries, coastal real estate development and unique mangrove ecosystems.

The LUTAQ project (2001-2002) produced a simulation of the interactions among urban planning variables and transportation use variables (Stave 2002; 2010). LUTAQ shows that urban densification is ambiguous: densification alone leads to more private car use. In contrast, densification plus specific sustainable lifestyle supporting measures such as carpooling, infrastructure to active mobility and access to urban green areas might lead to positive outcomes for sustainable mobility. The system view resulting from LUTAQ did not remain just academic wisdom without connection to the societal dynamics of change. As stated in the detailed analysis of the case, “the entire working group was engaged in all phases of the model development except the detailed equation development and testing” (Stave, 2010). As a result of the knowledge co-production, the project changed the stakeholders’ perspectives, created new competences for systems analysis for urban planners and transportation officials, and enhanced the collaboration among actors from various departments.

The TERIM project provided an agent-based model that simulated the action and interactions of various stakeholders in the energy system in the Weiz-Gleisdorf region in Austria (Binder et al., 2014). The project led to a strong shift in understanding of action priorities by the multi-stakeholder steering board of the energy region Weiz-Gleisdorf. Initially focused on reaching regional energy sufficiency through using local biomass, the research team gradually shifted the focus towards reducing energy demand through renovation as the main action priority. In addition, despite a highly technical focus on satisfying energy demand through local/regional energy sources, the project gathered new evidence on the importance of social networking for motivating sustainable energy choices and documented the key role of the involvement of diverse social groups in the governing body of the energy regions.

Table 3.7. Overview of the case studies discussed in section 3.2.2. (a)

Participatory complex systems modelling										
Project name	Topic of multi-dim (envt., social,econ.) sustainability research	Co-production			Scientif. outcome		Type of societal outcome			
		co-design	Joint anal.	Disc. Results	New data	Integr. Learn	Collaboration	Strategy	Competences	Solutions
Food, agriculture and forestry										
NATCAP, Belize	Integrated planning that safeguards ecosystems, lobster fisheries and balances multiple objectives in coastal Belize	*	**	**	**	*	*	**	*	*
Urban/rural living environments										
LUTAQ, Las Vegas, US	Impact of land use choices for built infrastructure (housing, services, work) on sustainable mobility.	***	***	***	**	**	**		**	
Energy production and consumption										
TERIM, Austria	Renewable energy options that enhance economic self-reliance	**		*	*	**		**		*

Legend. Scale for co-production: consultation only (*), joint research on some aspects (**), on nearly all aspects except some technical issues (***). Scale for scientific outcome/ societal outcome: mentioned in project publications (*), well documented (**), with in depth analysis (***).

Despite this contribution of these various methods participatory modelling to the understanding of sustainability transitions, the integrated analysis of the environmental, social and economic dimensions of sustainability still remains a considerable challenge. First, in relation to environmental sustainability, the review by Maja Schlüter and her colleagues of dynamic modelling tools, which was mentioned above, shows that many computational models lack links to the real world, particularly regarding the integration of context specific and historical path dependent features of real world social-ecological processes (Schlüter et al., 2019).

In contrast, as shown through the many successful cases discussed in the companion modelling handbook by Michel Etienne and his colleagues, hybrid approaches combining agent-based modelling with real-world role-playing games have shown to be able to generate collective learning, and improve the understanding of dynamics and drivers of sustainability transition processes. For instance, the agent-based modelling co-designed with local farmers in the highlands of upper northern Thailand highlighted the interdependencies between soil erosion, access to rural credits and the selection of erosion resistant perennial crops. Among others, the model highlighted how the irrigation needs for the perennial crops could result in social tensions around equitable access to agricultural water. In the end, the process resulted in a better understanding of the various social actors' perspectives on these problems and a collective identification of socially acceptable solutions (Barnaud et al., 2008; Barnaud et al., 2010).

Second, in relation to inclusive economic sustainability, one of the key principles of the companion modelling approach is to promote equity in participation and empowerment of more marginal actors to bring their knowledge to the modelling process. This inclusive approach has shown to enable the creation of new mutually supported insights, which are not anticipated by the actors of the transition processes. For instance, the participatory design of a computational model for the sustainable management of a community forest in Southern France revealed the potential contribution of practices of wood cutting by small-scale farmers, as it both contributes to their own economic subsistence and provides for tangible biodiversity benefits. In the first round of simulations, such practices were not included as they were considered contrary to science based rational forest management by the regional forest administration (Simon & Etienne, 2010).

Third, in relation to the improvement of social sustainability, computational models as such often fail to address the more qualitative aspects of social sustainability, such as building of social bonds, social integration of disenfranchised social group or improving quality of life. Therefore, as highlighted by various case studies, combining computational modelling with other research tools and methods such as field work and surveys, shows the highest potential for contributing to enhance the scientific basis of a multi-dimensional understanding of transition processes (Schlüter et al., 2019). Indeed, one of the largest benefits of participatory modelling may be their potential as a learning tool to challenge thinking in disciplinary silos and highlighting differences in values and worldviews between different knowledge systems. As a result, combining participatory modelling with social science field work and surveys has the potential to provide a more differentiated and adequate picture of the problems at stake, beyond existing disciplinary and sectoral boundaries.

b. Integrating environmental, economic and social sustainability in participatory multi-criteria assessments

The EU project TIDE on sustainability impact assessments for urban mobility innovation produced a well-documented handbook based on multi-criteria assessment in local policy making (TIDE, 2015). Although dealing more specifically with socio-economic measures in the field of mobility, the general discussion also applies to the other fields of system-wide transitions such as energy and housing among others.

As mentioned in the handbook, the multi-criteria approach makes it possible to assess difficult-to-quantify or monetise effects by assigning them performance scores and giving weights to the importance of the various criteria. These scores and weights can be informed by the results of structured surveys, meta-analysis of literature or impact evaluations from similar policy making contexts. When these data are not available, or difficult to obtain, experts and/or stakeholders can be called upon to assist with the assessment. Operationally, the performance can be assigned in numbers directly within a preferred scale (for example -10 to +10) or can be based on a scale described in words that can be converted to corresponding numerical values.

Although participants can always visualise the various choices made by the research team on criteria, weights and scoring methods, the assessment results mostly is synthesized by the research partners, while attempting to minimise bias from expert and stakeholder inputs. Obviously, for some factors more prone to bias, more in-depth research can be needed. In addition, when participants express doubts on one of the data sources for one of the criteria, researchers can conduct a sensitivity analysis. Such analysis tests the effects on the overall results of changes to the values of one of the criteria. If the result doesn't change much, the assessment can be said to be insensitive to changes within the range of uncertainty over possible bias on that criterion. Otherwise, more in-depth analysis of that specific criterion will be needed.

To deal with the huge diversity of potential measures, the TIDE handbook discusses three generic categories of integrated sustainability assessments. The first deals with measures with significant economic implications such as those with high investment costs or which might cause undue economic hardship for certain groups. The economic significance of these measures justifies extensive assessment of the economic variables using quantified data for key impact areas. For instance, figure 3.15 illustrates a multi-criteria assessment of congestion charging measures, such as those introduced in the city of London, Stockholm, or Milan (TIDE, 2015, p. 35). As can be seen form the illustration, many social effects, such as changes in travel time or the share of walking and cycling, can be quantified in this case, based on structured surveys on the impact of measures introduced in various pilot cities (boxes in grey in the figure). Others, such as the equity of the scheme in relation to the various population groups involves value related choices in the assessment that cannot be quantified and need to be clarified through deliberative workshops with the project team (boxes in white in the figure).

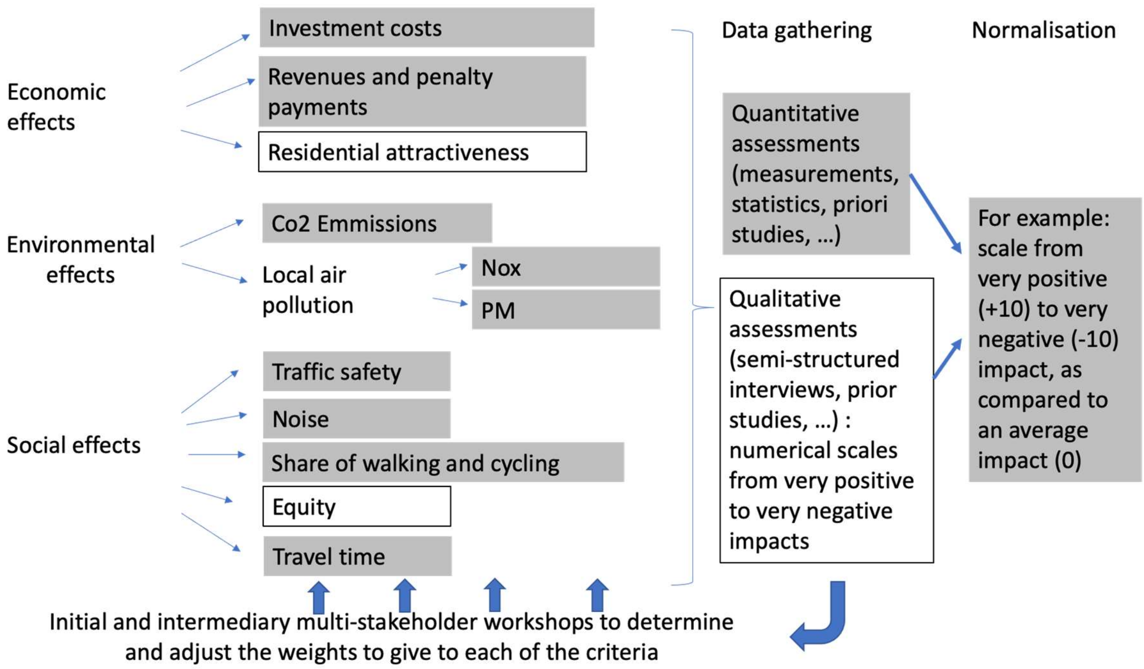

Figure 3.15. Example of a multi-criteria assessment of congestion charging measures, based on cost-benefit and multi-criteria analysis conducted in various pilot cities in the EU. Boxes in grey: quantified criteria; boxes in white: qualitative assessments (source: own figure, based on the discussion in TIDE, 2015).

The second category deals with measures that have primarily qualitative effects or are small-scale. This category covers assessments with mainly qualitative scales. The importance of the social sustainability dimension, such as in projects around healthy and people-friendly cities, justifies the investment in research tools for obtaining scientifically credible qualitative assessments of the key social sustainability variables, such as surveys or meta-analysis of literature. In addition, some economic or environmental dimensions can be assessed through qualitative scales as well, especially if the quantitative assessment of these dimensions would require disproportionate efforts as compared to the overall project goal.

For instance, in the ClimPol project discussed above, the key focus was on environmental health and people-friendly cities. Therefore, most of the criteria were assessed through qualitative scales, while the air pollution data was gathered through quantified pollution measurements. The TIDE handbook presents another case, which is the multi-criteria assessment of policy options for people-friendly streets through measures such as wider footpaths, separated cycling and walking lanes, tree planting or playground construction to name just a few. Typically, the assessment would compare various options of people-friendly streets to the car-oriented designs, which requires to assess also potential side effects such as changed traffic in neighbouring areas. Overall, however, the assessments' focus on the residents' quality of life will require investing in qualitative assessment of the key social variables, as illustrated in figure 3.16.

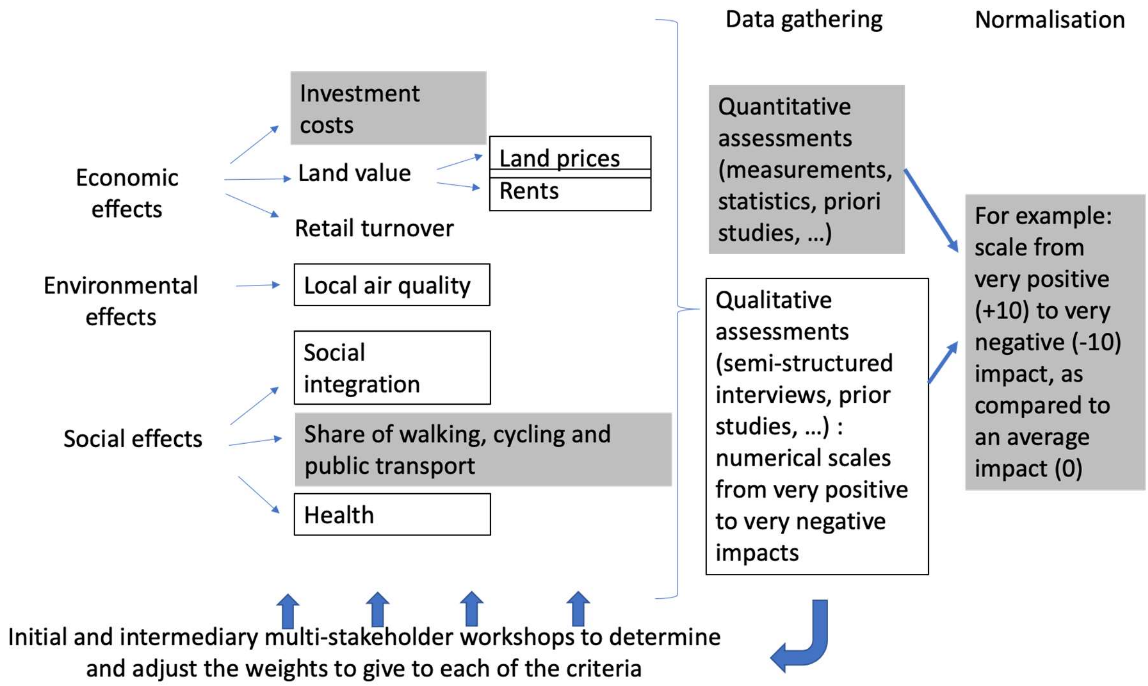

Figure 3.16. Example of a multi-criteria assessment of people-friendly street design. Boxes in grey: quantified criteria; boxes in white: qualitative assessments (source: own figure, based on the discussion in TIDE, 2015).

As shown in the TIDE project, by combining quantitative and qualitative research methods, multi-criteria assessment has evolved into a powerful tool for integrated sustainability assessment of the socio-economic lever of change. Scholars have also discussed and improved other aspects of the methods. For instance, in their review of the assessment tools, Oliver Lah and Barbara Lah highlight a set of tools that do address the social, economic and environmental sustainability dimensions but within "rapid assessment" methods that need less data input (Lah & Lah, 2018). Such tools might be appropriate for situations where quick and easy to perform integrated assessments are needed, such as illustrated through the United Nations-Habitat rapid assessment tool of urban mobility (UN, 2013).

Other scholars developed improvements to make the weighting of the various criteria more reliable. Direct weighting of the importance of the criteria, as in the case of the TIDE handbook, has the advantage of very low resource requirements and high transparency of the process. Such an approach is appropriate if the complexity of the various scales and indicators is not too high and if sufficient project time is foreseen for discussions on adjustments to be made to reduce the possible bias. More resource intensive techniques introduce pair-wise comparisons of the criteria in the weighting procedure, with the view to better account for the interdependencies among the criteria, and several techniques to check the consistency among the assessment scales, often using software (for an overview see for instance, Németh et al., 2019). Finally, statistically decomposition methods such as discrete choice experiments theoretically could be used to weight the importance of the criteria. Nevertheless, in practice these methods, which are already complex to handle for one or two discrete choice experiments, lead to an exponentially increasing number of questions in case of multi-dimensional criteria (Wainwright, 2003), which make these methods overly resource intensive for multi-criteria sustainability assessments of transition processes

For complex assessment processes, some of these technical improvements will be useful. However, independently of the choice among these techniques, the participatory nature of the process remains an essential attribute and the improvements need to be adjusted accordingly. Indeed, any integrated sustainability transformation can be implemented through a diversity of desirable pathways, based on different ways to provide desirable co-benefits among sustainability goals. Therefore, when co-designing the research protocol, the research partners need to carefully consider the balance between the increasing complexity of the computational algorithms that can be used with the transparency and the quality of the deliberation over the social value choices involved.

A well-developed case of complex assessment processes concerns choices among alternative pathways for the energy transition. In this area, decision makers often rely on scenario models that search for optimal solutions that satisfy quantifiable criteria such as energy security, some degree of self-sufficiency, environmental benefits and cost-effectiveness. However, as shown in chapter two, environmental benefits of new energy production choices can often be undone through social-behavioural factors such as life-style choices that impact on increasing energy demand or the difficulty to reach persons in low-income categories due to the cost of initial investment in renewable energy choices.

Participatory multi-criteria assessments seem well placed to addressing these decision options in a more integrated manner. The ARTEMIS project, briefly assessed in the table 3.8 below, gathered 25 stakeholders and experts in energy, to provide a ranking of the most optimal sources of renewable energy in Austria (Madlener et al., 2007; Kowalski et al., 2009). The project team used a very broad set of 12 environmental and socio-economic impact variables, which were selected and weighted through expert workshops and project interviews. The best scenario recommends a combination of housing renovation and efficient heating with long-term support for decentralized generation of electricity, among others through rooftop photovoltaics. The strong preference of decentralized solutions resulted from a high weight given by the experts and stakeholders to social impact variables related to social cohesion and regional development.

The project on the Valuing of Ecosystem Services from URBAN GREENERY (2015-2016) produced an estimation of the total value of ecosystem services of various urban greenery types in Gothenburg, Sweden (Andersson-Sköld et al., 2018). The project was highly participatory and partners from the city of Gothenburg contributed by giving weights to the assessed values through a pairwise comparison methodology of various criteria. Stakeholders gave a high importance to socio-psychological values, such as experience of wild/uninhabited nature through accessing urban or suburban woodlands. The research team summarized the methodology in a project handbook that was further used by the municipality in new areas in the city of Gothenburg.

In contrast, the BIOFUELS OPTIONS project remained highly technical and only had a scant impact on the societal transition outcomes. This project gathered 40 stakeholders and experts to provide feedback and inputs to scenarios for biofuel use in Europe (Baudry et al., 2018a; 2018b). For instance, food security in developing economies was a major social concern for the NGOs and the government, while environmental concerns were shared by most of the other stakeholders. The project shows that microalgae biodiesel is a suitable option for the NGOs and the government. At the same time it is also competitive with other advanced biofuel options, which makes it an acceptable option also for the other stakeholders. Nevertheless, participation was mainly limited to consultations in the design and analysis phase and no strong collaboration was set up in the dissemination phase to discuss the results with policy makers, entrepreneurs, or other social stakeholders.

Table 3.8. Overview of the case studies discussed in section 3.2.2. (b)

Participatory multi-criteria assessment										
Project name	Topic of multi-dim (envt., social,econ.) sustainability research	Co-production			Scientif. Outcomes		Type of societal outcome			
		co-design	Joint anal.	Social Val.	New data	Learn	Coll.	Strategy	Competences	Solutions
Urban/rural living environments										
URBAN GREENERY, Gothenburg	Socio-psychological and environmental value of urban greening	*	**		**	**			**	
Manufactured products and consumption										
BIOFUEL OPTIONS, France	Multi-stakeholder ranking of ecologically and socially sustainable biofuel options.	*	*			**				**
Energy production and consumption										
ARTEMIS, Austria	Ranking the most optimal sources of renewable energy provision.	*	*	*		**			*	

Legend. Scale for co-production: consultation only (*), joint research on some aspects (**), on nearly all aspects except some technical issues (***). Scale for scientific outcome/ societal outcome: mentioned in project publications (*), well documented (**), with in depth analysis (***)

3.2.4 Methods for knowledge co-production in participatory modelling and assessment

Resulting from over two decades of improvements, transdisciplinary scholars and social actors have a broad variety of methods at their disposal for multi-dimensional modelling and assessments of transition processes. These methods provide a holistic view of the system dynamics, or the system trade-offs, through a high degree of knowledge integration. As such they allow a synthesis of various sources of knowledge to guide system-wide action, in contrast to disciplinary models which might provide a more detailed analysis of the system components but with a loss of understanding of the overall picture.

As can be seen from the above review of methods and approaches for participatory modelling and assessment, scholars especially highlight the potential of the following approaches for contributing to an integrated understanding of the social, environmental and economic co-benefits and/or trade-offs of sustainability transition pathways (Macharis & Bernardini, 2015; Schlüter et al., 2019; Elsawah et al. 2017, p. 141):

Participatory complex system modelling:

- First, in so-called agent-based modelling (AB), the various roles of the social actors are directly integrated as virtual agents in the dynamic system. This allows to model the impact of the strategic behaviour of various types of actors and to understand social network effects resulting from multi-actor interactions.

- A second type of model, the so-called structurally realistic model (RM), integrates the social dimension through an aggregated representation of social drivers of change, through a set of variables that are represented as nodes in the network of interactions. Structurally realistic models are realistic but simple enough to serve as a tool in interdisciplinary and participatory modelling processes. Indeed, the latter require a high degree of transparency in the choices made by the scientists and an iterative process of collaborative model development with the social actors. The structurally realistic models include as a sub-case so-called formative scenario model (FSA). In the latter, the use of structurally realistic model leads to learning by the social actors on real-world constraints that limit the scope of possible future scenarios.

- The third type, system dynamic modelling (SD), is similar to the second type, except that the goal is not to obtained structurally realistic representations of the system but to understand general system features, such as the reaching of tipping points, adaptability to change and the role of stabilizing factors. System dynamic models typically provide simulations of system level features, based on the recognition that the structure of any system and the many relationships among its components are often just as important in determining its behaviour as the individual components themselves (see figure 3.12 above).

Multi-criteria analysis

- Multi-criteria Decision Analysis (MCDA): computational tool for ranking alternative projects/measures/scenarios on several quantitative and qualitative criteria; the importance of each of the criteria is quantified through a transparent weighting procedure, allowing to rank the various decision options (see figure 3.10 above).

- Multi-actor multi-criteria analysis (MAMCA): the same as above but with different weighting values proposed by the different stakeholders, resulting in different rankings for different stakeholders (see figure 3.17 below).

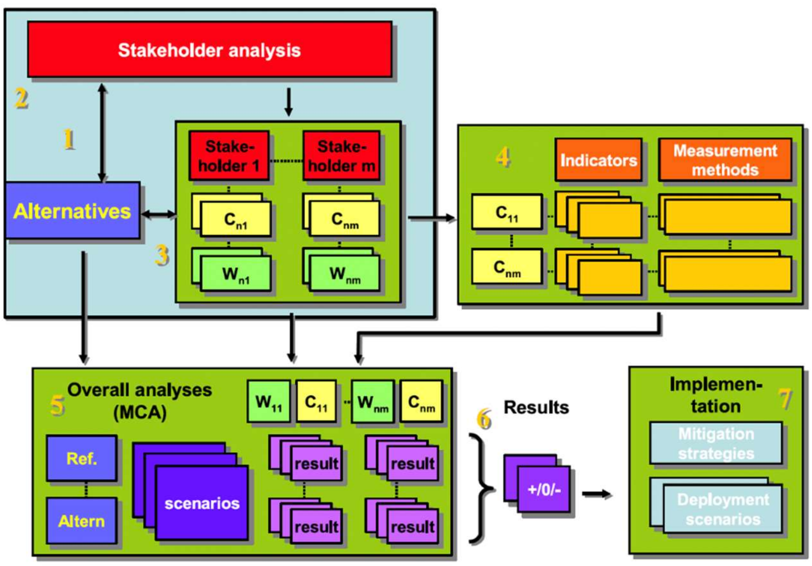

Figure 3.17. Multi-actor Multi-criteria analysis (MAMCA). The weights (in green) given by each of the stakeholders lead to different rankings of the alternatives (« results » in the figure), which contributes to reveal the preferences of the various stakeholder groups (source: Macharis & Bernardini, fig. 7.).

In practice however, the use of these models might lead to fancy simulations and sophisticated results but at the expense of a proper organisation of the knowledge co-production with the social actors. Indeed, researchers that produce computational models might experience difficulties in organizing the active involvement of social actors in the co-design of the research framework, in the analysis or in the interpretation of the results. As a result, even though these models might formally consider the multiple sustainability dimensions, they are likely to fail in building social legitimacy and in integrating context specific social possibilities of transition envisioned by the social actors.

The possibility to compare and cross-validate the results of a given participatory modelling or assessment exercise from one context to another is another main concern for transition scholars. On the one hand, seen the plurality of possible desirable pathways, there is no general recipe that can be used in all contexts. On the other hand, mutual learning between initiatives and projects is key to accelerate transition processes. For the latter, each participatory modelling exercise needs to provide sufficient information on the context specific features of the case, so that social actors can assess the structural similarities and differences between their context and the context of the original modelling exercise.

Fortunately, over the last two decades, in many areas of transition, a proliferation of participatory modelling and assessment approaches has led to a critical mass of research projects that are both highly participatory, interdisciplinary and informed by context specific field work. Table 3.8 below presents an overview of a literature search of scholarly work in the field of participatory modelling and assessment. Only projects are presented that are published in peer review journals, which are highly participative and address the three dimensions of sustainability in an integrated manner. As can be seen from a quick scan of the table, a strong research tradition has been built in the fields of modelling of energy and mobility transitions, which now supports mutual learning among social actors in various regions throughout the world. In other areas, scholars are still doing the groundwork to adapt the computational modelling and assessment tools to the specificities of the transition sectors.

Of course, even if the research projects built upon each other and use similar methods, in-depth knowledge of each of the contexts is crucial for the quality of the learning and knowledge transfer process. For instance, in the case of URBAN GREENERY discussed above, the meaning of wild/uninhabited nature is likely to be very different in Sweden, where the case study is conducted, and other regions, as for example in densely populated areas in the Netherland, Belgium or the Ruhr Region in Germany. Nevertheless, the framework used to identify the relevant cultural services, and the protocol to analyse socio-psychological motivations for valuing nature, still can be used in other contexts (for an overview, see Charoenkit and Piyathamrongchai, 2019). Moreover, the knowledge of the context specific features, such as general cultural preferences or population density, allows to assess if certain results are likely to be transferable to a new context and therefore are a good candidate to be included in the new research protocol.

Table 3.8. Methods for transdisciplinary participatory modelling and assessments

Participatory complex systems modelling
Food, agriculture and forestry

Protection of lobster fisheries and sensitive coastal habitats, Belize (See text above, NATCAP)	RM	Verutes et al., 2017; Arkema et al., 2019
River pollution and recreational fishing, Switzerland	RM	Burkhardt & Zehnder, 2018
Intensive grazing in mountain landscapes, France (see also follow-up project ROMANCHE VALLEY, table 3.10)	RM	Lamarque et al., 2013
Companion modelling book: description of 27 participatory modelling projects in agricultural research (Overview in Etienne, 2013, p. 321)	AB DS	Etienne, 2013
Management and re-use of organic waste in Brussels, Belgium (PHOSPHORUS)	RM	Bortolotti et al., 2019
Sustainable land use in the Upper Valais mountain area, Switzerland	FSA	Brand et al., 2013
Small-scale sustainable forestry in Larzac, France	RM	Simon & Etienne, 2010
Housing and mobility in urban/rural living environments		
Sustainable mobility and urban densification in Las Vegas, Nevada, US (see text above, LUTAQ project)	RM	Stave 2002, 2010
Built environment and river flooding in mountain areas in the Alpes and the Himalayas	RM	Ceccato et al. 2011; Flügel, 2011
Urban traffic slowing and cultural identity, Australia (see text above: Future Streets project)	RM DS	Macmillan et al., 2014; Macmillan & Mackie, 2016 ; Mackie et al., 2018
Modal shift and urban planning in Basel, Switzerland	FSA	Stauffacher & Scholz, 2013
Sustainable development and small-scale tourism in a mountain area in Grindelwald, Switzerland	RM	Hadorn et al., 2008, ch. 3
Energy production and consumption		
Renewable energy options through local/regional energy sources, Austria (see text above, TERIM)	AB	Binder et al., 2014
Housing insulation for the energy transition in Bottrop, Germany	AB	Bierwirth et al., 2017
Sustainability assessment of housing renovation in Zurich, Switzerland	AB	Pagani et al., 2020

Participatory multi-criteria assessment models		
Food, agriculture and forestry		
Loss of peatland through reforestation, Finland	MCA	Saarikoski et al., 2019
Loss of traditional vineyards, Spain	MCA	Langemeyer et al., 2018
Housing and mobility in urban/rural living environments		
Assessing social and environmental value of urban green in Gothenburg, Sweden (see text above: URBAN GREENERY)	MCA	Klingberg et al., 2017a; 2017b; Andersson-Sköld et al., 2018
Public transport in park and ride facilities for urban mobility in Potsdam, Germany (see text above: ClimPol project)	MCA	Schmale et al., 2015; 2016
Common vision for user-centred urban mobility in Europe, Mobility4EU project	MCA	Keseru, Coosemans and Macharis, 2021

Multi-actor multi-criteria analysis (MACMA) overview; 13 research projects on transport (Macharis et al., 2012, p. 613)	MAMCA	Macharis et al., 2012
Production and consumption of manufactured goods		
Scenarios for biofuel use in Europe (see text above, BIOFUEL OPTIONS)	MAMCA	Baudry et al., 2018a; 2018b
Energy production and consumption		
Energy transition scenarios, Austria (see text above, ARTEMIS)	MCDA	Madlener et al., 2007; Kowalski et al., 2009
Sustainable energy options, (electricity, heating) in Ebhausen, Germany	MCDA	McKenna et al., 2018
Sustainable energy options (electricity, heating) in Urnach, Switzerland	MCDA	Trutnevyte et al., 2011; 2012

Legend: Successful research projects based on partnership research and a multi-dimensional approach of sustainability (collected from google scholar and selected collective volumes on transdisciplinary research). Projects are considered successful if they (1) produced integrated knowledge across the social, economic and environmental sustainability dimensions, (2) were validated by the science and social actor participants and (3) were disseminated both in scientific and social actor arenas. Acronyms for the methods are explained in the text above.

3.3 Multi-stakeholder policy implementation research

Sustainability scholars highlight innovations in public sector governance as an important third lever to address the current global ecological and social crisis. More specifically, they underline the crucial role of improved coordination between social actors from various policy fields for addressing the cross-sectoral and multi-actor nature of society-wide transitions in mobility, food and energy systems among others. In response, social actors and policy officials search for greater involvement of practitioners, citizens, and social movements in real-world policy implementation through so-called multi-stakeholder governance arrangements (Folke et al., 2005; Jordan et al., 2018).

Moreover, as stated in the 2019 Sustainable Development Report (UN, 2019b), government actors will be effective only in bringing policy implementation to the largest number when they work with other key social actors at the regional, multilateral and international levels (Galaz et al., 2016). Inclusive governance that involves State and non-State actors at these various levels will be able to support more effective policy interventions by shifting the incentives of those with power, reshaping their preferences in favour of sustainable development and considering the interests of previously excluded participants (Leach et al., 2018).

Further, the implementation of transition policies creates different opportunities for various social groups, with potentially important distributional consequences. For instance, low-income groups are more exposed to being excluded from new opportunities that arise from transition pathways, as compared to higher-income groups. On the other hand, the involvement of all the concerned actors might also strengthen certain co-benefits for fragile social groups and contribute to long-term support for transition process. The case of the emerging movement of traffic closure in so-called school streets is a case in point. In this case, the concern of parents' associations and environmental health movements for the traffic related safety and pollution exposure of school children led to promoting sustainable mobility solutions with important co-benefits for climate, health and safety (McConnell et al., 2010; Giles-Corti et al., 2011; Davis, 2020).

However, experience in various fields, reaching from labour politics, community health schemes to participatory budgeting at municipality level, shows that without persistent efforts for capacity building and social learning, it is unlikely to accomplish much progress through multi-stakeholder policy involvement. A prominent example are the poor results of a major citizen consultation in France in 2020, organized with the view to reaching consensus on a set of climate policy proposals (Courant, 2020). This initiative, which was informed by extensive expert input to the citizen jury, directly supported by the French presidency and highly publicised in the media, in the end only led to the adoption of a very small portion of the proposals by the parliament, often in areas where agreement on action plans already pre-existed.

Without a clarification of the role of existing capacities for effective social learning and resources for joint decision making, multi-stakeholder governance risks becoming a rhetorical device to legitimate the status quo around existing policy intentions, rather than an incentive for real change. To overcome the limits of multi-stakeholder involvement in public deliberation, scholars and social actors propose various means to better connect the public debates to concrete real-world processes of problem-solving. In such a perspective, multi-stakeholder policy implementation is rooted in various degrees of collaborative design, decision making and evaluations of concrete initiatives, in which participants are led to question and jointly reframe their values and understandings. In this context, collective learning on policy implementation is not understood as a purely institutional exercise separated from practical action but rather as a creative process, whereby new information and understandings generated from participants' ongoing involvement in implementation pathways leads to critical and transformational social dialogue (Lévesque, 2013; Pahl-Wostl, 2009).

Conventional ivory tower science is ill-equipped to generate the knowledge base to support policy implementation in such multi-actor and evolving multi-stakeholder policy implementation contexts. Among others, field researchers are confronted to a lack of trust of already time-constrained social actors, who do not see the benefits of providing data and information to the scientists. Other obstacles are the lack of clarification of the value orientations that motivate the scientists' research questions into ongoing policy interventions, and difficult to access know-how and expertise on the implementation of certain policy tools.

For instance, one of the most prominent research tools for obtaining data from real-world field knowledge, so-called random controlled trials, have become popular tools to analyse the impact of policy interventions over the last decades (Banerjee & Duflo, 2011). In these methods, scientists randomly allocate individuals to several groups that are subject to different interventions and compare the measured responses. Copied on the model of laboratory science, these real-world trials, while appropriate to analyse the effect of one specific measure or one dimension of a specific measure, fail to capture the multi-dimensional and heterogeneous multi-actor nature of real-world sustainability policies.

First, in such random trials, to control for possible bias between different situations of various individuals, the number of individuals to include rapidly increases with the number of policy measures or variables to be included (Black, 1996). Therefore, in practice, seen the high number of individuals to include, random controlled trials need to focus on one or few dimensions of the problem to be addressed. The case of the successful North Karelia health prevention campaign discussed earlier is a good example, where a random approach to sampling was abandoned in favour of a more feasible and robust multi-dimensional case study approach to health surveying (Puska et al., 1983). Second, for rigorous control, the researchers need to apply the interventions to a unique and complete group of people belonging to a given category (school students, members of an associations, inhabitants of a region, etc.) and in similar contexts (Melia, 2015). The latter is obviously rarely the case in the implementation of policy measures for multi-dimensional sustainability transitions. Finally, the method requires to compare the results with a control group that does not benefit from the envisioned policy interventions. Nevertheless, in some situations, isolating a control group that does not benefit from proposed policy interventions is ethically inappropriate (Goodkind et al., 2011) or unrealistic (Puska et al., 1983).

In contrast to the laboratory-like random controlled trials, to support multi-stakeholder policy implementation processes, researchers need to conduct real-world field research that addresses the multiple dimensions of the sustainability transitions in an integrated manner. Moreover, a fair partnership is required that lead to useful knowledge outputs for the social actors who participate in providing and sharing rich context specific information and knowledge. Typically, to gather reliable scientific data and information, and to support effective policy implementation of integrated sustainability transitions, researchers and social actors will need to use systematic quantitative and/or qualitative field surveying tools in comparative or in-depth case study analysis. These tools are well-adapted to comparative implementation research, while at the same time providing for highly context specific and multi-dimensional information sources (Alasuutari et al., 2008, ch. 12).

In addition, to generate a more complete view of the implementation process in society-wide transition processes, knowledge from fields surveys and case studies need to be combined with feedback from the change agents involved in the policy implementation process. To clarify these transdisciplinary research needs for supporting inclusive multi-stakeholder policy making, the Transdisciplinary Lab of the Swiss Institute of Technology in Zürich (ETH Zürich) gathered 20 experts that had a long-term involvement in collaborative research, from nine different countries, in a two-day workshop in June 2017. According to this working group, capacities for multi-stakeholder governance are especially enhanced through research that considers system-level characteristics in the research design, builds conflict resolution and leadership skills, and creates mechanisms for adaptive learning with and among the social actors involved in the policy implementation process (Hitziger et al., 2019).

Whether research partnerships are conducive to such capacity building for multi-stakeholder policy implementation depends on many factors, such as specific research capacities, the successful mobilisation of social actors and the context. Nevertheless, the effectiveness of these partnerships can be promoted by building upon experience with methods and approaches used in existing partnership research. This section reviews some of these methods and approaches, with the view to enrich this knowledge base and analyse design principles for the knowledge co-production process on multi-stakeholder policy implementation.

3.3.1 Community health surveying of asthma prevalence in New York

A well-documented case illustrating the failures of ivory tower, disciplinary research for data gathering on policy implementation and evaluation is Jason Coburn's study of environmental health in the Williamsburg neighbourhood of New York City, in south-east Manhattan (Corburn, 2005). The context of this study is the continuing increase of asthma prevalence throughout the world, especially in urban areas (Flies et al., 2019).

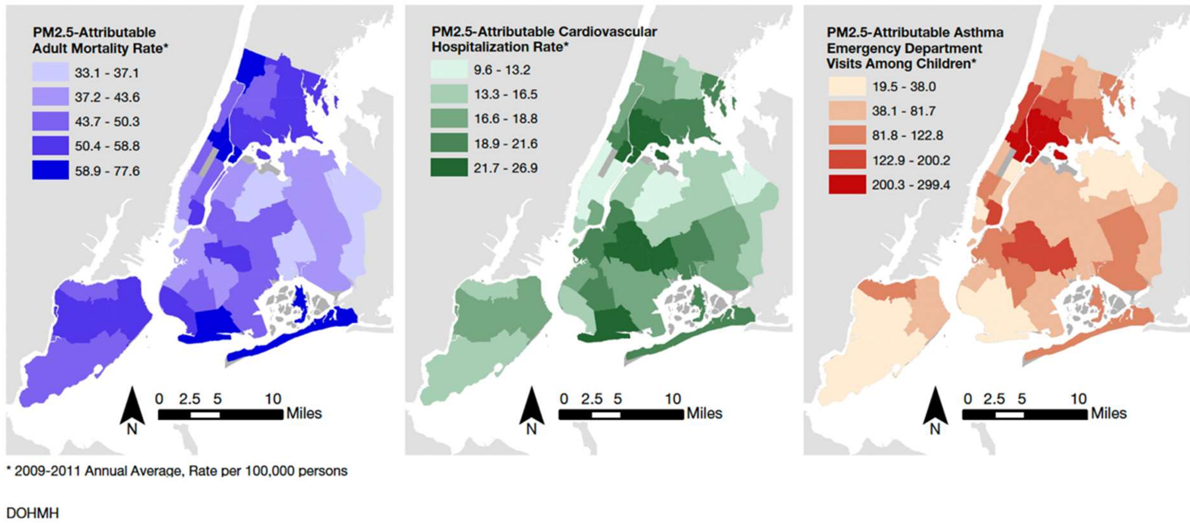

Figure 3.18. Mortality and morbidity due to fine particles pollution (PM2 .5) in New York City. Data obtained through mapping Air Survey data to community health survey data by the New York Department of Health and Mental Hygiene (DOHMH) (source: New York City Mayor's office, 2015, p. 190).

Gathering data on asthma can be difficult, as patients do not systematically search for or have access to medical care, especially in low-income urban neighbourhoods. In this context, through improvements in mix-methods research, combining both conventional randomized telephone surveys and community led data collection and intervention studies, public health researchers have been able to identify general trends in health impacts of major traffic and industry related pollutants, as illustrated in figure 3.18. Nevertheless, as discussed below, such general aggregated data needs to be combined with more fine-grained and multi-dimensional approaches if policy makers and social actors want to understand the specific causal pathways leading to high asthma incidence and formulate policies for the most impacted social groups.

In 1992, a conflict over the operation of an incinerator in the heavily industrialized Williamsburg neighbourhood led to a highly contested neighbourhood health study. In this study, researchers from the City University of New York Medical School (CUNY-CHASM), along with the New York City Department of Health (DOH), concluded that there did not appear to be an asthma problem in the neighbourhood, even though the authors of the study recognized the limits of the adopted methodology, based on an analysis of statistics produced by the local hospital (Kaminsky et al., 1993). Interestingly, this way of data gathering based on the best available quantitative data is still a usual practice in this field. The latter clearly appears in the 1999 update of asthma statistics for highly affected New York neighbourhoods that appeared in the journal "Pediatric Research" published by Springer Nature (Lovinsky-Desir et al., 2019). In this journal, asthma prevalence is again measured through data provided from visits to emergency departments in local hospitals and data are only analysed at an aggregate scale.

As noted by Corburn in his field work on the 1992 study, from the outset the residents dismissed the methodology of the epidemiological study for failing to disaggregate results by age, gender and ethnicity, and, perhaps most importantly, for "only using hospitalization data from a local hospital which most neighbourhood residents rarely if ever visited" (Corburn, 2005, p. 119). By ignoring such crucial local knowledge, the CUNY-CHASM/ DOH study not only compiled very poor scientific evidence but, more importantly, further alienated the residents from professional decision makers and scientific experts. In response to community concerns, El Puente, a local community organization, together with CIET, a non-profit research consultant specialized in community-based survey tools (CIET: Community Information and Epidemiological Technologies), organized three community-wide surveys between 1995 and 1999. Through these surveys, the researchers were able to show high asthma rates among sub-groups of the community, most prominently among school children and women over 45, which previously did not appear in any statistics. Follow-up focus groups were able to relate this high prevalence to the women's occupations in laundries, dry cleaners, beauty salons or sweatshop-like textile factories.

Collaboration between researchers and social actors at all the stages of the project was crucial in reaching both successful scientific and societal outcomes of the project. These process features can be further analysed in the framework of the three-stage model of transdisciplinary partnership research used throughout this book, ranging from co-design to knowledge co-production and co-dissemination of research results.

a. Collaborative problem formulation and constitution of the research team

As clearly documented by Corburn, none of the major scientific results of the study could have been obtained by a traditional top-down, principal investigator-led, epidemiological study into asthma prevalence and its environmental causes. The main reason is that to overcome distrust, the research team trained by El Puente and CIET had to act as community-health workers and not just survey administrators (Corburn, 2005, p. 127). El Puente therefore recruited 10 community members with a personal or family stake in asthma and trained them with the help of the New York City Department of Health (DOH) and public health professionals from Hunter College at the City University of New York.

According to Cecilia Iglesias-Garden, one of the coordinators of the research team, health workers had to be able to speak credibly about more issues than just asthma. If the researchers could not answer questions that residents had on health and social issues other than asthma – or at least refer them to someone who could answer – the residents were not going to trust them or talk to them. The survey team therefore focused in the first round of surveying on the multi-dimensional social welfare and well-being issues of the community.

b. Integrated scientific analysis and science/social actor knowledge co-production

El Puente and CIET determined the specific research questions to be tackled in subsequent phases of the research. The results of a round of surveying in the first year were discussed with the community members and led to the implementations of new solutions. On this basis, topics for investigation were gradually broadened for the next year of field work (Corburn, 2005, p. 121). Using this kind of iterative process, the information gathered during one phase provided the starting point for a critical dialogue on the analysis of the results, their local relevance and their relationship to the follow-up research questions. This led to three major surveys, conducted between 1995 and 1999. The first focused on the general community problems related to environmental health issues and general community concerns. The second targeted specific categories of the population, such as women and children. The third finally aimed to improve the understanding of the efficacy of traditional remedies widely used in the immigrant communities of the neighbourhood.

c. Joint interpretation of the research results, dissemination, and societal valorisation

The results of these studies were widely publicized and led to a series of peer reviewed publications in high profile medical journals (Ledogar et al., 1999; 2000). Beyond these scientific results, the project led to various health interventions that significantly advanced the situation of the population. For instance, after learning from the second round of surveying that adults – and not just school children – in the community also suffered from asthma, an asthma plan for adults was developed by the community organization. Another innovative community outcome was the initiation of a programme addressed to the professional healthcare providers, to learn about asthma home remedies and their cultural significance in the immigrant communities. Further, beyond these community specific initiatives, the research project also contributed to advancing the research tradition of community health surveying, adding to the body of the emerging partnership research in public health throughout the world.

3.3.2 Designing multi-dimensional policy implementation research

As highlighted in the discussion above, multi-stakeholder involvement in policy implementation often fails to deliver the expected benefits for reaching more inclusive and effective transition processes. An important factor contributing to these frequent failures is the lack of individual and organisational capacities for collective learning among social actors and policy makers from ongoing initiatives and social transformations. In this context, knowledge co-production in transdisciplinary research can contribute to building capacities for social learning in multi-stakeholder governance, by enhancing knowledge sharing and strengthening of social networks.

Scholars and social actors embarking upon partnership research on policy implementation can rely on some well-established partnership research traditions in some fields such as community health interventions or international development cooperation. In other areas, the development of tools and methods is still in an early phase of experimentation and evaluation of progress made. As highlighted in scholarly reviews of partnership research projects on policy implementation, a major challenge remains to address the respective environmental, social and economic dimensions of sustainability transitions through these participatory partnership approaches. Before analysing in more depth some cases of knowledge co-production across the various steps of the research cycle, this section first briefly reviews some of these challenges.

First, in relation to the implementation of environmental targets of sustainability policies, scholars highlight the importance of creating a balance between research on the bio-physical and the societal aspects associated to the environmental dimension. Indeed, an overly strong investment in highly technical and time-consuming bio-physical research might lead to neglect research into the societal values. The latter might result in a partnership that only reaches certain categories of social actors.

For instance, in their short opinion piece in the journal Conservation Biology, Susanne Menzel and Jack Teng reviewed recent published studies on ecosystem services and found a lack of explicit inclusion of the human dimension in the research, such as consideration of peoples' values and needs (Menzel & Teng, 2010). As they clearly state, to implement programs or policies that address provision of ecosystem services, biophysical studies play a prominent role, but these should not guide the overall process. Typically, ecosystem service projects start with identification of natural processes that benefit humans and with the gathering of biophysical data of services that support these natural processes. Only in a later phase stakeholders are included to discuss the recommendations following from this analysis (see for instance, Cowling et al., 2008). By separating the bio-physical identification of services from their social valuation, researchers suggest that the ecosystem services can be defined without reference to social values. However, to make ecosystem service research useful and supportive of desirable social change, the values and the needs of local users should guide the process. Therefore, users of the ecosystem should be engaged early in the research process.

An example of a framework that can be used for policy implementation research is the ecosystem management approach, starting from human demands for ecosystem services, developed in the so-called cascade model of ecosystem services (Spangenberg et, al., 2014). Similar reasoning on the importance of a balanced investment of research into bio-physical and societal values applies to other integrative integrated human-environmental frameworks, such as environmental health research or research into the human dimensions of environmental change (Cummins et al., 2007; Young and Gasser, 2002).

Second, in relation to the implementation of inclusive economic objectives of sustainability policies, an important challenge is to combine objective measurements of distribution of outcomes over the various social groups with an improved understanding of the way that individuals and groups perceive justice and injustice of these distributional outcomes. For instance, in a research project on ecosystem services, Adrian Martin and his team at Sussex University found that local respondents mostly preferred an egalitarian approach to distributing payments (each household receiving the same amount). However, dominant utilitarian ideas hold that payments according to the household's contribution to the service provision would be fairer (Martin, 2017, p. 158). This specific context-based analysis of local conceptions of justice is crucial in understanding how social legitimacy can be built around the contextual implementation of general and more abstract principles of justice. For this, not only a broad participation of multiple stakeholders is needed in developing general framework principles for assessing various approaches to equity and justice, but also contextual research is needed into the way these general principles can accommodate various local conceptions of justice.

Third, in relation to the implementation of social welfare co-benefits and synergies pursued in sustainability policies, various case studies highlight the importance of involving research partners in the selection of the specific area of intervention or target group of the co-benefits. Indeed, as we argued above, research on integrated sustainability outcomes requires highly contextual approaches, which focus on the specific sustainable development goals that are relevant to the case at hand. Inevitably, in such a contextual approach, some social actors can favour a definition of the problem to be addressed that is conducive to promote their core interests, as compared to investigating co-benefits that might benefit other social groups. Therefore, the choice of the specific context of research and the specific research goals needs to be carefully justified with the various social actors concerned by the policy.

A telling illustration of these challenges is the transdisciplinary research on improvement of education and access to basic social services of an immigrant population in Albuquerque, United States (Goodkind et al., 2011). In this research project, researchers evaluated the contribution of a godfathering program to the improvement of the situation of the immigrant population. However, when selecting individuals to participate to this action research project, some individuals declined to participate, as they estimated that other members of the community should first be involved, even if they were not originally part of the research protocol. As a result, the research team entered in a dialogue with the community members and opted for a purposive sampling of the possible candidates for the godfathering program co-constructed with the community members.

Similarly in sustainability research, when dealing with social welfare co-benefits of sustainability transitions (such as co-benefits for health, education, or poverty alleviation), a careful co-construction of the research sample and target groups will be essential to avoid bias and to build social legitimacy for the research endeavour.

As can be seen from this short review, each of the sustainability dimensions raises specific challenges for science-social actor knowledge co-production in policy implementation research. At the stage of problem formulation and constitution of the research partnership, special care needs to be given to the selection of participants from all categories of social actors and possible beneficiaries of sustainability improvements. At the stage of analysis and knowledge integration, researchers should invest from the very beginning in appropriate tools and methods for analysing both bio-physical and social variables that drive implementation process. In addition, as highlighted above, to enable knowledge exchange, scientists should present intermediary results in formats that can easily be appropriated by all the project partners. Finally, at the stage of co-dissemination, the synthesis and reporting of project results should reflect the social demands formulated within the various context-based conceptions of justice and perceptions of the problem situation.

A broad set of successful cases of policy implementation research for sustainability has shown the benefits of such a careful design of the knowledge co-production features in partnership research. Effective knowledge co-production between scientists and social actors has proven to be particularly useful for broadening the knowledge of the plurality of possible perspectives on co-benefits and trade-offs in sustainability pathways and for enhancing the social legitimacy of the research outputs. Nevertheless, seen the many possible hurdles, further learning on the design of the collaboration process in policy implementation research is crucial for improving the chances of successful scientific and societal results. To deepen the understanding of some of these hurdles and design tools used to overcome these, this section digs further into some case of partnership research in policy implementation (see table 3.9).

Table 3.9. Overview of the case studies discussed in section 3.3.2.

Multi-stakeholder policy implementation research										
Project name	Topic of multi-dim (envt, social,econ) sustainability research	Co-production			Scientif. outcome		Type of societal outcome			
		co-design	Joint anal.	Disc. Results	New data	Integr. Learn	Collaboration	Strategy	Competences	Solutions
Food, agriculture and forestry										
Romanche Valley, France	Balancing biodiversity, agriculture, tourism, and cultural heritage	***	*		**	**	**		**	
Social welfare co-benefits / reversing social welfare trade-offs										
Vaccination, Tchad	Public health, cultural heritage, and land rights	**	***	**	**	**	**	**	**	*
North Karelia	Public health and nutrition	**		***	**	*	**	*	**	*

project, Finland										

Legend. Scale for co-production: consultation only (*), joint research on some aspects (**), on nearly all aspects except some technical issues (***). Scale for scientific outcome/ societal outcome: mentioned in project publications (*), well documented (**), with in depth analysis (***).

a. How a landslide contributed to joint problem formulation in the Haute Romanche valley, France

The first case illustrates the role of immersion of the researchers in a specific research area. This social immersion facilitated common problem formulation with the social actors and the broadening of the researchers' perspective on the social values to be considered in the implementation of the sustainability transition. Even though the immersion in this case resulted from an external event, it nevertheless triggered a major shift in the framing of the research. Initially, the research team approached the climate related and biodiversity challenges of the small-scale mountain area mainly from a natural science-based perspective. After the social immersion, the framework was broadened to integrate various social and natural science aspects, among other to consider various possible sustainability transitions of the agricultural and tourist economy.

The area is well known to the French and international research teams involved in climate adaptation research of mountain areas. In particular, the area around the villages of Villar d'Arêne and La Grave see figure 3.19) is involved in the international network for long-term socio-ecological research (LTSER), through the establishment since 2008 of the so-called Zone Ateliers Alpes. Over a decade of research within this network has shown the negative impact of the decay of the traditional agricultural practices of hay land fodder production in favour of more extensive grazing practices and investment in the tourist industry, among other through detailed bio-physical dynamic modelling (Quetier et al., 2007; Lamarque et al., 2013). Nevertheless, despite a broad interdisciplinary set-up of the LTSER methodology, no partnership was built with the local population to turn this diagnosis into an analysis of feasible transition pathways.

Figure 3.19. The village of La Grave, the setting of the Long term socio-ecological research site in the French Alpes (source: Wikimedia, file File:La_Grave_2.jpg).

The 10th of April 2015 the main access road to the Haute Romanche valley in the French Alpes was closed due to a landslide (Bally et al., 2020). This event led to close the main communication road in the area, which is both used for tourists arriving in the valley and outgoing labour from the valley, and precipitated the region in a deep crisis. During six months, the over 900 inhabitants of the municipalities of La Grave and Villar d'Arêne had to experiment with alternative but less accessible modes of transportation, mainly a boat service over the lake and a helicopter service, until a temporary alternative road was opened in November 2015, although with limited traffic.

Due to this dramatic event, the researchers not only had to stay for longer periods in the area, seen the poor means of available transport, but they also started to participate in informal meetings and discussions around the possible futures of this fragile mountain area (Lavorel et al., 2019). As a result of these discussions, the research team realized the need to better connect their own research work to community concerns about the future of their local territory in a fragile and rapidly changing economic environment. First, the research team decided to broaden the research consortium, by calling upon social science colleagues from the University of Savoie Mont Blanc, who have experience in ethnographic research in mountain areas. Second, the discussions with the inhabitants and within the broader team led to the formulation of a set of new research questions related to identifying real-world windows of opportunity for implementing the climate adaptation strategies identified in their previous research.

After this initial phase of reframing, the research team conducted a series of structured interviews, organized workshops and participated to informal meetings, with the view to analyse the possible adaptation pathways and windows of opportunities for change. The main result was to identify the impact of various action strategies, rules and value related drivers on the likely evolution from one pathway of change to another. As illustrated in figure 3.20, the trend towards mass-tourism development and further shift to extensive grazing (the so-called "ranching" scenario on the figure) is not unescapable, despite the fragile economic situation. Instead, a plurality of pathways can co-evolve in the area, and various windows of agency already exist that can contribute to diversifying the local economy around high value products from sustainable agriculture and small-scale tourism (the so-called scenario of "seeds of hope").

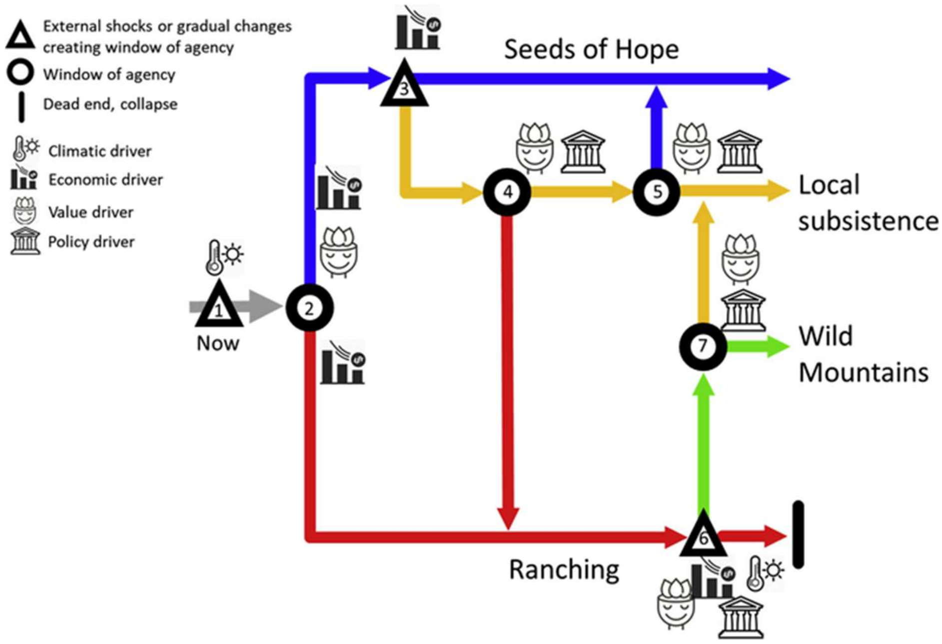

Figure 3.20. Pathways (arrows) and windows of agency (indicated by numbers) towards the four visions. Each window of agency is associated with specific likely events, documented through the structured interviews and workshops (source: Lavorel et al., 2019, fig. 3).

Overall knowledge co-production between science and social actors played a major role in the successful integration of the ecological and social aspects in the design of the adaption pathways. First, the immersion of the researchers in the local context allowed to build trust and to match the research question to the perceived needs by the local inhabitants. Second, the proposed framework of analysis in terms of windows of agency played a key role in the stage of knowledge integration. The stage of co-dissemination is still ongoing, along with further analysis of the results. Nevertheless, although most of the activities returned to “business as usual” after the re-opening of a new tunnel at the end of 2017, societal outcomes of the research are also clearly mentioned by the project initiators (personal interview, Grenoble, 10 December 2019). First, the project produced scientific knowledge that is directly relevant for assessing the various possible answers to the economic vulnerability of the mountain economy in the area. Second, the research project has strengthened the social networks among the actors involved in sustainable adaptation pathways and further consolidated the relations between the research team and the inhabitants of the study area of the long-term socio-ecological research site.

b. Overcoming mistrust in vaccination and health care delivery through iterative research design with nomadic pastoralists in Chad

The second case is a long-term and well-documented research project on health care delivery to nomadic pastoralists in Chad (Bergmann et al., 2012, ch. III.F; Hadorn et al., 2008, ch. 17). The health interventions’ project (1996-2006) was set up in Chad after the observation in the early 1990s that nomadic pastoralists did not visit the local health centres. This revealed a real-world problem: health care services were organized by the State in a form that the nomads did not use, so that in practice they were virtually excluded from primary social services. According to a 2015 report of the Swiss Tropical Institute, polio vaccination coverage was 11,6% among mobile pastoralists communities, against 80% among settled communities (Lechthaler and Abakar, 2015). Notably, among mobile pastoralist communities, vaccination coverage among livestock was significantly higher than vaccination coverage for children (Abakar et al., 2018). As shown in a qualitative focus group study, major barrier to vaccination uptake by the nomadic population are mistrust and difficulties of access to the health system (see figure 3.21).

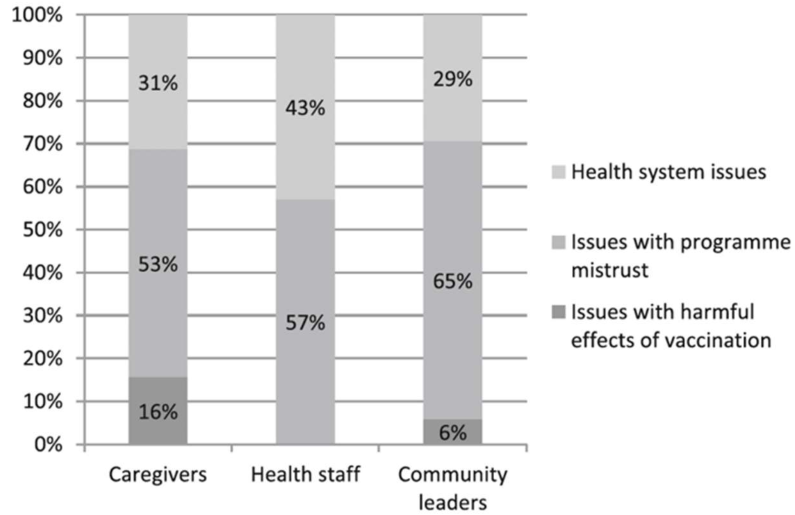

Figure 3.21. Concerns about vaccination reported by the nomadic pastoralists in the Danamadji district, Chad. Information collected through in-depth interviews and focus groups. Mistrust refers to issues such as lack of information to make decisions or lack of confidence in the program effectiveness. Health system issues refer to issues such as access problems or lack of training of the health staff (source: Abakar et al., 2018).

The research tasks were therefore defined as follows. First the aim was to get an overall picture of the traditional forms of health care practiced by the nomads. On this basis team wanted to understand the barriers to use of the medical services offered by the State and to develop health care services that nomads would effectively use. To this purpose the project combined anthropological field work into the traditional health system of the pastoralists with clinic surveys to map the main needs for interventions and socio-geographical surveys to understand their daily livelihood concerns.

The health intervention project illustrates a successful knowledge integration process in policy implementation research, based on an iterative research design. In this project, in a similar manner to the New York asthma study discussed above, after each phase of field research and surveying, the researchers organized a workshop with the main social actors to discuss the results and set the priorities for the next phase of research. The main difference with the New York study is that in addition, during the research project, the research team also implemented a set of interventions. The research team evaluated each round of interventions at the various workshops and used the research results of the previous phase to design the interventions of the next stage.

The first rounds of research did not only diagnose many health problems within the population but also revealed the importance of animal health to the nomadic pastoralists. Indeed, livestock is the basis of the pastoralists' economic wealth and social respect. Moreover, in contrast to Western medicinal practice, in the nomads' traditional health system animals and humans are treated by the same health practitioners. On this basis, the program adopted a so-called one health approach to the delivery of health services, which considers the synergies between animal and human health improvements and promotes the collaboration between human health and veterinary services (Schwabe, 1984).

After the second national workshop with researchers, traditional healers and members of the health services, the team decided to test run a joint human and animal vaccination campaign. To this purpose, the capacity of existing mobile veterinary infrastructures was extended for simultaneous vaccination. Further, schedules of public health and veterinary services were harmonized to avoid the establishment of parallel structures. During this campaign, the nomads started to regain trust in the health providers and people started to inquire about other health topics. In subsequent rounds of research and intervention, the program was further extended and eventually embedded in government health schemes for the entire pastoralist community, which represents around 10% of the total population in Chad.

The involved researchers mention three main reasons for the success of the research program. First, the research team took the perspective of the traditional community on the organisation of the health system seriously, which created trust and provided an entry point for the development of the new health care services. Second, the research was based on a solid institutional partnership between the Swiss Tropical Institute, the Chadian Veterinary Laboratory and the Chadian Ministry of Health, which secured a long-term commitment of all partners. This commitment allowed for a highly flexible and adaptive research design. Third, effective knowledge sharing among all partners facilitated knowledge integration between the livestock owners, traditional healers and the scientists. For instance, the detailed monitoring by the traditional livestock owners of animal health resulted in doubts on the efficacy of one of the livestock vaccines. This knowledge was taken up by the research team and later confirmed by laboratory analysis. The latter led to the replacement of the vaccine by a new one and an increase in trust in the usefulness of vaccination.

Overall, the knowledge co-production process was highly structured, with a clear division of work and well identified moments of sharing of results and joint planning, especially during the five national workshop that were held during the entire project. The formulation of the problem was gradually broadened, from problems of capacity building for health care delivery infrastructure, to broader concern with livelihood problems of the pastoralists, such as access to safe transhumance routes or grazing lands allowing for improved management of animal health and milk production. Scientific analysis and knowledge integration were based both on solid disciplinary work and exploitation of complementarities and synergies. Finally, dissemination of results was mainly organized during the national workshop but also strengthened through dedicated community outreach, such as through the development of pictograms and short movies for the beneficiary groups.

c. Partnering with media and local health workers to disseminate health and nutrition survey results

Most partnership research projects invest substantial time in activities for joint problem formulation and knowledge integration among researchers and social actors. Activities for dissemination and societal valorisation of results, in contrast, often remain less developed. Indeed, such joint dissemination efforts might be quite resource intensive. For effective dissemination, project partners need to present the results in diverse formats that are appropriate for various communication channels and beneficiaries, which often requires specific competences. Moreover, in many cases, researchers continue to analyse data and prepare scientific publications after the official end date of the project, when extra funding for dissemination activities is not any more available.

Nevertheless, many creative solutions exist for co-organizing dissemination of results, especially in the context of multi-stakeholder arrangements for policy implementation. The North Karelia project, already briefly mentioned in chapter two, provides an example of a research project with an active focus on dissemination of survey results to the broader public, through a set of innovative partnerships. As mentioned above, the area, with a population of around 160.000 inhabitants, was especially known for high incidence of heart disease and a rural diet with high intake of saturated fat. The project, nicknamed in the Atlantic magazine as “The Finnish town that went on a diet” (Buettner, 2015), organized during the 1970ies large-scale epidemiological and nutritional surveys in the North Karelia province of Finland. The main project partners for data gathering, in the various rounds of surveying, were the local health practitioners, mainly the doctors and the nurses of the local health centres. However, for the dissemination of the survey results, the project initiators collaborated with a much larger set of social actors that have an impact on food habits throughout the region (Puska et al., 2009).

Conventional dissemination activities that were organized included regular lectures by the project staff at schools, community centres and schools; the writing of leaflets; and extensive training of the local health staff by project partners of the National Public Health Institutes on the use and the interpretation of the survey results. One innovative dissemination channel was the so-called lay ambassadors or lay leaders program. Through snow-ball sampling, the project team and local officials identified the opinion leaders in the local villages. These leaders received training and information based on the project results in a weekend seminar and were asked to promote health-related lifestyle changes in their daily life. In a period of three years, between 1979 and 1982, almost 800 people participated in such training. Finally, the project was also able to get support for disseminating the survey results through collaborating organizations, such as the local clubs of a regional women’s organization and pro-active members of the food manufacturing and catering industry.

As stated by the project initiators in their evaluation of the project results, the North Karelia community-based research project has shown that a comprehensive and theory-based community programme can have a positive effect on health-related risk factors and lifestyles. Among others, broad collaboration, dedicated leadership and strong government support are mentioned as key factors for its success. Of course, the project’s design is highly contextual and related to a situation of health urgency that was related to considerable post-war dietary changes in a rural community, which probably created a momentum for change that contributed to its success. Nevertheless, the entire set-up of the project was ambitious, both in its multi-dimensional approach encompassing social-behavioural and bio-medical aspects, and its active partnering with local, regional and international social actors.

3.3.3 Combining methods for multi-stakeholder policy implementation research

Scholars and social actors undertaking transdisciplinary research in multi-stakeholder implementation contexts use a broad variety of research methods. However, not all the methods are appropriate for conducting the kind of multi-dimensional and highly interactive research that is required for addressing complex sustainability issues. As already highlighted above, the use of randomized experiments, based on the model of the bio-physical sciences, is very difficult to put into practice seen the large number of strongly interdependent variables. On the other extreme, context specific participant observation through field research would be a good candidate for reaching a thick multi-dimensional understanding of the problem situation. Nevertheless, participant observation typically is less equipped to produce research results that can be compared and tested across different cases and circumstances, which is a key research interest of policy implementation and evaluation research. At the same time, exploratory field research methods are likely to play a complementary role to other social science research methods, for instance to gain an initial understanding of a new research setting or exploring the key aspects of a problem that need to be addressed (Singleton & Straits, 2005, p. 308).

Survey research and analysis of publicly available documents and records both are situated in between these two extremes of highly focused laboratory-like experimental research and thick and contextual field work (Singleton & Straits, 2005, p. 399). They both allow a high level of replicability of the research and can accommodate complex multi-dimensional problem settings. As can be seen in the review of successful transdisciplinary research projects in table 3.10, the latter methods play an important role in these projects.

Table 3.10. Methods for transdisciplinary policy implementation research

Multi-stakeholder policy implementation research		
Food, agriculture and forestry		
Sustainable agriculture and small-scale tourism in a mountain area, France (see text above, Haute Romanche valley)	OE	Lavorel et al., 2019
Farming activities in biodiversity rich mountain areas in the Piedmont, Italy	SS	Höchtl et al., 2006
Nature conservation and agricultural production in the Elbe valley, Germany	SS, OE	Bergmann et al., 2012, ch. III.K
Environmental management in the Wadden Sea, the Netherlands	OE	Puente-Rodríguez et al., 2016
Indigeneous approaches to soil use classification, Brazil	OE	Matuk et al., 2020
Creation of a Nature Park designation in the Black Forest, Germany	AAR	Rhodius et al., 2020, ch. 6
Improved access to health services for nomadic pastoralists, Chad (see text above, vaccination campaign in Chad)	SS, PO	Bergmann et al., 2012, ch. III.F; Hadorn et al., ch. 17
Changing a rural diet with high saturated fat, Finland (see text above, the North Karelia project)	SS	Puska et al., 2009
Housing and mobility in urban/rural living environments		
Mobility style analysis in various cities, Germany	SS	Bergmann et al., 2012, ch. III.B; Hadorn et al., 2008, ch. 6
Partnerships with housing renovation companies in the Rhine-Main area, Germany	SS	Bergmann et al., 2012, ch. III.G
Community health surveying of asthma prevalence from transportation/indoor pollution in New York, USA (see text above, asthma prevalence project)	SS, OE	Corburn, 2005
Assessing the effectiveness of urban climate change, Brazil	OE	Di Giulio et al., 2019; Serrao-Neumann et al., 2020
Production and consumption of manufactured goods		
Indigenous knowledge of basket weaving in the Brazilian Amazon, Brazil	OE	Athayde et al., 2017
Meaningful and decent work		

Economic vulnerability of coffee farmers in Central America	SS	Castellanos et al., 2013
Assessing the social impact of a social enterprise in Brussels, Belgium	SS	Perilleux et al., 2016

Legend. Successful research projects based on partnership research and a multi-dimensional approach of sustainability (collected from google scholar and selected collective volumes on transdisciplinary research). Projects are considered successful if they (1) produced integrated knowledge across the social, economic and environmental sustainability dimensions, (2) were validated by the science and social actor participants and (3) were disseminated both in scientific and social actor arenas. Methods, SS: structured survey (with quantifiable scales); OE: Semi-structured open-ended interview; EXPL: Exploratory open-ended interview; AAR: Analysis of archival records.

3.4 Transformative learning on socio-cultural drivers of change

Thriving civic agency and social movements are an essential force for advancing the social and ecological transition. Indeed, as also highlighted in the 2019 Sustainable Development Report, enabling people to participate in setting priorities, monitoring results and holding decision makers accountable ensures that sustainability transitions are tailored to the livelihood concerns and needs of the population (UN, 2019b). In addition, enabling citizens and social movements to contribute to collective action contributes to problem solving and advances capacities for innovation in society-wide sustainability transition processes (Welch & Yates, 2018). Moreover, organized collectivities – Unions, political parties, village councils, women groups, etc. – are fundamental to empowering people to choose the live they have reason to value (Evans, 2002). They provide an arena for formulating shared values and preferences, and instruments for pursuing them, even in the face of powerful opposition.

For these various reasons, the expert group coordinating the 2019 report identified the active inclusion of engaged citizenry in individual and collective action for sustainability transitions as the fourth major lever of accelerating transition. This fourth lever is of a more cross-cutting nature as it also plays an important role in each of the three levers discussed in the previous sections. Indeed, in each of the previous levers, engaged citizenry potentially enhances the social legitimacy and the effectiveness of the outcomes. This was illustrated for instance in the analysis of technological innovation processes and the design of socio-economic measures, where stakeholders and members of civil society organisations provide essential contextual information on value-laden choices, or in the case of policy implementation research, where practitioners provide feedback on ongoing implementation processes.

Nevertheless, the current social and ecological crisis raises a set of new challenges for civil society mobilisation and collective action. Indeed, factors such as climate change, economic globalization and the spread of infectious diseases increasingly interact and create complex multi-dimensional problem settings. In addition, engaged citizens and social movements face increasingly value laden challenges to deal with society-wide change in energy provision, housing, mobility and agri-food systems among others.

In this context, sustainability scholars (Folke et al., 2003; Pahl-Wostl, 2009) highlight the importance of society-wide social learning to cope with decision making on complex multi-dimensional issues and under conditions of heterogeneity of social values. Indeed, experts and stakeholders are increasingly confronted to evolutions in other sectors of activities that question their own value perspectives and problem understanding. Through society-wide social learning, knowledge and the ability to act upon new insights can be continuously questioned, applied and evaluated under changing circumstances, or expressed alternatively by the various social groups involved in transition processes.

As shown in an in-depth review of 20 partnership research projects presented at sustainability science conferences in 2017, transdisciplinary scholars have developed a broad set of methods to generate knowledge that support such social learning (Herrero et al., 2019). Well-known methods are multi-stakeholder future visioning and scenario building, participatory mapping of systems dynamics and role-playing games. Depending on the research project, these methods were used to fostering convergence on values and meanings in situations of conflict, to empower specific societal groups or to promote the emergence of new and diverse perspectives in situations when a given consensus reinforced the status quo.

For instance, in a research project that will be further analysed below, in the informal settlement of Enkanini in South Africa, the installation of solar panels met with unexpected resistance of the population. In response, transdisciplinary researchers of the university of Stellenbosch in South Africa partnered with a neighbourhood association to organize a three days' workshop to collaboratively map the energy situation in the settlements. Several societal and scientific outcomes resulted from this participatory mapping exercise. The project fostered mutual understanding among residents with different energy needs, led to a better understand of the levers of change and empowered the community to speak with one voice on this issue.

Many of the methods used in transdisciplinary research for supporting multi-party social learning on sustainability use well-established tools and techniques from the various research traditions of group-based qualitative research, ranging from focus groups and group-based conceptual mapping to group experiments in social psychology or behavioural economics. However, to successfully adapt these methods to transdisciplinary partnership research, sustainability researchers need to overcome two major obstacles.

First, research in group-based qualitative methods has convincingly demonstrated that humans, to cope with their limited information processing capacity, employ biases and heuristics to reduce mental effort (Vennix, 1999). Humans seem to have trouble to thinking in terms of causal interdependencies and even tend to ignore feedback information from the field. Moreover, as individuals and groups come with a background of prior information, they may produce very different interpretations of similar situations. Because of these and other factors, especially in the context of multi-actor and multi-scale sustainability problems, interpretations, perceptions, and memory may be biased as compared to more fully informed information processing efforts. The various systematic and methodical approaches in group-based qualitative research, such as rigorous concept mapping tools, use of standard coding scripts and triangulation of information are therefore essential to develop successful research partnerships.

Second, in many cases, group-based qualitative research methods are used in conventional expert led research processes. A quick search on "google scholar" for publications that use methods such as focus groups or group-based concept modelling shows that both highly participatory uses and expert-led uses of these tools have been developed. A prominent example of non-participatory uses are the so-called focus groups used in marketing research. Group-based assessment of new consumer products in focus groups is a powerful method to uncover the participants emotional and nonverbal reactions and to observe group-based imitation behaviour. However, in such cases the focus group is not used for social learning in a context of knowledge co-production but rather as an improved data collection method for the marketing researcher and a useful complement to statistical user surveys.

In response to these challenges sustainability researchers further developed the group-based qualitative research methods with the aim to both overcoming the analytical failures and generating effective social learning beyond the interests of the researchers initiating the projects. To this purpose, the use of group-based qualitative methods in transdisciplinary research aims at a double outcome. First, from a scientific point of view, the research projects aim at discovering drivers and features of ongoing learning processes that can generate effective change in background understanding and values. Second, from a societal point, they aim at fostering change in background understandings and values that go beyond the individual and become situated within wider social units or communities of practice (Reed et al., 2010; Herrero et al., 2019; Scholz et al., 2014). The latter can require various changes in the social actor network, such as improving the trust between actors, bringing new actor groups into play, or changing power structures and boundaries between actor groups (Wostl, 2009).

3.4.1 Energy poverty in the informal urban settlements of Enkanini, South Africa

The Enkanini informal settlement in South Africa is an illegal settlement at 30 km of Cape Town, established in 2006 on land owned by the municipality of Stellenbosch. By 2015, about 8000 people lived in Enkanini in about 2000 rudimentary shacks (Van Breda & Swilling, 2019). They provide labour to the neighbouring cities, mainly in services and government, such as cleaning and security work. In addition, the inhabitants organize a small but vibrant informal economy offering a range of products and services, such as the sale of food and beverages, hair and beauty salons and childcare facilities (Smit et al., 2018).

The crux of the Enkanini case is the lack of provision of basic infrastructure services to this informal settlement by the local government, mainly in the areas of electricity, water and waste management (Van Breda and Swilling, 2019). The problems that have arisen due to this lack of services include high levels of vermin invasions, especially rats, indoor air pollution due to paraffin and candle use, very frequent fires and floods, and the associated increased health risks due to the above. To provide these services, the government first must regularize the land rights, which might still take quite some time.

Since 2011 researchers of the Centre for Sustainability Transitions of Stellenbosch University partnered with inhabitants of the settlement to set up a series of transdisciplinary research projects on improving the basic services. As mentioned above, one of the research teams organized between 2016 and 2018 a series of participatory surveys and workshop to address the lack of uptake of an initially successful introduction of solar panels. This project, the so-called “iShack project” (which stands for “improved shacks”), co-funded by the Bill and Melinda Gates foundation, brought solar panels to 767 households between 2011 and 2016 (Ambole et al., 2019) and was widely advertised as a major solution to decentralized renewable energy provision in off-grid settlements (see figure 3.22).

Figure 3.22. Solar panel infrastructure in the Enkanini informal settlement, South-Africa (source: sustainability institute
https ://www.sustainabilityinstitute.net/research-learning/collaborative-projects/ishack/).

Nevertheless, despite addressing a major energy transition issue in a country where 93% of the electricity is provided by coal fired power plants (Ndlovu é Inglesi-Lotz, 2019), the focus on a single technological solution has failed to generate a broader uptake by the community. The research highlighted two main reasons for this. First, the solar panels only provided energy for lightening and charging electric appliances but could not be used to address the energy needs of the poorest members, especially in relation to activities such as cooking and refrigeration. For instance, as illustrated in figure 3.23, only 27% of the dwellings stepped into the solar panel scheme and even most of these inhabitants (24%) continued to rely on gas or kerosene (so-called “paraffin”) for their other energy needs. Second, by providing support through a basic electricity subsidy for solar energy, the municipality has awakened fears within the population that this support would be used to postpone a more structural solution to their needs of basic infrastructure services.

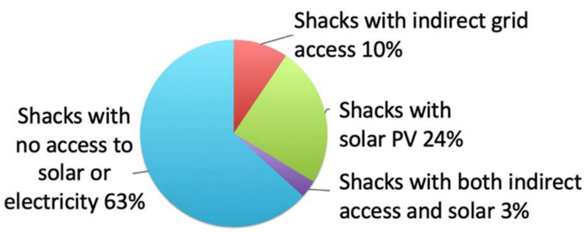

Figure 3.23. Energy access in the Enkanini informal settlement (figure redrawn from Smit et al., 2018).

To better understand these issues, researchers conducted surveys and organised a group-based mapping of the system dynamics of energy poverty in the Enkanini settlement through a series of interrelated research projects, respectively the participatory integrated assessment project (PARTICIPIA, 2013-2016), the qualitative systems dynamic mapping project funded by the Southern African Systems Analysis Centre (2016-2018) and the project on Co-Designing Energy Communities with Energy-Poor Women (funded by “Leading Integrated Research for Agenda 2030”, from 2017 to 2019).

The PARTICIPIA project and the systems dynamics mapping project provide a good introduction to the practice of qualitative group-based mapping, its role in generating social learning among social actors and the possible societal outcomes. The project also shows how a relatively modest group-based research exercise, in the context of one of the tasks of a PhD research, can provide an innovative social learning perspective and lead to a series of follow-up research projects.

a. Collaborative problem formulation and constitution of the research team

The main research question of the project resulted from the practical involvement of the lead researcher in the community in the context of her various PhD research tasks, especially through the close collaboration with the Enkanini community research centre. As shown above, the community members opted for very diverse solutions to the situation of energy poverty and there was a major distrust in the community towards the willingness of the municipality to provide for more structural solutions. Together with the community members, the researcher therefore chose to set up a three days' workshop to collaboratively map the levers of change that can be activated by the community.

b. Integrated scientific analysis and science/social actor knowledge co-production

Based on previous research involvement with the community, the research team selected a group of 30 participants more or less equally divided over the three main energy user groups, which are solar users, users with contracts for indirect access to the grid of the neighbouring township and the users of traditional off-grid sources of gas and kerosene. For each group, women constituted 60% and men 40% of participants.

Community-based systems dynamics mapping is based on an adaptation of system dynamics analysis to the requirements of qualitative participatory research and is originating from the work of Peter Hovmand at the Brown School Social System Design Lab (Hovmand, 2014). The key strengths of community-based systems mapping is to offer a science-based research protocol for systems analysis, in situations where quantitative research or mathematical modelling is not feasible or not very useful to address the identified social learning challenges. Simply abandoning the science partnership in situations that defy quantification is only likely to forego existing opportunities for reaching a more integrated understanding of sustainability. At the same time, only considering quantitative or computational formula as a valid input to the scientific process might lead to misleading simplifications of the problem at hand. The latter is clearly stated for instance by Geoff Coyle, a leading scholar in mathematic system dynamic modelling. At his 1999 keynote address to the Conference of the System Dynamics Society, he warns for the production of "seductive, plausible, nonsense" by quantitative modelling in cases where manifest uncertainties are present that cannot be quantified, such as the outcomes of a moral controversy or external shock and surprise. Moreover, when dealing with difficult to quantify variables, it is important to assess if the quantification adds something to the qualitative analysis, beyond something that the researchers already learned from a careful analysis of the qualitative data (Coyle, 1999).

As stated by Hovmand, community-based system dynamic mapping is about helping communities to co-create models that lead to new system insights. Through the proposed participatory mapping tools, the participants co-produce informal causal maps that make their various mental models of the system dynamics explicit. To this purpose, they jointly evaluate hypotheses about the logical implications of these causal relationships and identify the main feedback loops that can stabilize, improve or deteriorate the current situations. Facilitators and researchers play an important role in reformulating these various arguments in commonly agreed conceptual maps, reflecting the various hypotheses and positions of the participants.

The main shift in problem framing realized by the social learning in the workshop was a shift from a focus on technical issues to a recognition of the non-technical and aspirational factors that drive the energy behaviour of the inhabitants. For instance, women are searching for solutions that are both affordable and less time consuming in terms of accessing fuel sources for livelihood activities such as cooking, as this could free time for involvement in income generating activities. Other inhabitants were looking for alternatives to the use of kerosene (paraffin) as it “smokes and burns the eyes” (Smit et al., 2019, table 3). As a result, despite divergent opinions on the advantages and disadvantage of the solar solution, the participants converged on the importance of a deeper engagement of the population in innovations around energy solutions and the strengthening of the community organisation to speak with one voice to the municipality.

These insights from the participative system dynamics mapping workshops conducted in the context of the PhD project were further deepened in the follow-up project on Mainstreaming Gender for Energy Security in Poor Urban Environments. This follow-up project identified a set of interrelated feedback loops in the Enkanini energy system, or similar informal settlements, that indicate a possible pathway for improving upon the current situation (Batinge et al., 2021). As shown in figure 3.24, this pathway integrates the idea of a deeper engagement of the main users of the energy solutions in innovation, such as through the involvement of female users in community co-design of technological innovation (the “livelihood improvement and service fulfilment loops” in figure 3.24). When combined with governmental support for making these solutions accessible to the largest number, a dynamic of change can be initiated (the “technology accessibility loop”). In a next step, the project team envisions to quantify various components of the model (the needed services, stocks and flows in the available energy sources, etc.), with the view to produce a computational simulation of the envisioned pathway.

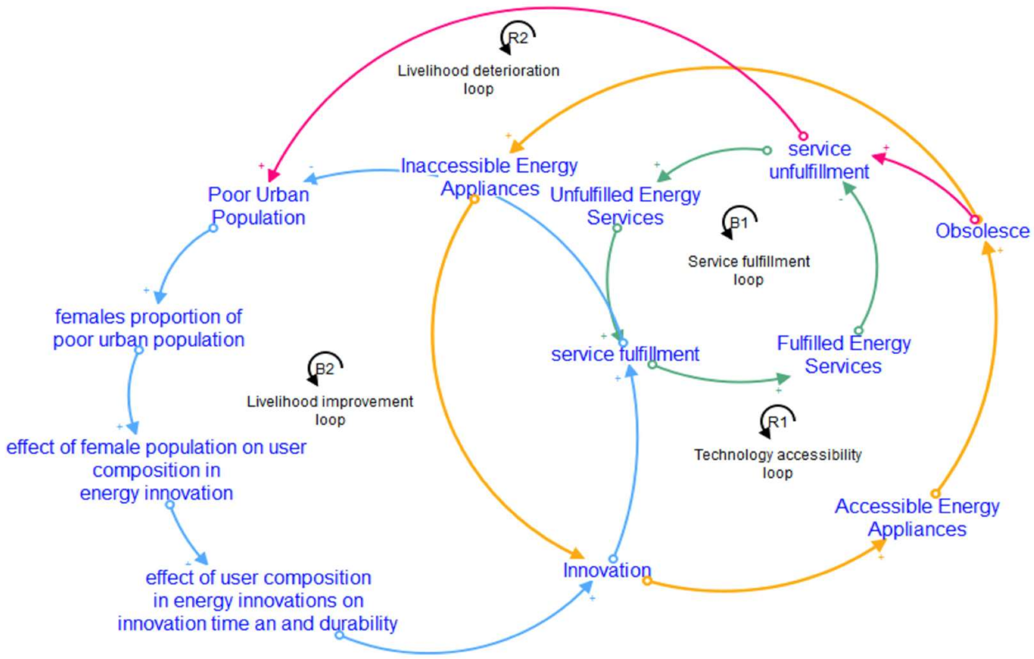

Figure 3.24. Causal loop diagram of the “gendered Innovation model” (source: Batinge et al., 2021).

Qualitative group-based research often leads to identify new research questions that can be further deepened with quantitative analysis of sub-components of the system. In this context, group-based qualitative mapping is often combined with a selected quantitative research tools such as computational simulations, questionnaire surveys or measurements of bio-physical variables. This was illustrated through the discussion in section 3.2 the Future Street project, which also used an initial qualitative group-based system dynamics exercise to identify the key model components of a complex system modelling method. However, even if combined with other methods, the group-based qualitative research effort itself needs to be carefully conducted. As also underlined elsewhere, the role of a professional team of facilitators is crucial in this regard, allowing for instance for cross-checking the participants' contributions and checking the consistency with already available data (Vennix, 1999; Hovmand, 2014).

c. Joint interpretation of the research results, dissemination, and societal valorisation

The results of the PhD work in the context of the participatory integrated assessment project (PARTICIPIA, 2013-2016) and in the systems dynamic mapping project led to a series of peer reviewed publications (Smit et al., 2018; 2019). In addition, as also highlighted above, the research results were used in various strands of follow-up research, especially on topics related to integrating general equity issues in research on energy access.

From a societal point of view, the results of the research project were used in a follow-up policy seminar in 2017, in the context of the project on "Co-Designing Energy Communities with Energy-Poor Women". In this policy seminar, policy makers representing different levels of government, community members and researchers discussed the various relations between energy, health and gender that were analysed in these various research strands. One institutional proposition that resulted from the seminar is to organized increase multi-level coordination between the regional government (Western Cape government) and the Stellenbosch municipality, with the view to solving the identified community challenges (Ambole et al., 2019).

3.4.2 Integrating a multi-dimensional approach to sustainability in social learning

As discussed in this section, sustainability scholars consider the empowerment of civil society and engaged citizenship as a powerful lever for accelerating sustainability transitions. More specifically, both for effective social innovation and participation to multi-stakeholder democratic processes, they underline the importance of adopting a socially inclusive perspective on social learning, with the view to attenuate counterproductive trade-offs and to promote co-benefits between the social, economic and environmental dimensions of sustainability (UN, 2019b).

In this context, scientists and social actors have built research partnership for enhancing the capacity to develop society-wide social learning and for translating the results of the learning process to action strategies and policy recommendations. However, it is obviously too simplistic to suggest that the adoption of participatory approaches to social learning on its own will directly improve the performance of stakeholders and policy makers involved in society-wide transformation processes. One of the reasons is the existence of persistent barriers to learning, not only cognitive, such a related to flaws in human mental models, but also social. For instance, in his analysis of social learning processes, Jac Vennix points to defensive positions in organisational change related to vested interests or ineffective communication about multiple perceptions of a problem situation (Vennix, 1999). Only if the research partners can deal with these barriers, they are likely to evolve towards a better understanding of the systems' interdependencies and opportunities for change. Group-based qualitative research is a way to actively involve all participants in such social learning.

For these various reasons, group-based qualitative research is likely to continue to play an important role in empowering social learning among civil society actors, or to improve social learning among civil society, policy, and private sector actors. Qualitative group-based research contributes to common conceptual diagrams of systemic interdependencies, detailed analysis of feedback loops and causal interactions, and identification of drivers and opportunities of change (Coyle, 1999; Flick et al., p. 36). To strengthen the science base of the process of qualitative group-based research, scientists mobilise the broad diversity of qualitative sources at their disposal, ranging from direct statements contributed by the participants in workshops, to textual sources in paper and on-line media, informal reports by civil society and policy organisations, and photo and video material (Singleton & Strait, 2005, ch. 11).

The facilitator team plays a key role to effectively use these materials as input to the group-based social learning processes. More specifically, from a scientific perspective, the role of the team or one its members is to record the various sources of information, cross-check with the participants if their statements have been understood appropriately and integrate the various inputs into the co-production of hypotheses related to the system-based understanding (Burke et al., 2005). A second role of the facilitators' team is to oversee the process of interaction, with the view to address the social barriers to the learning mentioned above (Vennix, 1999).

The active role of the team of facilitators and the importance of well-tested qualitative research methodologies in guiding the social learning process is also recognized by scholars of sustainability transitions. More specifically, to overcome persistent barriers to social learning in specific sustainability challenges, scholars developed protocols that support an integrated understanding of the environmental, social and economic sustainability challenges. In this context, scholars and social actors adapted existing methodologies so that they can be used in multi-actor and multi-dimensional partnership research. The three examples below illustrate some of well-established methodologies in transdisciplinary research, respectively future visioning workshops, group-based systems mapping and community science approaches (see table 3.11).

Table 3.11. Overview of the case studies discussed in section 3.4.2.

Group-based qualitative research for transformative learning										
Project name	Topic of multi-dim (envt., social,econ.) sustainability research	Co-production			Scientif. outcome		Type of societal outcome			
		co-design	Joint anal.	Disc. Results	New data	Integr. Learn	Collaboration	Strategy	Competences	Solutions
Food, agriculture and forestry										
Coastal fisheries (SPACES), Kenya	Access for women to income generating activities and biodiversity protection	*	***			**	**			*
Urban/rural living environments										
MUSIC, Europe	Energy efficiency, greening and citizen empowerment in urban transitions	*	***	*		**		**		
Social welfare co-benefits / reversing social-welfare trade-offs										

Food aid (ATD), Belgium	Dignity of urban poor, poverty alleviation and food aid	*	***	***		**		*	**	*

Legend. Scale for co-production : consultation only (*), joint research on some aspects (**), on nearly all aspects except some technical issues (***). Scale for scientific outcome/ societal outcome: mentioned in project publications (*), well documented (**), with in depth analysis (***).

a. The challenge of social learning from radical innovations in the MUSIC project.

Transition scholars point to the difficulty of connecting the learning on global environmental sustainability problems such as loss of biodiversity, climate change and depletion of natural resources to local-level structural change (Loorbach, 2007, pp. 12-13). The local-level initiatives often remain at the level of merely attenuating the negative impacts of global change, while more radical structural changes remain outside of the scope of the societal debate. Indeed, a major barrier to social learning is the disregard by established decision makers of more radical local innovations by engaged citizens or civil society organisations (Roorda et al., 2014, p. 20). Therefore, many local sustainability innovations remain disconnected from social learning on the transformation of larger regimes such as mobility, energy, and housing among others.

The methodology of future visioning workshops, developed by the scholars of the Dutch Research Institute for Transition (DRIFT), is a well-known research tool for promoting social learning based on such disruptive, so-called niche innovations. As illustrated in figure 3.25, the aim of the envisioned social learning process is to embed the niche innovations in learning processes related to the broader structural features of the economic, legal and governance regimes, with the view to transforming the latter. According to transition scholars, the up-scaling or dissemination of small-scale changes will depend on the interaction between a bottom-up and a top-down learning process: first, from the niche innovation to the emergence of new societal patterns or the reconfiguration of societal patterns in a given socio-technological regime and, second, from social learning in the broader socio-cultural environment on new values and principles to the emergence of new niche experiments (Geels, 2004).

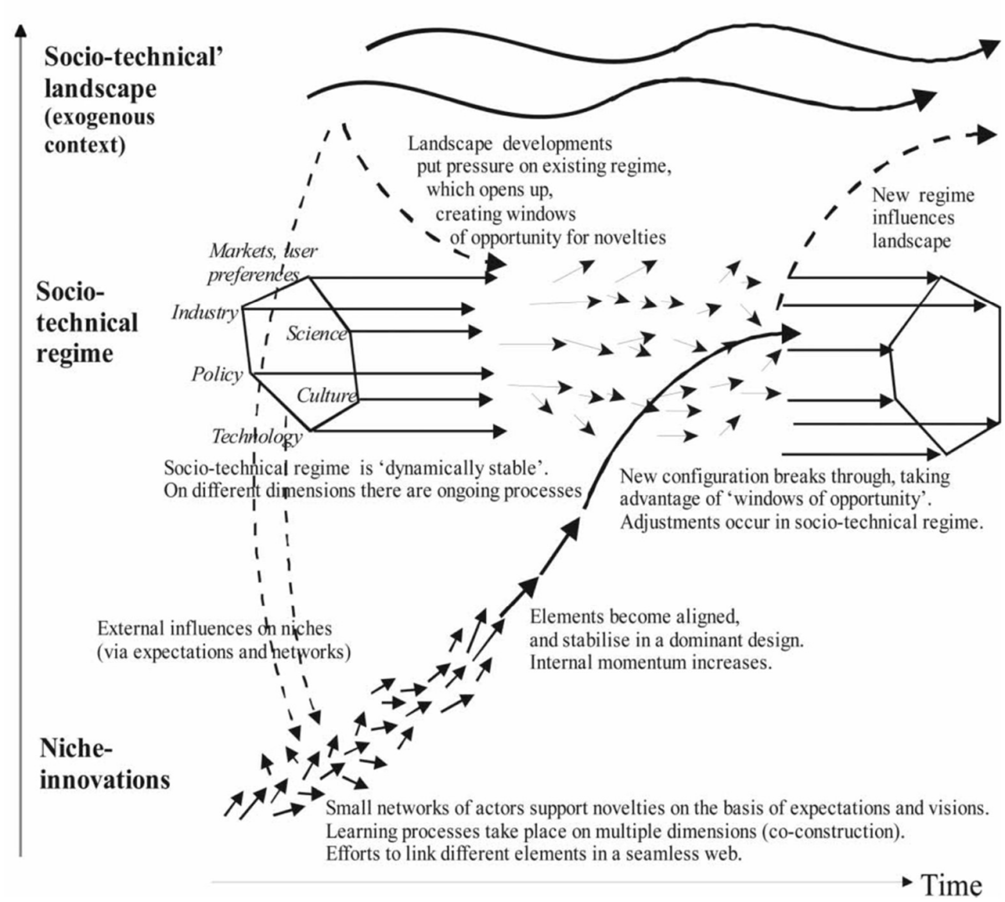

Figure 3.25. Social learning connecting future visions from disruptive niche innovations by change agents to transformations in economic, legal and governance regimes and broader changes in values in the socio-cultural environment (source: Geels, 2002)

The core of the proposed protocol for empowering these niche innovations is to identify and gather a diverse group of major change agents of sustainability transitions and to build a transition agenda with this group. Together with these change agents, the research team organizes a future visioning process fostering disruptive and transformative social learning. This process consists of two major components:

1) Workshops (or workshop sessions, depending on the available resources) on the visioning of a desirable long-term future. This visioning process is informed by existing system diagnosis and systems analysis, and a set of agreed upon sustainability principles.
2) Workshops/workshop sessions for "backcasting" of short-term actions, defined by taking the desired future as a starting point and going step-by-stem back in time.

The key point of these workshop protocols for social learning is that, by referring to the long-term desirable future, the group identifies solutions that go beyond business-as-usual and are not constrained by vested interests (Roorda et al., 2014, p. 10, p. 30). For instance, in the context of the MUSIC project (Mitigation in Urban Context, Solutions for Innovative Cities, 2010-2015), city officers, together with local change agents, organized visioning workshops on climate change mitigation initiatives in six different cities. In the city of Ghent, the backcasting exercise led to embed radical innovations such as neighbourhood initiatives for temporary car free streets into a larger narrative of Ghent as a climate-neutral city. Since then, the project has been re-iterated in other neighbourhoods and the creation of temporary “living streets” has now been recognized as a legitimate tool within sustainability mobility policies in the city.

Based on the experience with the use of the visioning and backcasting in social learning on sustainability transitions, the MUSIC project compiled a guidance manual reviewing some of the main challenges of the method (Roorda et al., 2014). The core challenge in relation to the compilation of the future visions is to think beyond our current frames of thought and enable thinking beyond what is possible nowadays. At the same time, the future visions should be sufficiently elaborated to produce meaningful debates among the participants on the most desirable futures. As the main goal of the transition management protocol is to empower the change agents, the backcasting of transition pathways based on the future visions should lead to formulating future-oriented strategies that go beyond business-as-usual solutions. Therefore, proposed short-term actions in line with the identified transition pathways should balance between radicality and feasibility. Transition management methods especially strive to identify initiatives that also have a strategic value in terms of learning about possible shifts in regime level aspects, such as shifts in economic and legal structures, and to generate broader values related changes in the socio-cultural environment of the regime.

b. The challenge of integrating gender in income generation activities from mangrove ecosystems in the SPACES project

There are many views of social justice and equity and what kind of interventions are most conducive to reach these goals in the context of research projects in developing countries. For instance, the use of the REDD+ voluntary forest certification scheme in a coastal community in Southern Kenya allowed the community organisation Mikoko Pamoja to sell carbon credits from locally certified mangrove forests to national and international buyers (ESPA Directorate, 2018). The revenues from this sale were invested in schooling, water distribution and forest protection. Nevertheless, even though this project brought much needed basic infrastructure to the community, such improvements remain dependent on external funders. To address the degradation of coastal ecosystems in the long term, a better understanding – and policy interventions – are needed to provide mechanisms for transforming the local economic opportunities of impoverished community depending on the mangrove ecosystems for their subsistence.

Two major challenges in biodiversity rich coastal ecosystems are, first, the sustainable use of products from fragile mangrove forests and coral reefs and, second, the empowering of women who are currently excluded from developing key income generation activities related to ecosystem services from the mangrove ecosystem. Moreover, in the coastal ecosystems in Southern Kenya, the coastal community experience major security issues, related to illegal fishing techniques and cross-border robbery and trafficking along the Kenya-Tanzania border. In response to these challenges, the SPACES project set up a group-based research process in four villages in Southern Kenya and four villages in Mozambique, with the view to better understanding the opportunities for men and women to improve their well-being through the sustainable use of the coastal ecosystem services.

From the beginning of the project, it was clear that the community members diverged on two possible implementation paths for poverty alleviation in the coastal ecosystem (Galafassi et al., 2018). Some members saw the lack of economic opportunities and the security issues as related to individual constraints and asserted the need for education and capacity building promoted by external actors. Other members highlighted historical social inequalities as a major barrier, especially related to gendered access rules to ecosystem resources that lead to very different access for men and women to capital, education, and mobility (Fortnam et al., 2019).

The proposed protocol for social learning in this situation was based on a combination of concept mapping and storytelling. The concept mapping aimed at identifying the main factors affecting the well-being of the community members and the strengths and direction of causal relations between these factors. A team of professional facilitators accompanied the process, organizing some of the prior knowledge through participants' surveys and engaging the community members in assessing the main findings. As shown in an in-depth analysis of the workshop recordings and transcripts, the major learning in the workshops occurred however through the sharing of lived stories and narratives that provided insights into the diverse meanings given by the community members to key concepts such as insecurity and well-being, as illustrated in the workshop drawings in figure 3.26 (Galafassi et al., 2018).

Despite a lack of convergence among the participants around innovative policy interventions, the process allowed the emergence of a "shared conceptual repertoire". More specifically, stories and lived experiences emerged as key means to shape the co-production of narratives of plausible and desirable future evolutions of the system. For instance, in the case of one of the project villages in Southern Kenya, situated along the Tsunza Mangrove, the increased knowledge of community members and associations resulting from the research process and the building of new social networks, led to a set of new initiatives. Among these are the formation of joined saving groups by women, the submission of funding applications for community forest conservation programs and training for women entrepreneurship related to identified small-scale business opportunities such as oysters trading and traditional poultry farming (Daw, 2018).

c. Social welfare co-benefits from reducing food waste in the ATD Food Aid project

As discussed in chapter one and in various case studies throughout chapter two, many of the environmental and social sustainability challenges directly impact the most disenfranchised parts of the population, whether it be in the field of environmental pollution, exposure to extreme weather events or access to a decent income among others. Nevertheless, persons living in situations of extreme poverty face many obstacles for taking part in social debates about social welfare provision or access to basic goods and services such as food, housing, and education. In response to these obstacles, social actors developed various social learning tools with researchers with the view to improve the understanding of situations of social exclusion and empower the persons in situations of poverty to voice their concerns.

In the research project by ATD Quart Monde on food aid and food waste, conducted from October 2018 to March 2019 in Brussels, Belgium, persons living in poverty were directly involved as situation experts on equal footing with co-researchers from social aid services and university (Joos-Malfait et al., 2019). The partnership research project aimed to understand the opportunities for improving the conditions of food aid distribution, especially from the point of view of the beneficiaries. At present, in Belgium, around 5% of the population turn to food banks for receiving food aid, which is slightly below the EU average of 6% (Greiss et al., 2019). At the same time, as a consequence of the policy for reducing food waste from the industrial food system, the donation of food products by supermarket chains has also increased.

However, the donation of food that would otherwise be wasted, or the provision of standard basic food items without much nutritional diversity, is often experienced by the persons in situation of poverty as failing to address their basic aspirations to social inclusion and improved livelihood opportunities (Joos-Malfait et al., 2019). In addition, the food donation is mostly accompanied by a set of eligibility conditions, which for instance verify if the level of revenue of the beneficiaries is below the national at-risk-of-poverty threshold. For many recipients these conditions reinforce the perception of social exclusion.

The proposed protocol for organising social learning on this situation of experienced lack of respect and dignity in the system of food aid was based on the method of "merging of knowledge" developed in various research programs co-conducted by ATD Quart Monde (Ferrand, 1999; Godinot and Walker, 2020; Osinski, 2020). This method has two main features.

First, workshop facilitators organize alternatively plenary reporting sessions and separate peer group discussions, as illustrated in figure 3.27. The peer group discussions gather persons that have similar sources of knowledge and experience, for instance a peer group of persons living in situation of poverty, a peer group of social welfare workers and a peer group of university researchers. This peer group approach has several objectives. For instance, the approach aims at balancing the power asymmetries between persons in situation of poverty on the one hand and persons/organisations that have the power to influence the conditions of delivery of social welfare services. Further, through separate group discussions, confidentiality of the shared knowledge is maintained. Also, by reporting to the plenary through a spokesperson of the group, participants do not have to expose themselves and can speak in the name of the group.

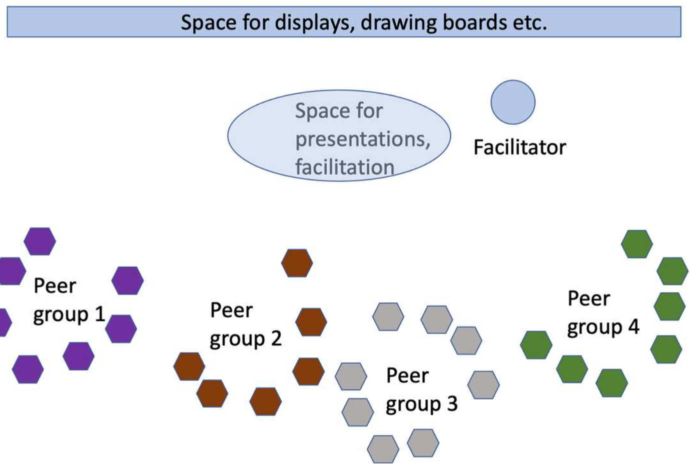

Figure 3.27. Organisation of the workshop space in peer groups. One of the peer groups is formed by persons living in poverty who are directly involved as situation experts (figure adapted from Monique Coillard, ATD Quart Mond – Ateliers du Croisement des savoirs et des pratiques, version 12, mai 2017).

Second, the "script" for organising the data and information is first and foremost based on the point of view of the person in situation of poverty (ATD Quart Monde, 2016). The voice of people experiencing poverty is both the starting point and the common thread of the process. In this context, the role of the facilitators is crucial to successfully identifying the unusual, offbeat, and disturbing points of view expressed by the persons in situation of poverty. Even if this specific point of view is sometimes uncanny at the beginning of the process, it nevertheless provides a strong incentive for learning of new understandings, imaging new practices, and generating more complete and precise knowledge on the problem situation.

The ATD Quart Monde project on food aid and food waste organized three successive workshops and a collaborative process of writing the project report with persons of each of the peer groups. One main result of the group-based research process is that a too strong conditionality in food aid delivery creates a competition for satisfying the eligibility conditions among groups of people in poverty, which goes against the community spirit of solidarity and mutual support that otherwise prevails. Further, the research shows that, even though increase in diversity of food items is a real concern, the most important demands are related to the defence of their broader socio-economic rights to work, housing, education, and culture.

Therefore, the research shows that the free provision of food cannot be separated from the creation of spaces where persons in situation of poverty can learn about and have access to other resources that can contribute to lifting them out of the situation of poverty. New urban food sharing initiatives in Brussels, even though they provide important environmental sustainability benefits, often do not include such a multi-dimensional focus. Food banks on the other hand do aim at improving the collaboration with organizations working in the field of poverty reduction, to respond to these broader demands. Participants to the workshops also identified alternative channels for distribution, such as neighbourhood restaurants and social groceries, as places with a more human way of food distribution and offering protective spaces for discussing opportunities for multi-dimensional learning and capacity building.

3.4.3 Adapting methods for social learning to multi-dimensional sustainability issues

The various cases of multi-actor social learning discussed in this section reflect the need for organizing new arenas for multi-dimensional knowledge integration on sustainability issues. These arenas are not only conducive to building mutual understanding but, through a better knowledge of the diversity of actor perspectives and action opportunities, they also facilitate social innovation. Further, through specific community-based methodologies, they also allow to empower disenfranchised social groups for participating in collective decision making. As underlined by scholars of social learning in sustainability science, by including a broad set of social actors, the ambition is to generate changes in understanding that go beyond the individual and becomes embedded in wider social units and communities of practices (Pahl-Wostl, 2009; Reed et al., 2010; Herrero et al., 2019).

As discussed in this section, transdisciplinary partnership research can contribute to overcome some of the barriers and challenges of the social learning processes. In this context, social actors and researchers can rely on a well-established research tradition of group-based qualitative research originating from concepts of organizational learning (Argyrisch and Schön, 1978), communities of practice (Lave and Wenger, 1991) and collaborative governance (Innes, 2004). Nevertheless, the integrated approach to sustainability, in terms of co-benefits and synergies between various sustainability goals and dimensions, raises a set of specific challenges for the social learning processes, which led to a set of methodological innovations and the emergence of new research traditions, as illustrated in table 3.12.

Table 3.12. Methods for transdisciplinary group-based qualitative research

Group-based qualitative research for transformative learning		
Food, agriculture and forestry		
Land-water-food nexus in subsistence farming, Zambia	GSDM	Kopainsky et al., 2017
Meaning of agro-ecology in Ontario, Canada	GSDM	Halbe et al., 2014

Woodpecker habitat project, Virginia, US	GSDM	Gray et al., 2017
Scenario building and empowerment in rural development, India, Philipinnes and Indonesia	ViBa	Bourgeois et al., 2017
Achieving a desirable future forest; backcasting with stakeholders, Sweden	ViBa	Sandström et al., 2020
Pathways for farming transitions in Aberdeen, UK, and Montermor-o-Novo, Portugal	GSDM	McKee et al., 2015; Pinto-Correia et al., 2014
Future scenarios for biosphere reserves, Bolivia, and Mexico	PSD	Ruiz-Mallen et al., 2015
ATD Food aid project with the urban poor in Brussels, Belgium (see text above)	CS	Joos-Malfait et al., 2019; Osinski, 2020
Housing and mobility in urban/rural living environments		
Climate mitigation options in urban environments, various cities in the EU (see text above, MUSIC project)	ViBa	Roorda et al., 2014; Tillie et al., 2012
Understanding values and impacts of bicycle infrastructure, Auckland, New Zeeland	GSDM	Macmillan and Woodcock, 2017
A framework for housing refurbishment, United Kingdom	GSDM	Macmillan et al., 2016
Participatory backcasting approaches for combatting climate change, Canada	ViBa	Robinson et al., 2011
Scenario backcasting of urban ecosystem services in Berlin and Rotterdam	ViBa	Frantzeska et al., 2016; Schewenius et al., 2014.
Water pollution, lead and cadmium pollution in poor peri-urban communities in New Delhi, India	CS	Marshall et al., 2018;
Production and consumption of manufactured goods		
Drivers of change in redesigning the material loops in the economy, Switzerland	GSDM	Kliem et al., 2020.
Integrating Backcasting and Eco-Design for the Circular Economy, United Kingdom	ViBa	Mendoza et al., 2017
Meaningful and decent work		
Income generation activities from mangrove ecosystems, Kenya (see text above)	GSDM	Galafassi et al., 2018; Fortnam et al., 2019
Energy production and consumption		
Energy poverty in the informal urban settlements of Enkanini, South Africa (see text above)	GSDM	Van Breda and Swilling, 2019
Water management in urban context, Switzerland	GSDM	Pahl-Wostl & Hare, 2004
Mental models of energy provision risks, Japan	ViBa	Kishita et al., 2017
Backcasting energy futures using industrial ecology, Australia	ViBa	Giurco et al., 2011

Legend. Successful research projects based on partnership research and a multi-dimensional approach of sustainability (collected from google scholar and selected collective volumes on transdisciplinary research). Projects are considered successful if they (1) produced integrated knowledge across the social, economic and environmental sustainability dimensions, (2) were validated by the science and social actor participants and (3) were disseminated both in scientific and social actor arenas. Methods:

- GSDM (Group-based system dynamics mapping): causal relations mapping and identification of main drivers and trends. A sub-set of GSDM is its extension into PSD (Participatory scenario development), where the results are used to co-design a set of plausible scenarios.
- ViBa (Visioning and backcasting): future visioning with change agents/niche innovators and backcasting of a list of short-term actions

- CS (Community science approaches): questioning of concepts and practices from the point of view of disenfranchised social groups, includes merging of knowledge (Osinski, 2020) and community based participatory mapping (Marshall et al., 2018).

4 Institutional mechanism for strengthening capacities for collaboration

Sustainability researchers, social actors and policy makers show an increasing interest in the multi-dimensional and multi-actor partnership approaches developed in transdisciplinary research. These approaches seem especially promising for addressing the present and urgent global social and ecological challenges, which require system-wide social transformations in basic human life-supporting activities such as food, energy, housing and mobility. Indeed, as illustrated in the previous chapters, disciplinary research projects, which are addressing one aspect of these challenges in isolation, are unlikely to provide the necessary knowledge support to navigate these system-wide transitions.

The mobilisation of individual and collective social actors, through representatives of associations, enterprises or public administrations, with the aim to build partnerships for knowledge co-production, is a key feature of transdisciplinary research for sustainability. Especially in the case of an integrated approach to sustainability as developed in chapter one, this multi-actor partnership approach has proven beneficial to increasing both the scientific quality and social robustness of research outputs. For instance, as seen through the case studies in chapter two, mobility transitions can provide many co-benefits among health, climate mitigation and social integration aspects among others. In this context, multi-actor research partnerships directly contribute to improve the understanding of social possibilities and drivers of change in specific contexts of transition.

The importance of the involvement of social actors in sustainability research is also underlined in a review paper in the prestigious journal *Nature Sustainability*, co-authored by 36 researchers from throughout the world and coordinated by Albert Norström from the Stockholm Resilience Centre at the University of Stockholm (Norström et al., 2020). As stated in the paper, co-production of knowledge for sustainability must explicitly recognize the multiple ways of knowing and doing. More specifically, it is important to ensure that those involved represent a range of skills and types of knowledge and expertise. This diversity generates an enriched understanding of the ecological, political, and technical dimensions of sustainability challenges (Tengö et al., 2017).

The handbook on stakeholder engagement produced by the EU funded research network on biodiversity and ecosystems research BiodivERsA (Durham et al., 2014) reviews these benefits in more detail. The benefits listed in the handbook include access to information to tailor research outcomes to local contexts and situations, improving the relevance of research results to users and beneficiaries, and the promotion of learning by the involved stakeholders. Overall, the existing literature suggests that the benefits of engagement can far outweigh the risks, especially through delivering better knowledge on complex multi-dimensional societal problems (Durham et al., 2014, p. 13).

In general, empirical data on the role of social actors' contributions in research partnerships shows that their roles are even more diverse then presented in the handbook. For instance, a survey of the role of individual and collective social actors in technological innovation projects, funded through the multi-billion European Union Horizon 2020 funding scheme, shows a broad variety of contributions. In these projects, governmental organisations were mostly assumed to provide inputs on the societal needs and the ethical aspects, while civil society organisations are often mobilized for their specific scientific capabilities and expertise (Ahrweiler et al., 2019, p. 37). Civil society organisations were involved in all types of formal roles available in the consortia, ranging from research partners providing data and conducting field research, to advisory board members and sub-contractors on specific technical tasks or communication activities.

As can be seen from this short overview, engagement of social actors has become a central component of contemporary science, reaching out far beyond sustainability research. However, in many cases, the recourse to stakeholder involvement only serves instrumental purposes in the context of conventional disciplinary and expert-led science. According to the seminal analysis by Daniel Fiorino of stakeholder involvement in environmental risk assessment, such instrumental role of stakeholder involvement mainly serves to make the decisions based on research results more legitimate to the general public (Fiorino, 1990). Indeed, as shown by Fiorino, in the early 1990ies research institutions working on environmental risks were confronted to a crisis of confidence, as the lay public was increasingly unwilling to delegate decisions to experts and administrative authorities. In response, social actors were included in risk assessment procedures, to restore the confidence by including the social actors' value perspectives in the expert-led assessments and reducing the probability of error through additional inputs of data and information.

More generally, in the case of the instrumental role of involvement of social actors, the latter provide additional information or advise to a research team, but the researchers judge if these contributions are relevant or useful within their pre-defined research protocol. In many cases such instrumental role for participation can be sufficient. Indeed, in situations where the aim is to provide technical knowledge on system components and where the knowledge is relatively independent from specific contextual path dependent features and value choices, science can operate in a relatively autonomous sphere from the input of the social actors. In these cases, several instrumental roles might contribute to the quality of the research process, such as providing extra technical information and know-how from practice or contributing to research dissemination by translating the research results to the specific needs of certain social groups.

Importantly, the case of instrumental participation requires transparent agreements with the social actors and should be distinguished from the window dressing forms of participation where social actors are manipulated, so that researchers can more easily obtain data and information or legitimize their funding demands. A prominent case in point of such transparency requirements are the international agreements on prior informed consent of indigenous and local communities in research projects on the discovery of new drugs or plant varieties for agriculture (Dedeurwaerdere et al., 2016). In other cases, such as in the EU Horizon 2020 projects, the social actors are involved in various formal consultative bodies or even in the consortia agreements, so that their contribution is explicitly acknowledged in the overall research process. Obviously, these kinds of agreements are also important in transdisciplinary research, whenever social actors are mobilized for instrumental purposes contributing to the overall quality of the research outputs.

In the case of sustainability research such instrumental role of participation is likely to be insufficient however and a stronger form of involvement will be required, based on a partnership for shared knowledge production. Depending on the problem at hand, such partnership can take different forms. For instance, in many cases the partners agree upon a distribution of tasks for contributing to the co-produced knowledge, planning for moments of joint research and other moments of separated work. In other cases, partners might opt for so-called cooperative inquiry, where social actors are co-researchers in the major parts of the research process.

In both these cases, the main difference with the instrumental role is that, for those parts of the research that are co-produced, social actors contribute in substantive ways both to the content, the framing of the research questions and the interpretation of the results as much as the scientists. The reasons that require such substantive co-production can be multiple. For instance, as discussed in one of the examples in chapter two, the living lab for the renovation of the historical city centre of Cahors in Southern France, knowledge of old building techniques by local craftsmen was essential to co-develop locally adapted bio-based materials (ENERPAT project, figure 3.2). In another case, the implementation of a vaccination campaign in Chad, researchers and nomadic pastoralists co-designed a joint human and animal vaccination campaign, based on knowledge gained from anthropological field research on the traditional communities' integrated approach to human and animal health and livestock holders' knowledge about the efficacy of the livestock vaccination campaigns (HEALTH SERVICES project, section 2.3). In contrasts to the instrumental – and even more so to the manipulative – cases of involvement, social actors and scientists actively co-design the protocol and the research questions that guide the common knowledge gathering process.

In the field of research on integrated sustainability reviewed in this book, one can highlight at least two further reasons for such substantive knowledge contributions. The first is related to the knowledge on the context specific drivers and dynamics that contribute to the realisation of sustainability goals in transition processes. The second is related to the understanding of the legitimate social value perspectives that drive the action strategies of the main involved actors in the given transition pathway.

First, as also shown in the review paper in *Nature Sustainability* referred to above (Norström et al., 2020), the realisation of sustainability co-benefits is highly context specific, in the sense that these co-benefits have a very different focus in particular contexts, places or relative to specific issues. Therefore, both the scientists and the social actors will need a highly context-specific understanding of the interactions among social actors and the system dynamics, if they want to define their research questions in a way that reflect real social possibilities of change. In this task, the project partners are highly complementary, as social actors are likely to bring more accurate knowledge on the present intentions and strategies of the main players in the given context, while the scientists might be better equipped to critically discuss the diagnosis of past system dynamics that impact on future possibilities of change. Based on this complementarity, a joint framing of the initial research question seems the best possible alternative to a science only assessment of the initial situations, which might miss out important aspects of the ongoing dynamics.

The research on the identification of major livelihood challenges in two regions in East Africa by a research team of the Universty of Massachussetts (Boston, USA) and Addis Ababa University (Addis Ababa, Ethiopia) provides a telling illustration of the importance of knowledge co-production on the context specific opportunities of change (Denney et al., 2018). One case study in this research concerned the peri-urban area of Djibouti city, the capital of Djibouti. In this case study, the community members blamed a specific UN organization for introducing in the 1980ies a variety of the Prosopis plant in East Africa. This plant was introduced as a response to the global concern of deforestation, desertification, and fuel wood shortages. Today, Prosopis is one of the most problematic invasive plants in the world and is having dramatic impacts across the landscape in East Africa, where it has been ranked as one of the leading threats to traditional land use, exceeded only by drought and conflict (Argaw, 2015).

Nevertheless, as highlighted in an ex-post assessment of the multi-stakeholder process, the research team interpreted the Djiboutian community's mistrust of development agencies as a generalized mistrust of unknown external actors, and not as a specific mistrust of development agencies that had exacerbated local problems rather than solving them. As stated by the research team, the project failed to deal with questions that specifically addressed the past. As a result, the team missed knowledge about the understanding of landscape dynamics by the indigenous and local communities, which they could have further elicited by including small-group interviews in the local villages in the research protocol (Denney et al., 2018).

Second, in addition to their contribution to a better matching of research questions to the context specific constraints on the possibilities of change, social actors provide crucial knowledge for understanding the legitimate social values that motivate the social transformation processes. More specifically, when the research involves social actors with very heterogeneous value perspectives on specific sustainability transitions, knowledge on these values is crucial to define the desirable transition pathways in a socially inclusive manner. Both social actors and researchers play an important role in defining such a research framework that captures the values that are most salient for the main involved social actors and that are considered legitimate from a general interest perspective. On the one hand, researchers from academia, non-profit organisations and within public institutions are well equipped to bring an analytic perspective from a critical analysis of various well-established frameworks to define general interest values. On the other hand, social actors research partners are likely to provide the necessary insights on the relevance of these frameworks for the main players in the problem-situation at hand, along with knowledge on more marginal viewpoints that might not be considered in these frameworks. These types of knowledge input are highly complementary, as the research framing of sustainability challenges requires knowledge on real-world value-related motivations and action strategies, in addition to knowledge from the more general debate on frameworks for assessing sustainability values.

The long-term socio-ecological research in the Haute Romanche Valley, France, discussed in chapter two provides a good illustration of such substantive contribution of the social actors to the value-based framing of research. As reported in the discussion above, the research team from the university of Grenoble-Alpes, France, quite dramatically realized the need to broaden its value perspectives in a research on bio-physical models of biodiversity and ecosystem services, after a landslide cut off the valley for six months from the neighbouring areas. Through intensive debates with the local inhabitants, a more integrated value framework was defined that put an increased focus on combining biodiversity protection with the creation of new economic value chains around sustainable local tourism. Indeed, the landslide highlighted both the vulnerability of the local population to economic hardship and their desire to preserve the patrimonial value of their natural mountain landscape. Through a new consortium with the social science department of the University of Savoie Mont Blanc, a community survey was set up that provided a better understanding of the windows of opportunity that can support the transition towards local sustainable development. In particular, the process led to a vision of diversifying the local economy around high value products from sustainable agriculture and small-scale tourism (so-called scenario of "seeds of hope" in figure 3.20, chapter 2).

As can be seen from this short summary, the substantive contribution of social actors to knowledge co-production plays a role at various levels of the collaborative learning between social actors and scientists. The contribution to knowledge co-production may lead to changes in factual understanding, challenge the assumptions that underline the researchers' representation of the local context or lead to reflect upon the higher order values that underpin the actor orientations in the given context.

Transdisciplinary scholars have developed a wealth of tools and methods to support these collaborative learning processes and are involved in intense debates about the appropriate choice and effectiveness of the various methods (for proposed evaluation frameworks, see for example Lang et al., 2012; Hitziger et al. 2019). This book reviewed a set of methods that are used in the context transdisciplinary sustainability research, ranging from living labs, participatory modelling, and interactive policy evaluation to group-based qualitative research.

However, in the previous analysis, and in most of the existing methodological overviews, the focus is on the effectiveness of the various tools and methods, while the necessary capacity for scientists and actors to participate in the knowledge co-production is mostly presupposed as a given. Indeed, in the discussion on tools for effective transdisciplinary research, the major focus is on brining the relevant groups of social actors and researchers together and involving these groups in the various stages of knowledge co-production, from co-design, through joint analysis and interpretation, to co-dissemination of the research results. Nevertheless, without available capacities of these groups for effective knowledge contribution or without providing for capacity building tools when these capacities are lacking, transdisciplinary processes are unlikely to produce the expected scientific and societal outcomes. Therefore, the analysis of processes and methods in chapter two and three needs to be completed with an analysis of possible capacity tools, as illustrated in figure 4.1.

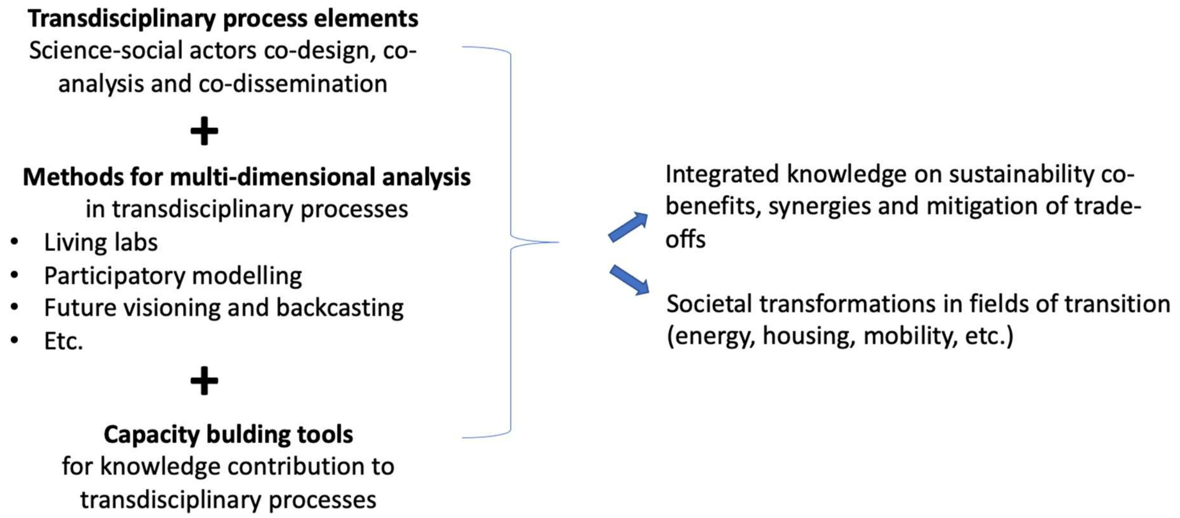

Figure 4.1. Key process elements, methods, and capacity tools in transdisciplinary research.

For instance, the comprehensive methodological overview of the BiodivERsA stakeholder engagement handbook referred to above provides many insights into stakeholder choice and motivation, while acknowledging potential barriers to successful collaboration in cases of pre-existing power asymmetries or highly unequal knowledge resources. To overcome these barriers, the handbook recommends conducting a systematic review and mapping of power differences and mapping of available knowledge resources. Nevertheless, the mapping exercise on its own, even if it can raise awareness about possible capacity problems for building a successful research consortium, is unlikely to provide sufficient guidance to the researchers and social actors to address the capacity issues.

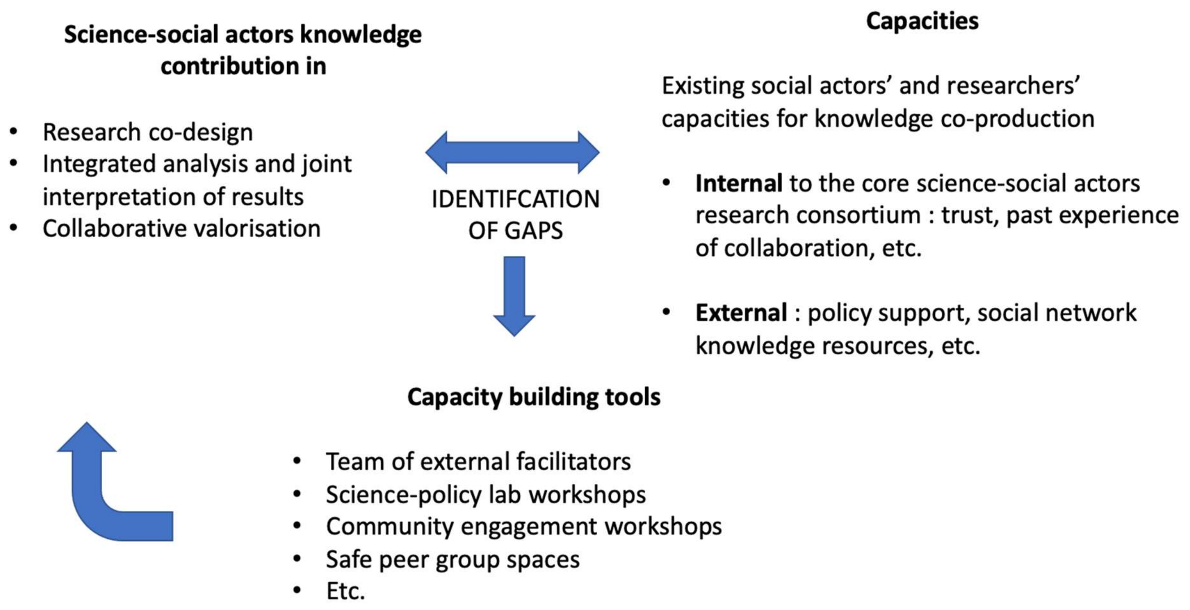

Figure 4.2. Identifying the capacity building needs for knowledge contribution in transdisciplinary research.

In case of major gaps, capacity building requires substantial additional time and effort from the research partners. Therefore, the choice by the partners to invest in organisational tools for capacity building is likely to depend on the purposes they agreed upon for building the partnership (for instance problem solving knowledge *versus* understanding of drivers of change) and the scope of the identified gaps, as illustrated in figure 4.2.

The origins of gaps in existing capacities for contributing knowledge to the co-production process can be multiple and overcoming them can be crucial for the success of the project at hand. In the case studies of sustainability research reviewed in chapter three, one can identify at least four important sources of insufficient pre-existing capacities that can be crucial for the success of a research project. The first two are internal to the research consortium and concern the inequal capacities for knowledge contribution between the project consortium members, the other two concern the capacities to mobilize knowledge resource in the social and policy environmental external to the consortium:

Internal capacity gaps (within the project research consortium)

1) lack of pre-existing capacities of certain groups of social actors as compared to other, better equipped, social actor groups
2) lack of recognized capacities of social actors, as compared to well-established authoritative capacities of researchers

External capacity gaps (between consortium members and external knowledge sources)

3) lack of access to networked knowledge resources of social actor peers
4) lack of policy support for knowledge gathering and knowledge contribution

Seen the relatively young nature of the field of transdisciplinary research, systematic knowledge on these gaps, and possible tools to overcome these, is still lacking. However, in various specific research projects, scholars and research partners have developed innovative organisational tools to address these gaps, based on the adaptation of tools known from other fields of collaborative learning. Therefore, this chapter takes a bottom-up approach to this issue. First, each section presents some well-developed examples of capacity buildings tools that are integrated in transdisciplinary research projects. Next, the analysis compares each of these examples to similar cases and draws some initial conclusions on their contribution to successful knowledge co-production in transdisciplinary research.

4.1 Strengthening collaborations across the science-social actors divide

Within transdisciplinary sustainability research, the mobilisation of various sources of non-scientific knowledge plays an important role in improving the quality of the scientific and societal outputs. Specific contributions in this context relate to accessing experiential knowledge and practitioners' know-how, identifying opportunities for context-specific co-benefits among sustainability goals or improving the understanding of value-based motivations that play a role in societal transformations among others. Debates on strengthening the capacities for this non-scientific knowledge contribution are perhaps the most prominent in the context of knowledge of traditional local and indigenous communities, but within sustainability science many other situations of lack of capacity for knowledge mobilisation have been identified, such as in relation to economically disenfranchised communities, situations of conflict over evidence or more generally situations where the collaboration with the scientists is perceived as knowledge extraction by the social actors in spite of the use of transdisciplinary co-production tools.

The case of the multi-stakeholder "working group for waders" that emerged from a research project on ground-nesting birds in Scottish Moorlands is a good illustration of the use of various capacity building tools to foster non-scientific knowledge integration (Ainsworth et al., 2020). The moorlands are well-known to provide high conservation value habitat for several ground-nesting birds, as illustrated in figure 4.3. All stakeholders and scientists agree that ground-nesting bird populations are declining in Scotland at an alarming rate but disagree both about the solutions and the evidence behind different proposed solutions (Hodgson et al., 2018, 2019). Among others, there is a lack of data on the decline of the population of Hen Harrier (top left, figure 4.3.), which might be due to illegal killing with the view to increase the presence of red grouse (bottom left), which is managed specifically for hunting. Further, for other ground nesting birds, such as the curlew (bottom right), the nesting habits are not well known, and their protection requires close collaboration between farmers, hunters and nature protection organisations.

Figure 4.3. Some typical birds from the Scottish Moorlands, illustrating the management conflict between predator management (the protected predator species Hen Harrier, top left) and creation of habitats for ground nesting birds (habitat management, middle pictures). Some other prominent ground nesting birds playing a role in the conflict: the red grouse (bottom left) and the curlew (bottom right) (source: Smith, 2019).

In response to this dispute over the available knowledge on good management practices, the Scottish Government provided some funding support and asked the Moorland Forum to use these funds to commission the "Understanding Predation" project with the view to initiate a conflict transformation process. The Forum decided to organise a transdisciplinary research project. Indeed, an earlier scientific effort to review the situations of the Moorlands produced a report that was not effectively used by policy and practice stakeholders (Park et al., 2008). The Forum members recognized that the integration of ecological knowledge and local knowledge was essential to achieve a more holistic understanding of the issues, and to identify opportunities for collaborative action.

According to Ainsworth et al. (2020), two major shifts in the approach played an important role in the successful overcoming of the lack of collaboration. First, the focus on gathering evidence on predator-prey dynamics of ground-nesting birds more generally allowed the research team to take a step back from the more acute conflict around hen harrier conservation and red grouse moor management. As stated by the research team: "we aimed to build a publicly accessible evidence base (…) from science and stakeholders' local knowledge (…) highlighting where these forms of knowledge agreed or disagreed and analysing the reasons for any differences" (Ainsworth et al., p. 47). As a result, the stakeholders and scientists realized that conservation-management of ground-nesting birds was a a priority objective for almost all participants and that the definition of healthy populations of predator and prey species was crucial, despite different ideas on the appropriate management methods among the scientists and conservationists on the one hand and the recreational users and hunters on the other.

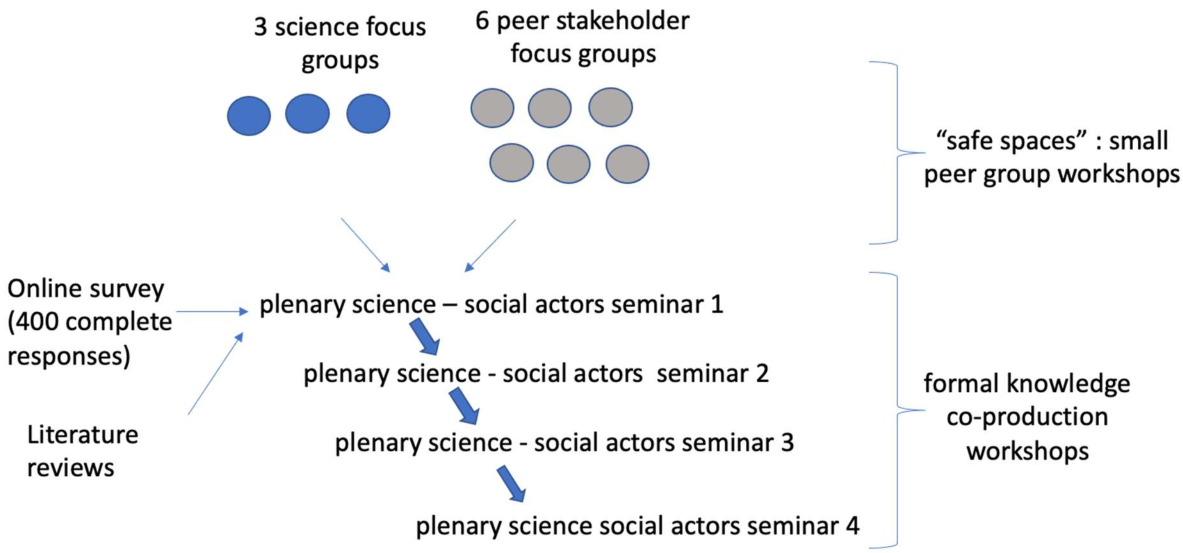

Figure 4.4. Two track knowledge diplomacy: small groups work in "safe space" workshops, organized among peers from like-minded organisation, prior to launching the formal co-production process (source: figure by the author, based on the discussion in Ainsworth et al., 2020).

Second, based on insights from the conflict transformation literature, the research team used both informal and formal institutional mechanisms for strengthening the capacities to contribute knowledge to the common effort. For instance, before gathering all the stakeholders and scientists in a formal plenary workshop, the research team organized a set of nine small-scale group meetings in a more confidential environment, with 62 participants in total representing 15 different organisations, as illustrated in figure 4.4. At the beginning of each of these meetings, the team red a confidentiality agreement and participants could approve the workshop report before the analysis by the research team. Further, as the conflict was too acute in the earlier stages of the project, the research team only invited stakeholders from like-minded organisations in the small group meeting, by using among others the results of on online survey that allowed a prior mapping of the main stakeholder values and areas of conflict. The research team asked the participants in the small peer groups to compare their own sources of data with the data from literature reviews, with the view to understand the potential disagreements between the two sources of knowledge. This approach enabled the participants to engage in meaningful deliberation, while maintaining overall consistency through covering in all the groups the same topics and referring to the common literature review and prior survey.

The combination of both small group "safe space" workshops and the regular plenary co-production workshops did not aim to reach consensus over all the issues but to create the conditions for trust and mutual understanding. In the first plenary meeting, participants with different interests were voluntary seated next to each other to encourage cross-sector relationship-building. In the final seminar, stakeholders mutually prioritized a list of future collaboration actions in the Moorlands. The continuing collaboration for knowledge gathering in the "Working for Waders" program, around a set of shared goals for conservation management, is also a clear indication of the success of the research project.

The paper by Ainsworth et al. (2020) on the Scottish Moorland case underlines that, in case of strong gaps in available capacities for collaboration, successful outcomes will depend on the combination of various capacity building mechanisms. Indeed, in the context of transdisciplinary research, researchers, social actors, and science policy funders have experimented with different ways to overcome the distrust and unequal access to knowledge and skills between scientific partners on the one hand and the social actor partners on the other, as illustrated in table 4.1. below.

The Moorland partnership mainly relies on insights from the conflict transformation literature, by organising a parallel space for trust building in more protected and/or informal environments (Redpath et al., 2013; Van Breda & Swilling, 2019). A similar approach is taken in the case of the project on food aid and food waste in Brussels that was presented in the section on group-based qualitative research above. In the ATD Food Aid project, the “safe space” was organized within the workshops itself, by alternating peer group discussions with plenary sessions. In these plenary sessions, spokespersons from the peer groups reported on the peer groups’ work and collected further questions and comments to be addressed in a next round of peer group discussions (Ferrand, 1999; Godinot and Walker, 2020 ; Osinski, 2020).

In the ATD food project, the organisation of the safe space was necessary to create a trusted environment for knowledge exchange, among participants that are mutually dependent on each other. For instance, the peer group of urban poor are directly dependent from the policies implement by the social workers, who in turn provide data to the scientists to assess the effectiveness of various welfare policy options. Through the multiple peer group design of the workshops, the project was able to create a better understanding of the perspectives of the urban poor and draw the attention to specific social values, such as solidarity values among the urban poor who depend on food aid.

A second strand of capacity building mechanisms for collaboration among scientific and non-scientific knowledge sources addresses capacity building in so-called community science projects, which are initiated and led by the social actors. In this approach, communities take the lead in formulating knowledge demands and in engaging scientists in research partnerships, with the view to address community relevant sustainability problems (Sato et al., 2018; Charles et al., 2020).

The community science approach can be illustrated through a well-documented case of scientific advice for sustainable small-scale fishery management in Galicia (North-West Spain). In the 1990s, the regional fishery administration appointed biologists as technical assistants to work with local shellfish organizations, called Cofradias, providing support with biological assessments and improving their fishery management skills. With this support, the administration wanted to improve the fragile economic situation of the fisheries and address growing demands for sustainable management (Macho et al., 2013). However, this scientific support did not lead to any significant new insights or societal changes for nearly a decade.

According to the Cofradias managers, the lack of progress was due to two factors. First, the appointed scientists largely operated based on the fishery administration’s understanding of the needs of the small-scale fisheries and, second, they were also ill-trained on the issues that the Cofradias deemed important. To overcome this deadlock, the fishery administration established a new system in 2000. Under the new rules, the Cofradias – rather than the fishery administration – were able to choose and appoint the scientists themselves and received support to host them physically in their own buildings. In addition, the members of the Cofradias community organisation involved local actors in co-determining the planning, management, and outcome of the research partnership. As a result, these “scientists in residence” or so-called “barefoot fishery advisers” (Macho et al., 2013) devised new research questions and ways of working directly with the local partners. One new line of research was related to the study of local market opportunities for the fisheries, specifically related to the involvement of women in the local shellfish harvesting. Another consisted in the development of a methodology for systematic data gathering on the available fisheries' resources, which involved forging new contacts with regional university partners. This research support had a major impact on the reorganization and professionalization of the sector.

A third strand of capacity building for knowledge collaboration among scientific and non-scientific expertise focuses on the building of new competences for knowledge gathering by the social actors. For instance, in a participatory research project on improving milk production and market access for local farmers in Kenya, farmers expressed distrust in the collaboration with the scientists, as they perceived the research project as extractive (Restrepo et al., 2020). The use of transdisciplinary process elements such as co-construction of the research consortium and the use of participatory photography tools for joint problem analysis did not change this situation of distrust, especially for the members of the local Mukinduri community.

One of the capacity building tools used in this project is the possibility to apply for financial support to produce participatory videos and experimentation with new management strategies in self-managed innovation funds. It is only in the next process phases, when community members started to voice their own narrative of the problem situation in participatory videos and using this narrative to manage the innovation funds that farmers acquired confidence in the project. As a result, as shown through semi-structured interviews with the farmers at the end of the project, the farmers acquired a better ownership of the results of the management experiments and increased their own competences for participating in joint research. In this case, these additional means of capacity building were necessary to the strengthen the knowledge gathering capacities by community members in a transdisciplinary research project that was initiated from outside the community.

Table 4.1. Institutional mechanisms for building capacities for collaboration among scientific and non-scientific knowledge sources (references in the main text, except if mentioned in the table).

Type of mechanisms	Cases of overcoming capacity gaps in transdisciplinary research projects
Safe spaces: small peer group workshops	• Food aid in Brussels, research among small peer groups of urban homeless, social workers and scientists • Conservation management in Scottish Moorlands, first stage of small focus groups with like-minded organisations
Research partnerships initiated and led by communities	• Funding to hire scientists by a local shellfish organisation, in Galicia, Spain. • Mobilisation of knowledge holders by a community of practice for watershed restoration in Hokkaido, Japan (Kitamura et al., 2018).
Training for community peer research	• Co-development of innovations by smallholder dairy farmer groups in Kenya • Community mapping of land use and ecosystem-based plan, Xáxli'p community, Canada (Diver, 2017). • Training community members from poor ethnic neighbourhoods to conduct field surveys of asthma prevalence in New York, see discussion in section 2.3 • Training community members from urban homeless communities to conduct field surveys in Toronto, Canada (Khandor & Mason, 2011).

Lack of trust and highly unequal access to knowledge resources and training between scientists and social actors pose serious and persistent challenges to transdisciplinary research processes. As the overview of mechanisms for capacity building for collaboration show, an early identification of major gaps in collaborative capacity is essential to select and implement capacity building tools. Indeed, in the absence of these tools, the various stages of knowledge co-production in the transdisciplinary research process risk to be hampered. Indeed, as shown in this section, various barriers to bridging the divide between scientific and social actor knowledge might exist, such as distrust over the validity of scientific and/or social actor produced knowledge, withholding of information by social actors who perceive the research relationship as being extractive or a lack of perceived ownership over the interpretation of the results.

4.2 Fostering community involvement in the knowledge co-production process

Many transdisciplinary sustainability research partnerships can rely on social actors with a relatively good access to various knowledge resources and a relatively well-established level of formal organisation. In such cases, the additional measures for internal capacity building among the consortia members envisioned above might be sufficient to address gaps in collaborative capacities. Nevertheless, when the social actors have only poor access to knowledge resource or when this access is highly unequal among consortia members, internal capacity building within the consortia is likely to be insufficient and a strengthening of the community or network ties might be required for successfully conducting transdisciplinary research (see the overview in table 4.2 below).

The in-depth analyses by Tischa Muñoz-Erickson of flood prevention research clearly shows the importance of access to knowledge networks (Hamstead et al., 2021). Tischa Muñoz-Erickson and her colleagues conducted research in various flood prone cities in the Americas, such as the city of San Juan in Puerto Rico or New York city in the USA, in the context of the Urban Resilience to Extremes Sustainability Research Network (URExSRN).

Because of their dominant position in knowledge networks, central well-connected actors have more influence over information flow on strategies for flood prevention and are likely to be opinion leaders in the network. For instance, as shown through a survey conducted in 2009 in San Juan, Puerto Rico, a set of well-established governmental agencies dominate the information flow on land use planning for balancing watershed development and the green zones in future city expansion (Munoz-Erickson, 2014, 2018, see illustration in figure 4.5.). The dominant vision of the State and the city places a great emphasis on sustaining economic growth and is supported by conventional urban planning visions. Non-governmental organisations more closely represent popular concerns over social development, especially of poor and marginal populations. However, the State agencies are not connected to actors at the city level, and even only to a small extent between each other.

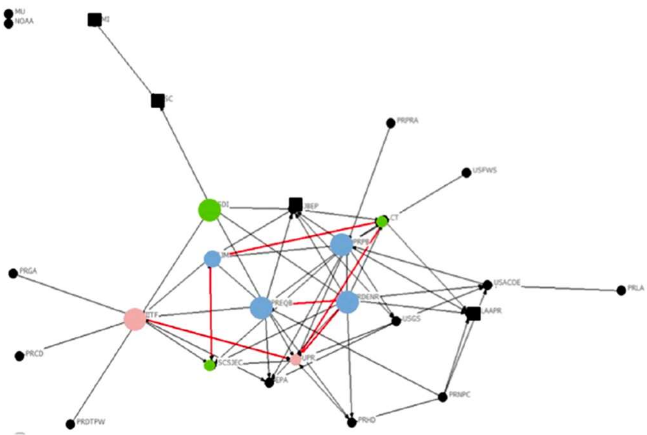

Figure 4.5. Social network analysis of knowledge flows in San Juan flood disaster planning. Most central actors in the network are in colour, showing some central network actors from the local or national State agencies (in blue), the local NGO's (in green) and research institutions (in pink) (source: Munoz-Erickson, 2014).

To strengthen the capacity of the knowledge system in San Juan for dealing with flood hazards, the research team of the Urban Resilience project organized a set of capacity building workshops in a follow-up project on so-called Resilient Coastal Cities Innovation Labs. The goal of these innovations labs was to access, use and share information among engaged city practitioners, neighbourhood residents, NGO leaders, researchers, and engineers. In the workshops, participants classified different types of data and data visualisation tools according to their relevance for different citizen related use cases, including climate education and implementation of climate adaptation strategies. Participants also created an actor map of the various organizations involved in flood and watershed planning. These innovation labs served as spaces to empower civic organisations to access and use knowledge and to evaluate the various tools that they can use to report to the municipality or in research collaborations.

As shown through this research, to overcome asymmetries in access to knowledge, knowledge networks should be designed to bring together the plurality of actors, ways of knowing and political expectations. Indeed, when addressing challenges related to extreme weather events such as hurricanes or flooding, established knowledge networks of powerful actors in large cities tend to perpetuate the conventional, dominant frames and knowledge system. As a result, research and planning tends to focus on a particular set of sustainability goals, such as urban development and economic growth, at the expense of other objectives, such as risks for residential homeowners in flood zones or possible environmental damages from flood disasters.

Similar capacity building workshops to overcome asymmetries in access to knowledge within social actor networks also play an important role in some of the research projects discussed in chapter three. For instance, in the case of the ASTHMA PREVALENCE project in New York, the research team organized yearly community workshops in the Williamsburg neighbourhood to disseminate and discuss the intermediary results. Through these regular workshops, the research team strengthened the capacity of the non-profit research partner, the El Puente neighbourhood association, to access and disseminate knowledge in the community. Such targeted capacity building activities contributed to create a more equal access to knowledge resources between El Puente and other already well networked partners, such as the neighbourhood hospital or the City University of New York.

The gap in knowledge mobilisation capacities between research partners can be especially challenging in situations where no formal stakeholder organisation exists or where the latter occupies a marginal societal position. For instance, in the South African ENKANINI ENERGY POVERTY project discussed in chapter three, the project started with a focus on informal and individual relationships in the community, with the view to allow for the emergence of research topics and community initiatives that reflected the local needs in the informal urban settlement (Van Breda and Swilling, 2019). Among others, the research team was offered the possibility of joining and supporting an emergent stakeholder discussion forum, led by the Stellenbosch municipality and an international NGO. However, the team decided against this involvement. Indeed, they feared that the research process would be locked into a multi-year process of formal institutional stakeholder engagement, in a context where the municipality was one of the sources of the problem, as it did not support the further basic infrastructure development in the informal settlement. Instead, the team developed a set of small-scale innovations with a group of shack dwellers and strengthened the local knowledge network through the establishment of the community led Enkanini Research Centre association.

Table 4.2. Institutional mechanisms for building capacities for accessing knowledge resources by research partners (references in the main text, except if mentioned in the table).

Type of mechanisms	Cases of overcoming capacity gaps in transdisciplinary research projects
Workshops to empower organisations to access and use knowledge	• Resilient coastal cities innovation lab
Community workshops to disseminate/discuss knowledge from the research consortium	• Asthma prevalence case, New York, see discussion in section 2.3. • Future Streets, see discussion in section 2.2 (engagement workshops, with social actor peers)
Establishment/strengthening of local community research organisation	• Enkanini energy poverty project, Stellenbosch, South-Africa, see discussion in section 2.4.

4.3 Mitigating poor policy support for science-social actors research partnerships

Policy makers at regional, national and international level increasingly recognize and promote transdisciplinary research, in addition to their support to traditional basic and applied research. As argued throughout this book, one of the major policy drivers for more transdisciplinary research are the research needs for an integrated approach to sustainability, addressing social welfare, environmental sustainability and economic sustainability dimensions in a socially inclusive manner.

In this context, the Global Science Forum of the Organisation for Economic Cooperation and Development (OECD) commissioned in 2020 a survey and two international workshops on “Addressing societal challenges using transdisciplinary research” (OECD, 2020). The report from this study clearly underlines that governments and public authorities have a critical role to play in establishing the overall framework that enables and supports effective transdisciplinary research. At the global level, there are a growing number of international research initiatives that recognize the value of interdisciplinary and transdisciplinary sustainability research, such as Future Earth, the African Transdisciplinary Network or the EU Horizon 2020 funding scheme, which explicitly uses transdisciplinarity as one of the evaluation criteria for research addressing complex societal issues (UN, 2019, *Global SD report*).

Policy support is not limited to the organization of the funding schemes or to proving the necessary financial and human resources for conducting transdisciplinary research. As indicated in the report of the Global Science Forum, at least three other enabling factors play a role in the success of transdisciplinary research partnerships (OECD, 2020). First, governments have a key role to play in facilitating and supporting the engagement of public sector actors in transdisciplinary research, among others to bring key expertise and relevant public sector data to research partnerships. Second, public policies can provide additional incentives for private for-profit actors and non-profit organisations to participate in transdisciplinary research, for instance through institutional recognition or support for knowledge and data sharing. Third, improving cooperation between sectoral ministries and public authorities dealing with different aspects of specific sustainability transitions can also contributed to facilitate knowledge integration in research projects on large-scale and society-wide sustainability challenges.

In practice, policy support for the implementation of science-social actor research partnerships can be highly uneven, with possible adverse consequences on the effectiveness of the collaborative processes and the social robustness of the outcomes. For instance, in a series of four international research projects on land and water management in China and Southeast Asia, supported by the German Federal Ministry of Education and Research (BMBF), the research promotors draw attention to a series of challenges that they encountered in these projects (Siew et al., 2016). Most importantly, the strong formal and informal hierarchies in land and water management administrations acted as a barrier – and sometimes as a benefit – to getting stakeholders involved in transdisciplinary processes. Under these conditions, only the research teams that contacted early in the project both people from as top as possible and informal multipliers at lower hierarchical levels were successful in organizing broad stakeholder involvement. Further, the integration of supportive and local project partners in the research consortium was key for facilitating communication, overcoming language barriers between foreign researchers, and building the network with the relevant policy makers.

In other cases, the interaction with policy makers is not necessary at the beginning of the project but is organized through dedicated science-policy events during the research. Indeed, even though the contact with public authorities might only occur at a limited number of occasions during a research project, it might nevertheless be crucial to foster social acceptance of the research results or to overcome the suspicion of certain stakeholders in the research endeavour. For instance, in one of the earliest experiences with transdisciplinary research in the 1980ies, in the context of UNESCO's Man and Biosphere programme, a research team from the university of Bern was confronted to scepticism from local stakeholders, when conducting research on the interactions between tourism, agriculture and the environment in the municipality of Grindelwald (Hadorn et al., 2008, pp. 50-51). More specifically, local stakeholders were doubtful of the value of scientific knowledge far removed from their own life-experience and insecure about any revelation of findings that could damage the image of the winter sport ski resort. In this context, the research team decided to limit the interactions with the policy stakeholders during the first field research phase. However, once this first round of field research was done, they presented their findings in the assembly hall of the municipality, which was the beginning of a fruitful interaction between the scientific experts, the local authorities, and the stakeholders (Messerli & Messerli, 2008).

Finally, the science-policy interface set up by researchers and urban planners in Berlin and Rotterdam, within the URBES research project (2011-2014), illustrates how more substantial efforts for science-policy capacity building can also be built into the transdisciplinary co-production processes (Frantzeskaki & Kabisch, 2016). The co-production process on urban planning described by the research team includes the regular transdisciplinary process components of co-design of the research questions, integrated analysis with social actors' feedback and joint dissemination efforts. At the same time, time and resources are also allocated for specific network building and dialogue with policy officials in each of these phases.

As stated by the Frantzeska and Kabisch, during the discovery phase, "local, insider and tacit knowledge on the planning and governance processes has been gathered by engaging with policy officers and planners from different departments and with different roles within the local administration" (Frantzeska & Kabisch, p. 93). In the knowledge consolidation phase, the team developed policy briefs for policy officers and planners, while broader community uptake of the outputs was fostered through social media. Overall, the process did not only lead to effective learning on urban sustainability issues but also to the endorsement of the integrated approach by the main policy officials and support for the further use of the produced knowledge within the city administration.

As can seen from the above, even though the importance of building capacity for policy support to science-social actor research partnerships varies from one project to another, in some cases such support is crucial for the specific goals of the project. Typical cases in point are transdisciplinary research projects with a strong focus on delivering policy recommendations (Pohl, 2008) or when there is a need to overcome a high level of initial disagreement between the social actors and the policy officials (Davila et al., 2018). In those cases, the research can decide to set up a dedicated initial capacity building activities for collaboration among social actors, policy, and research (see overview in table 4.3)..

Table 4.3. Institutional mechanisms for building capacities for policy support to transdisciplinary co-production processes (references in the main text, except if mentioned in the table).

Type of mechanisms	**Cases of overcoming capacity gaps in transdisciplinary research projects**
Early contact with policy officials external to the consortium, to leverage support	• The Youth Pathways Project (Erickson & Butters, 2011, p. 91) • Land and water management projects in China and Southeast Asia
Engaging with policy officials external to the consortium/workshop participants at various stages through science-policy-society interface workshops	• UNESCO Biosphere programme in Grindelwald, Switzerland • Research with the Tirani community in the Tunari national park, Bolivia (Boillat, 20017, p. 138).
Substantive policy engagements in each of the three process components of transdisciplinary research (co-design, joint analysis and joint valorisation)	• URBES research project • Policy labs for water and forest governance (Ojha et al., 2020a, 2020b, 2021)

4.4 Cross-cutting capacities for facilitating knowledge co-production

Sustainability science researchers have long documented the need to identify mechanisms that facilitate knowledge exchange among knowledge holders. As seen in the analysis of capacity gaps, fostering such exchanges is necessary both within the core group of researchers and social actors that are member of the project consortium and beyond, in the broader social networks around the project consortium and with the key actors in the policy environment. In many projects, this facilitating role is adopted by members of the research team. In those cases, the researchers play a double role of cross-boundary scientists and facilitator of knowledge exchanges (Sarrki et al., 2013). However, when the barriers to mutual learning are too high, it might be necessary to involve an independent facilitator (Vente et al., 2016; Reed & Abernethy, 2018; von Wehrden et al., 2019).

Table 4.4. The roles of cross-boundary scientists and the various facilitating roles fostering knowledge exchange in transdisciplinary research projects

Role		References to related concepts
Cross-boundary scientist	Validating knowledge, from the perspective of various disciplines	Reflective scientists (Pohl et al., 2010), Science arbiter (Pielke, 2007)

Facilitating role 1: Process facilitator	Organizing communication processes among various groups, with the view to reach common understanding of problem situations, foster collective action and promote mutual learning.	Facilitator (Pohl et al., 2010)
Facilitating role 2: Knowledge intermediary	Making explicit and articulating various possible approaches to discover, analyse and validating knowledge between disciplinary knowledge sources and between knowledge sources from various actor categories (public authorities, scientists, holders of local and traditional knowledge, etc.)	Intermediary (Pohl et al., 2010), Honest broker (Pielke, 2007)
Facilitating role 3: Science-policy intermediary	Making visible and articulating various knowledge needs of the project partners and the policy officials in the external environment	Intermediary (Pohl et al., 2010), Honest broker (Pielke, 2007)

In general, transdisciplinary research involves various types of facilitating roles, as illustrated in table 4.4. and in the case studies discussed below (see table 4.5.). In a 2010 review paper, a consortium of scientists involved in three large-scale transdisciplinary research projects funded by the Swiss North-South program of the National Centre of Competence in Research (NCCR North-South) highlighted three different roles intuitively adopted by the researchers (Pohl et al., 2010). The first role, the reflective or cross-boundary scientist, brings validated knowledge to the debate, from the perspective of the different disciplinary knowledge sources that are mobilized. The second role, the process facilitator, organizes communicative processes among the various groups, with the view to reach common understanding of the problem situation, foster collective action and promote mutual learning. The third role, the knowledge intermediary, aims at creating a dialogue between various recognized approaches that social actors use to discover, analyse and validate knowledge, for instance between knowledge sources from public authorities, scientists, and holders of local and traditional knowledge.

Transdisciplinary scholars produced a variety of similar assessments of the various facilitating roles in partnership research projects (Scholz & Steiner, 2015; Roux et al., 2017; von Wehrden et al., 2019; Herrero et al., 2019; Verwoerd et al., 2020). Most scholars introduce the same basic distinctions between the role of the cross-boundary scientists, the process facilitator and the knowledge intermediary. Nevertheless, to cover the various types of potential gaps in collaborative capacity analysed in the previous sections, it is useful to distinguish between two type of knowledge intermediaries. The first type is the knowledge intermediary who brokers between knowledge sources from various disciplines and various type of actors. This role is especially relevant in cases of highly unequal access to knowledge resources in the broader social networks. Second, when the main capacity gap concerns the lack of overall policy support for using transdisciplinary processes to address sustainability problems – and for recognizing the outputs of these processes, the knowledge intermediary needs to broker between the various projects partners and the external officials in the broader policy environment. In table 4.4 this second type is designated by the science-policy intermediary.

The research project on the management of the Tunari National Park in Bolivia provides a good example of a project that benefited from auxiliary human resources to support facilitation of science-policy interactions. The project team included human resources for most of the facilitation skills identified above. More specifically, as shown in the analysis by Pohl et al. (2018), the PhD researcher in charge of the field work in the Tunari National Park successfully adopted the role of cross-boundary scientist and process facilitator (see figure 4.6). First, the research explicitly mobilized boundary crossing activities. For instance, the PhD research showed the contribution of traditional farming practices to biodiversity in the park, through combining ethnographic field work on traditional knowledge of the indigenous' communities and plant ecology. Second, the researcher facilitated mutual understanding among the social actors and local researchers by organizing a broad variety of meetings and workshops (Boillat, 2007).

Figure 4.6. Acting as cross-boundary scientists in the Tunari National Park Research, Bolivia (source: Serrano et al., 2005).

However, in one instance, the research team needed additional capacities for facilitation of knowledge exchange. In the case of the collaboration with the Tirani community, the team was confronted to several difficulties. In particular, the team had to deal with mistrust in the initial phase of the research, resulting in interviews where only little or poor information was revealed and difficulties in gathering people for group activities. The university research team of the University of Cochabamba was unknown to the community leaders and distrust was at a particularly high level due to numerous conflicts in relation to illegal land zoning in the National Park.

Only after the Swiss National Centre of Competence in Research (NCCR North-South) organized a science-policy capacity building workshop in February 2004, the community started to become involved in the research project. The workshop attracted the participation of many indigenous leaders, representatives of the local municipalities, academic researchers, and government representatives. As stated by Sébastien Boillat, the research collaboration with the Tirani community only really took off after sufficient trust was built through the organisation of this regional workshop (Boillat, 2007, p. 138). Among others, the workshop initiated a broader debate on the governance of the National Park, which provide the opportunities to create mutual understanding among different perspectives on the overall options for the park management between the researchers from the University of Bern, the Cochabamba university and the local communities (Delgado & Mariscal, 2004).

In another project, on a research project gathering stakeholders from 16 Biosphere Reserves in Canada, the project team explicitly hired a facilitator who took on both the role of process facilitator and knowledge intermediary (Reed & Abernethy, 2018). In this project, the active exchange of knowledge among the partners only took off after the facilitator was able to overcome major cultural differences between the stakeholder representatives from different regions in Canada. Moreover, inequalities in initial resources and knowledge gathering capacities between the various Reserves also hindered the commitment of some partners and the possibility to organise inclusive decision making.

Dedicated small-group discussions organized by the facilitator, in coordination with the research team, allowed to adjust the planning to the constraints of each of the partners and to take the concerns of the smaller Reserves on board. As stated by Reed and Abernethy (2018:50), “this exercise in negotiation and joint decision-making early on in the process created a foundation of trust among partners and flattened the assumed hierarchy between the academic and the practitioners”. As a result, the partnership not only strengthened the learning on issues such as sustainable tourism and the provision of ecological goods and services in the Canadian Biosphere Reserves, but the partnership also led to a long-term knowledge partnership among these Reserves (Reed et al., 2014; Reed & Abernethy, 2017).

Table 4.5. Case studies on institutional mechanisms for building capacities for facilitation in knowledge co-production processes (references in the main text, except if mentioned in the table).

Type of mechanisms	**Cases of overcoming capacity gaps in transdisciplinary research projects**
External facilitator for communication process support	• Biosphere Reserves, Canada; • Natural Hazards, New Zealand, involvement of external skilled facilitator (Thompson et al., 2017)
External facilitator for knowledge intermediation	• Biosphere Reserves, Canada;
External facilitator for science-policy intermediation	• Tunari National Park, Bolivia;

5 Conclusion: mobilising knowledge for regenerative human development

The development model of advanced industrial economies since the end of World War II is based on growth in private consumption, technological innovation and the exploitation of material and energy resources on a global scale. This model brought increased material well-being for large parts of the human population and contributed to the building of modern welfare states in many countries of the world, which provide for basic education, health, and social insurance systems among others.

However, as witnessed by the increasing social mobilisation throughout the world – especially by the youth, citizens and social movements are increasingly worried about the negative impacts of this model of human development. Indeed, the continuing reliance on non-renewable resources has led to a global ecological crisis, which is most visible through the consequences of global warming on the increasing frequency of extreme weather events, and rapid decline of biodiversity and ecosystem services. In addition, many studies show that factors of human well-being such as social bonds, feeling of security and conditions for peaceful co-existence among cultures did not follow the same pace of progress as the progress in material well-being and even deteriorated in many parts of the world.

Policy makers and social planners have a series of measures at their disposal to alleviate some of these issues, especially through a better redistribution and allocation of wealth and improved international cooperation. Nevertheless, these adjustments, although important and necessary, remain within the existing model of human development and are unlikely to address the call of citizens and social movements for addressing the deeper human well-being and planetary health problems at least for two reasons. First, the current resource intensive development model does not allow to provide the same level of material well-being to all human beings on the planet, without further aggravating the ecological crisis. Second, to mobilise society-wide support for the vision of inclusive human development, the improvements in material well-being need to be matched with similar advances in regenerating the social fabric of social bonds, solidarity and empathy underlying many dimensions of human well-being.

In response to the limits of this growth model, researchers, social movements, social entrepreneurs and policy makers have developed a wide array of new approaches to human progress and well-being. Some of these initiatives are situated at the level of cities or local municipalities, such as the successful mobility transition in Copenhagen, Denmark, where the over 30.000 daily bike commuters outnumber since 2015 the cars that every day enter the city centre, following the example of some major Dutch cities. Others are regional, such as community supported agriculture schemes, initially developed in Japan and Switzerland in the 1970ies, which support regional organic food producers through organizing short food supply chains. Others are country wide, such as the successful energy transition in Uruguay, where the energy production was decarbonized in 10 years' time to reaching 95% of renewables in 2016, with an energy supply of 56% from pre-existing hydroelectric sources, 22% from new wind farms and 18% from biomass.

What is common to these initiatives is the ambition to go beyond piecemeal approaches to societal transitions, by designing entirely new systems that produce positive social and ecological outcomes, whether it be through soil restoration in agriculture, multi-modal mobility systems with positive impacts on human health or the shift to renewable energy. In contrast to the current policy to deal with limits understood as unavoidable by-products of the development model, these initiatives propose a different motivation, based on imagining and implementing transition pathways that provide co-benefits and synergies among various social developments goals, as discussed at length in chapter two. This shift from incremental change to entire system reforms with positive outcomes on multiple well-being dimensions is not only necessary for transitioning towards sustainable resource use but also potentially has a greater mobilizing power. Indeed, as found by studies in social and motivational psychology, even though external constraints might have an impact on motivations in the short term, only positive and intrinsically motivating drivers can provide motivations that last (Ryan and Deci, 2020).

Over the last decade, scholars of sustainability transitions have attempted to gain a better understanding of this emerging perspective on regenerative human development, which is at the heart of many transition initiatives (Du Plessis, 2012). The concept of regenerative development was initially conceived as designating the sustainable use of the Earth's resources, in a way that maintains or restore natures' self-regulating capacities. The latter can be situated at the local scale such as in the restoration of biodiversity rich ecosystems or at the global scale in relation to the regulation of the global climate or global nitrogen flows. In this context, a wealth of new societal movements and government programs emerged such as positive energy regions, zero waste consumption or cradle to cradle production in the built environment.

With the growing awareness of the strong interdependencies between the ecological and social dimensions of the current global crises, the limits of an overly technical bio-physical approach, already clearly articulated in the 1987 Brundtland report, became increasingly clear since the first major signs of the adverse environmental effects of the post-war mode of the development in the early 1960ies. The regenerative approach to human development therefore needs to be understood in a broad manner, as a mode of development and sustainable use of resources that regenerate both the Earths' life-supporting processes and the social fabric underlying many dimensions of human well-being. The resulting vision of sustainability therefore encompasses a combination of three aspects, as also elaborated in the 2019 Global Sustainable Development Report (see also figure 2.2 and accompanying discussion):

- Regenerative human development: human development within the limit of the planetary life-supporting processes, now and for future generations.
- People-centred: promoting basic human well-being features and capabilities, including strengthening of social bonds and empathy.
- Inclusive: "leaving no one behind" through pursuing social justice and equity.

Historically, reforms in scientific method and understanding have played an important role in supporting major societal transitions. Well-known examples are the developments in mathematics in Greek and Roman times that supported the building of large-scale urban public infrastructures among others, modern physics and chemistry that co-evolved with the innovations in the time of the industrial revolution, and contemporary statistics and survey techniques that supported many of the national welfare policies in the post-war welfare regimes.

Similarly, since the first major international gathering of transdisciplinary research scholars in the early 21st century, transdisciplinary partnership science emerged as a major actor for accompanying the urgent reforms needed to address the transition towards globally inclusive and regenerative human development. As shown through the extensive review of transdisciplinary research projects in this book, two major features characterize this ongoing reform.

First, the systemic interdependencies between the environmental, social and economic dimensions of sustainable development imply to adopt a multi-dimensional perspective to sustainability problems. As a result, as shown in detail throughout chapter three, transdisciplinary research efforts are both deeply multi-disciplinary and highly context dependent, in contrast to the disciplinary and ivory tower ideal of the organisation of 19th and 20th century science. Second, transdisciplinary sustainability science is intrinsically pluralistic and highly participatory. Indeed, to realize co-benefits and synergies among sustainability goals, a set of different pathways can be designed that all improve upon the current status quo. To match the scientific effort with an understanding of this plurality of desirable transition processes, sustainability scientists need to combine their expertise with the insights of the social actors on the socially legitimate social values that guide the choice among the possible sustainability co-benefits.

With the growing awareness of environmental problems and the continuing challenge to realize globally inclusive growth, science funders, social actors and researchers have initiated a wealth of transdisciplinary partnership research projects throughout the world. To make a long-lasting contribution to social progress however, a better understanding of the conditions of success for realizing high quality transdisciplinary research is required. This book took a bottom-up approach to this challenge, through an extensive review of projects, covering various fields of transition and various possible levers of change. Three core design principles resulted from the analysis of these projects, which are:

1) the use of methods for analysis that combine inputs from social/human and natural science dimensions, whether within a multi-disciplinary or an interdisciplinary approach,
2) the organisation of processes of knowledge co-production between researchers and social actors at the stage of problem formulation, analysis, and interpretation of the results, and
3) the organisation of capacity building for collaboration among researchers and social actors whenever major gaps in pre-existing capacities hamper the knowledge co-production process.

These design principles characterize transdisciplinary research projects that are highly successful in producing new knowledge on the integrated understanding of sustainability problems and/or solutions, in a scientifically credible and socially legitimate manner.

These three design principles cannot be analysed in isolation. The first design principle requires to adapt existing methods of multi-disciplinary and interdisciplinary analysis, so that these methods can be used in the context of science-social actors knowledge co-production processes, as specified in the second design principle. The second design principle is highly process oriented but to be effective it requires also inputs from state-of-the-art knowledge from multi-disciplinary and interdisciplinary understanding of the problem at hand, both from a technical and social value perspective. Indeed, as also underlined in the 2020 review paper in *Nature Sustainability*, high quality processes of knowledge co-production in sustainability research are characterized by an approach that is contextually informed, reflects the pluralism of values perspectives on the problem, clearly articulates its goals with the social actors and is highly interactive (Norstörm et al., 2020). Third, capacity building for collaboration concerns both the capacities for collaboration between disciplines in the use of the interdisciplinary and multi-disciplinary analytic methods, and capacities for collaboration between the researchers and social actors in the knowledge co-production processes.

As can be seen from the analysis of successful research projects, transdisciplinary sustainability research offers many opportunities for collective learning on the drivers and motivations to accelerate the transition towards regenerative and inclusive approach to human development. Seizing these opportunities will depend on the implementation of sector-wide collaborations among social actors and researchers in fields of transition such as mobility, housing, energy, and food among others. The latter can be very challenging as social actors in these fields of transition often hold very heterogeneous value perspectives and operate in highly dynamic contexts of societal and technological innovation.

What is the role of ordinary citizens or professionals in contributing to these society-wide transitions in specific sectors of activity? What kind of policy mixes do we need to promote these collaborative processes, which require intense social learning among the involved social actors around new values and modes of coordination? And how can universities support these new promising trends and produce the evidence-based knowledge needed to move from trial-and-error process to robust and long-lasting societal transformation?

These questions are at the heart of the initiatives by social actors, scientists, and policy makers throughout the world, who are building new networks and research partnerships to contribute to sustainable human development. In the context of transdisciplinary sustainability research, citizens, members of social movements and members of organisations are not just mobilized as volunteers to contribute data into science endeavours, but they are mobilized as social actors fully engaged in collective action in their communities and social networks. Through their privileged position as change agents, social actors acquire know-how on possible solutions and first-hand knowledge on social drivers and motivations for implementing value-based synergies among sustainability goals. As a result, through science-social actor knowledge co-production, new pathways that are actively promoted by social actors can co-evolve with innovative scientific perspectives and accelerate sustainability transition processes.

To be effective however, these promising knowledge partnerships need also to be supported both by policy makers and university researchers. Public sector officials are often first in line in the design, planning, implementation, and evaluation of supporting measures for transition processes. Through their expertise, and their privileged access to various policy and social networks, public sector officials provide and use many sources of knowledge on sustainability transitions. Therefore, policy makers, governments and public administrations can play a primary role in transdisciplinary research, through promoting the participation of public sector officials to transdisciplinary partnership research, along with providing broader institutional recognition and support for science-social actor knowledge co-production.

Universities, finally, occupy a pivotal role in the emergence and consolidation of these relatively new strands of integrated multi-disciplinary, interdisciplinary and transdisciplinary research efforts. First, through the basic research mission of the university, academic researchers can provide added value to transdisciplinary research projects, for instance by offering innovative perspectives and critical reflection on transdisciplinary research methodologies. Second, and even more importantly, by engaging actively in transdisciplinary partnership research, universities can provide training and capacity building for a new generation of young scholars and students, which are not yet acquainted with the new set of tools and methods for scientifically credible and socially robust knowledge co-production processes. As such universities can actively contribute to the further integration of the various approaches developed in transdisciplinary partnership science into the overall science fabric.

The steps to reach these various goals are especially challenging. Indeed, on the one hand we will need new knowledge to understand the nature of large-scale regenerative systems, such as cities, rural territories, or production systems. On the other hand, the systemic, multi-dimensional, and highly pluralistic nature of the collaborative efforts that are required resists the traditional disciplinary and ivory tower modes of conducting scientific research. Fortunately, as the many examples in this book extensively show, researchers at universities and in research institutes actively experiment and innovate with new multi-dimensional integrated and collaborative modes of research to address some of these challenges. This book aimed to take stock of some of these promising developments.

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