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Review

Ten essentials for action-oriented and second order energy transitions, transformations and climate change research

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ABSTRACT

The most critical question for climate research is no longer about the problem, but about how to facilitate the transformative changes necessary to avoid catastrophic climate-induced change. Addressing this question, however, will require massive upscaling of research that can rapidly enhance learning about transformations. Ten essentials for guiding action-oriented transformation and energy research are therefore presented, framed in relation to second-order science. They include: (1) Focus on transformations to low-carbon, resilient living; (2) Focus on solution processes; (3) Focus on 'how to' practical knowledge; (4) Approach research as occurring from within the system being intervened; (5) Work with normative aspects; (6) Seek to transcend current thinking; (7) Take a multi-faceted approach to understand and shape change; (8) Acknowledge the value of alternative roles of researchers; (9) Encourage second-order experimentation; and (10) Be reflexive. Joint application of the essentials would create highly adaptive, reflexive, collaborative and impact-oriented research able to enhance capacity to respond to the climate challenge. At present, however, the practice of such approaches is limited and constrained by dominance of other approaches. For wider transformations to low carbon living and energy systems to occur, transformations will therefore also be needed in the way in which knowledge is produced and used.

1. Introduction

In a world with a changing climate significant societal change is inevitable. Keeping the world well below 2 °C rise in temperature relative to pre-industrial levels will require extensive and rapid social and technological transformations, including in the systems, structures, worldviews and beliefs underpinning climate change and other contemporary challenges [1,2]. This raises a critical question for humanity: how can rapid and transformational societal change be achieved to prevent dangerous levels of global warming? While science has so far excelled at understanding the climate problem and identifying technocentric solutions, it has so far largely failed to seriously engage with the critical question of how to make transformational change happen.

Addressing this and other related questions requires a diversity of approaches to knowledge production [3]. Importantly, many contemporary challenges have emerged through the success of science over the last 300 years, such as through technologies to extract and use fossil fuels that have led to human induced climate change. Thus, while science has clearly brought many benefits, it has also resulted in new challenges that require new ways of thinking to address them [3,4]. These approaches need to be able to take into account normative aspects, inequalities, politics and power, and work more directly across the interface of science and practice [4–6].

Many alternative forms of research that are more democratic, inclusive, action-oriented and integrate different forms of knowledge have emerged over the last three decades. This includes mode 2, transdisciplinarity, post-normal, participatory, sustainability science and action research [7–12]. As yet, however, there has been no integration of these insights specifically for researchers aiming to inform and facilitate the transformational changes necessary to address climate change and help achieve more sustainable societies. Further, while all forms of research have value, effective responses to climate change require a much more direct and concerted effort towards learning from and through action [13].

This paper therefore presents 10 essentials we believe are important for researchers to achieve greater impact from their work in relation to energy transformation and climate change. The paper does not suggest that research that does not apply all of the essentials is not useful, and working towards applying any of these will add value. However, when applied as a collective, the essentials represent a considerable shift in the way research is conducted that will generate more significant impacts for addressing the climate challenge and legitimise the inclusion of a greater diversity of kinds of knowledge, perspectives, values, imaginations and approaches needed to facilitate transformations to a low-carbon, resilient world. Overall, while the emphasis is on climate change and transformation, the paper will be of wide relevance to any field of study that seeks to enhance societal outcomes.

The paper first explains the need for more action-oriented research and the concept of first and second-order science, which frames the rest of the paper. We then explain the 10 essentials, followed by a discussion about the challenge of encouraging greater attention to the kinds of research that will more effectively accelerate the learning needed to stimulate transformations in the context of climate change.

2. The need for greater attention to action-oriented transformation research

There is a growing emphasis on research agendas and programmes relating to understanding how to achieve deliberate societal transformations to avert the threat of climate change [1,14,15]. While there are many definitions [16], transformation is broadly a process leading to marked and qualitative change [17] and processes that lead to

Table 1
Types of change (modified from Waddell ([18], p. 15)).

	Incremental	Reform	Transformation
Learning type	Single loop	Double loop	Triple loop
Core questions	• How can we do more of the same? • Are we doing things right?	• What are the rules and structures? • What are the rewards? • Who should do what?	• How do I make sense of this? • What is our core purpose? • How do we know what is best?
Purpose	To improve performance	To understand and change the system and its parts	To innovate and create previously unimagined possibilities
Power and relationships	Confirms existing rules	Opens rules up to revision	Opens issues to the creation of new ways of thinking and action
Core dynamic	Replication	Reorganization	Transcendence
Archetypal actions	Copying, duplicating, mimicking	Changing policy, adjusting, adapting	Visioning, experimenting, inventing

fundamentally different forms of thinking, actions, systems and structures (Table 1) [18]. Clearly, such long-term changes come about as a collection of short-term, and often emergent actions [18] and that research processes are critical in shaping these. Thus, while there is extensive debate about whether transformative change can be achieved sufficiently quickly to mitigate and adapt to climate change [19,20], the challenge of finding ways to create the necessary shifts in the systems, structures, assumptions and worldviews underpinning climate change remain [21].

A considerable volume of untapped knowledge about social change from the arts, humanities and social sciences already exists that can inform transformations towards low-carbon, resilient living [22,23]. This includes, for example, a large and growing body of knowledge on large-scale systems change [18], historical dependencies, social and technical innovations, practices and processes for change [24–26], individual, cognitive, systemic, cultural, corporate, legislative, power and political dimensions that inhibit or enable change [2,27–31], climate policies and strategies [32–34], climate insurance [35], normative aspects (values, ethics, aesthetics) and how to work with uncertain futures [36–38]. Yet despite the vast amount of knowledge already accumulated, there is still limited emphasis on understanding how to implement change. This 'how to' question is now arguably the most important question for climate research.

One of the key reasons for limited engagement with the 'how to' question is because implementation has traditionally been confined to the domain of practice, in part due to a dominant culture in science where implementation is viewed as political, normative and future oriented and hence not amenable to scientific analysis [39]. This is highlighted by the work of influential organisations, such as the Intergovernmental Panel on Climate Change (IPCC), which has focused on providing evidence of the problem and identifying broad pathways. As a matter of principle, and through influences from UNFCCC, Conference of the Parties (COP) and national focal points, the IPCC aims to stay away from being policy-prescriptive. That is, it avoids normative statements about how assessment findings should be acted upon, under the assumption that the latter is the role of politicians. While there are good reasons for the approach (e.g. to appear impartial in a highly politicised context and avoid the problem that implementation often requires locally specific approaches), it has meant that most of the focus has been on understanding the causes and impacts of climate change. It also produces largely descriptive mitigative and adaptive solutions, including of their costs and barriers to implementation, but providing very little critical assessment of how solutions are being implemented and to what effect. This not only means that critical knowledge about implementation gets omitted in reports, but also contributes to wider perceptions about the usefulness of the different kinds of research and knowledge needed to address 'how to' questions, ultimately slowing progress towards identifying and learning about implementing solutions.

There are many examples of work at the interface of academia and practice and a growing trend towards more impact driven knowledge, co-creation of outcomes from research and practice, and greater engagement of researchers in interventions seeking to enact change [40]. Yet such work still remains at the fringes of more dominant approaches. If the goal is to enhance understanding about how to make transformative change happen, a massive upscaling of research that works more directly with practical domains will be needed. Nothing less than a radical shift towards large-scale expansion of more action-oriented knowledge production will be required that: takes into account the real world of politics, values, and ethics that characterise societal change [3]; works with academic and practical forms of knowledge; embraces creativity, imagination and innovation as a form of knowledge production [6,41]; and is more explicit about its relationship to society [4]. Thus, while the major advances in knowledge production over the last 300 years are extremely important, a major shift towards acceptance and incorporation of new forms of science and research is also needed [4]. In short, transformations towards more viable systems of knowledge production and use are required for wider societal transformations in response to climate change to occur.

3. Science as intervention and second-order transformation research

One of the reasons why there has been limited attention in research on solutions and their implementation is the primary assumption underpinning much of the sciences and social sciences that an observer is, and can be, independent to that which is observed [42]. Invoking this assumption has had a powerful effect on the ability of humanity to produce certain kinds of knowledge, even though this assumption is largely flawed. It is widely recognised in the social sciences and humanities, for example, that it is impossible for a researcher to be independent: cognition, prior experience, understanding, scientific paradigms, and societal influence such as cultures, politics and the 'hot topics' that receive funding all affect how research is conceived, conducted, interpreted or used [13,43–46]. Through theories, concepts, and findings researchers also influence society, which in turn reinforces how researchers or the public perceive and approach the world in which they are embedded [45]. Thus, researchers are inevitably embedded within, and not separate from, the systems they seek to observe.

Researchers are also arguably always interveners. Intervention is the "*purposeful action by a human agent to create change*", where action is influenced by knowledge, including perceptions, implicit understandings, conscious and unconscious motivations, as well as values, morals, ethics and norms and behavioural habits ([47], p. 113). Science can thus be understood as an active process of intervention, either directly in practice or more indirectly through the generation of knowledge. This includes both applied science (e.g. climate science to develop knowledge to inform policy or agricultural science to directly improve farming practices) as well as curiosity-driven research (e.g. the production of a research paper which 'intervenes' in the thinking of other scholars). Because observation is just one type of intervention, scientific techniques are part of a more pluralistic set of intervention methods, including methods for exploring values, reflecting on subjective understandings and planning future activities [48].

Viewing science as intervention places greater responsibility on researchers to be more explicit about the reasoning behind the decisions they make throughout the process of scientific enquiry. Importantly, choosing to focus on one form of intervention means avoiding doing another. Researchers therefore need to be more explicit about what kind of intervention they choose to engage in [47]. For an unprecedented issue like climate change where urgent action is required, what is researched and where resources are allocated matters [49]. Focusing on gaining a better understanding of the climate problem on the assumption that this will lead to formation of policy and change may be laudable, but in the context of constrained research budgets and value-driven budget allocations, a focus on problems may be at the expense of arguably more urgent 'how to' questions that can no longer be ignored. Acknowledging that science is essentially a choice about focusing on a particular kind of intervention thus frees up possibilities for new questions, domains of application and different ways of learning about, and influencing change.

These issues are well recognised in the field of cybernetics [50] where distinctions are made between first- and second-order forms of science. Second-order science rejects the assumption that an observer can or should be independent to what is observed [42]. This then leads to the opening up of many possibilities (Table 2). For example, researchers making choices about how they intervene highlights the normative nature of science and that it occurs in conditions in which truth is not absolute [13]. Acknowledgment of this can then lead to greater acceptance of multiple ways of knowing and recognition of the need for transdisciplinary approaches to science that actively include diverse stakeholders, which then provide new opportunities to learn

Table 2
Key assumptions underpinning second-order transformation research and their relationship to the ten essentials. The first three assumptions broadly relate to the focus of the research and the other essentials to how this research is conducted.
Primary sources: [13,42,47,106,107].

Key assumptions	Explanation	Implications	Relates mostly to the essential of:
Significant and transformative societal change is needed to address climate change	• Climate change is a 'symptom' of the current way society operates and is organised, and thus addressing climate change requires approaches that challenge structures, systems, mindsets and cultures.	• There is a need to focus on transformative rather than incremental or marginal forms of change, such as through research and practice focusing on addressing underlying structures/systems that perpetuate unsustainable activities, e.g. governance, power, values and cultures, as well as technology.	1. Focus on transformations
Greater focus is needed on learning how to make change happen	• Science has excelled at identifying problems and solutions but has had limited impact on shaping the societal changes needed and for implementing solutions.	• Greater focus is needed on solutions and processes for change.	2. Focus on solution processes
Need to focus on practical forms of knowledge to address critical questions about solutions and their implementation	• Focusing more on solutions and their implementation requires engaging more with practice • Practical know how knowledge is embodied and often developed through many years of experience and relevant to specific contexts; • Practical knowledge is different to epistemic academic knowledge, which is abstract and often generalised.	• Emphasis on epistemic knowledge has resulted in limited engagement with practical knowledge; • Need for greater focus on practical forms of knowledge and methods where practice can better inform research	3. Focus on 'how to' practical knowledge
Researchers are not independent from that which is studied and scientists are interveners	• Science and research influences and is influenced by the world; • Because scientists are part of, not separate from, the systems in which they work they inevitably influence something, such as changes in knowledge or practice.	• Science is an active part of social systems and is therefore itself an intervention; • Science can be part of action and involved in shaping the world; • New opportunities for innovation emerge when a scientist reflects on how they influence systems in which they are a part.	4. Approach research as occurring from within the system that is being intervened
Science is inherently normative	• Acknowledging scientists as interveners highlights that all science is inherently normative and value laden because choices are implicitly or explicitly made about what is intervened in and how that intervention occurs.	• What scientists choose, or choose not to focus on, or how they approach their science always has important implications for society; • There is a need for explicit acknowledgment of the normative component in research; • Science needs to actively work with the messy world of politics, values and change and incorporate ethical and aesthetic considerations, in addition to new knowledge.	5. Work with normative aspects
Many contemporary problems cannot be addressed by the same kinds of thinking that created them	• Problems like climate change are partly the result of centuries of scientific and technological developments that have led to capacities for unsustainable behaviours; • Thus, while science has clearly brought many benefits, different kinds of thinking will be required; • An example of this is re-entry, which involves applying the building blocks from the 1st order level on those same blocks (e.g. sustainability of sustainability, transformation of transformation).	• New kinds of thinking, like re-entry help move towards new research domains, academic fields, research challenges and new forms of trans-disciplinary research and co-operations; • Possibilities for developing higher generality; • Post-disciplinary science – where research focuses on issues across traditional disciplinary boundaries.	6. Seek to transcend current thinking and approaches
Truth is not absolute	• There will always be multiple perceptions, concepts, framing and subjective experiences of phenomena for complex actions in relation to climate change; • The world is increasingly complex and uncertain with change accelerating, and issues being highly interdependent; • Climate change requires a future orientation, which increases uncertainty e.g. for knowing how to implement climate pathways.	• Transdisciplinary approaches are required to take into account multiple perspectives, knowledge and ways of knowing; • Democratisation of knowledge is important because if truth is not absolute, there will be multiple interpretations and views of how new knowledge should shape actions and decisions;	7. Take a multi-faceted approach to understand and shape change
Learning about change requires practice and experience	• Focusing on practical know how knowledge requires getting 'hands dirty' and learning from experience; • This requires ways to accelerate learning about doing transformative change.	• A researcher or practitioner may need to be flexible in the role they play in the research process.	8. Acknowledge the value of alternative roles of researchers
Learning about change is iterative	• Transformative change is a complex process where the implementation of solutions can be challenging and messy	• Structured processes (experiments) are needed to enhance learning through iterative attempts to create change.	9. Encourage second-order experimentation and change
Reflexivity is critical for the practice of second-order transformation research	• Reflexivity involves scrutinising aspects usually taken for granted and that seem to have become self-evident. It is essential for carefully considering and being aware of the	• Opens space for innovation and change (e.g. for focusing on new ways of approaching science); • Helps make explicit the implicit values, frames and assumptions of individuals/collectives;	10. Be reflexive

(*continued on next page*)

Table 2 (*continued*)

Key assumptions	Explanation	Implications	Relates mostly to the essential of:
	role of a scientists as an intervener, and the practice of all other essentials	• Assists management of the challenges of simultaneously working to generate knowledge and action and the ethical and normative aspects involved in science.	

more directly from and shape action [13,42,51]. It also demands critical reflexive practice by individuals or collectives involved in research about their role as interveners and how they carefully balance the challenges of achieving methodological rigour while also being part of the system they are studying [51,52]. In second-order science this may include researchers 'dipping in and out' of action to enable them to enhance learning about practical elements of change while also providing opportunities for more critical thought and analysis [47].

Viewing research through the framework of first- and second-order science helps clarify the nature of different kinds of transformation and climate change research (Table 3). First-order transformation research involves describing and analysing processes of change [53,54], where results are then disseminated to beneficiaries through some kind of knowledge transfer [55]. Examples include research on technological innovations, systems science research on global change and climate change [56], and historical analyses of large-scale socio-technical transitions [26], as well as many of the research questions proposed as core for climate and sustainability science [8].

In comparison, second-order transformation research is more likely to view action, learning and the generation of new knowledge as being more closely intertwined (Table 3). It places greater emphasis on the research as a reflective practice [51], and focuses on creating change from within the system being studied rather than viewing it as an external problem [57]. Importantly, while both first- and second-order

Table 3
Tendencies in first and second-order transformation research.

Key assumptions:	More likely in 1st Order Transformation Research	More likely in 2nd Order Transformation Research
Aim:	To improve understanding and knowledge of change.	Both improving understanding of, and contributing to, change.
Validity and rigor:	Assumed to come from the ability of researchers to be independent of the practice of change.	Assumed to come from researchers actively engaging in doing and learning from change and where practitioners are involved in the process of research.
Embeddedness:	Research is conducted from without the subject of study, as if looking at the issue or system from the outside.	Research is conducted from within the subject of study, with recognition that researchers are one of many actors in the process of change.
Transformation is best served when:	Research is seen to be produced independently by researchers to ensure results have credibility and impartiality.	There is greater involvement of researchers in action and multiple stakeholders in the research because this encourages and accelerates mutual learning and ensures research is grounded in social reality.
Knowledge of researchers:	Greater tendency to assume that researchers are in a good position to know what knowledge needs to be produced to ensure research contributes to transformation.	Greater tendency to assume that researchers are not always in the best position to know what knowledge is needed and that there is a need to learn from doing practice and/or from involving practitioners in shaping the research.
Context:	Research is often assumed to be largely context free	What is researched and how action is achieved is recognised as being context dependent.
Engagement with values and aesthetics:	More likely to assume research can be conducted value free. Thus while research may include developing knowledge about values there is less emphasis on how values underpinning research affect outcomes.	More likely to assume that research is normative and thus more likely to explicitly articulate and work with a set of values and aesthetics to guide what and how research is conducted.
Framing:	More often needs of research (i.e. to produce knowledge) frames society	More often needs of society (i.e. social or environmental improvement) is assumed to frame the research
Focus of the research:	Exploratory problem solving of natural and social science questions relating to social change and environmental sustainability. This may include building large datasets and analysing patterns, as well as more fundamental and context specific research.	May include re-entry oriented questions about change and transformation, e.g. researching how change is changing, transformations of transformation processes, facilitation of facilitations of change, research on the research of transformation, politics of the politics of change, or ethical issues associated with research on ethics.
Dominant mode of research:	Often analytical and deductive, dominated by naïve or critical realism.	May be more purposive, participatory, action-oriented, dominated by pragmatism and radical constructivism.
Role of researchers:	Researchers usually separate from practice and outside of observed system.	Researchers engaged more directly with practice and embedded in the observed system.
Practitioners:	Usually separate from research, and mostly viewed as sources of data or knowledge.	Engaged more actively in doing research as research provides important opportunities for enhancing learning about practice.
Sharing of knowledge:	The knowledge produced is disseminated in some way to practice after it has been produced. Greater emphasis on linear communication.	Active engagement of researchers in practice and practitioners in research enhances uptake of findings and learning. Greater emphasis on conversation and exchange, rather than communication and dissemination.
Learning:	The majority of the learning from the research is mostly confined to researchers and majority of the practical know how of doing change remains confined to practitioners.	Application of action research can result in learning by both researchers and practitioners and practical 'know how' is less confined to practitioners.
Reflexivity:	Thinking about thinking, how researchers come to know something, and about complexities of social engagement processes in research receives less attention.	Thinking about thinking, how researchers come to know something, and about social engagement processes becomes critical as reflexivity is a fundamental source of innovation and important for managing the multiple objectives or issues involved in complex, collaborative and action-oriented research.
Institutions for research:	Tendency towards the development of knowledge production institutions (e.g. Universities or research centres) separate from systems studied.	More likely to encourage greater embeddedness of researchers and trained learners within boundary organisations or in institutions involved in implementing practice.

Table 4
Examples of research that has components of second-order approaches.

Project	Goal of the research	What is intended to be transformed	Approach undertaken	Why it might be considered to be second-order transformation research	Reference
Scottish Borders Climate Resilient Communities	To develop and apply processes for enhancing resilience of local communities	Relationships between local communities and local authority and other actors and increased resilience to climate change taking into account systemic issues	Action-research with close collaboration between researchers, local authority and communities	• Researchers facilitate learning and interactions to help develop practical knowledge aswell as taking more traditional roles (e.g. as evaluators of process) • Research is iterative, and highly reflexive in relation to emerging needs	[92]
Travel emissions of sustainability science research	To understand size, carbon emissions of sustainability researchers	The way researchers view their actions in relation to sustainability	Quantitative data analysis of travel of participants in Maine's Sustainability Solutions Initiative	• Involves re-entry second-order question about the sustainability of sustainability initiatives • It is reflexive in the sense of turning questions back on researchers about their research	[105]
Baltic Sea Fisheries 2020	To understand and communicate how Managing Authorities interpret and implement the European Union Common Fisheries Policy concept of 'regionalized fisheries management"	To change the locus of responsibility for fisheries management to achieve a better fit between social and ecological systems.	Action research by designing, arranging, documenting, analysing and communicating an annual conference for Baltic fisheries stakeholders in cooperation with regional authorities and municipalities.	Research results include a new arena for communication between local, regional and national managing authorities. Researcher's actions have direct impact on national fisheries strategies and the understanding national authorities have of their own mission and mandate.	[118]
Network Interventions by Private Partners for Responsible Innovation	To provide support to sustainability initiatives through action research and improve understanding of social learning processes and methods	The relations and practices in the value chains in the Dutch greenhouse and dairy farming sector	Action research (Reflexive Monitoring in Action) to support critical reflection and system learning among the innovators	Strong emphasis on critical reflection in the process of shaping action and production of knowledge through: (a) researcher engaged as critical analyst; (b) reflection by wider research team on the role of the research in the change process; (c) findings presented and discussed in role plays with innovators and action researchers.	[173]
Individuals in Context: supportive environments for sustainable living (EU FP 7 project: InContext)	To understand and support transformations in local communities in relation to well-being	The way local communities envision and create their future and the role of community members in this process	Action-research with close collaboration between researchers, and communities, applying a contextualised transition management approach and using network analysis	• Researchers facilitated a process of problem-framing, envisioning and experimenting and supported implementation of projects and experiments • Researchers critically reflected upon (and adapted) their own roles, the research approach used, the normative dimension (sustainability focus)	[119,131,174]

science are inherently normative, a key distinction is that second-order science directly accepts this normativity and actively seeks ways to work with it in a meaningful way. First-order science, however, tends to assume that it is possible and desirable to work in a normative vacuum. This has enabled first-order science to make major advances through developing certain kinds of knowledge, but at the exclusion of others. This, in turn, has limited development of new kinds of strategies for addressing contemporary challenges like climate change. Overall, second-order science is more likely to privilege approaches like purposive transdisciplinary and action research which may explicitly focus on practical resolution of real-world issues and which challenge traditional notions of the validity of different kinds of knowledge [36,58,59]. Some of the many examples of the application of key assumptions from second-order climate research are outlined in Table 4.

Viewing research as first and second-order is helpful because it provides a meta-framing that makes explicit the underlying assumptions and features of many research approaches like transdisciplinarity, mode 1 and 2 science, or action research. The concepts of second-order science are also just as applicable to bio-physical as well as social research, with many aspects of first-order science still having a legitimate place within second-order science when observation is the intention [47]. Importantly, while second-order transformation research itself has many challenges and is not a panacea [42,59–62], it does open up possibilities for more direct development of practical forms of knowledge, which are essential for informing how to implement change. At present, however, effort is still massively skewed towards first-order approaches [41,63]. If the intention is to help bring about transformative change for societal benefit, then much greater focus on second-order science will be required [13].

4. Ten essentials for second-order transformation research

As yet there has been no synthesis of the diverse insights from second-order science and other traditions specifically used to guide those attempting to engage in more action oriented transformation, energy transition and climate change research (Fig. 1). In the following sections we therefore present ten essentials for second-order action-oriented transformation research. The essentials emerged over a two-year period from individual and collective reflection of the authors during three consecutive workshops at the Transformation conference in Sweden in 2015, a two-day professionally facilitated intensive International Futures Forum workshop in 2016 in Scotland on second-order science, further conversations at the International Sustainability Transitions conference in Germany in 2016, and many iterations and different discussions among the authors involved in this work. The process began with a collective frustration about the limited acceptance of second-order science in a world dominated by first order approaches, despite a real and urgent need for a greater diversity of scientific work. The iterative process initially led to the identification of key essentials, but without a conceptual foundation and sufficient clarity about their underlying assumptions. The concept of second-order science was then chosen as the most appropriate foundation and the essentials were further modified and developed under this framing.

The process led to the essentials outlined below. The primary intention is to highlight critical assumptions and outline what is needed for a comprehensive approach to second-order transformation research rather than prescribe how to apply the essentials in practice. Nevertheless, many examples and references are also provided about their application. The first three essentials generally relate to the focus

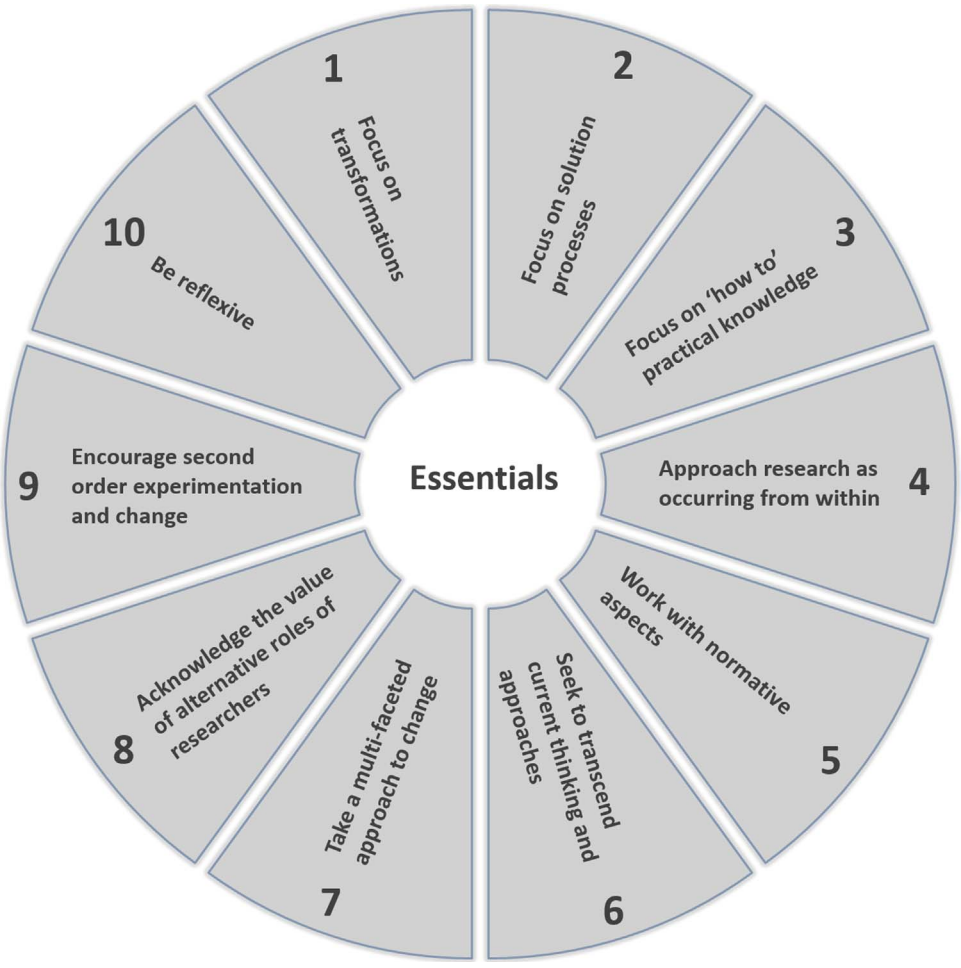

Fig. 1. Ten essentials for second-order transformation research.

of the research: transformations; solutions; and practical forms of knowledge. These are then followed by seven essentials for practicing second-order transformation research that begin with wider aspects relating to how research is framed and approached and then moving towards more specific methodological aspects.

4.1. Focus on transformations towards low-carbon, resilient living

The first essential is the need for research to explicitly focus on transformational change and how this is brought about. This can be through, for example, examining drivers and mechanisms of transformational change, the role of different kinds of disruptive changes and/or different transformative pathways, and the range of possibilities and uncertainties involved [64]. It also requires being explicit about what is meant by transformation to avoid all types of change being labelled as transformative [65] and clarifying what is to be transformed and for whom transformation is intended.

Importantly, the criteria for deciding what is or is not transformation is normatively defined by what is desired or considered legitimate. For climate change, consideration is needed as to whether change is of sufficient depth (e.g. intensity, quality, or whether it results in systemic forms of change), breadth (widely distributed), and speed (rapidly resulting in intended outcomes) [6]. These dimensions may apply to different domains, such as cognitive, structural, relational, and functional aspects of the social, ecological, and technological (Table 5). Importantly, sustainable human-environment relationships are also critical aspect of considerations of what counts as transformation, and ecological and environmental aspects cannot be ignored in the attempts to shape societal change [66]. This highlights the need for clarity about the normative goals of any transformative research (essential 5), which in the case of this paper is broadly towards social and environmental sustainability, such as that outlined in the UN 2030 Agenda for Sustainable Development [67]. Overall, transformation research is inherently subjective, requiring researchers to be explicit about how their understanding of transformation and values and motivations shape their work and how they can more effectively contribute to facilitating transformative change.

4.2. Focus on solution processes

Second-order transformation research also needs to focus less on understanding problems and more on how to effectively and efficiently steer and facilitate transformations towards mitigation and adaptation [68]. Problem-oriented research typically involves identifying the dynamics, impacts and causes of climate change and assessing who or what is affected [69,70]. Understanding causes and effects, however, does not explain how to mitigate and/or adapt to such changes [71]. Research instead needs to generate actionable knowledge contributing to processes giving rise to solutions to climate change problems.

In research on solution processes, problem analysis is typically conducted less comprehensively and is viewed as a *means* to an end, and not an *end* in itself. Research on solution processes also then addresses two additional aspects: First, it addresses the aspired outcomes (e.g. desired states and dynamics) such as the future state of climate conditions suitable for human and ecological wellbeing; what the (transformed) human activities and emission pathways might look like in such a future; and aspects that need to change for such conditions to materialize, such as the values, norms, and legal structures [31,72]. Second, it focuses on the processes that lead to the outcomes [73], such as understanding the pathways needed to achieve transformation; who would need to take what kinds of action and when; the resources needed to deliver the actions; and the kinds of barriers likely to be encountered on the pathway to change and how to overcome them [74–77]. Examples of these kinds of projects include work on disaster recovery, renewable energy provision, alternative administrative purchasing practices, as well as substitution of chemicals and materials that have adverse impacts [63,68,78]. These examples are a form of experiment, which is itself a key component of second-order transformation research (essential 9). Overall, this indicates that such action-oriented research requires combining problem analysis, visioning, assessment, and intervention methodologies [79].

4.3. Focus on 'how to' practical knowledge

Learning about change requires more than identifying solutions: it also requires knowing how to implement change in practice. It is often not acknowledged, however, that this involves engaging with different kinds of knowledge to that traditionally found in much of academia. Academia is dominated by '*episteme*', which is teachable and abstract [80]. Practical knowledge, however, includes both 'know how' knowledge (techne), such as that used to install solar panels or to facilitate complex climate negotiations, and ethical and political-practical knowledge (phronesis), which relates to the ability to know what makes a good end and a viable, morally defensible path toward that end [80]. Practical knowledge is typically embodied, difficult to articulate and often built experientially over many years for particular circumstances or contexts [81,82].

Failing to acknowledge distinctions between academic and practical forms of knowledge has led to a largely misconceived gap between research and practice and attempts to make academic knowledge or theory more practical, rather than focusing on development of practical forms of knowledge [83]. That is, reducing carbon emissions cannot be taught only through abstract knowledge like a powerpoint presentation: a learner also has to learn from doing it in practice [84,85]. Failure to

Table 5
Some of the key domains of transformational change (as highlighted by authors such as [2,6,15,53,158,175]. Many of these domains are mutually reinforcing and multiple domains may need to change for genuine claims for transformation to be made.

Domain of change	Explanation
Cognitive (values, thinking)	Significant shifts in societal beliefs, norms, values, and understandings, which may manifest as radically new concepts, ways of viewing the world, or notions of progress.
Structural (institutions and governance)	Significant shifts in institutional arrangements and governance processes for enhancing sustainability, such as major policy change, institutional reform, or new feedback and accountability mechanisms that enhance the responsiveness of governance systems to uncertainty and change. This may include significant regulatory shifts that open up spaces for change or significant improvements in governance systems that are better able to respond to feedback (e.g. social, ecological), improve fit between social and ecological contexts, and/or allow decision-makers to anticipate and be pro-active in the face of change.
Relational (interactions among actors)	Significant shifts in relationships between actors and institutions, such as moving from siloed to integrated decision-making processes, new collaborations among diverse stakeholders that enhance science-policy-practice linkages (e.g. boundary organisations or knowledge brokers), or new accountabilities between public, private and civil society actors.
Functional (system behaviour/outcomes)	Significant changes in the behaviour and function of a system, for example, diffusion of innovative sustainability practices, or changes in technology that reshape human activities of communication, production, and consumption. This may include the major technological or practical advances that disrupt the status quo and allow opportunities for more radical changes to occur and for more sustainable outcomes.

focus on these practical forms of knowledge can result in knowledge being produced that is distantly related to the actual and action-oriented needs of practitioners.

There are three broad ways in which research around practice can be conceptualised [86]. First, there is *research into practice*, where researchers observe that practice. Second there is *research for/as practice*, where practices are the intended outcome and researchers work with practice or as practitioners to develop knowledge, such as a when developing a new process of change or new technologies through experimentation and iteration [86]. Here the outcome is usually a written report on the practice or the lessons learned and the impacts emerging from action. Research methodologies and theories are also likely to be developed during the process of doing practice rather than prior to engaging in it. Finally, there is *research through practice*, where the act of practice itself becomes the research [86]. Here the emphasis is more towards developing the practice (techne and phronesis) rather than the epistemic knowledge about that practice. Thinking is then embodied in the artefact that emerges, such as a process or tool for change.

Research through practice is generally lacking in the humanities, social sciences and sciences, although it may sometimes emerge in transdisciplinary and action research. It is, however, much more common in the arts. Artists are increasingly finding ways to demonstrate their work has rigor and quality that does not rely on the written epistemic word [86]. Shifting towards research through practice that more directly recognises techne and phronesis has major potential for encouraging a more engaged and rapid approach to transformation research. For example, it is not inconceivable to have a research project that creates an imaginative and transformative policy. Here the policy development is the act of knowledge creation itself, with the outcome being the final policy (artefact) that embodies extensive creative, discursive and collective know-how and phronesis forms of knowledge. Thus, in addition to developing more actionable epistemic forms of knowledge (essential 2), approaches from the arts can provide more radical and direct approaches to learning about social and environmental change. Examples of such work already exist from action, transdisciplinary and activist research traditions [87,88]. Ultimately, a focus on practical knowledge for stimulating transformations and moves towards low-carbon, resilient living will only emerge when different forms of knowledge and different ways of assessing them are more widely accepted. This is challenging given that existing disciplinary structures and cultures tend to be very resistant to more pluralistic forms of producing and using knowledge.

4.4. Approach research as occurring from within

The fourth essential involves conceptualising research as being conducted from within the system being studied. Developing practical knowledge requires a shift from researchers viewing themselves as being '*apart from the universe*', such as looking as if through a peephole upon the unfolding universe, to viewing themselves as '*a part of the universe*', implying that when they act, they are also changing themselves and the world around them ([89], p. 293]. These different ways of conceptualising science have significant implications (Table 6). Importantly, moving towards conceptualising science as being from within allows for a powerful widening of the scope of research processes and for a shift towards explicitly acknowledging research as being an actor that is part of the process of promoting change [90].

While there are a large and growing number of examples of approaching research from within (e.g. [91,92]), the vast majority is still conceptualised as being from outside that which is being studied. This leads to an emphasis on working with data, statistical methods, models, and development of theory rather than practical problem solving, how research findings can be implemented, and limiting reflection back to question how the research is being framed [39]. This is particularly prevalent in many high-profile climate change research syntheses. Conceptualising research as being from within enables the goal to focus on social improvement as opposed to primarily knowledge production which dominates research that is viewed as being conducted from the outside [39]. It encourages greater acceptance that applied work lies within the realm of science and a greater focus on knowledge about implementation and action [39]. Finally, it places considerable emphasis on the need for researchers to be more cognisant of the role of their own underlying assumptions that shape the nature of the questions posed (e.g. essential 6) and to continually reflect on their role and influence in the processes of research and change (essentials 8 and 10).

Viewing science as being conducted from the outside has led to separate institutions (e.g. universities) as the legitimate producers of knowledge which perpetuate distinctions between knowledge production and practice. There are now a growing number of alternative institutions that have a stronger focus on climate change solutions rather

Table 6
Key implications of conceptualising science as being from without and within (based on insights in [39,89]).

Conceptualising Science as being from Without	Conceptualising Science as being from Within
More likely to assume the world and researcher are separate: This leads to focusing on what the world appears to be and the emergence of separate institutions (e.g. Universities) as the most legitimate producers and holders of knowledge.	**More likely to assume the world and researcher are one and the same:** This leads to greater acknowledgement that a researcher inevitably intervenes in the world by being an actor in what is being researched and understood.
Greater focus on describing: The researcher assumes they are separate from the world and therefore their role is primarily to describe it. This reduces emphasis on being explicit about their influence on the research and its outcomes.	**Greater focus on creating:** The researcher is more likely to accept that they are already and unavoidably an actor in change and therefore are more willing to engage in helping being creative in shaping action.
Tendency to be monologic: where there is one way interaction between the researcher and what is researched. For example, in relation to how knowledge is shared and used, the orientation is towards approaches where people are viewed as data sources and where the production of knowledge is separate from its dissemination. Researchers then strive to impose their truth or programme on others or to be heard. This closes down possibilities for different interpretations and limits opportunities for learning and gaining new insights, and disempowers other kinds of knowledge.	**Tendency to be dialogic:** where there is a two way interaction between the researcher and what is researched. For example, the production of knowledge might include much wider engagement of different stakeholders with multiple iterations of feedback, co-production of findings, and where the act of learning through research is shared among different stakeholders, and where there is a greater focus on communicative relationships that can elevate non-researchers as equals in learning and generating action.
Approach is more denotative: Where the meaning of something is taken to be explicit or direct. The 'standard' dictionary type meaning of the language used is then assumed. This can result in less attention to different interpretations and to the cultural and personal ways in which meaning is shaped.	**Approach is more connotative:** Where something is recognised as having multiple meanings depending on the person using it, and on cultural context and personal associations. This requires greater engagement on meaning and interpretation of concepts, ideas and actions by those involved in the research.
Greater orientation towards "you say how it is": Through describing the world as an objective phenomenon, emphasis is placed on searching for a 'truth'. This can de-emphasise perspectives that recognise that reality is subjective, uncertain and complex and the need for considering and working with multiple perspectives.	**Greater orientation towards "it is how you say it":** This emphasises that what is observed and how it is interpreted depends on the cognitive, theoretical and methodological approaches used to describe it. This highlights the subjective and socially constructed nature of all research and the need for careful consideration of the role of the researcher in shaping the reality described, including engagement with multiple perspectives.

than on generating knowledge directly. Examples include the Coastal Resources Centre (http://www.crc.uri.edu/), the Dutch Institute for Research Transitions (https://www.drift.eur.nl/), the Edinburgh Centre for Carbon Innovation (http://edinburghcentre.org/), and the MIT Climate CoLab (http://climatecolab.org/). Such institutions are situated at the interface between academia and practice and involve participatory projects with measures of success relating to implementation and change as well as generating knowledge. They represent examples of the kinds of transformative institutional innovations that are needed that can challenge structures and norms developed to support first-order patterns of knowledge production and use [93].

4.5. Work with normative aspects

While there has been extensive research on identifying values [94] and identifying the normative challenges in transformational change processes [31], researchers across the social and natural sciences rarely acknowledge the values and ethics that shape their own research [95]. Values and norms always shape what and how research is conducted [96]. Failure to acknowledge this can, at best, lead to omission of important perspectives and opportunities for learning that affect what and how something is understood. At worst, it can also lead to deliberate production of ignorance, where science may be used to exploit uncertainty, such as has occurred for tobacco, asbestos and climate change [97]. Engaging with climate research, for example, raises important ethical responsibilities of researchers in supporting others to adapt and find ways to reduce carbon emissions [49]. Given that all researchers are essentially interveners [47] climate researchers need to be more than just informed by past science: they also need to be transparent and accountable about the choices made about what science is undertaken, and how it is funded and communicated [49]. This requires acknowledging the normative role of the researcher, critically questioning and reflecting on the values underlying choices early on in research [98], being transparent about these, and taking responsibility to consider how their research will contribute to addressing the unprecedented challenge of climate change.

One way to approach this is to actively acknowledge and build normative aspects into research programmes. Normative aspects have, for example, been explicitly integrated into the British Permaculture Association's research strategy, where researchers trained in formal research working with and within the permaculture movement conform to three permaculture ethics (earth care, people care, fair shares). This has significantly changed the aims, processes and outcomes of the research [85] and has encouraged framing of research in societal terms rather than research framing society [99].

Greater receptivity to ethical concerns and the need to negotiate normative aspects in science will grow as demand for practical outcomes from research increases [39]. More specifically, key issues emerge when focusing on transformation and climate research which implies being involved in a process of changing the status quo. Second-order transformation research is thus inherently political, as it involves exploring how incumbent systems and power might break down allowing for a broader societal shift towards transformative alternatives. This poses key challenges for operationalizing second-order transformation research in a world dominated by assumptions that knowledge creation is separate from politics and where knowledge creation occurs first, followed by dissemination and then decision-making about how to act. One solution to help address such challenges is to co-develop ethical codes with participants [100] and facilitate dialogue over important concepts such as value, resilience, agency, ideology, knowledge, and power as part of the research process[101]. Without doing so, there is a danger of transformation research becoming a powerful depoliticizing practice [102], unintentionally reproducing unfavourable market settings, social inequalities and exploitive institutional relations inherent in the systems and structures of society that continue to contribute to climate change.

4.6. Seek to transcend current thinking and approaches

Transformation is a change process that involves creation of previously unimagined possibilities including new ways of thinking and action (Table 1) [18]. As Moran highlights, being intelligent about complexity involves exploring possibilities without being restricted to what is formally probable [103]. Yet science and research are naturally conservative, with a tendency to progress incrementally rather than through more fundamental change. The seventh essential therefore involves seeking new ways to open up space for new questions, insights and solutions that can transcend current paradigms and disciplines. An example of such an approach is re-entry, where first order concepts are applied back on themselves resulting in new meta-concepts and emergence of new questions (see examples in Table 7). Through re-entry, old concepts "*appear to close around upon themselves*" while also leading outward to transcend existing boundaries in ways that seem to "*have turned inside out, [where] the inside is the outside*" ([104], p. 131).

An example of applying re-entry is asking questions about the

Table 7
Examples of applications of the re-entry approach to generate new research questions relevant to change and transformation.

Domain	Examples
Change related disciplines and fields	• What are the politics of political science? • What is the sociology of sociology? • To what degree is sustainability science sustainable? • How are transitions emerging in transition studies? • What behavioural changes are needed in behaviour change research?
Cognitive aspects of change	• What are the values of values and how does this affect engagement with climate change? • How do beliefs about beliefs influence our understandings of change and transformation? • What norms shape norms associated with climate related behaviours? • How does understanding of understanding influence transformation research? • How does the theory of theories influence approaches to transformation?
Structural aspects of change	• How do systems of systems inhibit or enable change? • How resilient are approaches to enhancing resilience?
Relational aspects of change	• How do collaborations of collaborations give rise to or inhibit change? • Who are the change agents of change agents? • How can the leadership of leadership be encouraged?
Functional aspects of change	• How does knowledge about knowledge influence transformation? • How does the governance of governance influence transformations? • How are regulations regulated? • How can technology influence technological development? • How can the innovation of innovations be encouraged?

sustainability of sustainability research and initiatives, such as the extent to which sustainability research and action projects contribute to production of carbon emissions [105]. By asking how sustainable sustainability projects are, attention is drawn to wider systemic issues associated with the delivery of sustainability initiatives that may conveniently be ignored because they are usually seen as too difficult to address. For example, asking how sustainable approaches to sustainability research might be implemented raises questions about the way in which research is part of and reinforces internationalisation and economic growth agendas or why funding regimes for research construct ever more intricate understanding of problems without proper investment in solutions. Applying the process of re-entry to many other questions would stimulate new thinking about transformations, such as when asking about how transitions of transition research occur; how systems of systems inhibit or enable change or how knowledge about knowledge influences transformation. Re-entry thus provides new ways to frame problems, identify questions, generate new research fields, and to enhance innovation [106,107]. By applying re-entry, attention is opened outwards as well as forced back on the assumptions underpinning the methods, approaches, and the paradigms underpinning research and climate change projects.

Re-entry is an example of highlights the need for new ways to generate questions that will lead to more transformative findings. Such approaches require higher degrees of integration, recognition of the systemic nature of issues like climate change, reflexively thinking back on the systems being studied and the need and possibilities for more post-disciplinary forms of science [13,42,103,104,106,107]. Thus, while many important first-order questions need to be answered to inform sustainability [8,108], transformation research needs to find new and diverse ways to help researchers transcend and critique the very systems in which they are themselves embedded.

4.7. Take a multi-faceted approach to understand and shape change

The sixth essential to support second-order transformation research in the context of climate change involves taking a multi-faceted approach. It is well known that different paradigms, methodologies and methods affect the interpretation of phenomena and the way in which subsequent actions are prescribed [45,109–114]. Climate research has been heavily criticised for being dominated by particular ontological perspectives about what is considered real and epistemological perspectives about what constitutes knowledge and knowing. These lenses have led to the promotion and acceptability of certain kinds of questions, approaches and knowledge at the expense of others [46,112,115–117] and to the framing of climate change as an environmental rather than a social or political problem [46,115].

Ontological and epistemological lenses also have a major influence on the nature of the solutions that emerge from analytical insights

Table 8
Examples of possible roles of researchers in second-order transformation research (based on [131]). In the examples researchers often took on more than one of the roles simultaneously.

Role	Description of role	Example
Process Facilitator	Facilitating the learning process including initiating the process; selecting participants, locations; initiating and facilitating concrete (short-term) actions; designing the social engagement.	In the Scottish Borders Climate Resilient Communities project funded by the Joseph Rowntree Foundation academics acted as process facilitators by designing and convening spaces that brought together national, local organisations and authorities and local communities to identify actions for addressing sustainability issues. http://www.scotborders.gov.uk/info/119/emergency_planning/1211/resilient_communities/2
Knowledge Broker	May include mediating between different perspectives and mediating different contextual and normative perspectives on sustainability.	In the EU FP7 project InContext researchers acted as knowledge brokers using reflexive questions to operationalize sustainability instead of using a pre-conceived definitions. This included mediating between different world-views to establish common problem perceptions and shared future visions http://www.incontext-fp7.eu/pilots
Change agent	May include explicitly participating in the learning processes or short term action with the aim to address real-world problems or motivating and empowering participants.	In the EU FP7 project InContext researchers as well undertook a transition management project in the Austrian village of Finkenstein. They acted as change agents by facilitating a process that was oriented towards real life change (e.g. establishing a welcoming culture, bicycle tourism, future vision) http://ww.incontext-fp7.eu/pilots
Experts in learning	Assisting practitioners or citizen scientists to become better learners and researchers, such as helping them design processes and methods of data collection and analysis, including reflexive practices.	In a research programme of the UKs soil association researchers acted as experts in learning by supporting farmers to conduct their own on farm 'experiments' of organic farming rather than being traditional researchers. http://www.soilassociation.org/fieldlabs
Reflective scientist	Includes activities closest to what is traditionally understood as being part of good 'research', such as: reflecting on how collecting, analysing, interpreting and reporting data from an observer point of view can be improved in accordance to the quality criteria of their disciplines and in relation to the reliability of findings.	In the Transdiciplinary case study project of ETH Zurich in the Swiss canton of Appenzell-Ausserhoden researchers acted as reflective scientist by conducting a system analysis of the investigated industries, doing a literature review and draft project outline as well as by develop final recommendations for the stakeholders. http://www.tdlab.usys.ethz.ch/
Self-reflexive scientist	Researchers act as a self-reflexive scientist by using reflexive processes to critically evaluate their role in shaping the research, action and learning including: how their epistemological, ontological positions, norms, values, concepts, methods and paradigms influence understanding about change and how they are part of, reinforce and influence the systems they seek to change.	In the EU FP7 project InContext researchers, doing transition management processes in three communities, acted as self-reflexive scientist by taking fieldnotes on experiences and observations, by working in a team and jointly reflecting on implication of own actions as well as own values and emotions in the process and by publishing reflexive articles on the own roles in these processes. http://www.incontext-fp7.eu/pilots
Reflexive facilitator	Where researchers act as critical friends or sparring partners to help encourage reflexive practices of others. The capacity for researchers to encourage reflexivity emerges both from using new knowledge from research as it emerges and by being asking critical and challenging questions to keep ambitions for transformative change high.	Examples include attempts to generate systemic change towards sustainability in the Dutch agricultural sector using Reflexive Monitoring in Action. This approach stimulates recurrent reflection to support continuous learning and systemic level changes, partly through use of a reflexive monitor (a researcher) who observes the interaction and change process and stimulates reflection on the extent to which new rules, relations and systemic level changes are being achieved and stimulate continued change [30,153].
Project manager	Researchers act as project manager of action oriented research projects including coordination and steering projects to achieve desirable outcomes of a project. Such work is often conducted by a principle investigator or an assistant tasked with project management.	In the Interreg-IV funded MUSIC project ('Mitigation in Urban areas: Solutions for Innovative Cities'), researchers also acted as project manager in that they had to plan, implement and account for the resources received as part of the project across five Northern European cities and two research institutes to catalyse and mainstream carbon and energy reduction www.themusicproject.eu

[115,118]. A well-documented example includes analysis of decision-making for fisheries management in Sweden, where positivist lenses led to a focus on calculations and modelling of the fisheries at the expense of social complexity, such as human agency, power, and influence [118]. This resulted in the predominance of market-based resource management as the primary guide for solutions, such as emphasis on privatization and on values related to entrepreneurship or investment power, as opposed to solutions focusing on participation and dialogue that acknowledge dynamics of conflict [118]. This example shows how ontological perspectives implicitly shape both social reality and the nature of outcomes at the expense of others and illustrates how closely research is intertwined with politics, norms, values and culture [118].

Pluralistic approaches can help to avoid narrowly prescribed solutions [109,111]. In pluralistic approaches the objective is not to unify multiple lenses, which can reduce diversity, but to mesh or link different ways of understanding the world. This may involve diverse societal values and perspectives. One way to approach this is through applying different ontological perspectives relating to four domains of complexity [109]: (1) Natural-world complexity through focusing on 'what is' through the search for truth; (2) Social-world complexity through focusing on 'what ought to be' in relation to actual or potential action through the search for what is right; (3) Subjective-world complexity through focusing on understanding what individuals are thinking, intending, or feeling; and (4) Interaction complexity, by focusing on the interactions between the other three domains. These domains can be used to help guide the development of pluralistic methodologies (e.g. quantitative approaches for natural world complexity; quantitative and qualitative approaches for social world complexity; and qualitative approaches to subjective complexity) that then lead to the application of mixed methods [109]. Importantly, this approach does not claim that it is possible to work *across* paradigms. Instead, it seeks to promote the setting of a new position to encourage learning *from* different paradigms by incorporating different ontological positions [109]. In order to have significant (transformative) shifts in thinking through these processes it is critical to find a common language to facilitate exchange and ensure that potentially transformative transdisciplinary work does not get subsumed back into multi-disciplinary ways of operating. Overall, to generate more relevant, salient, legitimate and transformative insights, second-order transformation research will need to apply such multi-faceted approaches and find ways to facilitate communication across paradigms.

4.8. Acknowledge the value of alternative roles of researchers

Enhancing learning about how to foster change often requires greater flexibility in the roles undertaken by its participants to assist collaboration, co-creation of 'know how' knowledge and to stimulate action [84,119,120]. Sometimes multiple roles are taken, with those involved regularly switching between them and which evolve over time [121,122]. There are diverse roles that may be undertaken by researchers (Table 8), such as facilitating interactions [123], mediating between different frames [123], acting as knowledge brokers [73,124], assisting putting sustainability into action [125] or guiding action [84,87,88,126] (Table 8). Practitioners may also take a much more active role in research as they are often in better positions to learn about practice than an external researcher [120]. They can play important roles in framing questions, developing methodologies or even conducting research [101], such as through Science Shop arrangements, (http://www.livingknowledge.org/livingknowledge/science-shops), Public Laboratory Networks (http://publiclaboratory.org/) or in participatory action research and evaluation [127,128].

Applying alternative roles is common in design [129], transdisciplinary [59], participant observation [43,130] and action research [84,120]. A good example where both researchers and practitioners took on different roles was the UK's Soil Association programme on research into organic farming, where farmers conducted their own on-farm experiments while academics provided advice about how they could improve the research (http://www.soilassociation.org/innovativefarming/duchyfuturefarmingprogramme/fieldlabs). Here the farmers were the researchers while the academics helped to improve the learning. Together this generated more practically focused work but also capitalised on the expertise researchers have in enhancing the production of knowledge.

While such approaches can enhance learning, they also present challenges. This includes potential conflicts between roles, such as when a researcher simultaneously needs to be an independent facilitator while also being dependent on activities that enable data collection [128], or when trying to shape action whilst attempting to retain rigor in their analysis of change [131]. Attention therefore needs to be given to cultivating skills and dispositions for towards self-reflexivity (essentials 4, 5, 7, 10) and developing awareness of the limits to skills and knowledge regarding the different roles undertaken.

4.9. Encourage second-order experimentation and change

An important task for second-order transformation research is to produce evidence and enhance learning about the actions and solutions that lead to desirable social, cultural, ecological and economic futures. Experimenting with change processes, such as through local and context-specific actions, projects and initiatives is therefore a critical part of transformation research [132–136]. In first-order science, external control is a critical hallmark of experiments. In second-order science experimenting, however, the intervention happens from the inside where researchers have differing degrees of control on the intervention, system and context (essential 4). This is different to the concept of natural experiments, which still generally assume that research is conducted externally [137].

Second-order transformation experiments are more akin to learning by doing. This can include four processes: (i) Integration, where external knowledge is incorporated and coordinated to inform interventions and actions; (ii) trial and error, where new actions are undertaken until it succeeds; (iii) repetition, whereby activity is improved by undertaking it multiple times; and (iv) extension, where the learning is used for larger and more complex activities [138]. Participatory methods are often likely to be used to foster learning among actors, encourage systemic thinking, enhance social outcomes and encourage questioning of underlying assumptions [128], as well as simultaneously producing evidence about, and action for, solutions. Overall, conceptualising second-order transformation research as experimenting helps ensure focus on learning from the action as much as generating tangible and actionable outcomes. It places onus on the actor and/or researcher to be clear about who is supposed to learn (the researcher, immediate stakeholders, or wider practices or academic communities) and on finding the best way to improve rigor of both the methods used to learn (the research) and the intervention itself (the action).

Opportunities for second-order experimenting emerge from a focus on solution processes (essential 2) with diverse examples from: community development [119,139]; mobility and healthcare; sustainable urbanization [140] and climate change (e.g. urban, transition and social innovation labs) [133,141–143]. Such experiments deliver innovative practices and require an open and inclusive governance context [140]. They follow a prescriptive and normative logic and actively seek to be part of the process of fulfilling societal needs in fundamentally new ways [39,136].

Second-order experimenting is not without challenges. Standardized methods to replicate results are not likely to be possible and notions of reliability, scalability and transferability will not always hold [72,144]. The advantage of second-order experimenting, however, is that it provides real-time opportunities for learning that cannot be achieved through traditional approaches and flexibility in being able to respond to the challenges of attempting transformation in practice. The key issue for second-order experimentation is thus to capitalise on the

opportunities for learning provided by interventions that are already happening and more quickly feed this back to enhance action.

4.10. Be reflexive

Engaging in second-order transformation research requires those involved to be reflexive (Table 1) [13,30,145,146]. Reflexivity is the critical exploration of how perceptual, cognitive, theoretical, linguistic, political and cultural circumstances influence interpretations [147,148]. It is a deeper learning process to the relatively superficial act of reflection [149] and enhances capacity for innovation and insight (e.g. [145,146,149]). Reflexivity entails scrutinizing the "*things usually taken for granted, in such a way that their historically grown self-evidence is challenged*" ([150], p. 84), similar to what Latour framed as critique and critical inquiry as core principles of science [151]. This includes engendering scepticism concerning one's knowledge and value stances as well as the views of others and making explicit underlying values and assumptions [114]. Reflexivity is important for ensuring research opens up, rather than closes down, space for active critical contention over the emergence of alternative societal pathways and attention to marginalised interests [152]. It can also help actors or researchers of change examine how they are part of the system in which change is desired [52,148]. Transcendent forms of reflexivity [148], for example, may involve the researcher critically reflecting on how they may need to undergo their own transformations in order to be in a better position to understand or shape transformative change in the systems in which they are embedded.

An example of an effective approach that capitalises on deep reflexivity to learn from and simultaneously encourage change is Reflexive Monitoring in Action. This involves continual reflection on long-term goals and supports learning and systemic level changes [30]. A reflexive monitor (e.g. researcher) stimulates reflection through being a sparring partner of the change agents involved. Emphasis is placed on the extent to which new rules, relations and systemic level changes are being achieved while maintaining sufficient distance to take a critical stance if and when needed [30,153]. The reflexivity keeps ambitions high and helps break through path-dependency in situations where relapses into old patterns are likely to occur [153]. Such approaches have helped reorient existing socio-technological systems (e.g. animal husbandry, water management, and local food chains) [153–155] and are applicable to the arts, humanities and the social and natural sciences [156].

These examples highlight how reflexivity is important for helping action-oriented research to: maintain emphasis on transformational change (essential 1); ensure continued focus on practice (essential 2–3); assist in identifying questions, conception, design and implementation (essentials 4–9). Reflexivity is also a skill and capacity, which in turn requires practice, training, and being disposed towards applying it on a regular basis [131]. Overall, reflexivity provides an overarching approach to assist the other essentials outlined in this paper and to enhance the ethical conduct of second-order transformation research.

5. Discussion

This paper has provided ten mutually reinforcing essentials for second-order transformation research in the context of climate change which incorporate many of the rich and diverse traditions of action-oriented ways of producing and working with knowledge. The essentials are underpinned by explicit assumptions and together open up space for more engaged and interactive forms of research that can work with normative dimensions, seek new ways of understanding, more directly support action and societal goals and provide new ways to enhance learning about the practice of transformative change for a low-carbon, resilient world.

While application of individual essentials will enhance action and understanding about the implementation of transformative solutions, the greatest impacts will be achieved when the essentials are applied together. Jointly practicing the essentials will create a highly adaptive, reflexive, relational, collaborative and impact-oriented form of research that has a strong impetus to engage with action. Their joint application would provide coherence and intellectual depth in ways that expand the explicit and normative aspects of research needed to address the climate challenge while also encouraging recognition of the responsibility of research and researchers in this process. Applying appropriate forms of monitoring and evaluation will be important to both guide the joint application of the essentials and to enhance learning about the practice of second-order climate change and transformation research.

While the essentials highlight much about what needs to be applied, they do not fully prescribe how this should be done. A full prescription is beyond the scope of this paper and much has already been written relating to the specifics of method and how to achieve standards of quality [87,88,157]. Nevertheless, application of the essentials is challenging and requires developing skills not often supported in current research training and learning from what is already known about how to conduct action-oriented research. Thus, in addition to working more closely to develop practical knowledge about transformation, researchers and practitioners will also need to develop practical knowledge about the practice of doing new kinds of research [158].

Greater attention to the practice of second-order science would have many benefits. It would encourage expansion of the scientific focus from being predominantly theoretical to being a more mixed form of theoretical and practical problem solving. This, in turn, would help facilitate the development of more practical theory while also improving theoretical approaches to practice [39]. There is extensive demand for a greater mix of the conceptual and practical, as highlighted in the recent publication of the top 100 solutions to climate change, which was instigated by a non-academic frustrated with the lack of emphasis in research on climate solutions and which underwent four reprintings within six weeks of initial publication [159]. Such work helps form new bridges between basic and applied research and can lead to more rapid diffusion of new research approaches and solutions.

Unfortunately, wider-scale engagement in second-order science is still heavily constrained by societal and scientific norms, worldviews, values and political and institutional structures. While some shifts are beginning to occur, many of the ideas are not widely accepted or are only implemented in tokenistic ways. Some of the positive changes include tendencies towards interdisciplinary research, demands for research to be accountable to society which provide greater opportunity for engaging with practice and different perspectives [4,39,40,160] (essentials 2–6, and 8–10), and increasing access to technology for collecting and analysing data which enhances opportunities for second-order level investigations (e.g. through re-entry, essential 7) [161]. Access to outcomes for research is also increasing (e.g. a strong emphasis on 'open science' in EU research funding) as well as trends towards greater participation in science by the public that encourages inclusion of more diverse stakeholders in research (essentials 3, 5 and 8). Finally, growing recognition that current ways of doing things are no longer fit for purpose are resulting in new practices associated with transformation and change [162,163] (essential 1).

While these changes are helpful, they cannot always be taken at face value. Very little has changed in climate research over the last 25 years [23] and existing systems and structures that support first-order kinds of thinking have a powerful influence on what research gets funded. Climate research lacks certain critical voices [112] and interdisciplinary research can be more about realigning elite power bases in the face of change, such as through co-opting language and discourses, rather than representing deeper transformational change [4,99]. Further, an integration imperative does not always equate to pluralism, and can exclude more innovative approaches to understanding and responding to climate change [164]. Importantly, when usefulness is defined by those who seek to maintain the status quo, it constrains acceptance of the kinds of research which promote transformative

change or which question dominant paradigms [163]. Who decides what research is useful and for whom therefore matters. Overall, in the experience of many of the authors of this paper, there is a growing frustration by those outside of academia with the inability of traditional knowledge producers (e.g. higher education and research institutes) to contribute more directly to climate solutions. Much of the climate innovations come from the world of practice and the authors are aware of many academics who are struggling to understand how their work can become more relevant in a rapidly changing world.

One of the major barriers to the application of second-order science is that funding for traditional institutions of knowledge production are usually tied to, and revolve around knowledge production rather than social and environmental improvement [39]. New approaches are often not accepted or may even face fierce resistance because they do not conform to established first-order traditions. Incentives for academics are also heavily directed to first-order kinds of knowledge production, which severely limit opportunities for engaging in more action-oriented research. New ways of recognising and validating second-order science will therefore be needed, such as those that encourage development of practices of change through research as a practice [86] (essential 3). Shifts towards new forms of training of undergraduates and post-graduates that involve students being embedded in the practical context of their studies will also be required [50,131,165].

The challenges of moving towards more fluid, iterative and action oriented research are not just confined to academia: deeply entrenched views on what research is supposed to look like, how it should be conducted, and how knowledge is used are also held in government agencies, non-government organisations and the public. Action-oriented research is inherently political and counter cultural [166,167] and can be heavily constrained by the limited time and resources of non-academics that may need to engage in the co-production of knowledge [101]. Such research often experiences resistance, such as when organizational and individual norms and beliefs are challenged during a reflexive process [60,168]. This is particularly the case for transformation research, which is likely to require questioning the social, governance, institutional and power dynamics that reproduce unsustainable or inequitable patterns in society. Change can be hard to realize, and unless there is generalized commitment to developing an organisation by learning from practice and to move away from formalized and codified forms of science and policy, outcomes will likely be instrumental rather than transformative [118,169]. As such, researchers engaging in second-order science will require political acumen and well-honed adaptive expertise to flexibly apply a variety of strategies appropriate to different circumstances [167,170]. They will also require appropriate support and enabling conditions to help them navigate the complexities of the political and normative issues involved.

To enable second-order transformation and climate research, extensive and concerted efforts will be needed that challenge current systems and structures of the way in which knowledge is produced and used. This is a major challenge given the dominance of first-order approaches and powerful disciplines which are backed up by well-established assumptions, structures, institutions and finance mechanisms. Given the need for system transformation to enable greater engagement with second-order science, joint action at four levels will be required. First, support is needed for innovative researchers to actively practice and further develop second-order science as a viable and mainstreamed complement to the practices of first-order research. This would include initiatives such as building knowledge networks of champions of innovation; directly funding action-oriented research; strategically funding research on research (e.g. how to more effectively combine normative dimensions and rigour) and providing safe spaces at the boundary of science and society to test and apply innovations. Second, at a political and structural level bold and strategic action of politicians and funders is needed to pioneer and provide the supportive conditions necessary for second-order transformation research to flourish. Third, intermediary actors, such as advisory bodies (e.g. the newly formed International Council for Science and WBGU), will be required to strategically mediate between coal-face and political levels to further enhance enabling conditions. Finally, work is needed at public levels to increase demand for the co-production of action-oriented research (e.g. through engaging student projects in local communities or participatory forms of research) to help create a new social contract that provides greater support for action-oriented research [171,172].

6. Conclusion

In conclusion, this paper has argued that while first-order modes of research are important, much greater emphasis is needed on second-order approaches that can accelerate learning and actions that lead to transformations towards a low-carbon, resilient and sustainable world. The paper has provided a framework for conceptualising such research and presented a set of ten mutually reinforcing essentials to guide its application. Currently, broader trends in society are unlikely to be sufficient for facilitating the massive upscaling of second-order transformation research we believe will be necessary to appropriately respond to climate change and many other contemporary global challenges. More deliberate and fundamental changes towards a greater appreciation of research for, or as, practice and research for societal improvement will be required. This, in turn, requires establishing enabling conditions, such as incentives, greater integration of research and practice, new forms of training, reconfiguring institutions, overcoming entrenched disciplines, and the legitimisation of diverse forms of knowledge and knowing. This needs to occur at all levels, including within research communities and in wider institutional and political systems and societal structures that influence the way knowledge is produced and used. Ultimately, this highlights that to accelerate the kinds of learning needed to enhance transformations for sustainability, transformations will also be needed in the way in which knowledge is produced and used.

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