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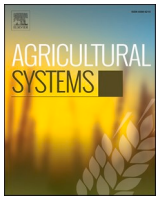

Sustainability transitions in the making in agroecosystems: Changes in research scope and methods

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HIGHLIGHTS

- Special Issue shows the broadening scope and methods of systems agronomists engaged in transitions-in-the-making.
- Papers provide evidence of a change in scope from transformation knowledge towards transformative knowledge development.
- The articulation of knowledge and change processes constitute an important extension of the systems agronomist's toolkit.
- The 'how-to' questions of transformative change call for a continuous reflexive stance on research's direction and position.

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ABSTRACT

CONTEXT: The urgency of redesigning the way food is produced and consumed has implications for the systems perspective of agronomy. An increasingly important strain of research addresses the 'how-to' question associated with the transformation of 'maldesigned' agricultural systems and produces 'transformative knowledge' as part of transitions in-the-making. Such knowledge production goes beyond 'transformation knowledge' resulting from the more classical analytical agronomic approaches and stances. Contributing to transitions in-the-making thus calls for systems agronomists to question their profession's why, what, and how.
OBJECTIVE: This special issue brings together contributions by systems agronomists collaborating with other scientists and societal actors revealing the less visible stream of fine-grained work to support transitions in-the-making in agroecosystems.
METHODS: In this introductory paper, changes in research scope and methods emerging from the contributions are highlighted to reinforce the engaged systems agronomist's roles in contributing to food system transitions.
RESULTS AND CONCLUSIONS: Three results stand out: 1) Contributing to transitions in-the-making necessitates going beyond analysis-oriented research stances to address the 'how' of transformative knowledge, and move beyond the more time-efficient dominant 'what' and 'why' questions; 2) Meta-methods are emerging about how to adapt and embed existing agronomic knowledge products within change processes. Reflection on the overarching transformation dynamics and on how to articulate knowledge products and change process will constitute an important extension of the systems agronomist's methods; 3) The efficacy of scientific transformative knowledge development may be enhanced if the notion of design is used more strictly in relation to engagement in societal change.
SIGNIFICANCE: The need to respond to the how-to questions associated with the transformation of the way food is produced and consumed requires systems agronomists to reflect on their stance in the research process, the way they design their research inclusively, and the way they shape their methods. This Special Issue provides promising examples of the (re-)emerging strain of engaged systems agronomists.

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1. Introduction

Rethinking food production and consumption for a future planet with a changed climate, limited availability of fossil fuels, and a larger world population than today is one of the great challenges of our times. The required long-term, multi-dimensional, and fundamental transformation of a range of interconnected socio-technical systems towards more sustainable modes of production and consumption are denoted as sustainability transitions by sustainability scientists (e.g. Markard et al., 2012). Research can contribute to what Elzen et al. (2011) coined 'transitions in-the-making':

> 'transitions where the initial impulse for change consists of normative contestation from regime outsiders [..], such as social movements or concerned researchers, who find certain performance aspects of existing socio-technological regimes normatively unacceptable and in need of change.'

They argue that many of the currently aspired transitions, such as moving towards sustainability, differ from most historical transitions in that they are normatively and socio-culturally driven rather than largely by commercial motivations. The transitions are called 'in-the-making' as they are part of developments that ask fundamental questions about how things are done, which may (or may not) result in a widescale transition to a new 'normal'.

The increasing urgency of redesigning the way food is produced and consumed has had important implications for the systems perspective of agronomy. Broadly speaking, we may distinguish changes in system delimitation moving from field to farm level around the turn of the century (in both crop farming (e.g. Carberry et al., 2002; Rossing et al., 1997) and livestock farming (e.g. Donnelly et al., 1997; Rotz et al., 1989)) with attention for human actors as part of the system, and a parallel accelerating increase in the attention for regional and global scales (e.g. regional agronomic diagnosis (Doré et al., 2008), global agronomy (Van Ittersum et al., 2013). The food system perspective emerged for agronomists (Francis et al., 2003) and gained attention triggered by well-argued calls for more attention for agricultural outputs beyond food, feed, and fibre (Kennedy, 2017; Renting et al., 2009) and for turning the agricultural sector from one that causes overstepping of global environmental and social boundaries to one that supports a safe operating space (Raworth, 2017; Rockström et al., 2009). These analysis-oriented scientific approaches as part of transitions in the making have been referred to as transformation research and result in systems knowledge (Fazey et al., 2018).

An increasingly important strain of research addresses the 'how-to' question associated with the transformation of 'maldesigned' (Hill, 1985) agricultural systems (e.g. (Duru et al., 2015; Fazey et al., 2018). Climate scientists co-authoring the paper by Fazey et al. (2018, p.56) even went as far as to state that "This 'how to' question is now arguably the most important question for climate research". With agricultural land use as a major contributor to climate change and biodiversity decline (Chaudhary and Kastner, 2016) and other global concerns (Foley et al., 2011), we considered this question equally relevant for systems agronomy. Research calls of the European Union fostering Multi-Actor Approaches and, more recently, Living Labs as vehicles to enhance the implementation of sustainability transitions provide further incentives for rethinking scientific practices. Approaches that show the options for change and their real-life consequences have been referred to as transformative research, resulting in transformative knowledge, which enhances reflection on governance and management of transitions in the making (Fazey et al., 2018).

Stimulated by the 6th Farming Systems Design (FSD6) conference (August 2019, Montevideo), and the European Conference on Crop Diversification (ECCD) (September 2019, Budapest), and building on special issues on farming systems analysis and design in this journal (Berthet et al., 2018) and in the European Journal of Agronomy (Reidsma and Jeuffroy, 2017), we initiated a special issue dedicated to bringing out the state of the art on agricultural systems research for sustainability transitions. We invited experiences and theoretical reflections on how agronomists, together with other scientists and societal actors, organised themselves to bring about changes towards greater systems sustainability. We encouraged contributions involving accounts 'half-way' through projects that described strategies, material changes, and processes as a basis to accelerate learning in the agricultural systems science community. The 13 papers in this Special Issue draw attention to the less visible stream of fine-grained work to support innovations in-the-making in agroecosystems and to facilitate their sustainability transitions (Prost et al., 2018). In the following section, we summarise each article regarding its scope, the methods used, and the highlights of each work. We end by highlighting themes emerging from the contributions for fostering transitions in-the-making by systems agronomists.

2. Scope and methods in sustainability transitions in-the-making in agroecosystems: a summary of the papers

Pelzer et al. (2020) describe work involving researchers and regional actors around the question, "How could legumes be reintroduced?" The study included collecting information to describe and characterise current and prospective crop management plans based on multiple criteria using national statistical data and farmer interviews to elucidate objectives. The results were used for territorial-level simulations of crop distributions and management plans as input for stakeholder discussion in a workshop. During the workshop, participants were also asked about objectives for territorial scenarios. The researchers then elaborated these by modelling crop management plan distribution using a regional linear program (LP) model. The results showed regional legume areas ranging from 8.8 to 22.8% compared to 5.9% at the baseline. Evaluation of the LP results from an agronomic (yields), socioeconomic (e.g. seminet margin, workload) and environmental perspective (e.g. nitrate leaching, pesticide treatment frequency indicator) was input for a second workshop. The stakeholders considered the approach successful, and some farmer-initiated projects emerged in the region as a follow-up.

Romera et al. (2020) report on a three-year transdisciplinary project to design futures for the New Zealand dairy industry in which the current sustainability problems were addressed systemically. They structured the design process according to the Reflexive Interactive Design (RIO) approach, which had been used before to navigate complex trade-offs in contexts where participants initially agreed on neither the objectives nor the solutions. Following a phase of system and actor analysis involving both desk research and stakeholder interviews, a first design was created following a workshop during which design goals were transformed into design concepts focused on desirability rather than feasibility. The result was tested qualitatively by discussions in workshops with farmers and policy makers and by engagement with industry. The research team developed the final designs as input for a second design workshop, this time only with non-farmer experts and a focus on feasibility. Visual representations were developed to capture and broadly share results at the national level. Two radically different dairy futures were developed, both taking a 'territorial' perspective in which farms were connected in material and information networks. These results await experimental implementation.

Aare et al. (2021) present a case study of on-farm participatory research with 16 farmers over two-and-a-half years to explore the potential of catch crop species mixtures. The researchers adopted an approach where the choice of particular issues to be studied was left open at the outset to accommodate the interests and emerging needs of the participant farmers. Work started by the researchers handing each farmer 25 kg of catch crop species mixture for experimenting. The joint on-farm observation was combined with biomass measurements to describe and analyse the results of the first experimental round. An applied game was introduced to reveal and share farmer knowledge on using diversified catch crops, resulting in concrete plans for the next experimental round. Various meetings resulted in identifying technical

and institutional barriers to adopting catch crop mixtures on the farms and farmer suggestions for overcoming them. The researchers were responsible for planning events, facilitating and analysing them and connecting the various activities in a logical sequence. In the paper, the process is analysed in terms of agronomic effects, the participants' motivation and behaviour at each event, and the researchers' justification of their involvement. Results highlight the need for role changes, with farmers developing a more strategic approach to learning on what they find relevant and researchers learning to engage in adaptive discovery.

Berrueta et al. (2021) identified synergies and trade-offs between greenhouse tomato yield maximisation and whole farm system improvement in a co-innovation approach with five farm families in the south of Uruguay. A previous tomato yield gap analysis led the researchers to propose redesign plans to the participating farmers aimed at improving crop management practices to maximise tomato yield and input use efficiency. This information was complemented with a farm characterisation and diagnosis. Based on their agronomic expertise, the researchers then proposed farm-specific multi-year cropping plans to improve the level and stability of sustainability performances, which were finetuned in concertation with each farm family. Accepted plans were implemented by the farmers and evaluated through 2–3 weekly researcher visits over the course of a year. Results showed the critical importance of considering multiple levels when supporting innovations. Farm system adjustment sometimes conflicted with tomato yield maximisation but there were also various instances where crop level constraints could be solved at the farm level. The co-innovation approach resulted in high uptake of proposed changes at farm level and even higher at field level.

Brun et al. (2021) present the application of two innovative design methods to aid two specialised scientific communities, those studying agriculture and food, respectively, to collectively explore cross-community research topics which could foster coupled innovation towards sustainable agrifood systems. The authors combined two Concept-Knowledge theory-based approaches pragmatically: Knowledge-Concept-Proposal (KCP), which promotes collaborative, innovative design and OPERA, which supports identifying common purposes. The overall approach started with the definition phase in which the steering team developed an initial set of 'innovation paths' in which ideas and knowledge were connected. These were then elaborated into seven 'spotlight' concepts to focus the subsequent workshops. Each workshop started with presentations that aimed to share knowledge, i.e. undisputed facts. The workshop then broadened to ideas, inviting speculation and creativity, resulting in trees of connected concepts. Ten researchers from the agricultural scientific community and eleven food scientists were involved in three workshops held within three months. In the final step, the steering committee selected three to four knowledge gaps from each main conceptual path in the trees. The result was twenty challenging and cross-community research topics organised around the concept of coupled innovation between agriculture and food.

Catarino et al. (2021) explored options for territorial crop-livestock systems based on regional collaboration between specialised farms. Using the agent-based MAELIA modelling platform the authors co-designed three scenarios of increasing spatiotemporal management interactions among five arable and two livestock farms in western France. Farm-specific data were obtained from three agricultural advisors and the seven farmers, from which farmer decision rules were derived. Nine criteria for evaluating simulation results were identified based on the interest of the participating farmers, advisors, and researchers, representing self-sufficiency, sustainability, and vulnerability. These were used to evaluate the farm, farm type, and territorial scenarios. The results show that there is potential to improve various criteria but at the expense of greater transaction costs and the appearance of 'winners' and 'losers' in the exchanges. It would have been interesting to see more about the reception of these results by the farmers and advisors.

Kernecker et al. (2021) analysed barriers to and enablers of adopting ecological intensification (EI) practices in case studies from Germany, India and the United States of America using the concept of innovation characteristics. Distinguishing the levels of the farmer, the farm, and the system, they evaluated EI compatibility with existing experiences, values, and needs; the complexity associated with the new way of working; the degree to which EI practices could be trialled; and the degree to which observations helped to support adoption. Their results show an intricate web of barriers interacting across the three levels, calling for conjoint solutions. Rather than for science to continue trying to convince farmers that EI practices are the solution, they advocate considering the adoption of EI practices as part of a broader food system change in which EI adoption co-evolves with adopting new ways of valuing and organising food production and consumption.

Puech et al. (2021) present a cropping systems co-design case study aimed at reducing pesticide use in the industrial vegetable sector in Brittany, France, initiated by a frozen products distributor. The case study was run by a working group composed of four farmers, the distributor, a processing company, a cooperative and a research team. For each of the four participant farms, an innovative cropping system was designed during workshops organised in 2016 according to agro-ecological goals using information from scientific studies and previous empirical trials by farmers. Each workshop lasted one day and was located on a participating farmer's farm. The four farmers tested their innovative systems in 2016–2018, mobilising 21 agroecological farming practices applied consistently. Despite an average reduction of 15% in the pesticide treatment frequency index, the multi-criteria analyses carried out as part of the study did not show significantly improved cropping system sustainability. Economic performance was identified as a major weakness because of the cost of alternative biocontrol products, the investment needed in specific farming tools, and the higher risk of yield losses. The processor and the distributor considered both the process and the results promising and committed to funding a follow-up project involving more farmers. They also concluded that farmers could not be asked to change their systems without increasing the purchase price of their vegetables.

Rossing et al. (2021) drew lessons from a suit of projects in which engaged researchers worked with farmers, advisors, and other actors to support farms' ecological intensification in Uruguay and Europe. They show how the co-innovation approach they coined in 2007 evolved in different contexts as a method to organise governance and management of systemic participatory research projects. Using a novel analytical framework for evaluating transition experiments, they analysed six cases from three projects. They showed that more significant sustainability improvements were promoted by the existence of social capital at the start of a project, a focus at the farm-level instead of the field or crop level, involvement of regional innovation system actors, and reflexive practices as part of project management to critically discuss the results and their broader implications. They recommend jointly considering three domains in change-oriented project governance and management to achieve such changes at scale: complex adaptive systems, social learning, and dynamic monitoring for reflection.

Ruggia et al. (2021) report on a co-innovation project in Uruguay to improve the sustainability of family-run grassland-based livestock farms through ecological intensification. A team of researchers and advisors started by characterising the farms using socio-technical indicators and then discussed the diagnosis and the redesign plans with farm families. After implementation, continuous monitoring and evaluation stimulated learning and allowed adjusting the designs over the course of three years. Ultimately, farm system redesign improved all three sustainability dimensions and resulted in synergies between productivity and biodiversity. These findings are scaled out to more farmers in ongoing co-innovation projects.

Salembier et al. (2020) applied design and agronomy theories to analyse a French R&D cooperative (Atelier Paysan) that supports farmers in designing farm equipment for agroecology. The Atelier Paysan roles included organising the sharing of on-farm equipment design

experiences, resources to stimulate on-farm equipment design, and connecting equipment designers. Analyses of 30 out of 670 implements registered in Atelier Paysan database showed that they were all designed to be appropriate for particular situations and they were adaptable to conditions other than the ones that gave rise to them. Three common features of the design processes emerged: (i) changes in implements were accompanied by changes in the cropping systems across agricultural contexts; (ii) development of the implements was associated with the generation of other resources (e.g. technical drawings); and (iii) farmers and R&D actors acted together as designers with complementary skills. The results of this paper question the historical separation of input design (e.g. by agro-industry) and cropping system design (by farmers).

Moojen et al. (2022) present the Brazilian Farm Coaching initiative, which combines technical and personal coaching to support transitions to integrated crop-livestock farming. The Farm Coaching workshop is a key element, which builds on four steps: deconstructing the current management, getting a better understanding of integrated crop-livestock farming, experiencing this farming model using a serious game, and co-designing a new lifestyle and farming system suited to each farmer. Between 2017 and 2019, the initiative was implemented with 90 farmers. An in-depth analysis of 12 cases describes the individual trajectories and related strategies supporting the transitions, such as implementing pilot tests and developing skills to deal with the new tasks. This experience illustrates the need to consider the practitioners' mindset changes that allow co-innovation and co-design processes to succeed.

Selbonne et al. (2022) developed a methodological framework to design and explore scenarios to upscale climate-smart agriculture (CSA), and applied it to Guadeloupe, France. The framework consists of five steps: Steps 1 and 2 characterise the diversity of current farming systems by building a structural typology and diagnosing each farm type using a set of researcher-defined sustainability indicators. This baseline was used to co-design agroecological crop management prototypes (step 3), one of which was implemented in an experimental micro-farm in step 4. The micro-farm provided an interface for the co-evaluation of solutions with stakeholders and input for model-based evaluation of scenarios in step 5. Indicators to describe the scenarios were chosen during workshops involving researchers, farmers, and politicians. Five scenarios were defined with increasing reliance on agroecological practices and support by policies and value chains. The results showed the trade-offs between substantially improving regional sustainability goals and increasing public expenditure. In addition, the results showed lock-in effects around limited workforce availability at the regional scale, orientating of current public incentives towards conventional systems, low profitability of CSA products, low work efficiency and high-risk aversion of farmers. For the next steps, stakeholder platforms where levers and lock-ins are discussed are recommended.

The 13 papers in this Special Issue put different emphases on transformation and transformative research. The focus of the contributions by Pelzer et al. (2020), Romera et al. (2020), Brun et al. (2021), Catarino et al. (2021), and Selbonne et al. (2022) is on transformation research. These papers describe the analyses and processes towards proposals, either qualitative or quantitative, for systems redesign. The contributions by Salembier et al. (2020) and Kernecker et al. (2021) fall into the transformation research domain by describing and analysing experiences that contribute to a change in the perspective of scientists when they become engaged in transformative research. The papers by Aare et al. (2021), Berrueta et al. (2021), Puech et al. (2021), Rossing et al. (2021), Ruggia et al. (2021), and Moojen et al. (2022) report on transformation research approaches but continue their accounts by engaging in transformative research during which redesign proposals were implemented and evaluated across one or more iterations.

Together, the papers describe the broadening scope and methodological toolkit of agronomic systems scientists engaged in transitions-in-the-making. They show how the definition of the systems engaged with includes societal actors beyond farmers and advisors and at scales beyond the field and the farm to include regions and value chains; considers time scales beyond the lifetime of research projects; and mobilises new methods and tools for supporting the transformational processes both analytically and in-action. The papers show emerging changes in roles that engaged systems agronomists assume in forging transformative change by drawing on other scientific disciplines such as psychology, innovation sciences, design sciences, and evaluation theory. In the next section, we address these emerging themes.

3. Themes emerging from the papers to support transitions in-the-making in agroecosystems

3.1. Broadening the research scope to engage with transitions in-the-making

Some contributions in this Special Issue focused on the overarching transformative process and described the various elements mobilised to bring about change. Other contributions focused on a specific element, such as defining indicators or developing modelling tools. In other cases, the overarching transformative process was only described superficially, focusing on ex-post analytical insights. The papers were all received in response to the Special Issue call on transition in-the-making, reflecting the diversity of perspectives of systems agronomists on what constitutes a contribution to agricultural change. Hazard et al. (2019) refer to perspectives on the implementation of scientific knowledge as 'research stances' and advocate that researchers become aware of the stance they take. Broadly, they distinguish between researchers believing that knowledge precedes action and informs decisions or that it is an integral part of the action. The first stance, they argue, results in advocacy, the second in inquiry. No matter the stance chosen, the merit of approaches that hold promise for contributing to change can only be assessed within the context of change processes, for instance, in terms of their contribution to change mechanisms such as learning, social capital building, or engendering action (Douthwaite and Hoffecker, 2017; Hoffecker, 2021; Van Mierlo and Beers, 2020). The 'how-to' question of using scientific knowledge as part of sustainability transitions thus challenges the role and organisation of research where training and reward systems favour analytical approaches - transformation knowledge addressing 'what' and 'why' questions – in favour of supporting less time-efficient transdisciplinary approaches for transformative knowledge. This Special Issue provides evidence of a change in scope towards transformative knowledge development, particularly by the young systems agronomist main authors who have developed the skills to closely interact with practitioners in many configurations and with different stances.

3.2. Broadening the methodological toolkit to engage with transitions in-the-making

Two application levels of methods may be distinguished in the contributions in this Special Issue. The first level concerns the generation or representation of knowledge. The second level involves the methods for embedding the knowledge produced in the overarching change process. Most of the contributions in this Special Issue used adaptations of existing methods to generate or represent knowledge. Existing methods adapted to fit the overarching change processes included agronomic diagnosis (Ruggia et al., 2021), yield gap analysis (Berrueta et al., 2021), qualitative context analysis (Romera et al., 2020), or quantitative sustainability indicator frameworks (Pelzer et al., 2020; Puech et al., 2021; Selbonne et al., 2022). Various papers reported on meta-methods, i.e. methods to deploy methods as part of transitions in-the-making, answering the 'how-to' key question of this Special Issue. The papers by Romera et al. (2020), Puech et al. (2021), Brun et al. (2021), Aare et al. (2021) and Rossing et al. (2021) provide attention to the governance of change and the interfacing of scientific and informal knowledge as part of transdisciplinary approaches featuring

participatory explorative research design, serious games, workshop design and facilitation formats, personal coaching, monitoring and evaluation using complexity-aware indicators, and visualisations. The articulation of knowledge products and change processes revealed by many papers constitutes an important extension of the systems agronomist's toolkit.

3.3. Design as part of transitions in-the-making

Various papers in this special issue refer to design or redesign as, in most cases, existing systems were the starting point. A sustainability transition in-the-making may bear a resemblance to design if the latter, as described by Salembier et al. (2020), is a process driven by a desire to generate something that does not yet exist. This process manifests in the actions of one or more designers, in the gradual emergence of a new object, either material or immaterial, and in its integration into physical, social, economic and virtual environments. Depending on the unknown object to be designed, such design processes may extend over considerable time periods: Rossing et al. (2021) describe design cycles across 20 years during which researchers connected themselves on and off to change processes at the farm and regional levels. Aare et al. (2021) emphasise that the project they analysed was only one step in a change process, yielding no certainty about the permanence of the agroecological change at the farm level. The ongoing engagement of scientists in societal change is what Lacombe et al. (2018) call a never-ending and non-linear design process.

This connotation of (re-)design contrasts with interpretations of (re-) design as an in silico (Pelzer et al., 2020; Catarino et al., 2021; Selbonne et al., 2022) or on-paper visualised object (Romera et al., 2020) resulting from the interaction of different contributors based on workshops or interviews. Such participatory work products may be considered intermediary results towards the aspired material changes after implementation and experimentation (Pelzer et al., 2020) rather than being design results themselves. To further add to the ambiguity of the notion of design, the organisation of the design process may - itself - be designed. Design of design processes is particularly pressing concerning the 'how to' question of Fazey et al. (2018), who argue for a repositioning of science to make insights actionable by combining zoomed-out perspectives and locally salient results, or, combining eagle-eye and worm-eye perspectives (Kaika, 2018; Leitheiser et al., 2022). Most papers in this Special Issue show how systems agronomists are increasingly engaging in these types of process design questions.

While there is heuristic value in maintaining interpretive ambiguity (see, e.g. Ison et al. (2013) on social learning), it will enhance the attention to and the efficacy of scientific transformative knowledge development if the term design in agriculture is more strictly used in relation to engagement in societal change.

4. Concluding remarks

Some of the papers in this Special Issue are the fruit of the perseverance of both the authors and the reviewers, as both had to rethink what they consider valid scientific contributions. Authors faced the difficulty of how to show the contribution of their work beyond the specific; reviewers had to consider the value of empirical accounts in fields with very limited theoretical development. Beratan (2014) identified the same cultural divide in a special issue of Ecology & Society on Collaborative Adaptive Management. Here, researchers may act as intermediaries to connect specific learnings to overarching theoretical frameworks.

Contributing to transitions in-the-making calls for systems agronomists to question their profession's why, what, and how. This brings many of us into largely unchartered and possibly uncomfortable areas. Aare et al. (2022) signalled: 'The researchers leading this case study balanced the obligation to deliver scientifically relevant knowledge for the funding research project with the need to ensure learning and engagement among the participating farmers.' Scientific engagement in transitions in-the-making thus calls for a reflexive learning attitude to identify not only opportunities to engage more effectively but also identify barriers in the scientific profession.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is contained in the Special Issue

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