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Detecting 'green shoots' of agri-food systems transformation: a framework and insights from the spread of non-pesticide approaches in South India

Costanza Conti [a], Andy Hall[b], Tim G. Williams[c], Vishal Kumar[d] and Giacomo Zanello[a]

[a]School Of Agriculture, Policy and Development, University of Reading, UK; [b]Commonwealth Scientific and Industrial Research Organisation (CSIRO), Canberra, Australia; [c]Environmental Geography Group, Institute for Environmental Studies (IVM), Amsterdam, Netherlands; [d]Humanitas Global School (HGS), Gorakhpur, India

ABSTRACT

System innovation is a signature feature of agri-food system transformation. Such system innovation often occurs in niches. However, how the "green shoots" of transformation can be detected and appraised through time remains ambiguous. This paper proposes, applies and tests a framework that could be used as a 'transformation assessment tool' to evaluate the level of system innovation in a domain of change. The framework is tested against a case study of a Non-Pesticide Management initiative in South India. The framework helps to reveal how, over 20 years, the initiative triggered a number of system innovations that opened a new development pathway, more aligned to environmental sustainability, equity and social inclusion. A critical enabling factor identified for the expansionand "blossoming" of this green shoot was its capacity to flexibly respond and adapt to emergent and largely unknowable agri-food systems dynamics. In its conclusions, the paper sheds light on the ongoing tensions around the defining benchmarks or thresholds for assessing the 'transformativeness' of initiatives and change processes. Finding a way of combining qualitative assessments of system changes with quantitative measures of social, economic, and environmental impact could be a valuable vein of research to enhance our understanding of transformative processes and how to enable them.

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1. Introduction

Urgent global calls for the transformation of agri-food systems towards more sustainable pathways have once again placed the spotlight on both the importance of innovation and the need to reconsider how innovation for sustainability should be enacted (Conti et al. 2024b; Schot and Steinmueller 2018). This is particularly urgent in the Global South,

CONTACT Costanza Conti c.conti@pgr.reading.ac.uk

where sustainability issues intersect with pervasive social concerns of inequity and food and nutritional security (Béné et al. 2019). A feature of the agri-food innovation landscape is the emergence of a constellation of place-specific, highly diverse, and often spontaneous initiatives that are attempting to pioneer more sustainable agri-food systems (Bennett et al. 2019). These initiatives are often driven by previously marginalized actors such as local communities, grassroots movements, and Indigenous Peoples (Gliessman 2013; IPES-Food & ETC Group 2021; Pereira et al. 2020). The agri-food system innovations that these initiatives are experimenting with are challenging the current unsustainable direction of development in favour of fundamentally different pathways rooted in principles of environmental viability, social justice, and food sovereignty (Sage, Kropp, and Antoni-Komar 2020).

Discourses in the sustainability transitions and food systems transformation fields recognize that transformative change processes begin in niches, which are protected spaces where innovation can emerge and be experimented with (Bui 2021; Bui et al. 2016). Innovation here is not conceived as purely technological, but rather, as system-level innovation, thus referring to all novel practices and rules spanning technological but also ecological, cultural, social and economic domains (Hall and Dijkman 2019). It is argued that the 'signature feature' of transformation is the presence of innovation in *all* system elements, i.e. existing behaviours and knowledge, values, capabilities and skillsets, consumer practices and markets, as well as infrastructure, institutions and policies (Ojha and Hall 2023).

Despite this conceptualization of transformation as systems innovation, the means by which ongoing transformation can be detected (and thus supported), and how niches can trigger such transformation remains insufficiently understood (Bui 2021), particularly, in the context of emerging economies. A part of the challenge is that initiatives that are cited as examples of transformation often do not exhibit the core feature of system innovation (Kirchherr 2022; Ojha and Hall 2023). This creates ambiguity in what transformation is, raising the risk of voiding the term of its meaning along with its analytical and planning power (Feola 2015; Scoones et al. 2020). Additionally, a major source of tension regards the metrics through which transformative processes are monitored and evaluated (Fanzo et al. 2021). Much of current discourses recognizes 'success' in change processes as increases in 'total yields of specific crops, productivity per worker, and total factor productivity' (IPES 2016). This framing of success is however deemed increasingly inadequate to capture the much more fundamental, long-term and systemic nature of transformative processes (Conti, Zanello, and Hall 2021b), demanding the adoption of different and much wider-spanning transformation-adapted metrics (Conti et al. 2024a; Kok et al. 2023, 2019). The other part of the challenge is that, without a clear understanding of the dynamics of agri-food systems' transformational processes, it is extremely difficult to identify the factors and enablers that allow niches to challenge the unsustainable status quo and start unlocking transformation (Bui 2021).

The purpose of this paper is to apply and test a path-dependency framework by Conti, Zanello, and Hall (2021b) as a 'transformation assessment tool' to detect a transformation underway at different points of maturity and to identify the factors that enable niche expansion over time. What distinguishes the framework from many of the transformation frameworks that have been proposed in the literature, is that it provides a way of investigating the unlocking of different sources of path dependency. In doing so it allows an assessment of the extent to which system innovation is taking place and highlights the temporal dimensions of transformation. The framework is applied to a detailed

case study of the growth and spread of a Non-Pesticide Management (NPM) social movement in Andhra Pradesh and Telangana states (AP and TN) in South India over an approximately 20-year period. The framework applied to the case study reveals the extent of system innovations underway, ultimately showing how it supports three critical transformation ambitions at a growing scale: (i) environmental sustainability; (ii) equitable economic growth; and (iii) social justice and inclusion.

The paper suggests that the chosen framework could be used as a tool to detect and monitor on-going transformation, helping to reveal the systemic nature (or lack of thereof) of emerging 'green shoots'. The discussion also surfaces the tension between tracking transformation progress in terms of economic and social metrics and the approach advocated by this paper of tracking the systemic change process needed for these types of impacts. Finally, the paper highlights how synchronizing innovation in different system elements (un-locking path dependencies) could be critical to accelerate transformational change processes.

2. Transformation as path-dependency disruption

The transformation agenda reframes and expands the innovation agenda from component innovations (specific technical, institutional and policy solutions) to broader 'system innovation' that will direct component innovation towards social and environmental concerns (Hall and Dijkman 2019; Ingram and Thornton 2022; Rockstrom et al. 2023). The concept of system innovation implies a realignment of system functions and the values that underpin actions and desired outcomes, with the new normative system performance objectives of sustainable development (Klerkx and Begemann 2020). However, how such fundamental reconfiguration processes take place, specifically in niches, and how they can be detected and adequately monitored, remains still an open question (Bui et al. 2016; Fanzo et al. 2021). The features or elements of niches needed to challenge the status quo and opening alternative pathways remain poorly understood, especially in the Global South (El Bilali 2019).

A recent systematic review on the causes of resistance to transformation in agri-food systems provides a novel transformation framework that sees transformation as the synchronized disruption of six mutually reinforcing path dependencies (see Figure 1) that, together, impede a shift to more sustainable development (Conti, Zanello, and Hall 2021b). The framework facilitates exploring transformation phenomena, through three key analytical insights:

(1) It identifies six key 'sub-domains of path-dependency' to be investigated in assessing system innovation processes: technologies, behaviours, policies, R&D activities, infrastructure, power and politics. These domains need to be tackled in an interconnected manner to redirect the performance of the system towards new objectives.
(2) The framework can be used to assess the extent of these interconnected changes across multiple system components, thus helping shed light on the often only theoretically acknowledged (Ojha and Hall 2023) systemic nature of transformative processes;
(3) Overall, the framework helps 'track' transformation through time (highlighting its temporal dimension), showing how both consecutive and parallel changes in multiple agri-food systems components are needed to unlock system innovation. This

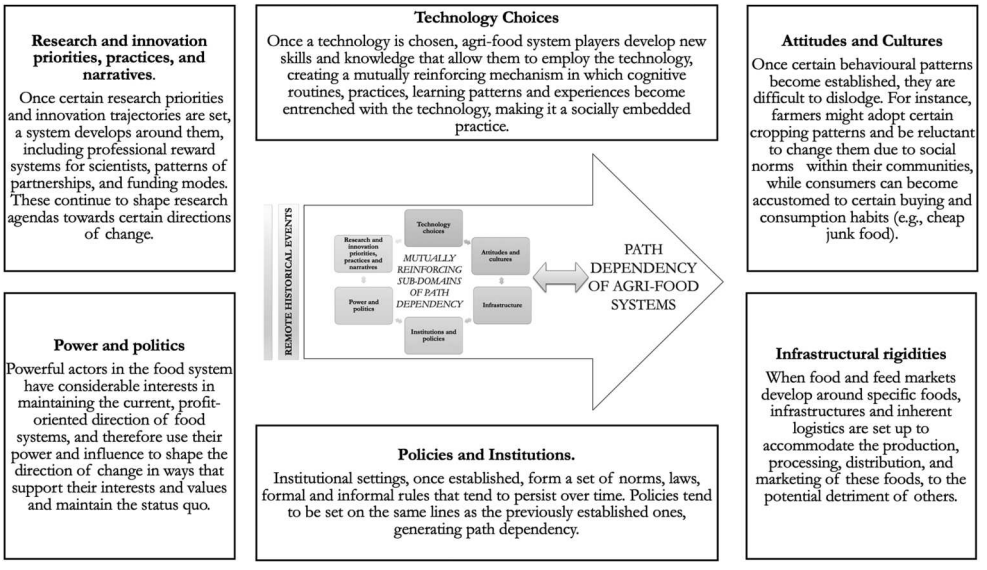

Figure 1. Domains of path dependency requiring disruption for agri-food systems transformation. Double-headed arrows represent the interconnected and systemic nature of these domains.

also sheds light on the temporal dimension of transformation, both in the sense of (i) showing how different food systems elements might change at different *speeds* (for example, changes in behaviours towards healthier and safer food consumption usually happen over the long term (Orr et al. 2022)); and (ii) how there might be a certain *order* in how components change, or how some innovation in some food systems elements might need to happen before innovation in other system elements can be unlocked (for example, targeted policy interventions (e.g. subsidies) might accelerate changes in consumer behaviour and open the way to a cascade of other changes, such as a gradual shift to farm practices that can supply healthier or safer foods) (IPES 2017).

These three insights provide a potential framework to explore the progress of system innovation and transformation. The paper tests the framework by applying it to our case study, determining whether the features of an ongoing transformation can be detected.

3. From path-dependency to system innovation: how an NGO opened a sustainable pathway in a South Indian food system

This case study documents the development and spread of a sustainable approach to food production and consumption, Non-Pesticide Management (NPM; see Box 1), in South India. The focus of the case is the evolving role of an NGO, the 'Centre for Sustainable Agriculture' (CSA), and later, its commercial offspring, the 'Sahaja Aharam Producer Company' (SAPCO). As we will see in the next sections, CSA and SAPCO started promoting NPM in the early 2000s and went through several developments that allowed

NPM as defined by CSA	NPM is defined an "ecological approach to pest management using knowledge and skill-based practices to prevent insects from reaching damaging stages and damaging proportions by making best use of local resources, natural processes and community action" (Ramanjaneyulu and Rao, 2008a). It is based on (Ramanjaneyulu et al., 2009): • Understanding the crop ecosystem and consequently adopt suitable cropping systems and production practices. • Understanding insect biology and behaviour, adopting suitable preventive measures to reduce the pest numbers. • Building farmers' knowledge and skills in making the best use of local resources and natural processes.
Crops covered	From a few crops in the early 2000s, to a wide range of products such as oils, pulses, millets, cereals and other
Products offered	More than 200, through an e-commerce platform and in-store (https://sahajaaharam.com/#quickshop)
Farmers reached	100'000
Farmer Producer Organisations (FPOs) set-up	66 directly, 154 as a resource agency
FPO Hubs set-up	7
Certified farmers (through PGS)	60'000
Acres covered with NPM	260'000
Indian states advised on NPM	Maharashtra, Tamil Nadu, Karnataka, Punjab, Himachal Pradesh, Sikkim, Manipur, Nagaland, Chhattisgarh and Odisha

Box 1. CSA and SAPCO at a glance. Source: CSA (2023); Ramanjaneyulu et al. (2009); Ramanjaneyulu and Rao (2008); Ramanjaneyulu (2011).

NPM to go from being a largely unknown practice to a nationally recognized 'alternative' that is both environmentally and economically sustainable and socially inclusive (Gupta et al. 2021). To achieve this, CSA had to reinvent itself and its approach a number of times in response to a continuously changing context and an unfolding system innovation of which it was itself intrinsically part of. Starting as a grassroots farmer empowerment agency promoting a novel agricultural practice – NPM – CSA gradually expanded its role and reach to become (1) an organization promoting natural solutions, (2) a regulatory body that can provide formal certifications for environmentally sustainable food and other products; (3) a successful business venture equitably redistributing profits along the value chain, and (4) an advisor and service provider to the national and state governments on issues of sustainability in domains where public agencies were struggling to find solutions.

As will be illustrated, their actions made a significant systemic contribution to tackling equity and justice concerns by securing farmers' democratic and inclusive decision-making power in value chains, as well as opening sustainable food choices for consumers.

The analysis of the case study is based on data and insights collected through a purposive literature search of relevant literature and 22 in-person interviews conducted by the first author. A detailed explanation of the methods used, interview questions and granted ethical clearance is presented in Annex 1. The six domains of path dependency presented in Figure 1 present guiding themes for a thematic analysis showcasing the historical evolution and key inflection points of CSA and SAPCO.

3.1. The 'modern' agriculture path dependency, its repercussions and first civil society responses (1960s–2000s)

In the early 1960s, geopolitical conditions promoted the Green Revolution (GR) in India. This initial historical choice, motivated by concerns over both economic growth and insufficient food supply for a fast-growing population, promoted the modernization of agriculture through technologies such as high-yielding varieties/hybrids and chemical inputs (Ramanjaneyulu et al. 2009). The GR aimed to raise food security by helping farmers increase production using these new technologies. However, in the study area, like many other locations in South Asia, the GR also had unexpected and negative consequences:

A shift in farmers' practices (and knowledge of those) towards intensive chemical input use. While farm productivity initially increasing, farmers gradually lost knowledge of natural farming practices that had been used for centuries (Kumbamu and Stone 2007). Chemical inputs started to have environmental consequences (e.g. damaging soils, polluting the water) ultimately making farmland less fertile. Pesticides created health issues for farmers spraying them as well as for people consuming the crops (Ramanjaneyulu and Rao 2008; Roberts and Reigart 2013).

A shift in policy and infrastructure. Initially supporting the GR through, for instance, integrated food grain price support, storage and public distribution system, in the 1990s onward policy further accommodated this mode of 'modern' agricultural development. For example, India's economic liberalization in 1991 promoted several changes (in trade, private and foreign investment, taxation, and fiscal discipline) to boost economic growth (Vaditya 2017). These changes resulted in cuts to farmers' profits by around 40%, due to increased chemical input costs. While R&D investments were directed towards the development of new, high-yielding varieties (Glover et al. 2021; Kumbamu and Stone 2007), this shift to industrial and chemical inputs concentrated the power in the hands of big agribusinesses in the post-economic liberalization era where state-owned agricultural input agencies where replaced by private enterprises (Gibson et al. 2024).

Progressive urbanization and consumption changes. While the urban poor suffered from a lack of access to (healthy) food, the availability and increasing popularity of junk and fast foods, coupled with limited awareness of nutrition, led middle and higher-class consumers to shift from traditional diets (rich in pulses, vegetables and fruits) to overconsumption of nutrient-poor food (Rajendran 2022).

These issues prompted the establishment in the late 1980s of the Centre for World Solidarity (CWS), a Hyderabad-based Non-Governmental Organization (NGO). The organization attempted to help farmers respond to increasingly persistent pests and weed problems while reducing their reliance on costly chemicals through NPM. Even if at the time, the concept of 'organic agriculture' was at the margins of consumer and political consciousness, initial successes built credibility for NPM (Nair 2009). However, CWS was not an agriculture-focused NGO and had no solid research background in agriculture (Vicziany and Plahe 2017). This opened the way for a new organization to emerge: CSA.

3.2. CSA's initial steps: altering technology choices and behaviours while leveraging policy support (2004–2008)

In 2004, a major shock affected AP and TN. An acute water shortage coupled with continuous and diverse pest attacks caused huge losses for already indebted farmers and led to 1200 farmer suicides in less than three months (Nair 2009; Ramanjaneyulu and Rao 2008). In this context, an agricultural scientist previously involved with CWS saw the potential of NPM and established CSA as an NGO dedicated to expanding this practice. He recovered pre-GR knowledge of environmentally viable agricultural practices and integrated it with his scientific background to improve and further develop NPM techniques (Box 1). To leverage NPM's potential to the fullest, the scientist understood the need for immediate changes in both technology choices (i.e. costly and environmentally damaging chemical inputs) and behaviours, both farm-level adoption of new practices and changes to consumption practices. He also recognized the need for consistent funding to run CSA.

From 2005 to 2008, CSA involved increasing numbers of farmers in NPM, 're-skilling' them to move away from the high-input agricultural model. As awareness spread and NPM solutions demonstrated their potential, many villages converted *in toto* to NPM. Initially, the major crops under NPM were castor, ground nut, sesame, sorghum and pigeon pea. Farmers were the first consumers of these crops, which later started being sold to urban consumers during weekly markets.

3.3. Institutional and infrastructural innovations: scaling in response to uncertainty (2008–2012)

By 2008, both the State and the National governments were explicitly recognizing the environmental and socio-economic damages of the GR and the importance of organic agriculture. For example, the Government of Andhra Pradesh states 'the need of change in farming system approach [towards organic agriculture]' (Government of Andhra Pradesh 2008). However, a change in the ruling party in the government of Andhra Pradesh in 2008 ended the collaboration and funding between the state and CSA. CSA continued training and technical support to farmers by using its own staff, but the withdrawal of government funding created financial limits to the expansion of NPM. At this point, CSA realized that the dependency on uncertain government support was not an appropriate way to pursue long-term goals and that CSA needed to be self-sustaining financially. The NGO identified two measures to achieve this.

First, the creation of farmers' cooperatives and FPOs, run by the farmers themselves. Cooperatives would have their own staff (which would be trained by CSA) to conduct NPM training and advise farmers, thus increasing accountability while reducing organizational load on CSA. CSA who would only train the cooperative staff and thus less frequently need to visit the expanding number of villages under NPM. In 2008, the cooperatives united to create a farmer producer company (an FPO): SAPCO, which is a federation of 23 FPOs and cooperatives, where each has a democratically elected chairperson. This process of institutionalization ensured that decisions around SAPCO's operations would be taken collectively and democratically.

Second, creating new infrastructure to better market NPM products and grant higher financial independence for CSA and SAPCO. To operate under their own funding, both organizations needed to increase production volumes – and thus profit. This was achieved through changes in the value chain, specifically concerning processing and transport infrastructure. Before CSA, farmers used to sell their produce to intermediaries (who would take a large profit margin). With CSA, farmers still had to bring their produce to the market themselves. This could work at scale. Cooperatives would ensure that larger production volumes would be achieved, and that produce would be uniform in terms of quality and production modalities. Cooperatives became novel infrastructure 'hubs' where farmers could bring their produce without having to transport it to the market. Progressively, CSA and SAPCO acquired processing facilities that helped increase profit margins (Vicziany and Plahe 2017) (Figure 2) and expand production through new corps (e.g. cereals, millets, pulses, oils, and spice) that could now be stored, processed, and packaged without the involvement of third-parties.

With the opening in 2009 of its first retail store selling organic products in Hyderabad, SAPCO (with the help of CSA) had managed to build a democratically controlled value chain in which the farmers agreed collectively about their production and other strategies through their representatives in SAPCO. The retail store allowed farmers and consumers a more stable outlet for selling and buying NPM products.

3.4. A TV show creates awareness at scale while changes in regulation bolster the initiative (2012–2016)

The growing outreach of CSA led the organization's work to be featured in a nationally streamed and extremely popular TV show, Satyamev Jayate, which aimed to raise awareness about environmental issues. The show shed light on the dangers of pesticides and

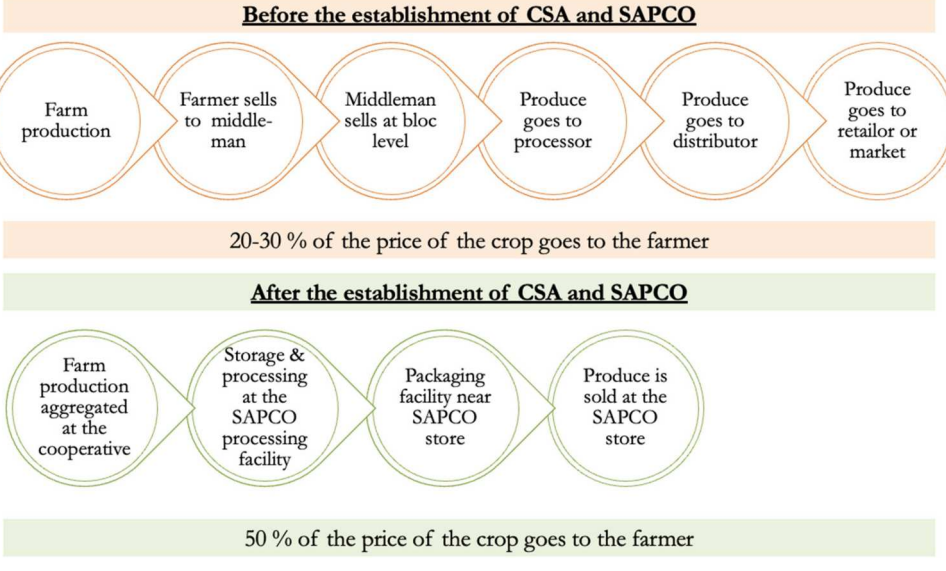

Figure 2. Value chain before and after SAPCO.

the benefits of consuming pesticide-free products. Soon after, and in part as a consequence of such media attention, the Food Safety and Standards Authority of India (FSSAI) analysed common food items and found that they contained pesticides in quantities 1000 times higher than permissible limits (Prasher 2013; Satyamev Jayate 2013).

NPM started being seen as a way to mitigate environmental degradation, health and poverty issues. Several government schemes were set up to facilitate NPM adoption, such as the Capital Investment Subsidy Scheme, the National Project on Organic Farming, and the National Paramparagat Krishi Vikas Yojana Scheme (Government of India 2017, 2010). Concomitantly, research started being conducted on CSA. Scholars from both Indian and international institutions came to observe their practices and business model, increasing its visibility, while CSA continued expanding its work by further exploring NPM to include new crops (for instance, expanding to vegetable crops, millets, rice, cotton).

CSA also received recognition for its efforts in terms of farmers' empowerment. SAPCO had a democratic structure, which made the government aware of the potential of cooperative models to further farmers' rights and reduce the vulnerability of rural livelihoods. In 2013, the government changed its regulations to favour cooperatives. Before 2013, the legislation for setting up cooperatives (despite its long history in India) was muddled, making it difficult for farmers to apply. New regulations simplified the process to ensure more farmers could form cooperatives.

The success of CSA was confirmed when the NGO won two national prizes in 2014: one for the 'Best Rural Innovation' and one for the 'Best Community Management Model'. This symbolized how both the technology and the institutional developments received recognition.

3.5. Awareness demands more regulatory changes, an unexpected shock boosts sale (2016–2022)

In 2016, the CSA funder and SAPCO executive director were invited to a TED talk on the importance of consuming organic foods. The talk went viral. The growing concerns over the danger of consuming foods produced with pesticides seemed to be the new norm in consumers' minds. Consumers demanded food that was organically produced and could prove to be so. Thus, the government was pressured for more regulatory changes. Particularly, it made efforts to improve an existing 'Participatory Guarantee System' (PGS), a system set up as early as 2006 to certify crops produced under organic principles. Until 2016, the PGS was dysfunctional: the implementation of the legislation had been scattered, and even if 327 PGS centres were allowed to certify, the process was slow, the quality controls weak and corruption frequent. Overall, the certification was unreliable. In 2016, the government started to scrutinize different centres, cutting their number to 65. CSA applied to become one of these centres, and its new regulatory role allowed it to make NPM more credible – and thus more marketable (https://pgsindia-ncof.gov.in/pgs-india; https://csa-india.org/services-2/). With the certification, farmers could sell at a premium price.

In parallel, CSA kept expanding awareness about NPM, partnering with the Grameen Academy to create 'FPOhub' and mentor farmers so that they could independently set-up and manage cooperatives. Consumers were equally involved: SAPCO continued to set up

consumer-targeted initiatives, such as nutritional counselling sessions, urban gardening, household waste management and composting, cooking festivals and exhibitions. SAPCO also started running activities in schools to create awareness in children about healthy consumption (Ramanjaneyulu 2019).

In 2020, the pandemic threatened the functioning of the retail stores, as lockdowns made it hard for the products to reach SAPCO stores, while the processing hubs had to initially halt production. However, CSA and SAPCO quickly resolved these issues by making several transport and storage adjustments and, ultimately, selling even more products to consumers who were more than ever aware of the importance of healthy nutrition.

Besides, the success of the cooperatives in empowering smallholder livelihoods ensured the support of the government in terms of cooperative-friendly policy measures, such as (i) an income tax exemption on cooperatives (2019); (ii) a guarantee of subsidies for the first three years of a cooperation's operation (in particular, covering administration costs) (2020) and (iii) the set-up of a National Ministry solely dedicated to cooperatives (the Ministry of Cooperatives) (2022).

Several other state governments (in particular: Maharashtra, Tamil Nadu, Karnataka, Punjab, Himachal Pradesh, Sikkim, Manipur, Nagaland, Chhattisgarh and Odisha) also began reaching out to CSA for possible R&D activities to promote organic farming. In 2022, CSA was actively involved in the drafting of an Organic Farming Policy in Kerala, Odisha and Madhya Pradesh. Today, CSA and SAPCO's primary mission has become to help the government (nationally and at the state level) 'in transitioning towards economically viable and ecologically sustainable agriculture' (https://fpohub.com/about/).

4. Green shoots for transformation: where? And how to?

Unfolding over a period of more than 20 years, the case study illustrates the cascading events, actions, and serendipitous responses that played in a broad agri-food systems reconfiguration process. Changes in multiple system elements, underpinned by sustainability, justice and inclusion concerns, worked together to open new opportunities for further system changes. While CSA clearly played a catalytic role in the study region, the organization was only part of a broader change in the values that frame a range of innovations happening in the AP and TN agri-food system. The case study highlights the importance of the context-specific nature of change, both regarding geography and temporality. Geographically, the NPM innovation was tailored to the agroecological and cultural conditions of AP and TN. Temporally, the case study reveals that different food systems elements undergo change at different speeds, and the pre-emptive disruption of some of those is required to open up successive windows of opportunity for others. This makes transformation a process where it is a cascade of changes across multiple system elements, happening at different levels of scale and at different points of time, slowly unlocking the overarching 'system innovation' needed for undertaking novel development pathways.

The starting proposition for this paper was that the path dependency framework (Section 2) can help with detecting green shoots and monitoring the extent to which they are disrupting the existing system – and thus opening the way to transformation – through time. The paper's proposition is also that by analysing the case study history in this way it could reveal the enablers of this. We now turn our attention to these two propositions.

4.1. Is transformation underway in our case study?

We now employ the framework as a 'transformation assessment tool' to explore the extent of systems changes that the case study illustrates.

Technology choices. The first element that underwent change was technology choices. Through CSA's work, farmers started switching from traditional and high-input production methods towards environmentally sustainable NPM methods, building knowledge and skills around the innovation, which continued to develop over the years, for instance by expanding to other crops and adapting to new agroecological areas. From a limited number of acres covered in NPM in the early 2000s, NPM now covers 260,000 acres of land (CSA 2023).

Attitudes and cultures. While the technology choices implied behavioural changes at the farm level, were there changes in consumers' attitudes? Although CSA only partially contributed to this, consumers did start to gain awareness about the dangers of consuming food with high pesticide residues. This new attitude generated emerging interest in NPM-produced foods. Consequently, this translated to new purchasing and consumption patterns (i.e. both behavioural and cultural change). The prevalence of this, at a regional level, is exemplified by the expanding reach of SAPCO and its growing number of retail stores (CSA 2023).

Infrastructural rigidities. The acquisition of collectively managed infrastructure enabled alternative ways to store, process, package, and sell the foods. Through this process, once again catalysed by the action of CSA and SAPCO, alternative value chains developed for NPM farmers' produce. This, in turn, supported fairer distribution to farmers of value add, increasing farm profits. Over the years, CSA contributed to the set-up of 66 FPOs in the AP and TG states and assisted the set-up of 154 more as a resource agency in other states (CSA 2023).

Policies and institutions. Political and policy support for NPM grew over time, but not without some bumps in the road. For example, CSA initially received some financial support from the government, but this was withdrawn after the four initial years due to changing priorities and political interests. However, a few years later, as national awareness over sustainability and healthy consumption increased, policymakers were prompted to look at NPM as a possible mainstream solution (instead of a side-line alternative). By restructuring the PGS, the government legitimized NPM at a national scale by ensuring reliable certification of NPM produce. Furthermore, the government's willingness to reach out to a non-government agency like CSA to provide expertise rather than relying on conventional public agencies (e.g. national Research Institutes) illustrates a deeper shift in policy and the values and norms that inform policy making. In particular, it demonstrates a greater degree of comfort with bottom-up and grassroot innovation as valid contributors to solve urgent environmental and socio-economic challenges, that range from soil degradation to farmers' indebtedness and food insecurity (CSA 2010; Morin 2016). At the same time, policies increasingly supported more socially inclusive cooperative production and marketing type arrangements (i.e. cooperatives and FPO). Again, this was in part a result of the efforts of SAPCO in developing these types of arrangement, as well broader shifts in attitudes towards these sentiments.

Power and politics (or the political economy of agri-food systems). In India, powerful actors shape the food system, often through commodity-based lobby groups (see for

instance, in the case of the sugar industry, Orr et al. 2022). The NPM approach partially rebalance, if in a limited manner, the political economy of the food system by empowering farmers. It did this by providing farmers technologies that made them self-reliant (i.e. as opposed to dependent on inputs supplied by big industries). Further, building more just value chains associated with NPM allowed higher profits for farmers and more democratically controlled business and marketing structures (compared to traditional agricultural value chains in India where most value is retained by middle-men and retailers). While 'green shoots' of change can be seen, altering the political economy of the food system remains a daunting task, involving many players and contending interests (Kalvelage et al. 2023; Kennedy et al. 2021; Williams et al. 2023), as well as forces at national and global scales that will need a multi prolonged and multiscale approach to disruption.

Research and innovation priorities, practices, and narratives. The case study provides no strong evidence of any shift in research and innovation priorities, practices and narratives. There does seem to be acceptance by State Government that CSA own experimentation with NPM is delivering useful solutions for farmers. However, this is a long way from breaking existing research and innovation path dependencies. If this was starting to happen, mainstream researchers might, for example, be observed doing collaborative research with CSA on jointly framed NMP research questions. This is currently not happening. But this is a finding in itself, suggesting path dependencies in research and innovation practice maybe some the more difficult to disrupt and take the longest timen.

What the analysis above, informed by the framework, reveals is that there are indeed 'green shoots' of transformation taking place, evidenced by innovation in different system elements and at different scales. CSA and SAPCO cannot be given credit for the totality of changes happening in AP and TG, or in India overall, but they have without doubt been an important player in those. The framework also helps to highlight the long 'storyline' that characterizes transformative processes. By observing and monitoring changes in multiple system components, the framework illustrates how these changes needed to be synchronized in time: for instance, technological and behavioural changes had to happen before infrastructural, institutional and political changes could be unlocked. Looking at the change in multiple system components highlights how these do not change all at the same speed: while technology and behaviour changes were relatively 'quicker', political economy dynamics and the R&D priorities seemed to be the lengthiest system components to disrupt. This mirrors similar acknowledgements in the literature (Anderson et al. 2023; Conti, Hall, and Hambloch 2021a; Conti, Zanello, and Hall 2021b; IPES 2016).

Overall, CSA and SAPCO's contribution was catalytic in helping open a novel pathway of agri-food systems development, that is at once

(i) environmentally viable (it reduces chemical inputs and promotes natural solutions)
(ii) socially just and inclusive, as it empowers small farmers, who 'by default command, a smaller voice than industry' (Morin 2016) to control their value chain democratically (through their elected representatives in SAPCO); and
(iii) economically equitable, as it more fairly distributes profits in the value chain and decreases reliance on big industry players.

4.2. A 'secret' ingredient? Navigating complexity as an enabler of transformation

The framework helps capture and monitor the level of disruption – and thus, the extent of transformation over time. However, what the framework could not capture, but the case study history nonetheless revealed, is the importance of CSA and SAPCO ability to respond and adapt to agri-food systems complex and unpredictable dynamics. The inability to engage with impredictability and complexity in agri-food systems is often seen as a barrier to change and transformation (Conti et al. 2024a; Orr et al. 2022; Orr and Muange 2022). CSA was able to turn unpredictable shocks and challenges into opportunities for experimenting with more sustainable pathways of development. For example, it was the water shortage and farmers' suicides that initially spurred CSA into action (Figure 3).

Similarly, the sudden withdrawal of government funding (due to a change in the government), instead of causing collapse, created an opportunity for CSA to build its infrastructure from scratch and set up its own institutional arrangements to market produce to consumers. Later, CSA leveraged the FSSAI report on pesticides, the invitation to participate in the Satyamev Jayate TV show, and the TED talk to increase its reach and boost consumer awareness. Following the government's reform of the PGS system, CSA seized the opportunity to become itself a certifying body for organic agriculture.

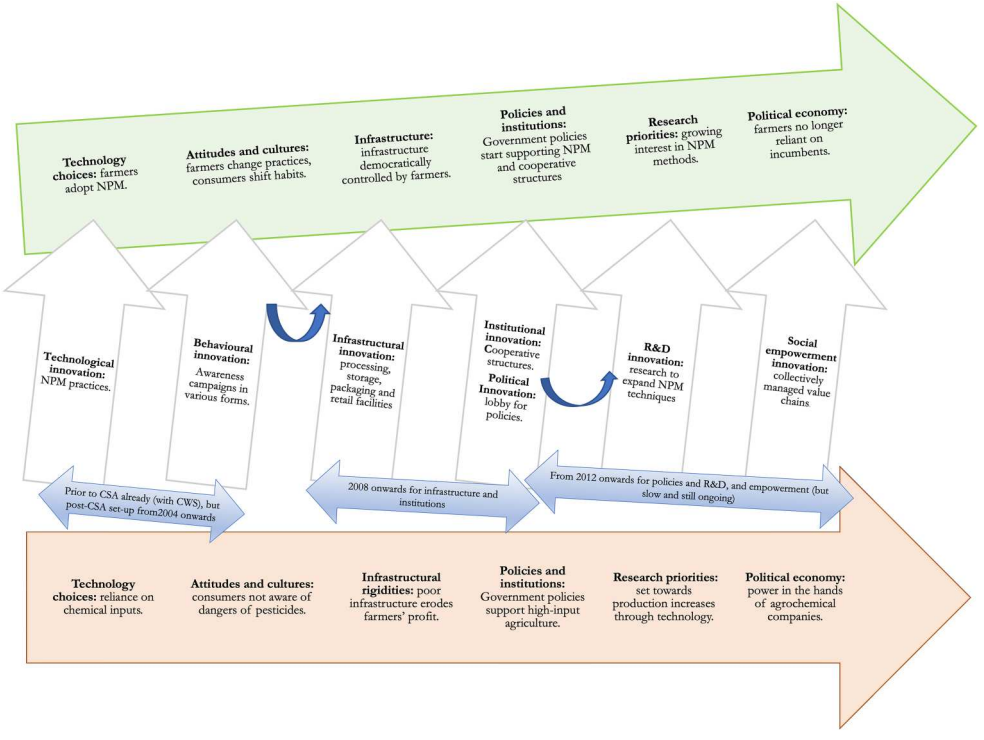

Figure 3. Disruption of path-dependent trajectory (arrow in red) and a shift to a more sustainable trajectory (arrow in green). The arrows outlined in grey represent innovations in all different subdomains of path-dependency. The double-headed arrows represent simultaneous changes. The curved C-shaped arrows represent consecutive changes.

Finally, the Covid-19 outbreak could have truncated its operation and put at risk hundreds of farming livelihoods (as it had happened in other parts of the country). However, CSA and SAPCO were once again able to turn the sudden disruption into an opportunity to make NPM even more appealing to consumers with renewed concern about their health and the importance of healthy nutrition sparked by Covid-19 (Das et al. 2020).

These responses and pivots reveal how engaging, and even possibly embracing, complexity, is a critical enabler for navigating the arduous process of disrupting path dependencies and pursuing novel (and clearly 'unknowable' (Stirling 2014)) pathways of development, especially in the already complex agri-food system space (Conti et al. 2024a; Hambloch et al. 2022). This observation is supported by a growing body of literature that suggests the importance of moving beyond efforts to steer change towards pre-established directions and to 'combat' shocks (Thompson and Scoones 2009; Wigboldus et al. 2016). Instead, in an era of fast-paced environmental and social change (Dekeyser et al. 2020; Feola 2015), it is critical to welcome unpredictable events (advantageous or less so) and 'disturbances' as ways to 'to create opportunities for doing new things' (Thompson and Scoones 2009) and leverage wide-spanning innovation that can open unexplored alternative pathways (Leach, Scoones, and Stirling 2007).

5. Reflections on the way forward: the need to understand both the directionality of green shoots as well as their length

The paper presented a case study of a sustainable transformation that has been ongoing in the Indian states of Andhra Pradesh and Telangana since the early 2000s. The initiative initially emerged as a response to negative outcomes associated with historical path-dependency, and challenged this path dependency by implementing fundamentally different modes of production and consumption. Different forms of innovation (technical, behavioural, cultural, social, economic) enabled changes in multiple domains to promote environmental function, economic viability, and social justice (some more 'quantitative' measures of success are also presented in Box 1). The framework proves to be a useful tool to capture and assess the extent of ongoing transformation in terms of the extent of systems innovation. However, the CSA and SAPCO story allows us to reflect on a much broader concerns around the identification, assessment, and monitoring of transformation, which is a significant point of concern due to the different understandings of transformation that still exist in the literature and beyond (Anderson and Maughan 2021; Schot and Steinmueller 2018).

Traditional measures of success are largely quantitative (e.g. measuring transformation in terms of crop yields and productivity increases (IPES 2016)) continue to be used in determining how transformation is be tracked and evaluated (Douthwaite et al. 2017; Partidario 2020). These traditional measures and metrics while necessary valuable are alone insufficient to capture the complex and long-term nature of transformation (Caniglia et al. 2021; Conti et al. 2024b; Hambloch et al. 2022). Some authors have even argued that orthodox measures of success might even become part of the lock-in that upkeeps current patterns of unsustainable food systems development (Conti, Zanello, and Hall 2021b; IPES 2016). Arguments have been made in the literature around the need for these traditional measures to be complemented with new and more qualitative measure that can reflect broader social, political, cultural

and other changes that need to happen for transformation (Conti 2023; Fazey et al. 2018).

This paper, telling the 20-year long story of NPM in South India, provides a systems innovation account of the early stages (green shoots) of a transformation process underway. One of the values of this is that system innovation is a leading indicator for transformation underway where as social and economic indicators (yield, price, health outcomes) are lagging indicators only fully revealing themselves much later on after system change has occurred. The value of leading indicators is that these allow impacts to be anticipated and point to opportunities to support useful systems innovations underway. However, there still needs to be a line of sight between qualitative measure of system changes (as discussed in this paper) and quantitative measure of social, economic and environmental impact (Fanzo et al. 2021; Fazey et al. 2018; Wassénius et al. 2023) – or what Midgley, Nicholson, and Brennan (2017) have called 'methodological pluralism'. This pluralism is needed to evidence how new food system goals are being achieved, although recognizing that impacts may lag system changes. There would, after all, be no point of transformation/systems innovation if these goals were not ultimately achieved. There is obviously value in rigorously tracking the extent of transformation, for instance, more precisely capturing variations in yields, profits, or even GHG emissions and food security levels among others (Fanzo et al. 2021).

The real opportunity here is to find ways to integrate these two perspectives of systems change and system impact. This raises many new research questions around the benchmark or threshold that would indicate the 'transformativeness' of the outcomes achieved – or in the case of this paper 'how long are the green shoots of transformation detected in the CSA and SAPCO story'? But then again, how would you measure the length? In terms of depth of system change or in terms of impact metrics (maybe a combination?). How do we attribute outcomes and impact to actions of organizations operating in the broader arena of change? What are the types of methods and data sets that are going to be needed to track the progress of systemic transformational change? This represents a significant future research agenda for the study of food system transformation. It holds out the possibility of reducing the risk of the 'transformation' label being used inappropriately (Feola 2015; Kirchherr 2022), while also helping identify promising green shoots that, with adequate support, could cumulatively help challenge existing path dependencies and 'unlock' transformation.

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ORCID

Costanza Conti http://orcid.org/0000-0002-6138-1543

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