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Contributions of Net-Map to sustainability action research

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Net-Map, an interview-based network mapping tool, has been applied across various scientific fields and purposes since its inception to study networks of influence. In this article, we first review the general uses and limitations of Net-Map and then share experiential knowledge gained from using Net-Map to develop an action-oriented research process focused on envisioning pathways to sustainable futures in Spanish drylands. Drawing from the literature and reflecting on our experience, we identified four practical contributions of Net-Map that support our action-oriented research process, including: 1) creating socially inclusive participatory spaces that capture a diversity of influential capacities for promoting sustainability transformations, 2) understanding how to articulate transformative changes at multiple scales, 3) anticipating conflicts and managing power imbalances across scales, and 4) building shared agency and capabilities for fostering collective action, while respecting differences between participants' perspectives. This paper argues how Net-Map can help overcome common barriers in action-oriented research.

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Introduction

In the face of pressing sustainability challenges, there is an urgent need for inclusive, pluralistic, integrated, and adaptive pathways to generate actionable knowledge that facilitates transformative changes. Action-oriented research (AR) in sustainability science is defined as collaborative efforts between academics and non-academics to produce and mobilize knowledge that enacts action for sustainability [1–3]. AR has evolved through advances in knowledge co-production [4] and has benefited from diverse conceptual perspectives, including transdisciplinary research [5] and participatory action research [6]. Hence, we understand AR as a range of research practices where actors from various disciplines and across science-policy-society boundaries co-produce context-specific and actionable knowledge toward sustainable futures. Unlike traditional research approaches, which produce knowledge in academic contexts and then disseminate it to the rest of society, AR adopts an enabling approach for designing and facilitating transformative interventions through social learning and capacity-building processes rather than merely studying phenomena [7,8]. On this basis, AR can contribute to producing scientific knowledge while achieving impacts beyond the academic sphere, catalyzing societal support for sustainability transformations [9].

The design and implementation of the AR process are challenging and, therefore, require combining various tools and approaches throughout all phases of research [10]. Over the past decades, methods and tools have been developed to analyze complex systems involving multiple societal actors and to engage with them in co-producing actionable knowledge for transformative change [11]. However, several challenges persist, for instance, in integrating knowledge from different systems and scales [12], addressing varying levels of agency and collaboration among actors [8], and managing power dynamics throughout the process [13,14]. These factors often underlie competing goals and values, differing problem ownership, and contrasting solution narratives among actors. If left unaddressed, they can undermine collaborative efforts or levels of engagement [13] and even compromise the representativeness and legitimacy of AR [2,9]. Consequently, there are growing calls for methodological innovations, particularly in exploring new ways of using existing methods and tools to understand their

nuances in specific contexts and to learn how to address these challenges in future practice [8].

In this perspective, we address the need for methodological advancements in AR processes for sustainability transformations, drawing from a three-year effort in the XPaths project (<https://www.xpathsfutures.org>). This international AR project aimed at co-creating pathways to the Sustainable Development Goals (SDGs) in drylands by engaging societal actors from different sites, scales, and sectors. Specifically, we focus on the role of Net-Map — a participatory social network mapping tool [15] — in designing and developing our AR approach in the case of Spanish drylands. Drawing on multi-method approaches, we first review the literature on Net-Map's applications, including its purposes, contributions, and limitations. We then outline the AR process used in the XPaths project, detailing how Net-Map was integrated. We present and reflect on four contributions of Net-Map to some challenges currently discussed in sustainability science literature that need to be navigated to better operationalize AR processes. These challenges include creating socially inclusive pathways, integrating cross-scale knowledge, managing conflicts and power imbalances, and fostering shared agency. We provide some practical insights from using Net-Map to enhance AR practice.

Literature review: Net-Map in sustainability science and action-oriented research

Net-Map is recognized as a suitable tool for mapping key actors and exploring power relations in complex actor networks. Net-map emerged as an innovative participatory method from the rapid evolution of social network analysis (SNA) to combine actor network visualization with power relations mapping through a qualitative approach, unlike most network studies [15,16]. Through structured in-depth discussion, interviewees and interviewers collaboratively create network maps based on their perceptions of actor (inter-) relations, goals, and influence levels [15]. Net-Map was initially designed for both research and project development purposes, illustrated through a case study on multistakeholder water governance in Ghana [16]. It later gained popularity in fields such as spatial planning [17–19], food systems [20–22], and public health [23,24]. For example, Net-Map was used to scale up breastfeeding strategies in Mexico [25,26] and to inform nutrition policies in Brazil [23], Ghana [27], Nepal [28], and Bangladesh [29] by identifying key actor networks involved. Net-Map has informed policy-making [25], social innovations [30,31], sustainability transitions [32,33], and it has also proven useful for studying interactions between actors and institutions in the governance of fisheries [34,35], agriculture [36,37], and mining [38].

Additionally, Net-Map can support participatory and transdisciplinary approaches [39]. For example, Net-Map

visualizations have acted as 'boundary objects' that fostered both individual and collective learning while facilitating constructive social interactions [31,40,41]. In an Ethiopian case study [40], network visual analysis following a Net-Map exercise helped participants understand everyone's positions in the network, which proved empowering. By conducting a real-time network drawing exercise, participants' goals, interests, and trust relationships were made explicit [32,41,42]. Alongside this, potential synergies and conflicts over goals or the issue at hand may also emerge [39]. As the data collection is transparent, it may create space for trust-building. This enables researchers and facilitators to improve strategies that strengthen cooperation and legitimacy in knowledge co-production [39,41,42]. However, empirical evidence on whether and how Net-Map supports AR processes (ranging from the shared design and enactment to the realization of change for sustainability) remains limited [40,42].

Limitations and critiques of Net-Map mostly concern sampling and perception biases. These issues arise when studies rely on a select few participants frequently defined as experts, potentially overlooking other groups (e.g. minorities) and reinforcing historical marginalization, as observed in a case study in China [42]. Additionally, asking "who is influential" is subject to actor interpretation, risking misinterpretation, stigmatization, or reappropriation by certain actors [30,40]. This challenge is worsened when actors perform multiple roles, complicating role assignment and the perception of power relations [42]. To reduce perception bias, it is suggested to add a second name generator question (e.g. "Who can be influenced/was influenced by XY?") or follow-up individual questions [25]. Recommendations to mitigate sampling biases include grouping participants by sectors and goals [24], selecting multiple participants per actor or group type [43], and conducting preliminary research on participant backgrounds or additional sessions with initially omitted actors [30,35].

Debates continue about Net-Map's suitability in hierarchical and conflicting settings. A comparative country case study highlighted challenges in Net-Map phases where engagement levels were associated with cultural and hierarchical factors [42]. In strongly hierarchical societies, participants seemed to withhold comments on out-group actors outside their social sphere, while those considered in power are more communicative (e.g. case studies in Germany and China [42]). Conversely, in less hierarchical societies, participants tend to communicate more freely (e.g. a case study in Costa Rica [42]). In some cases, participants avoid addressing explicit power imbalances due to cultural sensitivity [42], whereas in others, Net-Map helped to uncover implicit knowledge and sensitive issues [21,34,39]. Differences in education or social background are also argued to influence participant behavior in net-mapping [39].

However, this could be due to a lack of information or reflecting power-knowledge disparities [31] rather than education levels [42].

To address these limitations, Net-Map can be complemented with other methods. The initial Net-Map protocol outlines a structured data collection and analysis process [16]. Yet, some studies combined Net-Map with other qualitative methods to enhance output quality, ranging from participant observation and policy reviews [35] to content analysis [30] and focus group discussions [17,32]. Others recommend triangulating it with quantitative and statistical methods for comparisons across cases, between self-reported and stakeholder-created networks, or beyond network measures (e.g. a chi-square test) [18,30,42,44]. Given the flexibility, low-tech, and low-cost requirements of Net-Map, it can be easily conducted online or in-person, through individual or group interviews, and using either computer-processed or manually created network maps. This improves communication and inclusion, as seen in a Tanzania case study involving illiterate participants [41] and even in restricted circumstances like the COVID-19 pandemic [43]. Moreover, this adaptability can save time and resources compared to conducting traditional ethnographic studies [42] or large network surveys [35,45], potentially reducing 'research fatigue' and increasing actors' engagement [35,42].

Operationalizing Net-Map tool in Spanish drylands

The XPaths project: bridging knowledge and action across scales for sustainability transformations in drylands regions

XPaths is an AR project aimed at co-creating pathways to the SDGs across scales in the semi-arid regions of Spain, Brazil, and Senegal. This paper focuses on Spanish drylands in the southeast of the Iberian Peninsula. This region features an extensive network of National Parks and Biosphere Reserves that conserve high levels of biodiversity and habitats of priority interest at the European level. This case illustrates how increased intensive agricultural production in the driest area of continental Europe has led to economic benefits over the last decades while reproducing social inequalities and negative impacts on natural resources and ecosystems [46]. This intensive agricultural system serves here as a proxy for our social-ecological system (SES). Five study sites were selected at different scales that represent distinct contexts: the Almería province and the Murcia region (at the regional scale), and Campo de Níjar, Comarca Los Vélez, and Campo de Cartagena (at the local scale).

XPaths applied a three-phase AR process. The first phase aimed to understand the agricultural system by examining its key actors, existing collaborative networks,

and perceived levels of influence. The second phase aimed to co-produce knowledge about future scenarios, incorporating cross-scale perspectives by using the Three Horizons-Causal Loop Diagrams methodology [47]. The third phase involved co-creating an action plan to guide the implementation of interventions at different scales while addressing local priorities and visions in alignment with the United Nations' 2030 Agenda.

We applied Net-Map in the first phase of XPaths. Between November 2021 and March 2022, we facilitated five online Net-Map workshops, one for each study site. In total, 38 participants took part in the workshops, representing different sectors and expertise (e.g. universities, agriculture, NGOs, trade unions or cooperatives, and government), genders, age groups, and spatial scales of influence. They were identified through informal meetings with key informants and snowball sampling. Each workshop consisted of a two-hour online session via Zoom. We used MIRÓ, a digital collaboration platform that allows mutual visualization combined with video-conferencing software. Workshops were recorded and transcribed with informed consent obtained from participants.

Net-Map workshops consisted of three activities, each supported by a facilitator, note-takers, and digital assistants handling technical issues. The activities were structured around the following overarching questions: 1) Who are the key actors (e.g. institutions, individuals, or networks) in the agricultural system? 2) With whom and why do they collaborate? 3) How influential are they in the system's functioning, rated on a 1–4 scale (1 being the lowest and 4 the highest)? The facilitator began with a round of individual interventions, allowing participants to answer the questions and provide information on 3–4 actors. After everyone had shared their perspectives, a second round encouraged participants to add new actors and narratives. Based on the responses, the facilitator guided collective deliberations until the activity was completed. As a result, Net-Map facilitated the identification of 1) the key actors in the agricultural system, listed by name, 2) the type of their interactions (e.g. collaborative, conflicting, or none), visually represented with colored lines, and 3) the level of influence each actor holds within the system, assessed by participants with star symbols used to denote their degree of influence. Detailed methodology and results are available in five reports [48].

Methodological approach: unraveling Net-Map's contributions

Once the three-year project was finalized, we reflected on the outcomes and experiential knowledge gained from Net-Map. Reflective practice in AR is increasingly recognized as critical to accelerating learning and actions that lead to transformative change [7]. We analyzed

workshop reports, transcripts, and relevant literature to explore Net-Map potential for co-creating actionable knowledge for sustainable futures. Four key topics were identified to discuss how the tool addresses key dimensions and common challenges in AR practice: (1) "Social Inclusion and Pluralism": relates to the recognition and integration of multiple perspectives, knowledge, expertise, and factors such as gender and age [4]; (2) "Cross-scale Dynamics": refers to the understanding of interconnections between scales and "the influence of processes at one scale on those at another" [49]; (3) "Power imbalances": approached here as a dynamic situation where one actor or group exerts dominance over resources (e.g. human, mental, monetary, and natural resources), influencing in ways that disadvantage others or do not support the achievement of collective goals [50,51]; and (4) "Agency": concerns "the capacity of an individual or group to shape change within a specific context" [49].

Leveraging Net-Map's potential for sustainability action research

Based on knowledge gained through XPaths experiences, we argue that Net-Map can enhance AR process design and development for sustainability in four ways.

Creating socially inclusive participatory spaces that capture a diversity of influential capacities for promoting sustainability transformations

AR processes aspire to generate dialogue and cooperation to foster sustainability transformations. This entails embracing and engaging different actors, including well-represented and under-represented groups. However, this endeavor remains challenging as it requires practical guidance to navigate power dynamics and patterns of resistance to change [8]. To address this, literature on participatory approaches offers various methods to identify actors and understand their relationships (e.g. Interest–Influence matrices, Q method, and SNA) [52]. Net-Map proved to be a robust tool for the stakeholder analysis needed at the beginning of our AR process. In contrast to other methods, Net-Map helps to identify and select a diverse group of actors while gathering information on perceptions about actors' capacities to influence SES (i.e. 'influential capacity'). Moreover, it enabled real-time network visualization and analysis of the identified relations among several actors and across one or multiple scales. Knowledge about 'influential capacities' and relations (or lack thereof) within and across scales contributed to the design of a socially inclusive AR process in two ways. First, Net-Map allowed the identification of well-represented actors (e.g. public administrations, agricultural cooperatives, and universities), minority groups, and actors typically under-represented or facing systemic exclusion in a specific context (e.g. educational and migrant communities) based, in part, on how they are currently perceived or

associated as 'influential'. Second, Net-Map enabled the exploration of differing views on actors' influence within the system and the underlying narratives shaping these perceptions. For example, public administrations and the farming community (incl. farmers, cooperatives, and agricultural organizations) were perceived as the most influential actors in the region through their respective roles in shaping laws and controlling the region's main economic activity and practices. We also found contrasting perceptions of certain actors' influence over the system, such as environmental NGOs, for which some participants perceived that their capacity to influence was limited, while others believed they could mobilize and persuade large groups.

Given the varied perceptions of actors' influential capacities, we argue that these must be understood and acknowledged in AR processes to foster transformative changes. For XPaths, we used Net-Map data to establish a balance representation in workshops by mixing participants with different perspectives, competencies, skills, and capacities within a specific context. It also helped to design-inclusive interventions based, for example, on the diversity of influential capacities and relationships, which contributed to empower those actors often left behind or at risk of being overlooked. This allowed to create socially inclusive participatory spaces with diverse influential capacities to transform the studied system by addressing both with divergences and commonalities [2,53,54].

Understanding how to articulate transformative changes at multiple scales

Understanding cross-scale dynamics in SES is critical for sustainability transformations [55]. Solutions must match the scale of governance and consider interactions across scales to create coherent and coordinated multi-level actions [12]. SES literature identifies two key challenges: 1) determining which actors should address specific issues at particular scales and 2) fostering cross-scale interactions among diverse actors [55,56]. Although Net-Map is considered a well-suited tool for multi-scale and multi-site analyses that track network characteristics changes [17,43,57], most empirical studies focus on single cases. They rarely examine more than two scales (e.g. local and national) or integrate diverse social and institutional contexts, often missing high-level interconnected processes within SES.

Our study shows how Net-Map can guide strategy development for more effective AR design and implement AR processes through cross-scale and cross-site network insights. This was explored by identifying actors who might be involved in such processes. Our Net-Map results enabled us to identify two types of actors: 'bridging or intermediary actors' and 'context-specific actors'. Bridging or intermediary actors operate across scales or

sites and can amplify AR impact. An illustrative example of bridging or intermediary actors identified in our workshops included two regional administrations in the case study such as 'Junta de Andalucía' and 'Gobierno Regional de Murcia', who were identified by participants as the actors who could intervene at different scales and sites and influence in the implementation of the AR process. On the other hand, 'context-specific actors' play a significant role within particular scales or sites. In our study, these actors emerged as either potential allies or opponents of the AR goal. For instance, a local association promoting regenerative agriculture in Comarca Los Vélez was perceived by participants as their goals are aligned with Agenda 2030. Conversely, livestock owners in Murcia and Comarca de Los Vélez were seen as both key to systems change and potentially resistant to it. Since the inherent constraints of participatory approaches are the limited number of individuals who participate, Net-Map insights helped select key actors to be involved in AR processes while ensuring that influential capacities and diverse perspectives are considered.

Last, Net-Map's collective deliberations enriched our understanding of specific actors' networks, including their competencies and roles at different scales, facilitating the mapping of potential cross-scale interactions. For instance, the Andalusian Public Foundation 'Andalucía Emprende' and the Andalusian Entrepreneurship Centers 'CADE' are governmental institutions that operate symbiotically with different resources and scales. While the foundation develops regional strategies to foster entrepreneurship, CADE supports local farming entrepreneurs with the Foundation's agenda. These insights highlighted the need for integrative solutions, showing how regional strategies can be scaled down and operationalized locally and vice versa.

Anticipating conflicts and managing power imbalances across scales

Advancing sustainability requires transformative change, often challenged by differing visions and understandings of what sustainability means [58]. An underlying barrier is power imbalances upheld by social norms and legal rules, which dictate whose visions and values related to people and nature relations are considered [13,58]. These imbalances can lead to mistrust, tensions, and conflicts among actors [59,60], potentially hindering broader societal transformation and preventing outcomes from benefiting less influential groups [61]. Extensive literature addresses these power issues, offering typologies and frameworks to study and engage with various understandings and manifestations of power in different contexts and purposes [13,14,50,62]. However, few participatory tools are available that can help understand tensions between forces supporting and opposing

sustainability transformations while also aiding in overcoming them [59,63–65].

Net-Map helped us to address these challenges by enhancing cooperation and collaboration among actors and between participants and facilitators. In the Spanish drylands, we identified a complex network with diverse groups and numerous bi-directional collaborations. For example, farmers and seed companies frequently collaborated to exchange raw materials essential for developing agricultural practices and pest-resistant crops. However, collaborations specifically aimed at fostering sustainability transformations were not perceived. Notable exceptions included collaborations between cooperatives, universities, and research centers working, for instance, on eco-friendly technologies for natural resources management. These context-specific findings confirmed that multi-level collaborations must be created and strengthened to drive sustainability transformations effectively.

Second, Net-Map helped identify potential power-knowledge barriers like gatekeeping and bottlenecks. Gatekeeping occurs when influential actors hold significantly more connections or control access to vital resources (e.g. information, funding), often creating bottlenecks that restrict resource flow. Water management in the study area illustrates this dynamic. National and basin-level regulators are seen to act as gatekeepers by influencing water usage policies and indirectly affecting farming practices. Local actors, in turn, seem to create bottlenecks by controlling desalinated and groundwater distribution, presumably prioritizing more influential sectors. This information informed the initial phases of our AR process, helping to identify actors who might dominate or obstruct dialogues by excluding certain perspectives. It also guided strategy development to address these issues and refined the action plan implementation in later phases.

Third, Net-Map contributed to uncovering potential tensions and conflicts, raising awareness of problematic power imbalances. These tensions arose from participants' narratives about which actors collaborate within the system and for what purpose, while also revealing the presence of non-collaborating actors. This, in turn, led participants to share their perceptions on the absence of these collaborations, often attributing it to underlying tensions and conflicts. For example, it revealed strong tensions between agricultural cooperatives and civil society organizations over managing Mar Menor, Europe's largest saltwater lagoon. Net-Map also showed that large-scale intensive producers are perceived as more influential in shaping national agricultural policies and better access to subsidies, while small independent farmers reported struggling to receive financial support due to limited resources allocated to them and

administrative barriers. These imbalances risk powerful producers blocking initiatives that do not serve their interests, further marginalizing smaller producers.

Recognizing power dynamics was key to preventing tensions and avoiding a simplistic view. This awareness, along with insights from actors' narratives, informed our strategies for addressing power imbalances throughout the AR process. One of the adopted strategies to foster inclusive and constructive dialogues was to set agreements for open participation between participants and facilitators at the start of workshops in the latest phases of our AR process. We emphasized that 1) both convergent and divergent views would be embraced throughout the deliberative processes, and 2) the AR process would operate on a horizontal structure to prevent power imbalances and promote a safe and supportive environment. Each workshop included facilitators and note-takers to guide discussions and manage potential tensions. Facilitators were briefed on Net-Map insights regarding power imbalances and tensions linked to certain participants. Additionally, we hired a conflict resolution specialist to develop a tailored conflict management plan. This bundle of strategies enabled synergies, enhanced mutual understanding, and built new collaborations that might not have otherwise occurred.

Building shared agency and capabilities for fostering collective action

Fostering sustainability transformations requires collective action. The AR community has developed methodological approaches to support collective action for sustainability, such as scenario planning [66] and game-based approaches [67]. However, guidance on using participatory tools to build agency and support the mobilization of individuals for driving collective action is limited [68,69]. Collective action was an integral part of our AR process, and thus, we aimed to create conditions that increase a sense of agency and foster cooperation among actors.

Through Net-Map, we found that the perceived influential capacities of actors were often tied to specific scales and contexts, such as resources, power, and scale of operation [70]. This led us to design a methodological approach to explore how different actors' influential capacities could be combined to build collective agency for sustainability transformations. Our approach involved facilitating discussions with participants during the final stages of the AR process once they collaborated on defined strategies as part of the action plan. This provided practical insights into actors' capacities and how to leverage them to advance the action plan. Participants were invited to identify actors who might have the capacity and willingness to start implementing such strategies and the scale of their implementation (more details in López-Rodríguez et al. [48]). We found that

most strategies required coordination among multiple public administrations at different levels and external social support from other actor groups. For example, participants noted that public administrations exert influence through executive power, while others contribute via human capacity (e.g. universities), financial resources (e.g. companies, cooperatives), or moral persuasion (e.g. NGOs, local communities). This way, participants envisioned implementing co-designed strategies through supportive networks grounded in mutual aid and collective agency.

Net-Map laid the groundwork for collective action, helping actors coordinate their joint efforts to support the action plan by identifying actors best suited for specific strategies within the plan according to their agencies. It also guided our engagement with them to align the defined strategies with existing capacities and resources for cohesive AR implementation.

Conclusion

Net-Map proved to be a robust and flexible tool for enhancing stakeholder analysis, particularly by identifying influential actors across scales, sites, and sectors. It also translated network insights into actionable knowledge for designing and driving sustainability transformations. More specifically, Net-Map's insights provided a foundation for our AR by creating socially inclusive participatory settings with diverse influential capacities to transform the studied system, articulating strategies at multiple scales, anticipating conflicts and power imbalances, and building capabilities for collective action. These learnings provide practical guidance for using Net-Map to support sustainability AR processes worldwide.

Credit authorship contribution statement

SCS: Conceptualization, Investigation, Formal analysis, Writing – original draft; Writing – review & editing. **MDLR:** Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – review & editing, Supervision, Project administration. **AJA:** Methodology, Investigation, Writing – review & editing, Project administration, Funding acquisition. **AC:** Investigation, Writing – review & editing, Project administration. **MMG:** Methodology, Investigation, Writing – review & editing.

Data Availability

Data will be made available on request.

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.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT to improve the readability, grammar, and length of the text. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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