Agroecology as a Practice of Care supported by Blockchain and DAOs
The speculative case of Murcia's Mar Menor Lagoon

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DOI
10.1145/3681716.3681737

Publication date
2024

Document Version
Final published version

Published in
Mindtrek '24

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ABSTRACT

This paper speculates on using blockchain and Decentralized Autonomous Organizations (DAOs) in agroecological regeneration, focusing on the case of Spain's Mar Menor. It highlights the ecological challenges of intensive agriculture, drawing on theories like Haraway's cyborg metaphor and Latour's actor-network theory to contextualize the crisis within the interplay of human and non-human actors. The study introduces a conceptual blockchain-based prototype to automate ecosystem resilience through DAOs that manage land and agricultural practices. It proposes strategic interventions such as reforestation with nitrogen-fixing trees, cultivating flood-resistant crops, and the creation of new agro-settlements. The paper argues that blockchain technologies can optimize these strategies by enabling precise monitoring and management, thus enhancing soil fertility, sustainable agriculture, and community sustainability. It presents a vision of agroecosystems as resilient, autonomous entities capable of addressing ecological and economic challenges.

CCS CONCEPTS

• **Human-centered computing → Collaborative and social computing design and evaluation methods**; **HCI theory, concepts and models**; • **Social and professional topics → Government technology policy**.

KEYWORDS

agro-ecology, care, blockchain, DAOs, non-humans

ACM Reference Format:
Katerina Inglezaki, Nikos Katsikis, Diego Sepulveda Carmona, Mariana Pestana, and Nuno Jardim Nunes. 2024. Agroecology as a Practice of Care supported by Blockchain and DAOs. In *Proceedings of the 27th International Academic Mindtrek Conference (Mindtrek '24), October 08–11, 2024, Tampere, Finland*. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3681716.3681737

Mindtrek '24, October 08–11, 2024, Tampere, Finland

ACM ISBN 979-8-4007-1823-6/24/10
https://doi.org/10.1145/3681716.3681737

1 INTRODUCTION

Commodifying human and non-human landscapes through capital-intensive agricultural production systems marks a critical juncture in exploiting "ecological surpluses," essential for sustaining the capitalist accumulation process [57]. This issue is particularly pronounced in the agricultural sector, where reliance on non-specialized immigrant labor becomes indispensable as developed countries experience accelerated urbanization and demographic shifts. Consequently, rural landscapes and agro-food-related occupations are increasingly devalued. Drawing on theoretical and methodological insights from scholars such as Donna Haraway (cyborg metaphor), Bruno Latour (actor-network theory), and Erik Swyngedouw (analysis of Spanish hydro-modernity), alongside contributions from political ecology emphasizing nature's valuation [7, 75], this paper situates the Mar Menor within hydro-social landscapes. We examine the potential contributions of Decentralized Autonomous Organizations (DAOs) to agroecology [45, 69, 81], exploring how these technologies can address issues emerging from the confluence of digital systems of control and historical systems of land, living beings, and labor control in agriculture [52].

Intensive agricultural practices have led to significant ecological degradation, exemplified by the eutrophication of the Mar Menor lagoon in Spain. Traditional top-down control systems in agriculture contribute to this degradation and disenfranchise local farmers. There is a pressing need for innovative solutions that promote sustainable practices and empower local communities. By decentralizing governance and management, we posit that DAOs can offer solutions that empower farmers, promote sustainable practices, and mitigate the negative impacts of traditional top-down control systems in the agricultural sector, offering new sociotechnical outcomes through design or extravention [21].

Addressing this problem is crucial for advancing sustainable agricultural practices and mitigating environmental impacts. The relevance of this issue extends to human-computer interaction (HCI) as it involves leveraging digital technologies (DLTs) to decentralize agricultural governance (DAOs), enhance transparency, and promote equity [86]. This aligns with current trends in digital transformation and sustainability within HCI [8, 21].

1.1 The case of Murcia's Mar Menor

Murcia, an autonomous community in southeastern Spain, is a vast irrigation machine operated by farmers, cooperatives, and increasingly foreign-owned multinationals or supermarket chains. These entities either cultivate their land or lease from smaller plot owners, contributing to a sector that has made Southern Spain the "orchard of Europe," with a profit margin of more than 900 million euros in the Segura river basin and over 100,000 direct jobs. The industry depends on the extensive engineering works of the Tagus-Segura transfer, a significant infrastructure that transports water from the north to the south. Once a vibrant tourist destination and a haven for diverse marine life, the Mar Menor lagoon, the largest hypersaline lagoon in Europe, suffered a severe eutrophication event in the summer of 2016. This transformed its waters into a "green soup" of algae, leading to massive fish die-offs and the destruction of marine habitats. This ecological catastrophe was primarily attributed to the intensive agricultural practices in the region (see Fig.1), which have been expanding since the 1960s. Recently, the Mar Menor has gained growing attention when a group of environmental activists sought to protect it by changing its legal status. Following a vigorous campaign by the activist group ILP Mar Menor, 500,000 signatures were gathered in a petition calling for the lagoon to be granted legal personhood. The Spanish Congress of Deputies overwhelmingly approved this legislative initiative in April 2022, marking the first time a European region is classified as a legal person with all ensuing rights and protections. This historic decision means the lagoon is represented by legal guardians, a monitoring committee of "protectors," and a scientific advisory board. Additionally, any citizen can file a lawsuit on behalf of the Mar Menor [62].

1.2 Spain's cyborg hydro-landscapes

The transformation of Spain's landscape into a modernized, hydraulic society began post-1898, after losing its last overseas colonies when the country shifted toward internal development. This shift laid the groundwork for a vision aimed at remaking the national geography and addressing the dire conditions of rural Spain through modernization and development initiatives, particularly in hydrology and agriculture. Central to this vision was "hydraulic regenerationism," championed by intellectuals and technocrats like Joaquin Costa. They advocated for creating a new hydraulic geography to alleviate the arid conditions of the central plains and transform Spain into fertile land. This ambition led to establishing large-scale hydro-infrastructures, driven by the Corps of Engineers and marked by significant public works projects. These projects accelerated during the fascist period under Franco's regime, epitomized by the Tagus-Segura Water Transfer project, which exemplifies the nation's efforts to harness water resources to support agriculture and development.

This intensive cultivation system relies on the hydrological cycle and a migrant workforce seeking better livability. Over the last 20 years, the area has been supplied with precarious labor through a series of temporary migration programs (TMPs), combined with the employment of irregular workers and, more recently, with the rise of "private" programs run by local companies [56].

Figure 1: Aerial photograph of the territory of Campo de Cartagena around Mar Menor with and without the irrigated land.

Our work uniquely contributes to the HCI field by integrating DAOs and DLTs into the discourse on sustainable agriculture [21, 52]. We provide new empirical insights into how these technologies can decentralize control, foster community-based decision-making, and enhance transparency and traceability in the agricultural value chain [45, 69, 81, 86]. This study advances current knowledge on the intersection of digital technologies and agroecology, offering speculative applications for enhancing sustainability and equity in agricultural practices.

2 BACKGROUND AND RELATED WORK

The intersection of human and non-human entities in the pursuit of sustainable ecosystems has become an increasingly prominent theme in contemporary research [1, 17, 18, 31]. The increasing awareness of global ecological and climate crises has catalyzed calls for a fundamental shift in the core principles across various disciplines. Scholars have pointed out the shortcomings of anthropocentrism in addressing these challenges, advocating for a reevaluation of human-centered perspectives in philosophy, architecture, design, and science and technology studies [24–26, 30, 47, 54, 55]. Over the last four decades, theoretical frameworks that challenge the primacy of humans have emerged: Isabelle Stengers critiques the notion of a disenchanted modernity and promotes a more entangled understanding of science, nature, and society [77]; Donna Haraway discusses the interconnectedness of humans and non-humans, challenging anthropocentrism [35, 36]; Karan Barad introduces "agential realism," which emphasizes the interactivity between human and non-human actors [6]; Michel Serres argues against the dichotomy of natural and cultural realms, advocating for a collaborative approach with nature [71]; and Bruno Latour highlights the critical need to integrate nature into political discourses, suggesting nature be regarded as a political entity[48–50].

In the following subsections we present and discuss related work on more-than-human perspectives in HCI, capitalism and technocentrism and decentralized technologies for enviromental management and agroecology.

2.1 More-Than-Human Perspectives in HCI

This paradigm shift is also evident in Human-Computer Interaction (HCI), where there is a growing recognition of the importance of adopting more-than-human perspectives [17]. Scholars are increasingly challenging anthropocentric design and research stances, promoting sustainable and responsible approaches that envisage futures inclusive of both human and non-human well-being. For instance, Romani and colleagues introduce a "provotype" that enhances collaboration between human and non-human entities, aiming to rethink design contributions to sustainable futures [68]. Rice emphasizes the influential role of non-humans in shaping participatory design processes, enhancing the democratic nature of these interactions and advocating for a shift from traditional, rationalist design paradigms to those that prioritize relational dynamics [63]. However, Sheikh and colleagues point out that "smart city" thinking and practice, driven by technocratic approaches, are actually reinforcing human exceptionalism [73]. Their work critically reviews technocratic approaches to smart urban governance and offers alternatives on how digital technologies and politics can be reconfigured to care for the more-than-human world. A similar approach is described by Heitlinger et al. critiquing the global industrial food system, primarily driven by human-centered values and the commodification of food, leading to significant social and environmental inequalities [37]. The research highlights the potential of blockchain technology to foster new forms of value exchange and governance. The team engaged with urban agricultural communities through roleplay to co-design blockchain-enabled visions of food systems that could support a thriving multispecies food commons. Their project aimed to redefine algorithmic food justice by emphasizing more-than-human values and reconceptualizing food as a commons shared among various species. The study addresses several challenges and tensions that emerged during these innovative explorations, and the authors admitted in a later publication that the prototyping sessions did not produce a coherent narrative in the ways they'd hoped for, namely because of the impossibility of speaking for or standing in for more-than-human species [40]. Despite the material shortcomings of this project, we see the conceptual value in tinkering with the possibility of imagining more-than-human relations through a lens of ecological reparation. There is an abundance of technologies out there claiming to innovate the food sector; very few projects however, transition from extractive ontologies to multispecies futures, and these are precisely the ideas we need in times of ecological collapse.

2.2 Decentralized Technologies for Environmental Management

Decentralized technologies like blockchain and DAOs could significantly enhance the management of complex environmental issues, such as those faced in the Mar Menor lagoon watershed. In light of the historical patterns of agricultural technology and racialized land dispossession in the United States, Liu and Sengers examined the historical systems of control of land, living beings, and labor at work in agriculture at the confluence of digital systems [52]. They argue that legibility, the organizing principle in the design of digital agriculture systems, uses simplified understandings to control and direct action, often obscuring complex realities and reinforcing existing power dynamics[52, 53]. It is essential to consider how DAOs and DLTs might reproduce or challenge these legacies. This raises critical questions about what is made legible through these technologies and what remains hidden or illegible, particularly concerning who can participate in and benefit from agricultural innovations.

By leveraging the principles of sociomateriality[60], distributed ledger technologies (DLTs) and DAOs in particular can address key challenges in agroecology, such as improving production sustainability, enhancing farmer collaboration, and ensuring transparent governance of agricultural resources[8, 51, 86]. This alignment with sociomateriality theory underscores the transformative potential of DAOs in creating more robust and adaptive agricultural systems that benefit both human and technological actors[45, 86]. For instance, blockchain could provide an immutable ledger for transparently tracking pollution sources and remedial measures. At the same time, DAOs could democratize decision-making, allowing stakeholders, including local communities, experts, and government bodies, to collaboratively vote on and implement resource management and regulatory decisions[69]. These technologies ensure accountability and efficient resource allocation, facilitating the adoption of agroecology on a regional scale and creating a robust framework for sustainable management, potentially serving as a model for similar ecological challenges worldwide. Some research projects are considering addressing the potential of DAOs and DLTs in support of environmental issues [59, 72].

Critically, while these studies provide valuable insights, some scholars argue that they neglect the interplay between capitalism and ecological crises, often halting at speculative stages without pushing for deeper, systemic change [14, 22]. Indeed, while digital technologies are often critiqued for exacerbating capitalist and technocentric issues [37, 73], they hold the potential to alter our engagement with the environment and other species substantially [74]. The persistent focus on efficiency, productivity, and consumerism in tech-driven solutions can sideline more integral, holistic approaches to sustainability that include non-human entities. To harness these technologies for the betterment of broader ecological systems, there must be a deliberate pivot towards frameworks prioritizing long-term ecological health and resilience rather than short-term human-centered gains. Recent evaluations by Scuri and colleagues sustain this [70] suggestion that while sustainable HCI has focused on environmental and societal aspects, it often overlooks economic considerations, which are crucial for achieving a balanced and inclusive approach to sustainability.

2.3 Critiques of Blockchain and Technological Imperialism

Despite the potential benefits of blockchain technology, several critiques highlight its ethical and political issues [79]. Jutel argues that blockchain humanitarianism often serves as a public-relations function for the broader crypto-economy, perpetuating colonial legacies of experimentation in developing countries [42]. This approach, termed crypto-colonialism, aligns with Silicon Valley's cultural values and promotes technological abstraction that undermines developing world sovereignty [43]. The ethical failings of blockchain projects are attributed to the inability to operate outside the solutionist PR machinery, and the inherent obscurantism of technology [43], which contributes to new socio-technical assemblages emerging as complex predatory formations of speculation that are intentionally obfuscatory and difficult to regulate [19]. The Ethereum blockchain is an example of negative criticism on DAOs after a major scam that occurred a few weeks after it was first launched in 2016. Ethereum was the first permissionless network to offer smart contracts which is why there was so much excitement among the Ethereum community over the DAO. Soon after, malicious agents took advantage of a weakness in the smart contract code to pull almost 40% of the overall funds. The decentralized nature of the project made it impossible for a central controller to cancel the transaction, and so the core Ether developers had to make the choice of pulling a hard fork and rewriting transactions on the blockchain in order to return the funds, essentially compromising the immutability of the Ethereum blockchain. Given the novelty of smart contracts and their technical tools, failures are inevitable and when those failures occur on non-upgradeable smart contracts, there may be no solution other than a disruptive fork [82].

3 CAPITALISM, TECHNOCENTRISM, AND ECOLOGICAL CRISES

In the capitalist agro-economy, both human bodies and natural resources are commodified, reducing their value to mere labor or utility, with female bodies often subjected to further degradation through sexualization. In a recent feature on migrant seasonal workers in Spain in The Funambulist, anthropologist Salma Amazian explained how race, class, and gender are interwoven in the modern colonial order, stating that "when Moroccan women are displaced to Spain, they remain subject to a colonial relationship of domination that draws on a legacy based on economic extractivism... today the merchandise is the bodies, to use them for the jobs the Spanish don't want to do" [61]. The human body is stripped of its rights and ethical value and reduced to its labor capacity like the river has lost its pre-Western thinking sanctity. If the body is female, it becomes automatically sexualized and is viewed as a private satisfaction and utility-maximizing machine[34]. The migrant body doesn't age, tire, endure the sun's cruelty, and satisfy its owner as he pleases. This bodily productivity creates economic value and constitutes biocapital.

This perspective calls for reevaluating labor's value, emphasizing recognizing and regenerating undervalued or unpaid work as crucial human capital. The interconnectedness of local and global, human and non-human elements in the journey of a product, like a Murcian tomato in a German supermarket, illustrates the complex networks and socio-ecological processes at play (see Fig. 2). This web of interactions encompasses everything from social hierarchies and environmental transformations to global hydrological cycles and geopolitical struggles, underlining the active role of material objects and bodies within these networks, as described by thinkers like Latour and Swyngedouw [48, 78].

3.1 The Mar Menor Lagoon Watershed

In the Mar Menor lagoon watershed case, the current discourse revolves mainly around techno-engineered solutions for managing nitrate leaks like the project RemediOS by Hernandis and colleagues, within the framework of the Mar Menor Oyster Initiative, which introduces sixty million oysters in the lagoon to filter the nitrates in the polluted water [38] or the development of an environmentally-friendly fertilizer based on natural zeolites (porous volcanic rocks) led by ASAJA, the Young Farmers Agrarian Association of Murcia, that aspires to halt chemical pollution[58]. While many studies shed light on the hydrogeological configuration of the underlying Campo de Cartagena aquifer and reveal the catastrophic consequences of years of overexploitation on the aquifer [66], there seems to be a knowledge gap in developing holistic strategies for the regeneration of the agricultural landscape that is the main driver of pollution. The ecological crisis of Mar Menor has been characterized as a wicked problem because of the multitude of stakeholders involved in its socio-ecological system and their conflicting values. Boix-Fayos and colleagues conducted a content analysis of the stakeholders' values and proposed a new framework for finding common grounds for conflict resolution among the involved actors [11]. Nature-based solutions (Nbs) are an emerging alternative in urban planning and landscape architecture that use green-blue infrastructures as opposed to traditional grey infrastructures and provide environmental, social, and economic benefits. A recent study by García-Ayllón proposes Nbs as risk mitigation actions for the Mar Menor region based on geostatistical indicators, namely permeable pavements, infiltration ditches, floodable bioretention beds, and retention ponds [29]. However, such proposals have not yet been part of a regional planning strategy that should utilize them on a territorial scale and synergistically implement them within a socio-agroecological context.

Working through the lens of the Mar Menor as a techno-social cyborg entity, we understand the lagoon as an engine of the Anthropocene. From intense modes of production to worsening climate conditions, engineered topographies, contamination from toxic microorganisms, and marginalized people out of sight and out of mind, the entanglement of these processes situates Mar Menor in our new geological epoch. While the term Anthropocene has become a culprit for all humanity, posthumanist theories provoke a reexamination of how human cultures appropriate their territories. Extending the cyborg metaphor to a planetary scale, Collins proposes CyberGaia to describe our biosphere in a way that acknowledges human technology as an integral part of nature [15]. The CyberGaia concept concedes the power of technology over the natural world but goes deeper in seeing technology as nature, embedded in nature's cybernetics networks. And while the Anthropocene doesn't "take place" here, or there, some places leave their material mark as a manifestation of our era. All day and all night, the soil and its biotic elements, the water cycle and the sunbeams, and the hands and the bodies of some "others" tirelessly produce edible commodities that are processed, packaged, exported, and shipped over the world, creating a deep physical and cultural separation between people and place.

3.2 The Production of Nature through an Actor-Network Theory (ANT) Approach

The narrative of the Spanish hydro-social landscapes that have altered the ecosystems of Mar Menor leads us to view the lagoon as

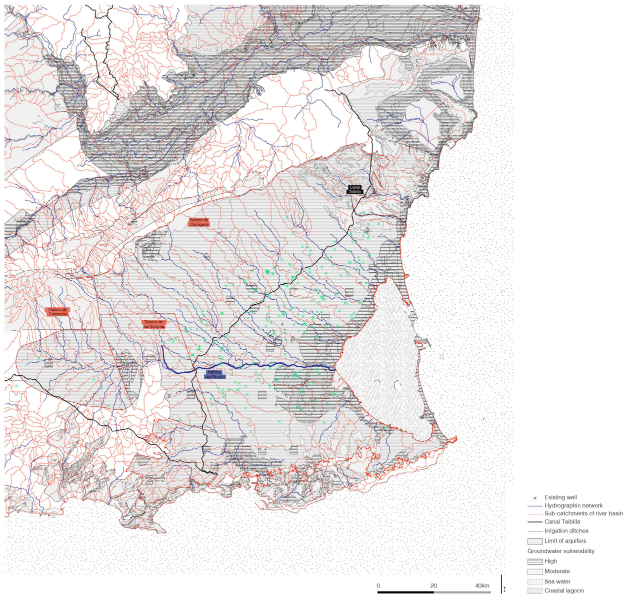

Figure 2: Visible and invisible infrastructures that compose Campo de Cartagena

an assemblage of human, non-human, chemical, biological, material, theoretical, organic, and mechanical processes, but ultimately political. The political drive to establish a robust economic sector in the countryside, defying the material limitations of the land, turns the social into nature and nature into capital. The thousands of processes that sustain the Murcian economy, and any peri-urban economy, blend society and nature into a cyborg entity where the boundary between human and animal is transgressed [34].

The protagonists of Spain's modernity and hydrology are people because social science follows a divide between human and non-human agency. Human agency is central, and the rest of the world is offered for action. However, the chain of events leading to the ecological disaster of Mar Menor resists conventional social explanations precisely because of the plethora of non-human agents. The hydraulic force of the Tagus River, the immense work of the Tagus-Segura transfer, the orchards of Murcia, the chemical properties of nitrates, the cross-contamination of aquifers, the asphyxiation of marine species, and the explosive growth of algae (see Fig.2) shape social processes, sometimes according to human rationality and planning, and sometimes not.

The material processes of the lagoon and the techno-natural infrastructures of the Iberian waters create cyborgs and hybrids. Efforts to tame and transform the hydrological cycle, engineer the land, and control nature are only partially successful. Water bodies get contaminated, dams fail, and ecological relations become unbalanced, with significant consequences for the social networks that rely on them. Building on ANT as the theoretical foundation of this study, we understand that the material agency of water, shifting through local, national, and global scales, assembles a new techno-natural "imbroglio" embedded in ecological urgency (see Fig. 3).

Material objects and bodies become actors with their own consciousness, as Langdon Winner describes the development of the mechanical tomato harvester introduced in the US in the late 1940s. This machine replaced handpicking and reduced costs, but researchers bred new varieties of tomatoes that were hardier, sturdier, and less tasty to fit the machine's requirements [85]. The design of any given technology marks a social choice of how people will work, communicate, travel, consume, and so on [85], leaving no room for innocence in the products we consume, the technological artifacts we use, or the information we process.

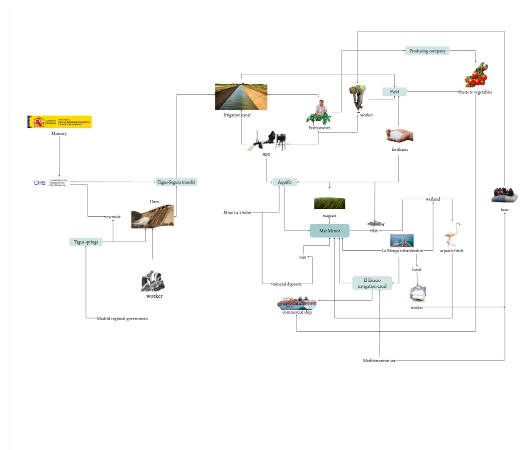

Figure 3: Actor-Network Theory applied to the case of Mar Menor

3.3 Distributed Ledger Technologies and DAOs in Support of Agro-ecological Regeneration

Digital agriculture systems are increasingly employed to boost productivity and reduce environmental impact through automated, data-driven decision-making processes. However, these systems often perpetuate historical legacies of control and simplification, resulting in unintended consequences such as increased labor governance, surveillance, and brittleness in farming practices [52].

Actor-Network Theory (ANT) provides a sociotechnical perspective to analyze complex interactions between technology and human processes, treating human and non-human actors equally [49]. As a theoretical basis, ANT is widely applied in computing research and is thus applicable to the context of Distributed Ledger Technologies (DLTs) and Decentralized Autonomous Organizations (DAOs). These technologies are increasingly recognized for their potential to drive agroecological regeneration practices by enhancing inclusivity, efficiency, and sustainability within agricultural value chains [51]. The secure, transparent, and immutable nature of blockchain and DLTs fosters trust and transparency, improving traceability "from farm to fork," as evidenced by various studies and initiatives [12, 23, 51, 80]. For instance, they enable precise tracking of food products through smart contracts and permissioned ledgers, offering substantial economic advantages, particularly to small-scale farmers and marginalized communities in developing regions [45, 80].

Additionally, DLTs provide a robust mechanism for registering assets like land titles on the blockchain, overcoming the inefficiencies and susceptibility to fraud of traditional land registry systems [2]. This enhances land ownership verification and enables farmers to leverage their land as collateral for financing [23]. In governance and ecosystem management, DAOs represent a transformative approach [69]. They automate governance and operational processes within agroecological systems governed by pre-set rules. A notable example is Terra0, an artistic prototype developed on the Ethereum network, which speculates about the potential implementation of DAOs to underpin technologically enhanced ecosystems capable of autonomous economic actions, contributing to their resilience and sustainability [69].

This decentralized approach can empower farmers by giving them more autonomy and reducing reliance on top-down models that have historically marginalized certain groups and reinforced inequitable practices. By integrating blockchain technology with agroecology, we can create more resilient and equitable agricultural systems that support sustainable practices and community-based decision-making, addressing both socio-economic and environmental challenges in the agricultural sector.

The concept of sociomateriality, which examines the entanglement between the social and the material in organizational life, provides a valuable framework for understanding the integration of DAOs in agriculture [51]. Sociomateriality focuses on how human and technological elements are intertwined and shape each other [60]. In the context of DAOs, this perspective highlights the conjoined agency of humans and machines, where advanced information technologies like blockchain and AI transform traditional agricultural practices and organizational structures [69]. DAOs, through their decentralized and automated nature, embody this sociomaterial entanglement, offering new ways to manage and govern agricultural ecosystems that are both efficient and resilient [69].

4 AGROECOLOGY AS A PRACTICE OF CARE

Agroecology is at once a scientific discipline, a movement and a practice [83]. The term "agroecology" emerged at the beginning of last century in the scientific publications of Basil M. Benzin [9], a Russian agronomist who used the term to describe the use of ecological methods in research on commercial crop plants. In the following years many related publications were produced without the use of agroecology in the title and instead they referred to agricultural zoology [27], ecology, and crop physiology [46]. Through the 1960s and 1970s the Green Revolution enabled a great increase in the production of food grains around the world and created greater intensification of production. At the same time, public awareness on the impact of human intervention over nature started coming to the fore after Rachel Carson's Silent Spring set the foundations of modern ecology with her meticulous description of how DDT, the most powerful pesticide the world had ever known, entered the food chain and accumulated in the fatty tissues of animals, including human beings, and caused cancer and genetic damage[13]. It wasn't until the 1980s that agroecology emerged as a practice with its own distinct conceptual framework and guidelines to design and manage sustainable agroecosystems [3]. Four main properties of agroecosystems were developed by Conway [16]: productivity, stability, sustainability and equity. As theories of sustainability and ecology were further explored, agroecology started gaining ground as a scientific discipline and moved from focusing on individual agroecosystems to a wider focus on the food system, defined as a global network of food production, distribution and consumption [32]. Agroecology has grown into a transdisciplinary field that includes the ecological socio-cultural, economic, and political dimensions of agro-systems, from production to the very consumption. Systems-thinking through holistic approaches is needed to address the complex interdependencies that derive from human activities in natural terrestrial ecosystems.

Depending on the context, agroecological studies might still focus on the agroecosystem scale. Rural landscapes can be divided into observable and measurable units based on agroecosystem age, management purposes, economic need, or land use compatibility. Productive units are divided into plots and agroecosystems, which can be the same or vastly different. The plot is essentially a management unit and the agroecosystem contains sets of plants serving a certain purpose. Plots are areas demarcated by either constructed boundaries (fences and hedges) or natural (streams, hills, etc.). A plot can consist of a single agroecosystem or a group of agroecosystems that perform a common function within the limits of the demarcated area. The agroecosystem is the central unit in any given landscape and is defined by its design role since all component plants are used to achieve a set of objectives (production, water retention, erosion control, etc.). The aim of our project, however, is to see agroecology as a holistic and integrated approach while applying both ecological and social concepts to the design and management of sustainable food systems. A system's optimization cannot be viable without taking into account the need for socially equitable conditions within which people can choose what they cultivate, how much, and how it is produced. The intrinsic relationship between people and the planet, and in particular the role of food systems, is at the basis of the 2030 Agenda for Sustainable Development. Providing food security (SDG number number 2) and ending poverty (SDG number 1) while responsibly managing the available natural resources are pillars of sustainability and can only be feasible through holistic approaches that comply with human rights.

Contemporary theories of ecology and posthumanism enforced by feminist theories are calling for a shift from extractive practices to regenerative alternatives of human and natural work through the notion of care. The work of Maria Puig de la Bellacasa and her matters of care is the most notable example of ethico-political reconfigurations of ecological relations. De la Bellacasa disrupts visions of innovation in technoscience through practices of "maintenance" and "repair". Care work becomes better when it is done again and again, as an everyday mundane, repetitive work[20]. The ecological turn is also part of soil science which in recent years has introduced the notion of "living soil", meaning that soil is not just a habitat for plants and organisms but it can only exist with and through a multispecies community biota that makes it. Such soil-friendly care practices are embedded in permaculture, an agroecological movement which is defined as "consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre and energy for provision of local needs[39]. Although being an international movement with a great number of practitioners, it has not been discussed widely in the scientific literature. Permaculture has become the foundation of many successful community-based projects for neglected communities, meaning, populations that systematically do not receive enough services from the government and are susceptible to diseases and water pollution due to waste and organic residues[5]. One such example is the Bucket Revolution Project (BRP) in the region of Florianópolis in Brazil. The Comunidade Chico Mendes is one of the most vulnerable communities in the region and has dealt with poor management of organic waste and infestations of rats, cockroaches, mosquitos, and other disease vectors. The initiative of local actors to discuss urban agriculture in schools and among communities attracted 95 families taking part in the project already six months after it started [28]. By implementing permaculture principles they engaged in composting practices by turning food "waste" into compost, transforming the organic residues into precious nutrients back to the soil. The basic mechanism of the project is based on the distribution of buckets to the families living in the community which they filled with household organic waste and then brought them to the "ponto de entrega voluntária", the site for collecting the organic waste[67].

4.1 A speculative future for the Campo de Cartagena territory

Since farming is a primary economic activity in the entirety of the region of Murcia and there is already a great investment interest in the land, the strategies presented here are working in line with this fact, attempting to restructure the kinds of cultivation and export as a means to moderate the existing intensive models and to pay respect to the natural systems they are based on. To develop the design strategies, the factors that have been used as a design framework are mainly the climatological classification of the region, the extent of the floodplain and its annual cycles, the zones of high nitrate concentration, and the orchards that are mainly producing this pollution. The first strategy entails reforestation with nitrogen-fixing trees and nitrogen management practices. Nitrogen (N) is considered one of the most essential elements for the growth of plants and can significantly benefit agriculture. Nitrogen fertilizers are responsible for feeding approximately 48 percent of the global population [64] but a large part of them is lost to the environment because nitrogen is a very mobile nutrient. Nitrogen can be transferred to the atmosphere, in the form of N2O, N2, and NH3 and can become a pollutant in surface waterways in the form of nitrate, encouraging eutrophication processes that result in a loss of biodiversity and loss in water quality, and in aquifers[33] as in the case of Mar Menor. Spanish agriculture is characterized by high inputs of fertilizers and high nutrient emissions to the environment [33], posing a threat to water quality, therefore it is imperative to manage the N cycle to prevent nitrate leaks.

Using organic and mineral fertilizers has successfully reduced N losses, improved N use efficiency (NUE), and reduced N surplus. N surplus is the difference between field N input and output. N surplus has been suggested as an indicator of the potential loss of N to the environment [39]. Besides N surplus, several crop and soil management practices can influence the N losses. Various species of legumes have been observed for their beneficial effects in agronomic systems. These legumes form symbiotic associations with bacteria called rhizobia which fix atmospheric N into biologically useful forms [41] (see Fig.4). In intercropping systems where legumes are the main component, the main sources of nitrogen are the atmospheric nitrogen fixed by the legume, the nitrogen available from the soil in organic or inorganic form, and the nitrogen contained in applied fertilizers. Nitrogen loss occurs through harvested material, principally seed, and denitrification, leaching, and volatilization. By and large, intercropping with a legume will maintain the system in a positive nitrogen balance and if there has been good growth of the legume, the nitrogen contribution can be significant. Intercropping is the cultivation of two or more crop species in the same field for the whole or a part of their growing period [41]. It contributes to high yields and high land use efficiency due to complementarity in resource requirements between plant species [87]. Intercropping legumes in fruit orchards is a method of sustainable land intensification providing a second crop in the alleys between the fruit trees[10].

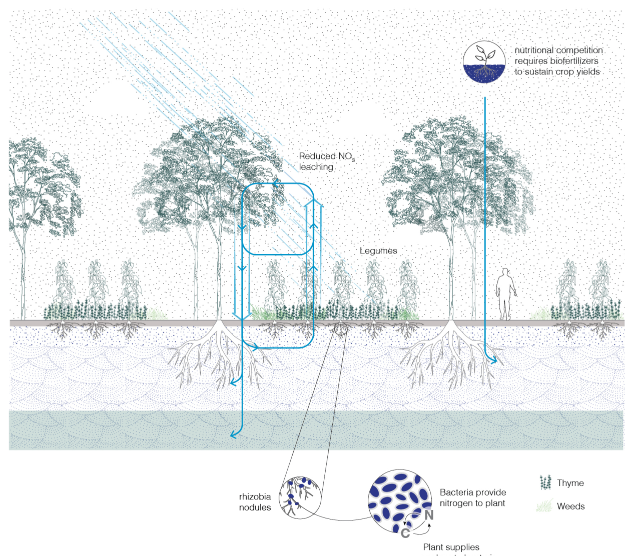

Figure 4: Schematic section of how intercropping legumes with fruit trees can improve the nitrogen cycle.

The second strategy introduces potential crops for production in flood-risk areas. The main crops suggested here comprise a tuber (taro), grasses (aleman grass, flood-tolerant sugarcane, and rice). Flooded biomass crops have a potential for production in large areas and can be distributed in large markets throughout Europe, given the proper economic conditions. The crops that are proposed here vary widely in yield and nutrient uptake. Rice, for example, can only thrive in low phosphorus conditions, whereas aleman grass may require additional phosphorus mineralization. Crops that thrive in oligotrophic conditions and those requiring large amounts of nutrients can be significantly useful in water quality management. Aleman grass can effectively reduce the phosphorus content from previously cultivated fields with crops that left behind large concentrations of chemicals (such as vegetables and fruits). Rice is also proven to decrease the chemical contents to levels of natural conditions. What is also important here is the low operating cost of such cultivations since periodic flooding helps with pest control [76].

- Sugarcane (Sacchantm spp. and related genera) are grasses that yield large amounts of biomass. In addition, their high sucrose content may facilitate a more rapid and economical conversion of biomass to other forms of fuel. Several accessions of the Saccharurn complex are well adapted to riparian habitat.
- Taro is a commercially important root crop in many parts of the world, including Egypt, the Philippines, the South Pacific, and Hawaii, which grows well under flooded conditions. One of the major expenses of taro production is weed control, which can account for as much as 47% of total production costs. Lowland cultivars would presumably have fewer weed and insect problems because of flooding [76].
- Alemangrass is an aquatic perennial that is used for grazing, silage, and hay, mainly in South America. It is adapted to infertile soil but responds well to nitrogen. It is a deep-water plant, tolerating floods up to 1 m in depth for short periods [84]. Indications are that two or three harvests per year result in greater yields than a single harvest at season's end. Alemangrass, because of its greater biomass yield per hectare, has far greater energy potential than the other crops of the proposal. However, sugarcane and taro have higher rates of biomass conversion than alemangrass. The energy value of a crop of alemangrass is estimated to be 350 MJ ha-1 of total yield, and 70 Mg ha-1 yield from two harvests per year). The energy value of taro tops is estimated to be 145 MJ ha-l of total yield, and 1'45 Mg ha-1 yield from three harvests per year). Methane production of flood-tolerant sugarcane ranges from 22 to 330 MJ ha-1 [44].
- Rice is an important crop worldwide. Rice production benefits the soil by reducing the rate of soil loss, and may improve yields and water quality when grown in rotation with other crops. In addition, the demand for water from rice planted in the spring coincides more closely with the rainy season than other crops in the region. It has also been suggested that rice grown in rotation with vegetables may improve the water quality of vegetable drainage [4].

The third strategy introduces new agro-settlements. The strategic locations for new settlement insertions have been chosen based on existing urbanization patterns and transportation connections. The logic of the strategy aims to create semi-autonomous settlements in close connection to existing urban areas to accomplish the social integration of the migrant communities and reverse the currently segregated status quo. The agro-settlement acts as a cultural repository, preserving knowledge and restoring the depleted rural lands to build healthy communities. Social interactions are cultivated on three different scales: i) individual - residents cultivate their plots to supply their food; ii) household - groups of 8 households share the responsibility for the maintenance of common productive land; ii) neighborhood - communities come together

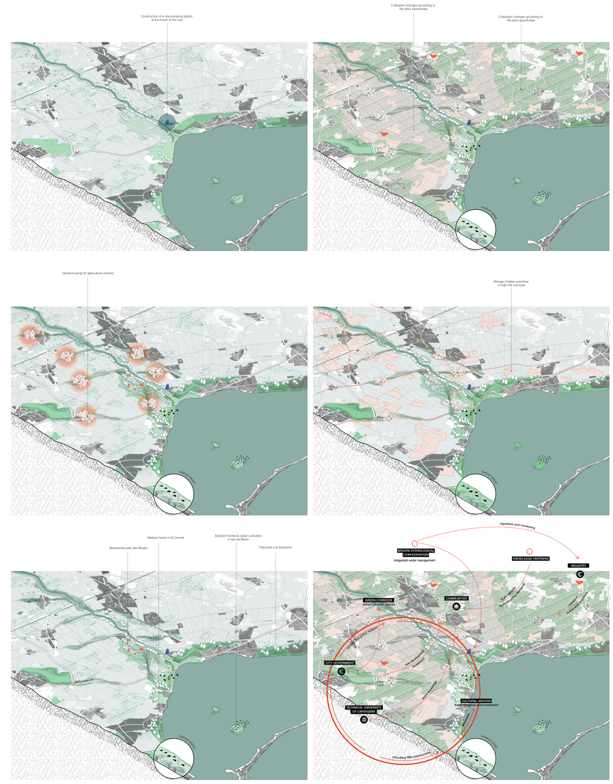

Figure 5: Phasing of the project implementation process.

to manage, harvest, and process the crops. Each new settlement develops along a central transportation axis between two existing urban areas. At the very core is a central square with a commercial center; around the various housing typologies unfold about smaller public spaces and at the edges of the settlement we can find manufacturing and processing facilities.

4.2 Blockchain Technologies for Agro-ecological Support

Digital technologies support innovative agroecological interventions, such as reforestation with nitrogen-fixing trees, introducing potential crops for flood-risk areas, and establishing new agro-settlements. AI can analyze satellite imagery and drone data to identify optimal reforestation areas by considering soil type, nitrate concentration, and existing vegetation. Machine learning algorithms can predict the impact of different species of nitrogen-fixing trees on local ecosystems, optimizing the selection and planting process to maximize nitrogen fixation and minimize adverse ecological impacts. DLTs ensure transparency and traceability of renaturalization processes, enabling stakeholders to monitor plants' origins, growth, and health. DAOs can create technologically augmented, more resilient ecosystems and operate within a predetermined set of rules in the economic sphere as agents. According to several authors, while theoretically promising, blockchain technology faces significant implementation challenges. In the case of cooperative agroecological supermarkets, despite blockchain's potential for transparency, traceability, and trust, the high costs and complexity of integration and the lack of technical expertise and regulatory frameworks have often proved insurmountable [65]. Despite these challenges, the proposed strategies remain viable. For reforestation with nitrogen-fixing trees, DAOs could automate the monitoring and managing these trees, tracking their growth and nitrogen-fixation rates and adjusting planting strategies based on real-time data. Intelligent contracts could trigger actions based on specific ecological indicators, ensuring that reforestation reduces nitrogen surplus and enhances soil fertility [8].For crops in flood-risk areas, DAOs could manage distribution and cultivation across identified regions. Leveraging the DAO's capabilities could facilitate resource allocation, monitor flood patterns, and optimize crop rotations and planting schedules to maximize yield while minimizing environmental impact. Smart contracts could automatically adjust crop choices and management practices in response to changing flood risks and water quality data, ensuring sustainable agricultural production [8, 65]. In establishing new agro-settlements, DAOs could integrate these settlements within a decentralized network managing production, resource allocation, and social integration efforts. Smart contracts could enforce agreements regarding land use, crop selection, and resource sharing, fostering cooperative management and ensuring these settlements' social and ecological sustainability. DLTs acting as agents within economic spheres could support financial viability by automating transactions, such as the sale of produce or profit distribution among community members, enhancing resilience and autonomy [8, 65]. While the past years have shown that blockchain development faces material and financial challenges, the potential for innovative agroecological interventions remains significant. By learning from previous projects and addressing scalability and regulatory issues, blockchain solutions can still be realized to support sustainable and resilient agricultural practices. As highlighted by Rocas-Royo, the key is to focus on practical applications and incremental adoption, ensuring that technological solutions align with the organizational capabilities and socio-economic contexts of agroecological initiatives [8, 65].

4.3 A Provotype DAO in Support of Agro-ecological Regeneration

4.3.1 DAO Structure and Objective. **Purpose:** The primary aim of the DAO would be to regenerate and preserve the ecological balance of the Mar Menor lagoon. **Stakeholders:** Include local farmers, environmental NGOs, government bodies, researchers, and local communities. **Governance:** Token-based voting system where decisions are made based on stakeholder consensus. Different tokens might represent different groups (e.g., farmers, researchers, etc.) to balance influence, ensuring that diverse voices are heard and reducing the risk of dominance by any single group [52, 69].

4.3.2 Smart Contract Applications. **Resource Management Contracts:** Automate the allocation and monitoring of water resources to optimize usage and reduce excessive nutrient loading, which leads to eutrophication. By using immutable ledgers, transparency and accountability are ensured [45, 86]. **Subsidy Distribution:** To minimize runoff, distribute subsidies or financial incentives to farmers who adopt sustainable practices such as reduced chemical usage, cover cropping, and buffer strips. **Compliance Monitoring:** Implement contracts that automatically monitor and report data from IoT devices or sensors placed in agricultural areas to ensure compliance with environmental standards. This addresses the need for reliable and real-time data to make informed decisions [60]. **Ecological Impact Credits:** Create a system of ecological impact credits where businesses and tourists can purchase credits. The funds from these credits would be used for conservation activities, and the credits themselves could be traded or sold, creating an economic incentive for ecological preservation.

4.3.3 Technology Integration. **IoT Integration:** Use IoT sensors to collect real-time data on water quality, soil moisture, and nutrient levels. This data would feed into smart contracts to enforce or adjust practices quickly, ensuring adaptive management of resources [51, 86]. **Blockchain for Transparency:** Use blockchain technology to ensure that all transactions, data logs, and decisions are recorded permanently and transparently, making it difficult to tamper with data or misrepresent compliance, fostering trust among stakeholders [42, 43].

4.3.4 Challenges and Considerations. **Technical Complexity:** Managing the integration of diverse technologies (IoT, blockchain, smart contracts) and ensuring they work seamlessly across different actors requires substantial technical expertise and coordination. **Stakeholder Buy-in:** Ensuring that all relevant parties are on board and understand the benefits and workings of the DAO, which requires extensive education and possibly demonstration projects to showcase the DAO's potential and functionality. **Legal and Regulatory Compliance:** Aligning the DAO's operations with local and national laws might involve navigating complex regulatory environments. Proactive engagement with regulatory bodies can help in crafting compliant frameworks [43]. **Initial Funding:** Could be sought from environmental grants, governmental support, or crowdfunding within the crypto-community. Emphasizing the DAO's potential for positive environmental impact can attract diverse funding sources. **Continual Operation:** Transaction fees within the DAO or voluntary contributions from stakeholders (like tourism operators who benefit from a clean and vibrant ecosystem) could support ongoing operations. Establishing a sustainable financial model is essential for long-term success.

4.3.5 Addressing Critiques. Critiques highlight that blockchain projects often face ethical and political issues, such as perpetuating colonial legacies and technological abstraction that undermines local sovereignty [42, 43]. To counter these critiques the development of the DAO should follow:

- **Inclusive Design:** Ensure that the DAO is designed with input from local communities to avoid imposing external solutions and to respect local knowledge and practices.
- **Transparent Communication:** Maintain open and transparent communication channels with all stakeholders to build trust and ensure mutual understanding.
- **Ethical Framework:** Develop and adhere to an ethical framework that prioritizes the needs and rights of local communities, ensuring that technological interventions do not exacerbate existing inequalities [19].

By addressing these challenges and critiques proactively, the proposed DAO can serve as a robust model for sustainable management and agro-ecological regeneration, potentially offering solutions to similar ecological challenges worldwide.

5 CONCLUSION

This paper has navigated the intricate landscape of agroecological regeneration, emphasizing the critical intersections where human and non-human actors converge within the hydro-social context of Murcia's Mar Menor. By employing theoretical frameworks such as cyborg theory, actor-network theory, and political ecology, we have examined the intertwined dynamics of agricultural commodification, ecological degradation, technocentrism, and the socio-political forces at play. The case of Mar Menor underscores the detrimental impacts of intensive agricultural practices and the pressing need for sustainable alternatives that prioritize ecological health and resilience. The proposed speculative spatial strategies for the Campo de Cartagena territory represent a holistic approach to agroecological regeneration, integrating traditional knowledge with advanced technologies to restore ecological balance and promote social equity. Restoring the nitrogen cycle is crucial for the ecological balance of any agroecosystem and can be easily applied by utilizing intercropping practices in the right combinations of crops. Mitigating floods in high-risk areas by making use of the floodplain to cultivate flood-tolerant crops such as taro, aleman grass, rice, and sugarcane can relief the territory greatly of the increased pressure it has been receiving in the last decades with high torrential rains that are mainly transported through the Rambla del Albujón canal. Lastly, constructing new settlements to house agricultural workers can act as a cultural repository of agroecology, preserving knowledge and building a closer bond between people and the land while providing the right to housing for migrant communities. These strategies, informed by blockchain and DAOs' potential, serve as a blueprint for reimagining agricultural landscapes as spaces of care, cooperation, and sustainable production. In exploring DLTs and DAOs conceptually, we have identified potential pathways for enhancing inclusivity, efficiency, and sustainability in agricultural value chains. While DAOs have been primarily used in technical and financial domains, this paper proposes them as speculative prototypes—conceptual tools rather than fully realized technical implementations. This approach allows us to critically assess and imagine how these technologies might be applied to agroecological contexts, facilitating improved traceability, secure transactions, and equitable resource access. Projects like Terra0 underscore the speculative nature of this exploration, which illustrates the potential for automated, resilient, and self-regulating agroecosystems. However, it is crucial to recognize that these ideas are still conceptual and require further development and empirical testing.

Moving forward, there is a need for continued interdisciplinary research, policy-making, and community engagement to harness the synergies between technology, ecology, and society. The path to agroecological regeneration is fraught with complexities and challenges, but it also presents abundant opportunities for innovation, collaboration, and transformative change. The future of ecology calls for cooperation between humans and non-humans, and embracing computational systems can help us foster multispecies relationships. This paper contributes a speculative yet credible vision for a more sustainable, equitable, and resilient future for agricultural landscapes and the communities that depend on them while problematizing the agency of technology in our changing world.

ACKNOWLEDGMENTS

This research was funded by LARSyS (Project UIDB/50009/2020). In addition, it benefited from the BIG ERAChair EU-funded project through Grant agreement ID: 952226 and the Blockchain.PT PRR Agenda PC644918095-00000033.

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