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New Water for a Thirsty Land: Sociomaterial Bricolage of Treated Wastewater Irrigation on Gozo, Malta

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ABSTRACT: This paper examines the sociomaterial bricolage that emerged on the island of Gozo, Malta, following the introduction of treated wastewater for irrigation, commonly branded as 'New Water'. Drawing on an actor-centred sociomaterial bricolage approach, the study investigates how farmers adapted infrastructures and institutions in response to the opportunities, constraints and inequalities created by the new-water system. Based on qualitative fieldwork involving interviews with farmers, Water Services Corporation employees, and local officials, the analysis compares four water dispensers that are each operating under different conditions of water availability and pressure. The findings show that infrastructural and institutional adaptations are closely intertwined and are shaped by material conditions. At water-abundant 'head-ender' locations near the beginning of the water distribution canal, farmers developed arrangements enabling simultaneous water sharing, while water scarcity and unreliable supply at tail-ender locations encouraged forms of time sharing and stricter coordination. These adaptations also generated new tensions that prompted interventions at broader system-level scales. The study demonstrates how sociomaterial bricolage is multiscalar and path dependent, with successive adaptations responding to the consequences of earlier interventions; it also highlights the importance of anticipating such dynamics when designing equitable wastewater reuse systems.

KEYWORDS: Sociomaterial bricolage, circularity, wastewater reuse, irrigation, Malta

INTRODUCTION

Water stress is a major environmental challenge across the globe (Steffen et al., 2015). Anthropogenic activities have disrupted freshwater systems, threatening their self-regulatory capabilities (Porkka et al., 2024). Islands are resource-constrained socioecological systems and thus are particularly at risk (Holding et al., 2016; Karnauskas et al., 2018). For most islands, freshwater stress is expected to intensify, particularly in (semi-)arid or Mediterranean climates (De Roo et al., 2021; Favretto and Stringer, 2024). Climate change-induced aridity and sea level rise affect freshwater quality and availability (Ault, 2016), while demographic growth and high dependence on tourism for economic development increase water demand, soil sealing (through the construction of buildings and infrastructures) and pollution (Singh et

al., 2022; Martin del Campo et al., 2023). These challenges pressure islands into exploring new sources of water and innovative approaches to freshwater management.

In arid regions, wastewater reuse is one of the new-water sources that is commonly being tapped into to relieve water stress (Roopnarine et al., 2023; Angelakis et al., 2023; Williams et al., 2023) and it is being promoted by the UN under SDG 6.3 to strengthen sustainable water management (UN-Water, 2018: 66). Treated wastewater reuse promises to improve the circularity of a scarce resource. It can be used for aquifer recharge or for industrial or domestic use, including for drinking water (UN-Water, 2017), but it is used mostly for irrigation (Fito and van Hulle, 2021). The implementation of treated wastewater reuse comes with a number of technological and infrastructural challenges along the operational chain, including its collection, treatment, and redistribution as treated water (Kesari et al., 2021). Given the long history of wastewater collection, disposal and treatment, attempts to adapt existing systems for reuse face significant infrastructural path dependency issues (Angelakis et al., 2023). At the same time, the growing awareness and knowledge of new or newly discovered types of contaminants in wastewater and the risks they pose for reuse require further innovation in treatment technologies (Kathi and Mahmoud, 2024; Trotta et al., 2024).

Treated wastewater reuse also comes with sociopolitical challenges. These receive significantly less attention than its technical and health aspects in empirical research (Williams et al., 2023); exceptions here, perhaps, are social acceptance/adoption studies (see Hui and Cain, 2018; Al-Khatib et al., 2022; Tawfik et al., 2023; Giannoccaro et al., 2025). Nonetheless, scholars have indicated a range of potential governance issues around the introduction of treated wastewater: infrastructure-driven changes in water rights, including shifts in upstream-downstream inequities, shifts from informal to formal arrangements (wastewater, especially in water-scarce environments, is often already being reused, also in its untreated form, Tawfik et al., 2021); and adaptations in the collective organisation of irrigation (Eid-Sabbagh and Nassif, 2021) can all lead to conflicts over distribution and allocation. Given its 'novelty', treated wastewater reuse also often struggles with incoherent regulatory frameworks outdated governance networks and obsolete infrastructures (Al-Khatib et al., 2017). Wastewater conflicts are not limited to end users; they can also involve the wider community when it is confronted with infrastructures and materialities related to wastewater treatment and use (Feng et al., 2023).

This paper adds to the literature by analysing the introduction of treated wastewater irrigation on the Mediterranean island of Gozo, Malta, from the perspective of sociomaterial bricolage. Wastewater reuse projects have been implemented across the Mediterranean (Angelakis et al., 2023), and have been promoted by the European Union (EU) through its European Innovation Partnership on Water (EIP Water) and its 2022 Urban Wastewater Directive. From 2017 onwards, Malta has been rapidly expanding its use of treated wastewater for irrigation. The archipelago faces severe water stress (Hartfiel et al., 2020), with its specific water demand estimated at 175% of its available naturally renewable freshwater sources (Sapiano, 2020). The Maltese administration has long recognised the need to develop additional water resources and it already has a tradition of rainwater harvesting (Attard et al., 2024) and desalination (Sapiano, 2008); treated wastewater reuse adds to these measures. Apart from a small 1980s wastewater irrigation experiment on the island of Malta, wastewater has always been dumped in the sea without recycling (Mangion, 2000). Treated wastewater irrigation is of particular importance to the more rural island of Gozo, where the agricultural and tourism sectors compete for water. Both sectors' water demand peaks in the dry summer season (Hartfiel et al., 2020; Speijer, 2022). Treated sewage is considered a solution to this conundrum in that it could secure a year-round stable water access for farmers by making use of tourism-driven sewage output (Mangion et al., 2005; Sapiano, 2020).

Developing wastewater irrigation on the island, however, has required considerable infrastructural and institutional changes. In this paper, we analyse these developments through the lens of sociomaterial bricolage, understood here as the way actors strategically adapt the infrastructures and rules available to them in order to make the system work to their benefit. Our main empirical finding is that the same new-water system produced markedly different forms of collective organisation depending on water

availability and water pressure. At the water-abundant head-enders, farmers adapted pipes, valves and card-use rules to share water simultaneously and to pool access more flexibly. At the water-scarce and unreliable tail-enders, simultaneous water sharing was less viable, and farmers instead developed turn-taking (time-sharing) schedules, stricter coordination, and a complementary reliance on groundwater.

These locally developed solutions did not simply resolve problems; indeed, some also created new inequalities and tensions that required further adaptations. This led us to emphasise three theoretical points about sociomaterial bricolage:

1. Infrastructural and institutional adaptations are deeply intertwined, as changes in one can lead to tensions that require adaptations in the other;
2. In a similar vein, bricolage is multiscale, and problems experienced at one scale may prompt adaptations at another if the actors involved regard infrastructures or institutions at that scale as more malleable;
3. Bricolage is path dependent in the sense that every adaptation causes specific tensions that require specific solutions, thus steering bricolage into a sequence of reactions in a certain direction.

In the following section, we elaborate on the concept of sociomaterial bricolage and explain its usefulness for understanding the politics of wastewater reuse development. We then present the Gozo case study and methods, before comparing how farmers around four dispensers adapted the new-water system under contrasting conditions of water availability and pressure. In the conclusion, we return to these concrete differences between head-enders and tail-enders and discuss what they imply for the design of more equitable alternative-water systems.

SOCIOMATERIAL BRICOLAGE

The concept of bricolage and the bricoleur was introduced by anthropologist Claude Lévi-Strauss (1962) to denote the practice of solving issues by using "whatever is at hand". He describes bricolage as a process that is simultaneously creative and bounded. It is creative in that it repurposes and redefines available materials, tools and ideas, and it is bounded in the sense that it always works within the limits of what is already around rather than inventing new solutions from scratch. Mary Douglas (1986) introduces the idea of bricolage to the study of institutions, defining institutions as socially constructed cognitive frameworks (beliefs, values, rules, taboos) that regularise social life by governing how people think and act. According to Douglas, institutions operate as labour-saving devices. They render decision-making easier by restricting options, ultimately making human behaviour more predictable and reliable and hence easier to act upon. Douglas suggests that institutions develop and change through a bricolage-like process and that existing institutions constitute the very horizon of thought from which building blocks are drawn to craft new institutions. As it is put by Campbell (2004: 72), "institutions provide the tool kit or repertoire with which actors modify institutions".

Adapting Douglas and Lévi-Strauss, Frances Cleaver (2001, 2002) applies this idea of 'institutional bricolage' to institutions for collective resource management. She focuses on institutional change and explores why this takes the form of bricolage. As a critical institutionalist, Cleaver deploys Douglas's ideas to confront attempts (in mainstream institutionalism) to scientifically design 'best fit' institutions for particular collective action problems. Such social engineering, she feels, ignores the depth of social embeddedness of the existing institutions they aim to replace or improve. Cleaver (2001) attributes this social embeddedness to 'bricolage'. Practices of institutional bricolage are reactions to changing circumstances and needs, but they are also informed by what is considered acceptable or appropriate in the framework of existing institutions; hence, "institutions for natural resource management are not necessarily designed for a specific purpose, but borrowed or adapted from other arrangements" (De

Koning and Cleaver, 2012: 279). Such bricolage knits together institutions in a fabric of social embeddedness which reinforces their legitimacy and impact upon social behaviour. Newly 'designed' institutions, Cleaver (2002) warns, cannot achieve the same level of embeddedness and legitimacy unless, after their introduction, they become subject to bricolage themselves.

Sociomaterial bricolage has been introduced to the study of resource management by Mirhanoglu et al. (2023) as one of several perspectives that acknowledge the important role of material infrastructures in resource access. They emphasise the conceptual and functional equivalence between infrastructures and institutions (see also Whaley and Cleaver, 2017; Kemerink-Seyoum et al., 2019; Mayaux et al., 2023; Venot et al., 2024). If we follow Douglas's definition of institutions, infrastructures perform very similar functions in social life, that is, they regularise and structure human behaviour. Both institutions and infrastructures render human interactions more predictable by enabling certain practices while disabling others (van der Kooij et al., 2015). Moreover, similar to institutions, infrastructures are socially produced and require maintenance and care to continue functioning (Guma, 2022; Aalders et al., 2026). Critical infrastructure studies have indicated how infrastructures are inherently "incomplete" (Guma, 2020) and dynamic (Hommes, 2022): they require permanent reconfiguring, patching up and adaptation if they are to keep running and to stay adapted to changing needs and demands (Benouniche et al., 2014; Anand, 2015; Guma, 2022; Brochet et al., 2025). Finally, infrastructures and institutions are increasingly considered to be codependent and entangled (Mayaux et al., 2023). Infrastructures are not only governed through operational rules and moral values; they are themselves also expressive of, and constitutive of, institutions (Finger et al., 2005; Ivars and Venot, 2018; Whaley and Cleaver, 2017; Hommes et al., 2022; Loopmans and Hoogesteger, 2024).

With sociomaterial bricolage, Mirhanoglu et al. (2023) describe a framework for understanding the *interactions and interrelations* between institutions, infrastructures and actors. It extends the concept of bricolage from institutions to infrastructures, but it also entails another empirical shift of focus. Most studies of institutional bricolage zoom in on (routine, unconscious, institutionally shaped) *practices* in order to understand *how* institutional change happens in the form of bricolage. The concept of sociotechnical tinkering, recently introduced by Kemerink-Seyoum et al. (2019), extends this practice-based approach to material, infrastructural change (see also Benouniche et al., 2014). In this view, practices provide the link between institutions (or infrastructures), figuring as vehicles for the 'leakage of meaning' from one institution to the other. Alternatively, Mirhanoglu et al.'s (2023) sociomaterial bricolage tries to understand *why* bricolage happens. This requires a *focus on actors themselves*, that is, on their interests and perspectives rather than on their practices; it also requires a sensitivity to conflict and power differences to understand change (Mollinga, 2008; Quintana and Campbell, 2019).

Drawing upon strategic-relational theory, Mirhanoglu et al. (2024) emphasise how infrastructures and institutions structure the distribution of resources, power and authority amongst actors. This *selectivity* by infrastructures and institutions creates inequalities between actors in terms of resource access and actors' capabilities for 'bricolage'. Bricolage happens because actors give meaning to, interpret, and try to reshape the selectivity of institutions and infrastructures in order to improve their access to resources, power and authority (Mirhanoglu et al., 2023). Much work on institutional bricolage assumes that institutional change is a response to changing *external* circumstances; a strategic-relational approach, however, explains how such change can also emerge *endogenously* (see also Ioris, 2012; Mollinga, 2019; Mirhanoglu et al., 2024) and how it can be initiated by actors who believe they might benefit from changing the configuration of institutions and infrastructures. Bricolage, in this view, is a reaction to the selectivity of institutions and infrastructures and the inequalities that are thereby produced (see also Kuper et al., 2017).

This change of perspective from practices to actors also has interesting theoretical implications, which we will elaborate empirically in our case study on Gozo, Malta. The case study presents alternative hypotheses about three important dimensions of bricolage studies: the coevolution of institutions and infrastructures, the multiscale character of bricolage, and the nature of path dependence.

First, sociomaterial bricolage offers us an explanation of how infrastructures and institutions can 'co-evolve', influencing each other. Rather than leaking meaning from one to the other, infrastructures and institutions influence each other via the inequalities they produce. Selectivities can vary amongst infrastructures and institutions, and actors can try to mobilize institutions to compensate for infrastructures that are unfavourable to them, and vice versa (see, for example, Sanchis-Ibor et al., 2017; Feng et al., 2023). Irrigation infrastructures, for instance, are known to create head-ender/tail-ender asymmetries (Ostrom and Gardner, 1993; Janssen et al., 2011). Mirhanoğlu et al. (2022) reveal how those who were disadvantaged as 'infrastructural tail-enders' invested in institutional changes that facilitated their becoming 'social head-enders'. In this way, they were able to mitigate the effects of their disadvantageous position within the infrastructure (see also Devkota et al., 2023; Werdiningtyas et al., 2026).

Second, this strategic mobilization of infrastructures and institutions suggests an explanation for the *multiscalar character* of bricolage beyond the simple upscaling through a multiplication of smaller innovations and adjustments (Mayaux et al., 2023). As Loopmans and Hoogesteger (2024) emphasise, scales of dependence (where the effect is felt) need to be distinguished from scales of engagement (where actors see possibilities for reacting). Actors may perceive the negative effects of an institution or infrastructure at a particular scale and then may look for a fix to that problem at another scale (see, for example, Vos et al., 2020), thus propagating bricolage not just between infrastructures and institutions, but also across scales.

Finally, a focus on bricolage as a reaction to the selectivities of existing institutions and infrastructures has consequences for our understanding of *path dependence*. Path dependence refers to past events constraining or offering direction to subsequent ones, thus limiting possible futures. In practice-based institutional bricolage, path dependence is conceived as being driven by the repurposing of existing institutions: the future is bounded by the contours of the institutional repertoire at hand (Sehring, 2009; Cleaver and De Koning, 2015; Carstensen, 2017). In a strategic-relational, actor-oriented approach to bricolage, path dependence instead presents itself in a dialectical manner, as the sequence of reactions by various actors to the selectivities of previous institutions or infrastructures. Each such reaction, in turn, is likely to exhibit a particular selectivity, thereby triggering further bricolage from other actors.

CASE STUDY

Gozo is the second island of the Maltese archipelago, with an area of just under 70 km² and a population of almost 42,000. Agriculture and natural areas cover three-quarters of the island, but urban areas are expanding under the impulse of a growing tourism industry. Between 1969 and 2018, overall freshwater consumption on Gozo increased by around 260%, driven predominantly by the expansion of irrigation and tourism (Damigos and Nakou, 2020: 91). Surface water bodies are mainly perched aquifer freshwater springs that are too scarce and too small to warrant large-scale exploitation. They are tapped only by local farmers who transport water to nearby fields via small channels or pipes or move it further away by bowser trucks. Since the 1990s, irrigation has expanded at the expense of traditional dryland cultivation; this shift has largely depended on unregulated groundwater extraction from the main sea-level aquifer through private boreholes (Papadimitriou et al., 2019). Groundwater is considered to be of lower quality, however, due to abstraction-induced saline intrusion and because of pollution from agricultural and urban activities (EWA and ERA, 2023: 12). Gozitan tourism is dominated by small-scale and private accommodation and it mainly consumes mains water that is a mixture of groundwater and desalinated seawater, though some facilities also collect rainwater or use groundwater that is extracted through private boreholes (Speijer, 2022).

As a response to over-extraction of, and competition for, groundwater by tourism and agriculture, Malta's Water Services Corporation (WSC) turned to treated wastewater for irrigation, branding it 'new water' for promotional purposes. Since the installment of water treatment plants, activated sludge-

treated sewage from WSC's wastewater plants was discharged into the sea. Now, however, it passes through three additional stages of advanced treatment – ultra-filtration, reverse osmosis, and UV-oxidation – before it is repurposed as 'new water' for irrigation in landscaping and agriculture. The aim of the project is not only to reduce wastewater discharge to the sea, but also to replace the increasingly problematised extraction of groundwater for irrigation. WSC thus claims that new water is providing a "lifeline to the agricultural sector and the water table at the same time" (WSC, 2018). Treated wastewater also decreases the competition between tourism and agriculture, as summer tourism increases wastewater – and thus new water – right at the peak of the irrigation season. The new-water project is part of Malta's 2nd Second Water Catchment Management Plan, which aims to achieve the objectives of the EU Water Framework Directive. The initial investment was co-funded by Malta and the EU, however Malta's national government now covers its operational costs (WSC, n.d.).

In Gozo, advanced treatment installations were added to the existing wastewater treatment (WWT) plant, which began operating in July 2018 (WSC, 2025). Five years later, in 2023, new-water production on Gozo had grown to about 300,000 m³ per year; however, around 90% of the sewage input was still being discharged into the sea, clearly showing the potential for further expansion (Table 1).

Table 1. Input/output of the wastewater treatment facility in Għajnsielem, Gozo

Flow (in m ³)	2017	2018	2019	2020	2021	2022	2023
Sewage input	1,398,833	1,489,956	1,902,388	1,894,767	2,025,470	2,071,456	2,348,082
Treated Water (discharged to sea)	1,398,833	1,481,767	1,856,142	1,689,518	1,748,458	1,767,208	2,045,083
Treated waterfor irrigation(New Water)	0	8,189	46,246	205,249	277,012	304,248	302,999

Source: WSC (2025).

Once wastewater is treated, it is distributed via a single pipeline that stretches from the plant in southeast Gozo to the west of the island. At the time of our fieldwork, the pipeline was feeding five dispensers (see Figure 1); four were open to farmers and one led to a government-run farm. A planned further extension of the network will supply 50 dispensers across the island.

Dispenser infrastructure and WSC user rules are relatively uniform. Each dispenser has a tap to which farmers can connect a tylen hose with a standard tank truck coupling (see Figure 2). This is connected to a card reader using a radio frequency identification (RFID) system, and registered farmers can get a card at a subscription cost of 25 euros per year. This card allows them access to a yearly amount of water that is calculated on the basis of the area of land associated with farmers in the registry of the ministry of agriculture. On swiping the card, the tap runs for one hour or until the same card is swiped again. Farmers can use the card until their quota is reached, but given the relative abundance of new water compared to the number of active dispensers, quotas are fairly generous and rarely exhausted.

Dispensers are mainly located in areas where farmers cannot access perched aquifer's freshwater springs (Figure 1). Irrigating farmers in these areas used to rely on private boreholes or rainwater harvesting and do not have a tradition of collective water management.

New water is quite popular amongst farmers, who consider it to be of better quality (less saline) and cheaper than water from other sources such as private boreholes or bowser companies that sell water treated by reverse osmosis. According to Zahra and Mifsud (2021), new water is used by around one-tenth of Gozitan farmers.

Figure 1. Map of Gozo's new-water plant, pipeline and dispensers



Source: Map by the authors.

Figure 2. Dispenser with a card reader box on top, a tap on the left side, and hoses that are waiting to be connected



Source: Photo by the first author.

WSC manages only the production of new water and its transport from the treatment plant to the dispensers; farmers are then responsible for the distribution and transportation of the water from the dispensers to their fields. This subsidiarity of governance continues traditional practices of user-managed freshwater springs, and copies an earlier, smaller wastewater irrigation system in Malta (Mangion, 2000); it is also driven by cost-effectiveness and pragmatism in the face of the highly fragmented land tenure on the islands (Papadimitriou et al., 2019). This approach, however, presents farmers with a challenge; lacking any tradition of joint water management, they are now required to collectively manage a shared water source and must invent ways to share, distribute and transport the water amongst their fields.

The new-water project thus constitutes a natural experiment through which we can observe how farmers collectively organise to manage and share water. The dispensers can be considered 'new' water sources around which previously non-existent 'user communities' take shape and structure their water use. Using the lens of sociomaterial bricolage, we analyse how infrastructures and institutions for water management develop in the process of their interactions. While the behaviour of farmers was of course already embedded in pre-existing institutions and infrastructures, we assume that these did not differ systematically between communities depending on different dispensers. Hence differences in institutions or infrastructures that have emerged around the new-water dispensers cannot be related to a pre-existing repertoire of institutions or infrastructures; such differences, rather, should be explained by considering circumstances related to individual dispensers and the interactions surrounding them. This allows us to explore the 'actor perspective' that is emphasised by the sociomaterial bricolage approach and to thus see how bricolage unfolds as a reaction to the inequalities and tensions produced by the new-water system.

Given the small scale of the new-water project at the time of research, it also presented a feasible opportunity for an actor-focused case study of bricolage. The small number of farmers and the handful of other involved actors allowed us to obtain a good overview of the various actors and of their interests and strategies. As the new-water project operates at two scales (a pipeline connecting all the different water users, and four dispensers on which smaller subgroups depend), we were able to also observe interactions between the respective scales.

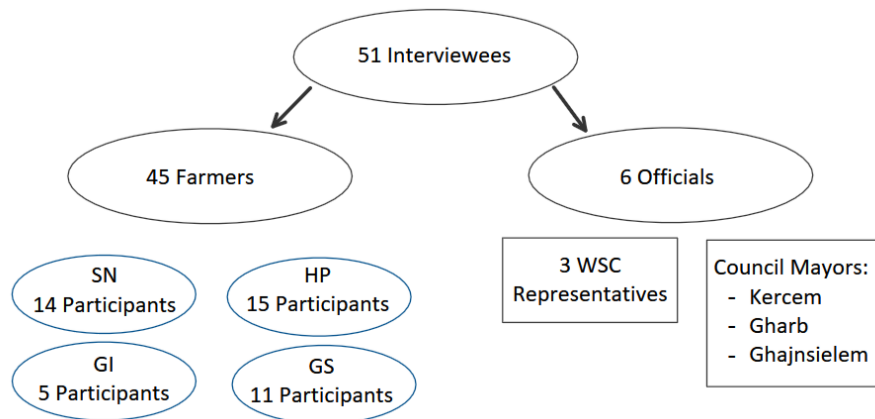
METHOD

The case study was developed in two phases. An exploratory visit took place in 2022, when contacts with government employees and with a small number of farmers were established by the third and fourth author. In 2023, a more intensive interview campaign by the first and second authors involved local government representatives, Water Services Corporation (WSC) employees and farmers.

Interviewees

Stakeholder interviews were divided into two main categories: farmers and officials. The officials were further classified as WSC employees including technicians and engineers, and municipal representatives such as mayors and other council members. Farmers were primarily grouped according to their use of the water dispensers located in Ġhajnsielem (GS), Heliport (HP), San Niklaw (SN) and Ghar Ilma (GI), as mapped in Figure 1 and illustrated in Figure 3 below. Additional farmers were recruited until information saturation was reached for each dispenser. In total, 45 farmers were interviewed either along roads, in their fields, or at the water dispensers. Six officials were also interviewed, including three mayors representing councils located near, or associated with, the dispenser locations.

Figure 3. Categorisation and numbers of interviewees



Note: WSC = Water Services Corporation; GS = Ghajnsielem; HP = Heliport; SN = San Niklaw; GI = Ghar Ilma.

Interviews with WSC employees were conducted at the beginning, midpoint and end of the study, allowing information and perspectives to be gathered as the research progressed. Mayors, by contrast, were interviewed only towards the end of the fieldwork, once a more comprehensive understanding of the current state of the island's new-water system (NWS) had been established and differences in farmers' use of the four dispensers had become more apparent.

By engaging with a diverse range of actors including technical experts, administrators and end users, the study developed a more comprehensive understanding of the NWS. This approach supports a more nuanced analysis by reducing reliance on the perspectives of any single group and facilitating a better understanding of the interactions and relationships among the different actors involved in the system.

Interview types

Given the exploratory nature of the study, unstructured interviews were preferred for their flexibility and their ability to adapt as new themes emerged (DiCicco-Bloom and Crabtree, 2006; Wildemuth, 2016).

More than 50 short interviews were conducted, each of which lasted 5 to 20 minutes; 12 longer interviews of more than 20 minutes each also took place. Short interviews were initiated spontaneously with farmers at water dispensers or in nearby fields, while longer interviews, generally lasting 30 to 60 minutes, were scheduled with farmers and officials. Some participants were interviewed more than once.

For short interviews, we spent time at the four dispensers, observed farmer activities, and approached potential participants. We also followed pipelines or visited nearby fields to identify interview opportunities. One researcher led the conversation while the other took notes, with both contributing when relevant. After each fieldwork day, notes were transcribed using Office 365 tools and then were jointly reviewed (Adeoye-Olatunde and Olenik, 2021).

Interviews began with a brief explanation of the authors' research on water use and governance in Gozitan agriculture. Initial questions were put to interviewees regarding crops, farming experience, motivations, age, occupation and family background. This helped establish rapport (Wildemuth, 2016), before discussions moved on to the NWS, its use and related challenges.

Early interviews focused on understanding the system and individual dispensers. As fieldwork progressed, questions were increasingly adapted to the particular dispenser and to specific interviewees. They zoomed in on the actors' perceptions of the infrastructure and institutions at that dispenser and on the bricolage-type actions they had devised to deal with the challenges.. Although most interviews were

conducted in English, the first author's fluency in Arabic facilitated communication with farmers who preferred to speak in Maltese, a related Semitic language. Repeated encounters and follow-up contacts with knowledgeable farmers further supported continued discussion.

Longer interviews with farmers and officials were usually arranged in advance and conducted in offices or on farmers' properties. Broad topics were prepared beforehand, while participants' knowledge and experience guided more specific discussion. When appropriate, permission was requested to record interviews and confidentiality was assured. Both researchers asked follow-up questions informed by previous interviews.

Repeated interviews with the same individual allowed earlier accounts to be compared with later ones and showed how trust developed over time. Interviews with officials also revealed perspectives that sometimes contrasted with those of farmers. Together, these interviews improved our understanding of the historical and spatial development of the NWS and informed adaptations to the theoretical framework.

Throughout the fieldwork, interviews both clarified the functioning of the NWS and generated new research questions, a process that continuously shaped subsequent interviews and emerging themes.

Data coding

The unstructured interview format played an important role in developing the theoretical framework. After transcribing a substantial number of interviews, a combination of inductive and deductive coding was applied. This approach helped identify recurring themes and shared ideas across interviews, while also linking them to key concepts derived from the literature (Fereday and Muir-Cochrane, 2006). Initial coding was conducted manually using open inductive coding of the early interview transcripts. Several recurring themes emerged and were checked through cross-coder comparison. These findings helped inform subsequent interviews by guiding the development of preliminary questions around the themes identified during the initial analysis.

Accordingly, a deductive coding approach was used to derive codes from the sociomaterial bricolage framework. By combining the inductive and deductive codes, a comprehensive code mind map was developed. Throughout the research, the coding was adapted in an iterative and reflexive way, with codes continuously refined in response to emerging findings (Fereday and Muir-Cochrane, 2006). The final coding framework was applied to the totality of the interview transcripts using computer-assisted qualitative data analysis software (CAQDAS) which also facilitated analysis and interpretation of the codes.

THE CHALLENGE OF SHARING NEW WATER: SOCIOMATERIAL BRICOLAGE UNDER VARIOUS CONDITIONS

During the fieldwork, it became evident how the four dispensers presented farmers with very different circumstances with regard to the materialities of the water involved. The two dispensers near the outlet of the WWT plant were offering an abundant and rather stable supply of water, while the two dispensers further away provided a very limited and unstable water supply which regularly ran dry. The two tail-end dispensers operated at an average pressure of 4.5 bar, which was significantly lower than the exit pressure of 14 bar at the head-end dispensers near the WWT plant. These differences in pressure had a significant impact on the farmers who depended on the respective dispensers for accessing irrigation water; it thus influenced the collective bricolage processes in which they engaged. Since no form of organisation pre-existed around the site of the current dispensers, pre-existing institutions can be assumed to be more or less equal across the cases, so that differences in infrastructures and institutions resulting from the bricolage process can probably be attributed to these different material circumstances and the way they shaped the interests of the actors involved.

Head-ender bricolage under conditions of water abundance

The first dispenser after the WWT plant in Ghajnsielem has the highest discharge rate, with hardly any interruptions (Figure 4). Farmers using this dispenser installed water reservoirs on their fields. Each hose from the dispenser is linked to the reservoirs of either one farmer or multiple farmers.

Figure 4. Ghajnsielem dispenser with tylene hose connected



Source: Photo by the first author.

To lay the pipes to their fields, farmers had to negotiate with each other to obtain right-of-way across their respective farms. The outcome of these negotiations was affected by pre-existing friendships or feuds, although WSC or local officials sometimes offered mediation. According to Local Official No. 5,

Well, the solution is: imagine you have a farm. The dispenser is here. The farm is here and then other farmers are in between. If there is some small alleyway we help them pass the pipe from here. If the farmer needs to pass through other farmer's fields, it gets more complicated. What we do is to speak with this farmer or visit the alley and to try to assist with that part. Here everyone knows each other, so we will try to sit down together and find the solution for everyone. In some cases, we managed and some others we didn't.

The main challenge farmers had to face, however, was finding a way to share the limited connection time. At a set discharge rate and with only one tap, farmers had to take turns to connect and take water from the dispenser. As a result, new infrastructures were constructed that had not been planned for by the WSC: instead of using their own private pipeline, neighbouring farmers would team up to install a collective pipeline with valves to each field, thus sharing the installation costs. Farmer No. 18 was one of the initiators of a collective pipeline to the dispenser; as they explained it,

My pipe is the one with the blue line. It is shared with 20 people. At first, we were with 3 people, but now they all want it. I pay 25 euro for the card. We all paid 200 euros for the pipe, but that's one time.

Extension of water service to farmers who joined later were covered by a fee paid to the emerging user community. Farmer No. 37 explained how the pipeline slowly expanded, with newly joining farmers paying back the original investment to him. As he put it,

I put the pipe after they installed the dispenser, first that farmer [*pointing to another field in the direction of the dispenser*] asked to join and later two farmers there [*pointing to fields away from

the dispenser*) also did. (...) I paid it [the pipe and its installation] and later when they joined they paid half of it back.

This infrastructural bricolage also led to changes to the WSC's one-card-one-user rule. The connected pipe gets one hour of water every time a card is passed and then all farmers sharing a pipe can open their valves along the pipe, even when another farmer has swiped his card. With no shortage of water, farmers began to tolerate and even institutionalise the practice of sharing quota. According to Farmer No. 19,

if someone else clicked (swiped a card), I can take the water. Maybe four people take the water at the same time, even the last one on the pipe because the pressure is very good.

Some farmers mentioned opening valves for neighbours when they were not around. This shows how water sharing is a widely accepted practice, as long as it does not put a burden on the neighbour's shoulders. As Farmer No. 8 reflected,

He opens mine (valve) and I open his (valve). But I don't like to ask, I prefer to do it myself. The man has more work than me, if I ask him (to open his valve) he will say yes, but I don't want to bother him.

The second dispenser is at the Gozo heliport near a group of larger farms. These farms were primarily commercially oriented, with produce sold mainly on the domestic market and, to a lesser extent, exported. This commercial orientation provided them with greater financial and material means, enabling investment in more robust equipment that was better suited to the available new-water infrastructure; for instance, they have their own private pipelines from the dispenser to their different fields and always connect their pipes for a full hour. Meanwhile, smaller farmers for whom a pipeline was too costly or whose fields were too far from the dispenser started picking up water with 1000-litre water bowsters on pickup trucks, or towable bowsters of up to 5000 litres. The heliport dispenser's pressure is also high with a rapid discharge rate, so it takes only a couple of minutes to fill up a bowster; bowster trucks would thus line up at the start or end of the workday to quickly pick up some water for their fields. The large farmers, on the other hand, would connect their hose for at least an hour, and often for several hours in a row, returning regularly to again swipe their card. Tension was created by these differences between small and big farmers in terms of the amount of time they claimed the dispenser for themselves. The latter made small farmers wait for hours, even though they only needed to connect for a few minutes to get their share. The conflict culminated in the sabotaging of the dispenser. According to Official No. 9,

At the heliport there are large farmers who have a lot of land and have a direct pipe connection to their land. (...) We had lots of complaints, because you know there are three big farmers and one of them was rude. Because they were always connected, people got angry, and the control box got vandalized. It happened twice.

The conflict was finally resolved through WSC mediation. Big farmers installed T-valve junctions on their pipes (Figure 5) which allowed small farmers to connect their hoses to those private pipes instead of directly to the dispenser. This way, big farmers could continue to pump water to their fields without interruption, and small farmers could at the same time fill their bowsters. As Official No. 9 went on to say,

The big farmers came to me because they depend on the water and asked for a solution. I said to them "You are the problem" since they are the heavy consumers, they have to fix it themselves. One of them came with the idea of the T's and convinced the other ones. Now it is good.

This material bricolage also required institutional changes in the form of WSC moving from its individual, card-based consumption rule to a flexible quota-sharing system. Instead of farmers 'swiping their own card for their own water', they now tolerate the parallel use of 'their' water by others. When the dispenser is not in use, the first farmer to arrive swipes, and for the rest of the hour others can connect their pipes to the T-valve junctions and use water for free. Throughout the day, whenever a big farmer swipes his card, farmers can fill up their bowsters for free via the T-valves. When a pipe-owning farmer is

not using water, farmers with bowzers can swipe their own cards, which allows the pipe user to take some of their quota. As the water pressure is high and quotas are generous, this sociomaterial change resolved the local conflict; however, the same kind of solutions were not possible downstream.

Figure 5. T-valve junctions at the heliport dispenser



Source: Photo by the first author.

Tail-ender bricolage under conditions of water scarcity

At the first tail-ender dispenser in San Niklaw (Figure 6), farmers use pipes as well as bowzers to transport their water. As was seen at the upstream dispensers, farmers near the dispenser have added shared pipes that allow several fields to be watered at once. At the San Niklaw dispenser, however, the farmers using bowzers do not rely on T-valve junctions to get their water as the WSC has provided an alternative solution; it has installed two dispensers: one which provides water for an hour (green circle in Figure 6) and another (red circle) that runs for only five minutes per swipe. The second dispenser, according to WSC officials, had a malfunctioning time counter which the WSC decided not to discard; they decided, instead, to prevent conflicts like those at the heliport dispenser by using it here to offer separate valves, one for pipe-based use and the second for bowser-based water transport.

Figure 6. San Niklaw dispensers – two outlets



Source: Photo by the first author.

This solved potential timing-related conflicts but did not address water scarcity. The intermittent water supply led farmers to combine the new-water system with other infrastructures and institutions. Bowser-using farmers first of all introduced a rule for themselves that parking your truck or tractor in front of the dispenser when the dispenser was not giving water would give you the right to take water first once it started running.

Second, most farmers made up for the unpredictability of new water by complementing it with groundwater extraction from the main sea-level aquifer. While the quality of this water is not preferred, boreholes have the advantage of being more reliable and do not require collective management as they are privately owned. According to Farmer No. 25, "[The borehole] is 450 feet deep. (...) It fills slowly from the rain. (...) No, I do not share it, everybody has a borehole here".

A second tail-end dispenser lies on top of the Ghar Ilma hill. It is mostly used by local people who attach tylenes tubes to carry water to their fields. Only six pipes are lying near the dispenser (Figure 7).

Figure 7. Ghar Ilma dispenser with hoses lying around



Source: Photo by the first author.

This dispenser is at the very end of the pipeline and frequently runs dry. Because of low and unreliable water pressure, water sharing through a collective pipe is not a viable option; instead, farmers added an institution to regulate turn-taking. The 16 users at this dispenser arranged themselves in two groups, each made up of a mix of small and big farmers. They agreed that the two groups would take their turn at the dispenser every other day. Each group would then divide the 24 hours of their 'assigned' day into eight parts and both groups would follow a strict rotating shift schedule. The schedule solved the issue of low water pressure as it allowed one farmer at a time to take water, but its rigidity conflicted with the unreliability of the water flow. When discharge was low or zero, however, some farmers in the first group tried to extend their access beyond the designated time; this led to conflicts and eventually to the abandonment of their group's schedule. An interviewer had this interaction with two farmers:

Farmer No. 28: There was a schedule but a month ago people started ignoring the schedule.

Interviewer: Why is that?"

Farmer No. 26: People are greedy. They would stay here for five hours at a time (to keep their card and take someone else's shift).

The other group was composed largely of members of one family. They worked with a similar schedule but applied it more flexibly. Mutual trust allowed group members to call each other and negotiate if they needed to use the dispenser beyond their designated time. This allowed them to maintain the schedule. As Farmer No. 31, a member of that group, put it,

We call each other, if you need more water, you just tell them that you need the water for 1 2, 3 hours, this way they know when you need water and [you know] when they need water.

The family group even tolerated a member sharing water outside the group. As Farmer No. 32, from that family group, told us,

There is a farmer from the other group that uses the water on our day (...) he takes water from someone in our group. A farmer from our group has a pipe connected to the other guy's land, so they go beep and both get water.

Ongoing problems and multiscalar bricolage

While head- and tail-ender farmers developed different solutions to the problem of sharing new water and transporting it to their fields from the dispenser, their bricolage also led to new problems. At the head-ender dispensers, the apparent abundance of water and the water-sharing solutions led to careless behaviour. Farmer No. 21, for instance, complained about colleagues wasting water, attributing it to the fact that nobody takes responsibility for the water because it has become 'collectivised'. In this exchange with a researcher, he commented that,

Farmer No. 21: If you notice, the T has a valve. So, when the guys come with a truck to fill up a tank they don't even use their card, they just plug in and open.

Researcher: Isn't that good?

Farmer No. 21: It is, it is, yeah, but it's like: "As long as my water keeps coming, you can eat. Don't worry. But mine has to keep coming", (...) I've seen pipes which have gone directly into a reservoir and the reservoir has been overflowing into the sea all summer.

The authors also observed water being squandered at the dispenser itself. When farmers were done filling up their bowser, they would sometimes disconnect before swiping their card to stop the water, thus spilling water onto the street. Again, farmers explained that this careless behaviour is related to the fact that there is no individual cost to wasting water. As Farmer No. 22 put it,

sometimes the whole street is wet, because they don't care about the water. Because the biggest problem with the NW is that it is free.

Water was also spilled when farmers did not treat the technology carefully. Connecting to the dispenser outlets requires rubber washers to seal the connection (Figure 10). Farmer No. 20 explains how this can lead to water spillage if not properly checked:

Figure 8. Hose without a washer



Source: Photo by the first author.

You see this washer, it costs nothing. One farmer comes, he forgot his washer at home, or he doesn't want to buy one, so he steals someone's washer (that has been left on a different pipe connection) (...). The other farmer connects his pipe without seeing that someone stole his washer, beeps his card and leaves 5, 10 minutes, the water comes and there is no washer. This happens! Now we cannot stop the water unless the same guy with his card beeps it, or we must wait for the hour to pass (...). I always remove my washer and keep it in my truck.

Farmers using tail-ender dispensers complained about this carelessness, as it reduces water pressure and availability to them downstream. Tail-ender farmers also commented that head-ender farmers were consuming too much water for water-intensive or non-agricultural purposes such as for watering trees or as drinking water for cows. Even construction companies or stone quarries were collecting water for their business. Farmer No. 39, for instance, explained how tail-ender farmers have no water because of head-ender crops such as,

millet, that they water a lot, that needs a lot of water. The ground has to be saturated in water for it and a lot of it is being used for that, and that is why it is not arriving here [at the last two dispensers].

Compared to head-ender farmers, tail-ender farmers show less tolerance towards non-agricultural users. When they notice a non-agricultural use at their dispenser, they do not hesitate to denounce it to the WSC and push officials to intervene. According to Official No. 11,

We will try to eliminate [the non-agricultural user] by giving all the other farmers a new card and not him. This way he cannot use the dispenser anymore.

In response to these complaints from tail-ender farmers, WSC officials elaborated plans for future changes at the scale of the entire NWS. These included software improvements that will allow the WSC to monitor farmers' water consumption and thus require them to take individual responsibility. A further change is that a farmer's water allocation will be based on the area cultivated, the crop type and the cultivation period, instead of merely on that farmer's land area; this will potentially reduce the available per-farmer water quota. These changes could alter the conditions for farmers' institutional and infrastructural arrangements at the dispensers, and could thus incite further sociomaterial bricolage.

DISCUSSION

Actors and selectivity

Our case shows how, after the WSC's introduction of the new-water complex of institutions and infrastructures, farmers started a process of bricolage to further tailor the project. This bricolage was not undertaken only by individuals who wanted to further their interests (Mirhanoğlu et al., 2023); it also appeared as a collective endeavour by the farmers grouped around the dispenser on which they depended. In the latter case, the purpose of farmers was to resolve internal contradictions and conflicts such as those between pipe-based and bowser-based irrigators. Importantly, these conflicts and interests are not only structured through infrastructures and institutions; they are also shaped by differences in water availability between the dispensers. Different circumstances have thus led to different forms of bricolage. Head-ender farmers resorted to a system for simultaneous *water sharing* in order to solve conflicts triggered by a shortage of time; tail-ender farmers, on the other hand, turned to time-sharing solutions in an attempt to resolve conflicts triggered by a shortage of water. These findings lend support to the actor/interest-based emphasis of sociomaterial bricolage (Mirhanoğlu et al., 2024), as opposed to the 'institutional leakage' focus put forward by more practice-based approaches (Cleaver and De Koning, 2015). We argue that the available institutional repertoire, being more or less equal across the four dispensers, cannot explain the wide divergence in the solutions arrived at by head-enders and tail-enders; for this we must consider the particular interests and conflicts the farmers try to solve.

Co-production of infrastructures and institutions

As emphasised in the literature, infrastructural bricolage stimulates institutional bricolage and vice versa (Whaley and Cleaver, 2017; Mayaux et al., 2023). Infrastructural adaptations create a need for institutional changes and vice versa. Actors appear as crucial mediators in this process (Mirhanoglu et al., 2023, 2024), shifting strategically from institutional to infrastructural changes according to their needs. The WSC's one-hour-use rule did not fit the temporalities of either pipe-based or bowser-based water users, with the former needing more time at the dispenser than the latter. The infrastructure was thus adapted by adding T-valves to allow bowser-based users to fill up without connecting directly to the dispenser and to enable the sharing of water pipes with each other. This, in turn, required a shift in user rules such that personal cards were abandoned in favour of pooled quotas, as farmers were not able to check on the amount each consumed from the common pool.

Multiscalar bricolage

Such interactions among actors, infrastructures and institutions also occurred at different scales (Mayaux et al., 2023), with actors linking not only between infrastructures and institutions, but also between scales. Triggered by tail-end users who were not able to resolve their water scarcity problems at the dispenser scale, the WSC felt compelled to adapt both technology and rules at the system scale so as to more closely check on improper water use and spillage.

Path dependence

Our case offered an account of a short five-year time period; it revealed, however, how bricolage is ongoing and it provided us with insights about path dependence. Each dispenser, as well as the system as a whole, revealed a certain path-dependent development. This was not in terms of the boundaries set by a limited institutional repertoire (Sehring, 2009); instead, the path dependence we observed is characterised by a dialectical string of events – the one following logically from the other – which is kept in motion by (groups of) actors who are trying to find ways to access water. Each moment of bricolage resulted in changes to infrastructures or institutions, which led in turn to new conflicts and contradictions to which the same or other actors again tried to find solutions. For example, bricolage to solve conflicts between bowser- and pipe-users resulted in water spillage; this led to conflicts between tail-end users, who then resorted to finding a solution to their problems at by proposing WSC to make changes to the system as a whole. The changes suggested by the WSC in response are, in turn, likely to create new tensions at the head-end dispensers. Indeed, the proposed changes that aim to reduce water abundance amongst head-enders are likely to render their earlier bricolage obsolete.

CONCLUSION

This study examined how farmers on the island of Gozo, Malta, adapted the treated wastewater irrigation system after it was introduced. In practical terms, the sociomaterial bricolage observed here consisted of farmers and officials modifying what was already available to them (pipes, valves, water cards, schedules, informal agreements and existing water sources) to adapt the system to local conditions. The main empirical observation is that these adaptations differed systematically along the pipeline. At head-end dispensers where pressure and supply were relatively abundant and stable, farmers developed arrangements that enabled several users to take water at the same time based on shared pipelines, T-valves and flexible sharing of individual water quotas. At tail-end dispensers, where pressure was lower and supply more irregular, farmers could not rely on the same forms of simultaneous water sharing and instead developed time-sharing arrangements (queues, rotating schedules), stricter coordination, and social control; many also continued to use private groundwater as a backup. The material distribution of

water thus shaped not only how much water farmers received, but also the social rules and infrastructures they created to manage it.

These findings clarify three theoretical points about sociomaterial bricolage. First, infrastructures and institutions change together because actors use the one to compensate for problems created by the other; thus, a rule that do not fit local use can lead to a material modification, while a new pipe or valve can require new sharing rules. Second, bricolage is multiscalar, as the scale at which a conflict or issue presents itself is not automatically the scale at which a solution can be found. When tail-ender farmers could not resolve water scarcity or unequal access at the dispenser level, they pushed the WSC to intervene at the level of the whole network. Third, sociomaterial bricolage is path dependent in time and space. In our study, path dependence presents itself differently from the way it is often conceived in more practice-oriented approaches to bricolage. Whereas practice-oriented approaches see path dependency as change bounded by a limited repertoire of practices, our actor-based approach sees path dependency more as a dialectical sequence of problem-solving reactions; in other words, each adaptation changes the conditions for later action and can also create new problems for other users, thus triggering reactions from their side. The development of the NWS was not a one-off local adjustment right after its introduction; rather, it was a sequence of responses in which a solution at one place or time became the source of the next conflict elsewhere.

The clearest example of such a sequence is the evolving interaction between head-ender and tail-ender adaptations. Upstream, abundant water made collective, simultaneous water-sharing arrangements possible, but they also reduced social control and led to wasteful and irregular practices. Farmers reported water being left to overflow from reservoirs, being spilled at dispensers, and being used for highly water-intensive or even non-agricultural purposes. Tail-ender farmers experienced these practices not as minor inefficiencies, but rather as a reduction in the pressure and reliability of the water reaching them. It forced them to develop a very different collective system at their dispensers, which was based on time sharing and much stricter social control. They perceived the head-ender water wastage as an infringement on their rights to water; this led them to lobby the WSC for system-level changes. The WSC reacted to tail-ender complaints with plans for more restrictive access to, and stricter monitoring of, new-water use.

The study also leads to relevant policy advice. Looking back at the sequence of sociomaterial bricolage actions that unfolded after the introduction of the new-water system, it is clear that policymakers need to assume that sociomaterial bricolage will take place; therefore, before making an intervention, they clearly should reflect on the direction this bricolage could take. Greater awareness of, and conscious speculation about, future bricolage pathways could help facilitate interventions such that inequalities are mitigated and foreseeable tensions and conflicts are avoided (Merrey and Cook, 2012; Whaley et al., 2021).

The lessons learned here on bricolage as a path-dependent interplay between actors, infrastructures and institutions can facilitate such scenario building. Take for instance the changes proposed by the WSC after instigation by tail-ender users. More restrictive water quotas and stricter monitoring of new-water use will reduce the water abundance at head-ender dispensers and may improve volume and reliability at tail-ender dispensers.

Better scenario building on the basis of observed bricolage processes could have helped predict that such measures would mitigate tensions amongst tail-enders and between tail-enders and head-enders of the NWS.. It could also have helped understand how current upstream arrangements that depend on abundant water and flexible quota-sharing could, in the process, be undermined. Head-ender farmers might need to 'learn' from tail-ender farmers how to make a water-scarce situation more manageable. The WSC could facilitate such 'repertoire transfer' from tail-ender to head-ender users by organising inspirational workshops and/or bringing together both head and tail-enders.

More broadly, anticipating likely changes – who gains, who loses, what local practices may stop working, and what new conflicts may emerge – can help policymakers design wastewater reuse systems that limit inequalities and conflicts while supporting workable forms of local collective management.

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