Transitions in water harvesting practices in Jordan’s rainfed agricultural systems: Systemic problems and blocking mechanisms in an emerging technological innovation system

Gregory N. Sixta, Laurens Klerkx⁎, Timothy S. Griffin⁎

⁎ Friedman School of Nutrition Science and Policy, Tufts University, Boston, USA
⁎ Knowledge, Technology and Innovation Group, Wageningen University, The Netherlands

ABSTRACT

This study identifies systemic problems and opportunities for transitions in water harvesting – a water conserving agricultural practice – in the context of a developing country pursuing greater agricultural sustainability. We utilize a combined and enriched functional-structural technological innovation system (TIS) analysis to identify systemic problems in the water harvesting TIS in rainfed agricultural production systems of Jordan. Results indicate Jordanian water harvesting TIS development is hindered by three principal blocking mechanisms: 1) inadequate financial resources to support innovation; 2) lack of a common vision across government ministries; 3) institutional problems that inhibit legitimizing the technology. These challenges are caused by interlocking systemic problems, which indicate the need for integrated policy approaches and interventions. Our analysis reinforces the concept that in developing countries, donor interventions should be centrally considered because they play a role in influencing priorities throughout the system and in supporting TIS development. Donors can counteract TIS development and contribute to directionality problems that favor one form of the technology over another, which gives insufficient protection for the water harvesting TIS until markets for technologies form. This would require more effective coordination between different donors’ efforts to develop critical mass in TIS development. We also show that cultural institutions and interactions between formal and informal land tenure laws play a significant role in causing an erosion of trust in the government and counter efforts to promote and engage farming communities in water harvesting activities and innovation. This requires recognition that, in developing countries, informal institutions may have the same status as formal institutions.

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1. Introduction

Population pressure, land degradation, and recent reductions in rainfall have led to concerns over the sustainability of dryland agricultural systems, which are often based on unsustainable extraction of surface and groundwater for irrigation (Qadir et al., 2007). Irrigation in some areas has reached its limits and results in aquifer depletion and salinization of agricultural lands. There has been a renewed interest in the utilization of water harvesting as a way of achieving sustainability transitions in water management (Humpal et al., 2012; Karrou et al., 2011; Qadir et al., 2007) – a diverse topic that has received considerable interest in transitions literature (see Brown et al., 2013; Fam et al., 2014; Moore et al., 2014; Van der Brugg and Rotmans, 2007).

Use of water harvesting as a supplemental water source dates back thousands of years (Critchley and Siegert, 1991; Oweis et al., 2001). Water harvesting is the collection and concentration of rainfall runoff from catchments for use in agricultural production, landscape restoration, erosion control, drought mitigation, and for domestic purposes (Karrou et al., 2011; Oweis et al., 2001; Ziadat et al., 2012). This practice is well-suited to dryland agricultural systems, where annual rainfall may be insufficient to meet crop water demand and where rainfall is unevenly distributed across the growing season – often coming in intense events interspersed with periods of little to no rain (Oweis et al., 2001; Oweis and Hachum 2006; Qadir et al., 2007). Water harvesting addresses one of the biggest challenges in dryland agricultural systems: precipitation is at its lowest point during the most sensitive growth stages (flowering and grain filling) of cereal and legume crops (Oweis and Hachum, 2006). Harvested water can be stored in the soil root zone of plants or in small reservoirs or cisterns for supplemental irrigation or for watering animals (Oweis et al., 2001; Qadir et al., 2007; Critchley and Siegert 1991).

Here we study the development and diffusion of water harvesting
practices in the Middle-Eastern country of Jordan, which suffers from over-exploitation of groundwater and resultant landscape degradation. Different types of water harvesting practices are suitable for different agricultural zones and scales of production in the Middle East, and can be grouped into two primary categories: micro-catchment and macro-catchment systems (Critchley and Siegert, 1991; Oweis et al., 2001). According to Oweis et al. (2001), micro-catchment systems are typically employed on individual farms and divert surface runoff from a small catchment area (ranging in size from a few square meters to 1000 m²). Macro-catchment systems are characterized by having runoff water collected from a catchment area greater than 1000 m². Two commonly used macro-catchment systems in the region are marabs¹ and hafirs² (See S-1 in Supplementary material).

The Jordanian government has identified the expansion of water harvesting as an important component in addressing the hydrological challenges in the agricultural sector (Ministry of Water and Irrigation, 2016). Multiple stakeholders, including government ministries, research centers, non-governmental organizations, and donors, are working to increase the improvement, adaptation, and integration of water harvesting within the agricultural system. Despite these efforts, rainwater harvesting practices are not widely implemented in Jordan (Ziadat et al., 2012). While several water harvesting projects exist, this sustainability transition in water management encounters significant challenges.

This paper focuses on the water management transition in Jordan, with a specific focus on water harvesting. This contributes to a developing body of work on sustainability transitions in developing countries, which has focused on: 1) different regions in the developing world where sustainability transitions take place, 2) the different types of transitions (i.e. sustainability issues addressed and technologies to replace incumbent technologies), and 3) the different systems analytical approaches used. Geographically, the focus has primarily been in Asia (e.g. Lachman, 2013) and Africa (e.g. Acheampong et al., 2016; Romijn and Caniêls, 2011) and minimally on Latin America (exceptions include Marques et al., 2016; Mejla-Dugand et al., 2013) and the Middle East (exceptions include Bichai et al., 2016; Moallemi et al., 2014; Vidican, 2015). The types of transitions studied have mainly been energy production, water management, and sustainable and urban development (e.g. Acheampong et al., 2016; Bai et al., 2009; Hamann and April, 2013; Meijerink and Huitema, 2010). Different frameworks from the family of transition approaches (Markard et al., 2012) have been used, such as multi-level perspective (MLP) and technological innovation system (TIS) analysis. TIS analyses in particular have increased in recent years (e.g. Binz et al., 2014; Gosens et al., 2015; Murphy, 2015).

In developing countries, formal institutional, legal, and regulatory frameworks are generally weak and have less reliable enforcement mechanisms, and the institutional frameworks on which innovation systems are built tend to be more informal (Altenburg, 2009; Szogs et al., 2011). Limited national financial capital has a negative impact on developing economically productive and competitive markets and on education systems (Altenburg, 2009). Political instability can act as a barrier to innovation through negatively impacting the quality of scientific institutions, inhibiting collaboration between universities and private industry, reducing the availability of scientists and engineers, and by retarding pro-business reforms that encourage entrepreneurial activities (Allard et al., 2012). Donors providing development assistance partly fill financial and capability voids and impact developing country sustainability transitions in two primary ways: 1) by supporting niche level experiments, such as through projects demonstrating the feasibility of specific technologies; or 2) by directly intervening at the regime level, such as through projects that actively work to overthrow existing technological and/or policy regimes (Hansen and Nygaard, 2013; Marquardt, 2015). Donors can also potentially play the role of intermediaries (Szgos et al., 2011) or so-called “institutional entrepreneurs” (Farla et al., 2012; Jolly et al., 2016) in emerging TIS, acting as catalysts for change by building linkages between users, consumers, and producers to stimulate entrepreneurial activities.

While the body of work on sustainability transitions in developing countries is growing, there is still a lack of knowledge on transitions in specific regions of the world and a need to analyze the different conditions that impact transitions in them, as well as how issues such as prominence of informal institutions, underdeveloped markets, lack of capacity, political instability, and reliance on donors work out in these different contexts (Bergek et al., 2015). The scarce literature on transitions specific to the Middle East has primarily focused on renewable energy (e.g. Moallemi et al., 2014; Vidican 2015; Vidican et al., 2012) and very little on water (an exception includes Bichai et al., 2016). In view of this literature gap, we present a study on a type of technology that has not been researched from a transition perspective — water harvesting — in an understudied region — the Middle East. In line with the trend of using the TIS approach for analyzing transitions in developing countries (e.g. Binz et al., 2014; Gosens et al., 2015; Murphy, 2015), we do a TIS analysis to identify key blocking mechanisms and opportunities for the integration of water harvesting practices into the Jordanian rainfed agricultural system, which we consider a sustainability transition. In doing this TIS analysis, the paper aims to realize two concrete goals: 1) specifically to provide actionable knowledge on the water harvesting innovation system to inform the transition of Jordanian agriculture towards more sustainable water usage; and 2) to contribute to the broader debate on sustainability transitions in developing countries (Berkhout et al., 2010; Markard et al., 2012; Rehman et al., 2010; Romijn et al., 2015; Hansen et al., this issue; Wieczorek, this issue), for which literature is still limited.

The remainder of this paper is structured as follows. Section 2 presents the analytical framework. Section 3 describes the research methodology, which includes the case introduction and scope of analysis and the methods for identifying systemic problems and for data collection. Section 4 presents the analysis and blocking mechanisms hindering the development of the water harvesting TIS. The discussion and conclusion are found in Section 5, which includes policy recommendations and the contributions of this paper to the broader literature base.

2. Analytical framework: combining functional-structural TIS analysis with the comprehensive transformative failures framework

Bergek et al. (2008, p.408) define TIS as, “socio-technical systems focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both).” A TIS may be a sub-system of a sectoral system (in this case agriculture). TIS analysis can be used to analyze and assess the barriers and drivers of a niche as it grows and “institutionalizes” to further challenge the existing regime (Markard and Truffer, 2008).

Following earlier transitions studies in developing and developed countries (e.g. Andersen, 2015; Blum et al., 2015; Gosens et al., 2015), we utilize the TIS approach to analyze the dynamics of developments in water harvesting in Jordan to overcome the current regime, which is characterized by overuse of groundwater for irrigation and rangeland degradation caused by overgrazing. For doing so, a TIS should employ a set of seven functions. The seven functions as described in Hekkert et al. (2007) are (See S-2 in Supplementary material for more detail):

¹ A Marab is a natural formation at the end of a wadi (a valley or channel that is dry except for in the rainy season) where the water flow terminates. In a Marab system, a series of check dams or bunds are built to slow the flow of water. As one check dam fills to capacity, the water flows around the edges and down to the next dam. Behind each check dam or bund, water and sediment accumulate allowing for cultivation of crops, usually barley.

² In a hafir system, a water channel is built off of a wadi along with a diversion that allows a flow of water to fill up a holding pond or reservoir.
1. Knowledge development
2. Knowledge diffusion through networks
3. Influence on the direction of the search
4. Entrepreneurial activities
5. Market formation
6. Creation of legitimacy
7. Resource mobilization

The execution of those functions is influenced by the presence and quality of four structural components, in which we follow the classification by Wieczorek and Hekkert (2012): actors, institutions such as regulations, norms, and values, interactions in networks of actors, and infrastructure such as physical, knowledge, and financial infrastructure (See S-3 in Supplementary material for more detail).

The combined functional-structural TIS analysis first analyses the functions of the system, followed by a second-tier examination of the performance of each of the functions through the lens of the four structural elements (see Wieczorek and Hekkert, 2012). When a function does not perform well, this can be traced back to systemic failures or problems in one or more of the structural elements (Wieczorek and Hekkert, 2012) (See S-4 in Supplementary material for full description of systemic problems). Often, these failures or problems have causal relationships that lead to blocking mechanisms (Turner et al., 2016). The blocking mechanisms are clusters of interrelated systemic problems (structural, transformational, and market), which can cause vicious cycles that negatively impact the functioning of the system (Klein-Woollthuis et al., 2005; Weber and Rohracher, 2012). These link to what Weber and Rohracher (2012) have called, transformational failures, which can be considered higher-level failures, to complement the examination of systemic problems. Different authors use the terms “failures” and “problems” synonymously; in line with Wieczorek and Hekkert (2012) we refer to them as systemic problems.

3. Methods

This section first describes the case study area and the spatial, temporal, and technological scope of the research. We then discuss the methods used for identifying the systemic problems in the TIS and close with a description of the data collection methods.

3.1. Case introduction and scope of analysis

3.1.1. Country context – Jordan’s rainfed agricultural system and water harvesting

Jordan’s population of about 9.5 million people is expected to double by 2050 (Ministry of Water and Irrigation, 2016). Jordan is one of the most water scarce countries in the world. Its current annual renewable per capita water resources are less than 100 m³ (Ministry of Water and Irrigation, 2016), placing it well below the water stress index threshold for absolute water scarcity of 500 m³ per capita per year (Falkenmark et al., 1989). The water shortage in Jordan is expected to become more severe over the coming decades, making the transition to a comprehensive approach to water management imperative (Humpal et al., 2012).

Agriculture is the largest water user in Jordan, accounting for approximately 60% of withdrawals (Ministry of Water and Irrigation, 2016). Despite representing only about 3–4% of Gross Domestic Product (GDP), agriculture is the main source of income for about 15% of the population, employs about 6% of the workforce, supports export-oriented value chains, and supports a large number in jobs in parts of the country where alternative job creation is difficult (Ministry of Water and Irrigation, 2016; Salman et al., 2016). Water harvesting can play a significant role in addressing the hydrological pressures from agriculture by reducing the amount of groundwater pumped from dwindling aquifers in Jordan, and can improve water security for vulnerable farming and grazing communities in the parts of the country with the greatest variability in rainfall and climate (Salman et al., 2016).

The country is divided into three major agricultural zones, each with different cropping patterns and water resources: the Jordan Valley, the Highlands, and the Badia (See Map S-6 in Supplementary materials). Agriculture in the Jordan Valley is characterized by the use of surface water and treated wastewater for irrigation of higher-value crops for domestic use and export (Talozi et al., 2015). Agricultural water use efficiency in the Jordan Valley is relatively high thanks to requirements by the Ministry of Water and Irrigation (MWI)/Jordan Valley Authority (JVA) that farmers use drip and micro sprinklers (Humpal et al., 2012).

The Highlands were traditionally a rainfed agricultural system, and rainfed production continues in the areas that receive sufficient rainfall. Beginning in the 1980s, irrigated agriculture using groundwater from the underlying aquifers began to play a more prominent role in the Highland agricultural system (Salameh, 2008). Irrigated olive production, which would be unprofitable without a regime of subsidies, accounts for roughly half of the Highlands water demand (Humpal et al., 2012). The 2002 Underground Water Control Bylaw (see Fig. 1) (THKJ, 2002) put in place surcharges for groundwater abstraction and appears to have slowed the rate of decline. However, abstraction is still unsustainable, and groundwater levels in the Highlands are declining by at least 1 m per year (Humpal et al., 2012).

The Badia region, comprising about 80% of Jordan’s area, is the driest of the agricultural zones, receiving less than 200 mm of rainfall annually (ICARDA, 2016a). It is characterized by sparsely vegetated rangeland that decreases in precipitation moving southward (Ministry of Agriculture, 2013). Some groundwater abstraction occurs in limited areas for irrigation of vegetables, fruit trees, and field crops (Ministry of Agriculture, 2013; Talozi et al., 2015), but the majority of the Badia is characterized by livestock grazing (Interviews 12, 21). The landscape has been severely degraded due to overgrazing and climate change (Akrouri and Tellier, 2013; World Bank, 2012).

3.1.2. Boundaries and history of the case under study

The geographical boundary of the system under study is the region consisting of the Highlands and the Badia. We exclude the Jordan Valley from our analysis primarily because efforts to promote widespread water harvesting in agriculture have focused on the Highlands and Badia, but also because agriculture in the Jordan Valley is significantly different from the other two regions, as described above.

There are a number of factors that make the Highlands and Badia suitable for widespread water harvesting: both include traditionally rainfed agricultural systems where there is a history of water harvesting use and that are now suffering from rainfall shortages; both have highly variable agricultural production and are experiencing land degradation; and neither have a steady supply of surface water for irrigation, making them reliant on rapidly depleting groundwater (Abu-Sharar, 2006; Interview 13). Specific foci for water harvesting in the Badia are remediation of widespread land degradation caused by livestock overgrazing and production of fodder crops for livestock feed. Water harvesting practices can stabilize crop production, restore degraded land, and provide a source of supplemental irrigation (Karrou et al., 2011; Oweis et al., 2001).

The technological boundary of the system is water harvesting for agricultural production and ecological restoration, and excludes domestic and urban use. Water harvesting exists within a broader agricultural system and its innovation is impacted by laws, strategies, and projects that are focused more broadly on agricultural water conservation. As a result, some interview responses included discussion of this broader context. We include this broader context only where it impacts and enriches the understanding of the water harvesting TIS functions.
The temporal boundary of the system focuses on the modern era of agricultural production in Jordan, ranging from 1960 to 2016, when data were collected for this research. The thrust of our analysis is water harvesting innovation in the last 24 years after water harvesting research began in the region in approximately 1992 to where the system was in 2016, but to sketch the overall context a timeline is given of the 1960–2016 period. This includes key events that have impacted current drivers and barriers in the water harvesting innovation system, including the build-up of an irrigation oriented regime since the 1960s. Fig. 1 shows these key events. Four multi-year periods (indicated in brackets on the timeline) show transitional eras that affected the usage of water harvesting today. The introduction of diesel powered groundwater pumps in the 1960s and a boom in irrigated agriculture fueled by the introduction of modern irrigation and cropping techniques in the 1970s and 1980s were largely responsible for the displacement of water harvesting practices in the traditionally rainfed production systems (Demilecamps, 2010). The mid-1990s marked the start of research on the applicability of water harvesting practices to modern agriculture (Oweis and Taimeh, 1996; Interview 2). Beginning around 1960, the government began a program to settle pastoralist, nomadic Bedouin tribes in the Highlands by convincing them to adopt groundwater-irrigated agriculture (Demilecamps, 2010). Relevant organizational, project, and geopolitical landmarks are also indicated in Fig. 1, as are strategy documents and laws that identify water harvesting as an important element to achieving sustainability or that were intended to reduce the impact of groundwater abstraction.

3.2. Methods for identification of systemic problems

Following Turner et al. (2016) and Wesseling and Van der Voooren (2016), this analysis is carried out for all of the functions (see S-2 in Supplemental Information) in the system as well as for the systemic problems (See S-4 in Supplemental Information) that contribute to the weaknesses. The sequence in which the different functions appear in the literature varies by publication, and because they are mutually reinforcing they are sometimes combined (Hekkert et al., 2007; Turner et al., 2016). In our analysis, we combine the knowledge development and knowledge diffusion through networks functions together into one function called, knowledge development and diffusion because they are tightly interconnected in the Jordanian water harvesting TIS. Evidence of this interconnectivity is discussed in Section 4.1.1.

The results of the functional-structural analysis for identifying systemic problems in the Jordanian water harvesting TIS is summarized in Table 1 and described in greater detail in Sections 4.1.1–4.1.6. The conditions impacting each system function are described in the sections below, and the systemic problems impacting them are indicated in brackets (i.e. [...]).

3.3. Data collection methods

Our study was based on semi-structured interviews (primary data), complemented with a literature review (secondary data), a method common in TIS analyses (Berger et al., 2008; Blum et al., 2015; Wesseling and Van der Voooren, 2016; Wieczorek et al., 2015). Semi-structured interviews allow for flexibility, so the interviewer can focus on interesting comments and on aspects of the topic on which interviewees have more expertise (Bruges and Smith, 2009; Turner et al., 2016). Interview questions were designed to cover two aspects of the analytical framework: functions, to show how well the innovation system is working (Berger et al., 2008; Hekkert et al., 2007; Wieczorek and Hekkert, 2012) and the structural components that can cause blocking mechanisms in the innovation system (Wieczorek and Hekkert, 2012) (See S-5 in Supplementary material for interview questions). The question format consisted of 22 overarching questions with probing follow-up questions designed to elicit in-depth responses, from which both aspects of the analytical framework could be assessed. The interviews systematically covered all functions for each respondent.

We conducted a pilot study in Jordan in spring 2015 to refine the scope of the research and interview questions and to develop a list of
Agricultural extension is a common name for dedicated advisory services aimed at farmers.

Interviewees. For this pilot, we selected twelve potential interview participants who are experts on water harvesting and agricultural water conservation in Jordan. Using snowball sampling, we identified a list of potential interviewees and scheduled interviews for May of 2016. Twenty-four interviews were conducted with a diverse set of subject matter experts representing: Jordanian government ministries and national research centers (10), non-governmental research centers and universities (6), international donors (4), non-governmental organizations (NGOs) (2), and the private sector (2). All relevant stakeholder groups were included to develop a clear picture of the functions and structure of the TIS, and the sample of interviewees represented local, national, and international stakeholders (Blum et al., 2015). Nineteen of the interview respondents were Jordanian nationals, representing each of the stakeholder groups. The identity of each respondent is protected by randomly rearranging the order of their interviews and assigning an anonymous interview number (e.g. Interview 1).

Each interview was conducted either in-person or over internet telephony and took 45 to 90 min. The interviews were recorded and transcribed for analysis using the NVivo for Mac software package (Version 11.3.2). Interview responses were coded based on the functions and systemic problems discussed in Section 2 of this paper. Secondary data sources were consulted to supplement interviews and, where possible, to verify certain claims by interviewees. Secondary data include reports from international donors, research centers, and NGOs (e.g. Humpal et al., 2012; ICARDA, 2016a; Karrou et al., 2011; Salman et al., 2016), national policy documents (e.g. Government of Jordan, 2015; Ministry of Agriculture, 2013; Ministry of Water and Irrigation, 2016), and peer reviewed studies on water harvesting in Jordan (e.g. Akroursh et al., 2017; Akroursh and Telleria, 2013; Ziadat et al., 2012). However, the peer reviewed literature specific to water harvesting in Jordan turned out to be of limited utility due to the narrow scope of the papers on either farmer adoption of the practices in specific pilot-study communities (Akroursh et al., 2017; Akroursh and Telleria, 2013) or on assessing the biophysical suitability of rainwater harvesting (Ziadat et al., 2012), but did provide additional insights.

4. Results and analysis

This section first discusses the functional-structural analysis to identify barriers to innovation within the TIS and to highlight potential opportunities within the innovation system. The section closes with an analysis of the structural conditions of systemic problems and how these create blocking mechanisms.

Table 1

| System Function | Systemic Problems Hindering Function | Description of links between systemic problems |
|-----------------|--------------------------------------|-----------------------------------------------|
| Knowledge diffusion and development | - Capabilities | Financial capabilities problems hinder the capacity of the national extension system, negatively impacting end-user engagement in innovation and causing demand articulation problems and information asymmetry. Capabilities problems negatively impact the development of a knowledge network and infrastructure, and increase reliance on donors. When donor funded projects end, there are no policies in place to ensure project continuity, representing formal institutional and reflexivity problems. |
| Influence on the direction of the search | - Capabilities | Financial capabilities problems leave the country reliant on donors to manage refugees. Donor and government focus on engineering-oriented water harvesting at the expense of on-farm micro-catchment systems represents a directionality problem. Lack of a common vision and policy coordination problems between government organizations negatively impacts complementary policies and hinders agricultural extension's engagement in the TIS. |
| Entrepreneurial activities | - Capabilities | Entrepreneurial activities are mostly limited to donor projects, and resources to encourage private sector carry-over after project completion are not in place, representing directionality, capabilities, and reflexivity problems. Low value production systems in the Badia provide little motivation for farmer investment and demand for private sector goods and services, representing information asymmetry and demand articulation problems. Infrastructure problems pose challenges for marketing and distribution of higher value goods. Formal institutional problems (i.e. subsidies) reduce demand by farmers for water harvesting. |
| Market formation | - Directionality | Incumbent groundwater subsidy regimes influenced by formal and informal institutional problems favor existing production practices and discourage formation of a market for water harvesting. |
| Creation of legitimacy | - Capabilities | Incumbent groundwater subsidy regimes influenced by formal and informal institutional problems favor the existing production regime and negatively impact the legitimacy of water harvesting. The informal institutional problem of water negatively impacts farmer engagement in the innovation process. Land tenure laws and culture perpetuate the existing production regimes, representing formal and informal institutional problems. Capabilities, financial infrastructure, knowledge infrastructure, and reflexivity problems lead to insufficient maintenance of water harvesting systems and impact legitimacy. Insufficient maintenance negatively impacts the physical infrastructure of larger water harvesting systems. |
| Resource mobilization | - Capabilities | A directionality problem does not prioritize campaigns to build water scarcity awareness in agricultural communities, and financial capabilities problems would make any such campaign dependent on donor funds. Directionality and formal institutional problems impact the development of financial infrastructure for providing credit, loans, and a subsidy regime for developing the water harvesting TIS. Infrastructure problems manifesting in the lack of a suitable physical infrastructure for distributing higher-value crops that could be produced using water harvesting. |

* Agricultural extension is a common name for dedicated advisory services aimed at farmers.
4.1. Functional-structural analysis

4.1.1. Knowledge development and diffusion

Knowledge development and diffusion is primarily affected by two systems: 1) the involvement of donors in building capacity for water harvesting innovation; and 2) capabilities problems within the public extension system (i.e. agricultural advisory services).

Multiple interviewees indicated donor involvement plays a positive role. The Middle East Water and Livelihoods Initiative (WLI) (see Fig. 1), a regional project funded by the United States Agency for International Development (USAID) and implemented through the International Center for Agricultural Research in the Dry Areas (ICARDA), was mentioned as playing such a role. In Jordan, ICARDA works with the National Center for Agriculture Research and Extension (NCARE) building capacity there and engaging with farmers to innovate water harvesting practices.

In a well-functioning extension system, a knowledge network utilizes feedback mechanisms to innovate a technology or set of practices – end-user experience is relayed to research and research knowledge to end-users through extension, which builds legitimacy and demand for the technology (Rivera and Sulaiman, 2009). Most donor-funded water harvesting projects have these feedback mechanisms in place, but donors must allocate limited resources throughout the country across multiple priority areas (Interview 6). When a donor project reaches the end of its funding cycle, support for knowledge development and diffusion activities either ends or is significantly diminished, leading to problems of continuity [formal institutional, reflexivity problems] (Interview 6). Additionally, only a small number of donors are focused on water harvesting (and even then not as a top priority), and each donor project only engages with a small subset of government partners and has a relatively small number of demonstration projects [network problem]. As a result, the community of actors focused on water harvesting is rather small and somewhat insular when compared to other priority areas (e.g. refugee response and urban water management), impacting engagement with farmers to build widespread awareness of the water crisis and benefits of water harvesting (Interviews 2,7,8,13,19).

The primary public organization responsible for water harvesting research and extension activities is NCARE, which is a semi-autonomous organization with its own Director General under the authority of the Ministry of Agriculture (MoA). Despite the positive collaborative activities discussed above, eight interviewees spoke of severe capacity challenges within NCARE [capabilities problem]. There are currently only 70 extension officers for the entire country, with little technical specialization and advanced training, and without the financial resources to attend additional training abroad (Interviews 9,11,15,22). The understaffed extension system is an outcome of the 2007–2008 global financial crisis, which led to a hiring freeze on new extension officers that remains in place (See Fig. 1) (Interview 2). In many countries, universities also play a role in connecting research and extension. However, only two universities, the University of Jordan and the Jordan University of Science and Technology, have any substantive research on water harvesting, and they are limited by a lack of financial resources [capabilities, knowledge infrastructure problems] (Interview 12).

The capabilities, institutional, network, knowledge infrastructure, and reflexivity problems in the system lead to interaction with only a small subset of farmers. As a result, their demand for water harvesting and their goals for its utilization are not known, and their involvement in the innovation system is limited.

4.1.2. Influence on the direction of the search

Influence on the direction of the search refers to the development of a common vision for the innovation system and orientation of other functions towards that vision (Turner et al., 2016). There are three key elements that significantly affect this function: 1) the current influx of refugees from Syria and Iraq have impacted development planning at the national level and contribute to Jordan’s dependency on international donors; 2) the priorities of international donor organizations play an important role in defining the agenda for development across the whole country, and priorities differ between donors; and 3) a lack of policy coordination and a common vision for agricultural water management between key ministries has negatively impacted water harvesting innovation.

There are more than 1.4 million refugees in Jordan, with over 650,000 having come from Syria since 2011 (Ministry of Water and Irrigation, 2016; UNHCR, 2016). Responding to the refugee crisis has seriously strained Jordan’s water and financial resources, making it more reliant on donor aid [capabilities problem] and has contributed to the prioritization of resources for short-term crisis response over mobilization towards long-term development goals [directionality problem] (Interviews 2,3,15).

Donor aid influences the direction of the search in both positive and negative ways. On the positive side, donors have priorities for how aid money is spent and conditions that the government must meet to receive it. As a result, donor priorities often become the priorities of the different government ministries that receive aid money (Interviews 3,6,7,9,13,15,19). Water harvesting was initially prioritized almost exclusively by donors, and most of the activities are still donor-driven in some form (Interviews 3,9). By prioritizing water harvesting, donors have begun to influence the direction of the search towards the practices within different ministries, even while the government struggles to respond to the refugee crisis.

On the negative side, donors have contributed to the focus on engineering-oriented or industrial-scale water harvesting technologies at the expense of simpler, on-farm micro-catchment systems. Research has shown the benefits and applicability of both types of water harvesting (Oweis and Hachum, 2006). Interviewees noted that the focus on only the engineering/industrial water harvesting types, rather than on both those and the on-farm micro-catchment types, leaves out of the system a set of important water harvesting practices that could be highly beneficial in achieving greater agricultural sustainability [directionality problem] (Interviews 17,18,20). There is anecdotal evidence that these farm-level micro-catchment systems are widely used, but there have been no studies on the extent of their use, how the innovation system for these systems functions, and what the demand among farmers is for them (Interviews 2,17,18,20).

One reason for the lack of focus on these systems is the lack of resources to study them [capabilities problem] (Interviews 17,20). However, the preference towards the engineering/industrial water harvesting technologies is also partially due to the requirement for donors to produce measurable indicators of success at the end of the project cycle (Interviews 11,17,18,20). The construction of marabs or hafirs is more quantifiable over the timeframe of a project than changes in behavior and individual values (Interview 18). While the donor project cycle contributes to directionality problems, conditions endemic to the different Jordanian government organizations involved with water harvesting play a more significant role.

Many respondents indicated that there is no common vision for water conservation in agriculture, ecological restoration of degraded lands, or innovation of water harvesting practices across relevant government organizations (Interviews 2,3,6,9,10,12,13,17,18,20,22,23). There is also very little collaboration on water harvesting projects between the MWI, MoA, and NCARE [policy coordination problem] (Interviews 6,13,22). Each ministry has its own vision for agricultural water management, and their strategies are developed without extensive policy coordination with other ministries [directionality, network, policy coordination problems] (Interview 2). It was also noted that these ministries do not readily share centralized databases, so information on groundwater levels, runoff, and irrigation water volumes, for instance, can deviate between ministries by as much as 10% (Interview 20).
4.1.3. Entrepreneurial activities

The unique nature of water harvesting from the technical perspective and the agricultural systems of the of the Badia and drier parts of the Highlands impact opportunities for entrepreneurial activities in ways that traditional TIS studies do not normally see. Within these contexts, it is important to identify who the potential entrepreneurs in the TIS are.

Water harvesting differs from the types of technologies frequently analyzed in TIS studies because it is a suite of practices and low-tech solutions based on agricultural practices that pre-date modern agriculture, rather than a technology in the traditional sense. Thus, water harvesting can be considered a “retro-innovation”, as it combines a set of ancient practices with modern ones and configures them to meet current and future needs (Stuiver, 2006; Marques et al., 2010). In this case, the land preparation techniques for the different water harvesting modes have been known for a long time, but now they can be prepared with modern and sometimes specialized machinery.

Private sector entrepreneurial activities are challenged by the fact that, given its characteristic as a retro-innovation, water harvesting presents less of an opportunity for a tangible marketable product than do other higher-tech agricultural technologies, such as precision irrigation. The introduction of precision irrigation in the Jordan Valley provides an example of how private sector-driven change has traditionally occurred in the Jordanian agricultural sector. Entrepreneurs were engaged in the expansion of precision irrigation in the Valley because it is a technology used in the production of higher value crops, and one for which goods and replacement parts can be sold and for which private extension services can be marketed. The government mandate required its usage, and its linkage with higher-value crops meant that farmers could see a return on their investment and that entrepreneurs had a market for goods and services (Interview 6). These types of linkages are less obvious for water harvesting at first glance, and engaging entrepreneurs in this TIS requires a different approach, which will be discussed later in this section.

Entrepreneurial activity also links to the type of agriculture done in systems served by water harvesting. The production systems of the Badia and the drier areas of the Highlands suffer from low yields and produce low-value crops, or are rangeland grazing systems that produce fodder crops for livestock (Interviews 2,6,18). The low market value of the crop production system outputs and the nomadic nature of herding provide little motivation for farmers to invest in their production system, reducing demand for goods and services from the private sector [information asymmetry, demand articulation problem] (Interviews 2,6,13). Multiple interviewees spoke of production of higher-value crops as a precondition to any increase in private sector activity in the production system, requiring government oversight and/or permitting, which would put additional strain on the financial capabilities of government organizations.

While there is currently limited entrepreneurial activity in the water harvesting TIS among the private sector, donors could be considered partial or quasi-entrepreneurs. According to Hekkert and Negro (2009, p.586), “[t]he role of the entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete action to generate and take advantage of business opportunities.” Donor activities do play an integral role in directing knowledge generated from water harvesting research through networks to generate projects that provide employment and services (an example of this would be the USAID funded, ICARDA implemented WLI project). However, donor activities do not participate in a market for water harvesting goods and services, as this is generally outside of the scope of traditional international donor mandates.

Donors are engaged in a nascent effort to encourage entrepreneurial activity in the private sector. Many donor-funded projects require engagement with the private sector, so some projects have utilized private contractors for construction of water harvesting structures or have partnered with local consulting firms to assist in project management (Interviews 2,15,17,20). However, water harvesting activities currently remain almost completely project based, and the resources to encourage private sector carry-over after the completion of projects are not in place [reflexivity, directionality problems] (Interview 19).

Although currently unrelated to water harvesting, there are multiple projects being funded by international and domestic donors (e.g. the
USAID Hydroponic Green Farming Initiative\(^4\) and the Hashemite Fund for the Development of the Jordan Badia\(^5\) that are developing production systems and markets for higher value-crops through the introduction of hydroponic systems, developing nurseries to produce indigenous shrub species for restoration of the Badia, and building value added chains for milk processing. Projects like these have the potential to integrate water harvesting systems as sources of water. Integration of water harvesting into these projects is currently not in place, but one interviewee (2) spoke of this as a being a potential opportunity for entrepreneurial activities.

4.1.4. Market formation

We noted in Section 4.1.3 that information asymmetries on year over year water availability impact entrepreneurial activities for water harvesting. They also play a role in the development of a market for them. While variability in the amount of water that water harvesting provides does not inherently make it an undesirable technology, it does make it undesirable under current groundwater subsidies. In the driest parts of Jordan, water harvesting may not provide a reliable source of year-round water, but it can extend the time in which a farmer does not need to irrigate with groundwater by 3–9 months (Interviews 2,5). If the cost of irrigation water were not so artificially low, an investment in water harvesting could potentially be more desirable (see Section 4.1.5 for more detail on subsidies). In effect, the incumbent subsidy regime is sustaining current production practices and discouraging the formation of a market for water harvesting [informal and formal institutional problems].

There is also no financial infrastructure for providing loans or credit for financing water harvesting activities to farmers and communities or for investment by the private sector [financial infrastructure, directionality problems] (Akroursh et al., 2017; Interviews 1,4,7,15,18,22). Nor are there any subsidy or cost share regimes in place to provide for the development of a market for water harvesting construction, maintenance, extension, and innovation (Interviews 1,7). Finally, as noted in Section 4.1.3, the existing physical infrastructure in the Badia is not sufficient for a distribution system for higher-value crops, should there be a production system shift in that direction [physical infrastructure problem]. While the lack of financial infrastructure for providing loans and subsidies primarily represents directionality and formal institutional problems, the limitations within the physical infrastructure for distribution of higher-value crops (should a market for them be developed) is largely driven by the lack of financial capabilities to build and maintain this infrastructure across a large, sparsely populated area (Interviews 3,7).

4.1.5. Creation of legitimacy

For a technology or set of practices to develop effectively, legitimacy for it must be built to overturn the current technological regime or to become part of it (Hekkert et al., 2007). In the case of the Jordanian water harvesting TIS, the following conditions block the creation of legitimacy: 1) subsidies on the cost of groundwater used for irrigation; 2) wasta (an Arabic word that translates loosely to ‘connections’, ‘clout’, or ‘influence’); 3) land tenure laws and customs; and 4) lack of carry-over from donor-funded projects.

The cost of groundwater for irrigation is driven by both the cultural aspects of water in Islam, under which the price of water should not exceed that of cost recovery [informal institutional problem] (Faruqui, 2001; Interviews 11,13,19), and by policies that subsidize the cost of energy for groundwater abstraction that lead to a unit price for water to farmers well below cost recovery [formal institutional problem] (Interviews 11,13,19). Analysis done by the 2030 Water Resources Group (2011) found that the average price Highland farmers pay for water from all sources is about JD 0.02/m\(^3\) (1 JD = approx. 1.4 USD), while the true cost of bulk supply is JD 0.15, amounting to an approximate subsidy of JD 0.13/m\(^3\) (Humpal et al., 2012). The Groundwater Control By-Law No. 85, passed in 2002 and amended in 2004 (See Fig. 1) (THKJ, 2004, 2002) established a quota of 150,000 m\(^3\)/year, with the amount up to the quota being free and increasing block rate tariffs for amounts beyond that (Venot and Molle, 2008). The block rate tariffs were supposed to increase in the year 2008, but rates were not changed and have remained at the same rate as they were in 2002 (Humpal et al., 2012). Additionally, malfunctioning meters at rates as high as 40% are a recurring problem [physical infrastructure problem] (Venot and Molle, 2008).

Wasta was cited by 17 interviewees as being responsible for an erosion of trust in government, counteracting government efforts to promote water harvesting [informal institutional problem]. While cultural equivalents of wasta exist in many countries, its role in impacting legitimacy was so frequently cited that it deserves attention. Through wasta, powerful farmers in the Highlands have personal connections to upper levels of government (or in some cases are members of the government). This influence has been used to maintain the current system of subsidies for groundwater abstraction and olive production (Interviews 9,11,19). Wasta was also noted for its role in helping some individuals obtain influential jobs in government (Interview 22).

In the Highlands, land tenure and subsidized olive production are closely linked [informal and formal institutional problems]. This situation has its roots in policies from the 1960s to settle the nomadic Bedouin tribes (See Fig. 1) (Interview 2). These policies included land ownership rules stipulating that sustained development of public land for over 15 years conferred ownership rights, and olive trees became the means through which sustained development was demonstrated (in fact, it is not clear whether this right is conferred more by tradition or by rule of law) (Humpal et al., 2012; Interview 2). Thus, land development confers ownership, olive production demonstrates development, and olive production is possible because of subsidized groundwater, which externalizes the true costs of production and acts as an economic deterrent to farming communities investing in water harvesting (Interviews 9,11,19). This type of land development has made a comparatively small number of Highland farmers wealthy and influential (Interview 2).

Multiple interviewees (Interviews 2,11,16,19,21) noted some promising initiatives that are working to build trust in government. In 2013, the Minister of Water and Irrigation began a campaign to cap illegal wells in the Highlands (Ministry of Water and Irrigation, 2016). This campaign has penalties for drilling illegal wells that include jail time and has even targeted political elites and tribal leaders engaged in illegal pumping. Two projects funded by USAID, the Non-Revenue Water project and the Improving Water Sector Management and Governance project, have partnered with the government of Jordan to increase capacity for monitoring and maintenance of well meters.

Land tenure in the Badia is also a legally grey area [informal and formal institutional problems]. Officially, much of the land is owned by the government, but from a cultural-historical point of view, many of the tribes in the Badia view it as their land, because they were using the land before the country of Jordan was established (Interview 21). Engagement with leaders of tribes that graze on traditionally communal land is important to build legitimacy for water harvesting landscape restoration projects (Interviews 17,21). Representatives from MoA and the Badia Restoration Program (BRP) acknowledged the importance of community engagement in the early phases of a project, but other interviewees (2,14) indicated that the necessary level of engagement is still insufficient (both from the government and donors), and that lack of trust in government hinders this engagement. Interviewees (1,2,9,13) noted that the projects run by ICARDA in the Badia effectively engaged local communities but failed to sufficiently coordinate with Bedouin groups who nomadically graze the areas. So at some of the project sites, while the local villages had buy-in, the Bedouin did not see the benefit

\(^4\) https://www.usaid.gov/jordan/fact-sheets/usaid-hydroponic-green-farming-initiative-hgfi
\(^5\) http://www.badiafund.gov.jo/en
Finally, legitimacy is negatively impacted when water harvesting activities fail to continue after the duration of a project [reflexivity problem]. Multiple interviewees noted that while some projects have effective end-user engagement during the project cycle, there are no effective policies in place to hand over projects once the cycle ends [formal institutional problem]. There are also insufficient follow-up studies after the completion of projects to see what kind of carryover they have over time, primarily due to limited financial resources [capabilities problem] (Interview 23). Most water harvesting systems require regular maintenance to function properly, and experience on some projects has shown that this maintenance has not been properly kept up after the after completion of the project. Three interviewees (2, 18, 20) noted that while the communities involved in the projects highly value the water harvesting systems, they did not have sufficient financial resources or training on the skills necessary to maintain them, which has links to the knowledge development and diffusion functions. This was especially the case with the larger, engineered water harvesting structures, such as hafris and marabs.

4.1.6. Resource mobilization

While resource mobilization in the water harvesting TIS remains limited, there are some examples of a nascent activities in this direction. Examples of this by the Jordanian government include the BRP and the Hashemite Fund for Development of the Jordan Badia (HFDJB) (See Fig. 1). Under the umbrella of the Ministry of Environment, and in collaboration with ICARDA, the BRP is researching, developing, and implementing industrial-scale water harvesting projects for ecological restoration in the Badia using a specialized plow (ICARDA, 2016a). The HFDJB is financing the construction of two hafr water harvesting systems in the Badia, which is being implemented by NCARE (HFDJB, 2016). Another example of resource mobilization is the campaign by MWI to cap illegal wells discussed in Section 4.1.5.

Donors play the principal role in resource mobilization for water harvesting. The most direct example of this is the partnership developed with USAID, ICARDA, and NCARE in the WLI project. In the WLI, ICARDA has used USAID funding to conduct research and extension on water harvesting at benchmark sites in the Badia. They are implementing these activities in partnership with NCARE, working to build human capacity at the Center and overcome some of the capabilities problems discussed in Section 4.1.1 (Interviews 7, 13). These donor supported activities provide a mechanism through which field trials and feedback from farming communities can be used to innovate and improve water harvesting practices. It is unclear what the carry-over from this project will be once all activities are complete.

With funding from USAID, MWI launched a campaign in the cities to build awareness of the water shortage among domestic water users, but no resources have been mobilized for a similar campaign in the agricultural communities of the Highlands and Badia [directionality, capabilities problems] (Interviews 2, 15). Not extending this awareness campaign to agricultural communities represents a directionality problem because it is not addressing water conservation in the economic sector that is responsible for most of the water use. It also represents a capabilities problem for the government, because without donor support, such a campaign will not be possible.

The examples above demonstrate what could be defined as the early phases of resource mobilization in the water harvesting TIS. However, absent from resource mobilization activities (as discussed in Sections 4.1.3 and 4.1.4) are financing and credit mechanisms to promote entrepreneurial activity and market formation.

4.2. Blocking mechanisms hindering development of the water harvesting TIS

The functional-structural analysis for the Jordanian water harvesting TIS has facilitated a study on how interaction between the different structural components leads to realization of the functions and what problems occur in this regard. Collectively, these interactions form the blocking mechanisms for achieving the goal of the TIS (i.e. the establishment of water harvesting practices in Jordan). Three key structural conditions are responsible for triggering a chain of problems that reverberate throughout the system, and the feedback between these problems causes so-called “vicious cycles” (Hekker, 2007). These are: 1) financial capabilities problems impact multiple TIS functions and increase reliance on donors; 2) lack of a common vision for water harvesting and for the agricultural system impacts every other function in the system; and 3) informal and formal institutional problems (e.g. wastu and land tenure) impedes the creation of legitimacy for water harvesting. Fig. 2 shows systemic problems and blocking mechanisms for the whole water harvesting TIS. Along the top are the
three key structural conditions that trigger the chain of systemic problems. Each of these is discussed in Sections 4.2.1–4.2.3.

Overcoming these structural conditions will require novel institutional arrangements, policy change, and infrastructural changes in the agricultural and water sector, which connects to the politics involved with the water management transition in Jordan. As Meadowcroft (2011, p.71) points out, “Politics is the constant companion of socio-technical transitions, serving alternatively (and often simultaneously) as context, arena, obstacle, enabler, arbiter, and manager of repercussions.” We acknowledge the importance of politics in overcoming the existing water management regime, but also point out that as with most countries, the dynamics of the political system in Jordan are complex. Due to this complexity, full understanding the governance dynamics would require more investigation, which was beyond the scope of our TIS analysis. However, this research has shown some elements of politics that will be briefly discussed in Sections 4.2.1–4.2.3.

4.2.1. Financial capabilities problems impact every TIS function and increase reliance on donors

Jordan is a developing country with limited financial and natural resources. This structural problem has impacts throughout the entire TIS and acts as a catalyst for a series of causal mechanisms that negatively impact every function in the system. However, this research has shown some elements of politics that will be briefly discussed in Sections 4.2.1–4.2.3.

Overcoming these structural conditions will require novel institutional arrangements, policy change, and infrastructural changes in the agricultural and water sector, which connects to the politics involved with the water management transition in Jordan. As Meadowcroft (2011, p.71) points out, “Politics is the constant companion of socio-technical transitions, serving alternatively (and often simultaneously) as context, arena, obstacle, enabler, arbiter, and manager of repercussions.” We acknowledge the importance of politics in overcoming the existing water management regime, but also point out that as with most countries, the dynamics of the political system in Jordan are complex. Due to this complexity, full understanding the governance dynamics would require more investigation, which was beyond the scope of our TIS analysis. However, this research has shown some elements of politics that will be briefly discussed in Sections 4.2.1–4.2.3.

We see a feedback loop between creation of legitimacy and entrepreneurial activities, where a lack of legitimacy hinders entrepreneurial activity in the TIS, and low entrepreneurial activity hinders advocacy for water harvesting by entrepreneurs. Another feedback loop exists between the mobilization of resources and entrepreneurial activities, where without sufficient protection for the water harvesting TIS and financial infrastructure, entrepreneurial activity will be hindered, which in turn limits advocacy by entrepreneurs. The feedback loops in the TIS can also be viewed as interactions between the functions that create vicious cycles that slow down progress in the innovation system (Hekkert and Negro, 2009). Hekkert et al. (2007) indicate that the influence in the direction of the search function is often a trigger that can shift vicious cycles to virtuous ones. The role of this function in the TIS is discussed more in Section 4.2.2.

The examples of Jordanian-driven efforts to expand water harvesting discussed in Section 4.1.6 demonstrate that there are influential domestic actors who could play a role in changing the incumbent agricultural and water regime, but that the scale of their efforts to expand water harvesting are impeded by a lack of financial resources. Financial capabilities problems also inhibit the government’s ability to mobilize resources, in the form of financing and credit, for development of a market for water harvesting practices and services and the entrepreneurial activities that would function in that market (Interviews 1,4,15,18,22).

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The reliance on donors indirectly impacts influence on the direction of the search, resource mobilization, and creation of legitimacy functions in both positive and negative ways. Donors represent strong political actors whose activities can directly influence the priorities of the national ministries. They contribute to creating the conditions that can both overthrow the incumbent technological regime or maintain it. Some donor projects have helped to build capacity at NCARE, which has had a positive role in the knowledge development and diffusion functions and thus on the creation of legitimacy function. However, as discussed in Section 4.1.2, reliance on donors also negatively impacts the direction of the search through the focus on engineering-oriented water harvesting practices and through the discontinuation of water harvesting activities upon completion of donor funding cycles. This has a negative impact on resource mobilization and through this function, on entrepreneurial activities and market formation.

![Diagram](image-url) Fig. 3. Financial capabilities problems form a core element in a series of causal mechanisms that negatively impact every function in the system.
4.2.2. Lack of a common vision for water harvesting and the agricultural system impacts every other function in the system

In the case of the water harvesting TIS, the lack of a common vision has reverberations that affect every TIS function to varying degrees. As noted in Section 4.2.1, there are influential actors who could play a role in changing the incumbent regime to promote water harvesting innovation. Their efforts are not only impeded by financial capabilities problems, as indicated above, but also by the lack of a common vision among them for water harvesting innovation (Fig. 4).

Lack of a common vision, which represents the underperforming of the influence in the direction of the search function, is partially responsible for the existing policy coordination problems, for the current water subsidies aimed at groundwater extraction, and for the lack of focus on-farm micro-catchment water harvesting systems. This negatively impacts the creation of legitimacy, entrepreneurial activities, market formation, and resource mobilization functions in ways that were discussed throughout Section 4.1. It impacts knowledge development and diffusion through the deprioritizing of extension at NCARE, which in itself impacts creation of legitimacy through not improving farmer awareness of the water crisis and of the benefits of water harvesting. We see the same feedback loops between entrepreneurial activities and creation of legitimacy and mobilization of resources for development and protection of the TIS as discussed in Section 4.2.1.

4.2.3. Informal and formal institutional problems impede creation of legitimacy for water harvesting

As discussed in Section 4.1.5, aspects of both formal and informal institutions block the creation of legitimacy function in the water harvesting TIS (Fig. 5). The policies (formal institutions) that subsidize the abstraction of groundwater and animal feed perpetuate an agricultural system in which the short-term costs to farmers of maintaining unsustainable groundwater irrigation practices and livestock overstocking are low enough to act as disincentives to pursuing water harvesting technologies. The mixture of official policies and cultural (informal) institutions around land tenure also contribute to the blocking of this function. Particularly, the cultural institution of wasta plays a role in perpetuating the continuation of the subsidy regimes and in mistrust of government, which indirectly impact legitimacy for water harvesting practices. Wasta and land tenure institutions form a feedback loop: the lack of a common vision for water harvesting and the agricultural system impacts every other function in the system.

Greater influence in shaping the agricultural production regimes. That the current subsidy regime remains in place is due to both informal and formal institutional reasons. Almost every interviewee, and notably those employed by the government, acknowledged that subsidies negatively impact water harvesting innovation and that ultimately, they have to be reduced or ended. However, while wasta plays a key role in keeping the subsidies in place, they also remain in place because their rapid termination could cause social unrest, which is linked to cultural norms around the price of water.

5. Discussion and conclusion

This paper had two goals: 1) to provide actionable knowledge on the water harvesting innovation system to inform the transition of Jordanian agriculture towards more sustainable water usage, and 2) to contribute to the growing literature using TIS analysis in identifying systemic problems and opportunities in developing countries undergoing sustainability transitions and adding empirical knowledge on the specificities of these transitions from a particular context that has not yet been studied. To conclude the paper, we will now provide some policy recommendations (Section 5.1), and reflect on the contributions of this paper to the broader literature on TIS and sustainability transitions in developing countries, including raising some topics for further research (Section 5.2).

5.1. Policy recommendations

Regarding the first goal of our paper, we identified two policy priority areas towards which efforts should be directed to overcome the current challenges facing the innovation and implementation of water harvesting practices. These are: 1) improving coordination across ministries and donors to develop a holistic vision for water conservation in agriculture and for how water harvesting innovation and utilization fits into that vision; and 2) supporting TIS development for water harvesting practices, including resource mobilization for the formation of a market for them and for the involvement of entrepreneurs in that market. Our analysis highlights that donors are currently fundamental to developing the water harvesting TIS, and thus should play a central role in efforts to achieve these policy priority areas.

With regard to priority area 1, efforts to increase policy coordination across ministries can be seen in the existence of the National Water
Advisory Council and the Highland Water Forum, which were created to coordinate water sector strategy and funding and to find collective solutions to groundwater management, respectively (Humpal et al., 2012). However, as of 2014, the National Water Advisory Council had only met once (OECD, 2014), and while the Highland Water Forum has played a role in the campaign to cap illegal wells, its activities are limited to the Highlands (Humpal et al., 2012). Additional policy action must thus occur to achieve policy priority area 1, in which donors can play key roles in the following ways: 1) by acting as intermediaries who build linkages between currently disconnected actors and by playing the role of institutional entrepreneurs acting as change agents (in line with ideas of Hansen and Nygaard, 2013 and Szogs et al., 2011); 2) as financial capabilities problems are identified throughout the water harvesting TIS, by providing a stable source of funding and increasing advocacy for water harvesting practices; and 3) by playing an integral role in supporting and helping to develop policy mixes for sustainability transitions.

Donors could play a central role in inducing and enacting niche protection and technological regime destabilization policies (following Marquardt, 2015) as institutional entrepreneurs (Jolly et al., 2016; Meijerink and Huitema, 2010), influencing and collaborating with domestic policy makers to support the development of an inclusive innovation system (Andersen and Johnson, 2015). However, this would require the will and ability to navigate the complex political dynamics in Jordan as well as coordinated efforts among donors to have sufficient political clout. As donors currently contribute to directionality problems, coordination between donors (following Lawson, 2013) and donors and government ministries (following Mockshell and Birner, 2015) should be improved.

There is a ministry whose role is to coordinate funding between donors and relevant ministries, the Ministry of Planning and International Cooperation (MoPIC). MoPIC could be the government actor that plays the principal coordinating role of integrating policies and visions across all ministries that work with water harvesting. MoPIC has already demonstrated its ability to play this role with funding from the United Nations High Commission for Refugees. This management structure, which could be applied to water harvesting, consists of MoPIC and the international donor at the top, under which are a series of working groups. Within each working group is a lead donor agency, a lead ministry, and a lead NGO. These working groups then work with local stakeholders, maybe taking the form of what have been called ‘innovation platforms’ (Kilelu et al., 2013) or ‘transition labs’ (Nevens et al., 2013), being a space of joint learning and innovation. We advocate for a similar structure to be followed for water harvesting.

With regards priority area 2, in line with the policy actions identified by Kivimaa and Kern (2016) who focus on both supporting niche developments (i.e. supporting TIS build-up) and ‘regime-destabilisation’ measures (i.e. making continuation of irrigation less attractive), we recommend the following actions for development and protection of the water harvesting TIS: 1) development of a subsidy regime for farmers that supports construction of water harvesting systems and the training necessary to effectively utilize and maintain them; 2) in partnership with the government and private banks, establishment of a low-interest loan regime for water harvesting; and 3) strengthening of the research and extension system by providing funds for training extension officers, increasing linkages between research and extension, and increasing the number of demonstration projects for the diffusion of knowledge on water harvesting practices. After feedback from multiple interviewees, we also advocate for exploring the potential for complementary pairing of water harvesting with other water conserving, higher-value crop production systems, such as the hydroponic systems that are currently in the early phases of support by USAID.

Besides these niche support policies, to develop the water harvesting TIS and form a market for water harvesting goods and services, one of the most important steps is policy support for destabilizing the incumbent dominant regime technologies (Kivimaa and Kern, 2016) – which implies the reduction or elimination of subsidies for groundwater abstraction and animal feed. As noted above, ending these subsidies will prove difficult for social reasons, and for this reason we advocate for a gradual reduction of them over time. It is imperative that instability not be an unintended result of changing the existing water management regime in a country surrounded by regional instability.

As indicated in Section 4.2, the dynamics of the politics in the water transition in Jordan are complex as these involve multiple formal and informal as well as regional, national and international level institutions, so deeper knowledge of these political dynamics is needed to inform implementation of these policy recommendations.
5.2. Contributions of our study to the broader literature on TIS and sustainability transitions in developing countries

Regarding the second goal of our paper, we support the assertion by Tigabu et al. (2015) that the TIS approach is sufficiently generalizable to study different types of developing country innovation systems. In our analysis, we identified three key structural conditions that are responsible for triggering a chain of problems that reverberate throughout the system and form blocking mechanisms. Identification of these structural conditions adds to the existing literature on the TIS approach in the developing country context. In particular, these are the influence on the TIS by donors and informal institutions or customary law (e.g. wasta).

Like Gosens et al. (2015) and Binz et al. (2012), we found that the Jordanian water harvesting TIS is in fact a sub-system of an international TIS. In this case, it is connected to the international level through donor interventions, connecting to ideas on transnational linkages in sustainability transitions (Hansen and Nygaard, 2013; Wieczorek et al., 2015), which prove to be very important in the context of developing countries (Gosens et al., 2015). We showed that an important implication, therefore, is that different from many developed country TIS analyses, donor interventions should be centrally considered, as they play a role in influencing the direction of the search and in contributing resources towards the knowledge development and diffusion functions. In line with Hansen and Nygaard (2013) and Marquardt (2015), we found that development aid can support TIS development by providing resources for projects that demonstrate the technological, ecological, and economic viability of a technology. However, in the case of the water harvesting TIS in Jordan, we found that this impact has thus far been limited, primarily due to the lack of a concerted, coordinated effort with a common vision to develop the water harvesting TIS. A broader theoretical implication that nuances earlier findings on donor support of TIS development is that donors can contribute to directionality problems that favor one form of the technology over another, and that by not building sufficient capacity to ensure continued innovation activities upon project completion, can provide insufficient protection of the TIS until markets for technologies form.

We found that wastå plays a significant role in causing an erosion of trust in the government and works counter to its efforts to promote and engage farming communities in water harvesting activities and innovation. In conjunction with a mixture of both informal and formal land tenure laws, wastå contributes to the perpetuation of subsidy regimes that are central to maintaining the status quo production regime. Further, the land tenure institutions sometimes help to reinforce wastå through their enriching of a select number of individuals.

From our study emerges that formal and informal institutions go hand in hand in a country like Jordan; for example, the lack of clarity on which aspects of land tenure institutions are formal and which are informal is a condition that is highly influential. This confirms earlier work on regimes and innovation system contexts in developing countries, where informality and instability are common (e.g. Arocena and Sutz, 2000; Verborg et al., 2010; Wirth et al., 2013). Related to this, our analysis also touched upon the issue of politics, and revealed some political issues (e.g. the role of wastå in the political system and power dynamics within and between different ministries). However, to go deeper into the informal and formal politics would require a more dedicated analysis (following Avelino and Rotmans, 2009; Avelino and Wittmayer, 2016; Kern, 2015).

A concept that has emerged from this research that warrants additional research is the role of retro-innovation in sustainability transitions. Retro-innovation involves the adaptation of traditional practices into a modern innovation system (Stuiver, 2006), as is the case with water harvesting. This topic has received little attention in the developing country transitions literature, with Marques et al. (2010) paper on novelty production of medicinal plants in Brazil being the only example we have found. Additional research on retro-innovation and the role of locally-driven development and adaptation in the process warrants additional attention in transitions and innovation systems studies, as it is a means to counteract by often simple interventions the negative side effects of modern technologies (such as irrigation technologies in this case). This may also be linked to the biophysical aspects of innovation processes (Andersen and Wicken, 2016) and to current debates on “Jugaad” or “Frugal” innovation as a way to achieve inclusive innovation incorporating smallholder farmers in developing countries (Radjou et al., 2012).

Finally, we advocate for further research on how to adapt the structural-functional analysis as outlined by Wieczorek and Hekkert (2012) for use as an applied pre-project/program assessment tool (in a similar vein as Schüt et al., 2015 have done for structural analysis, Alkemade et al., 2007 have done for functional analysis, and Andersen and Andersen, 2014 have done for innovation system foresight). In assessing the Jordanian water harvesting TIS, we have found that the clear picture of the innovation system that develops from this analysis could be useful for developing a thorough understanding of the system into which a new project or program occurs. This analysis could help in developing projects and programs at their inception to make them more in-line with a common vision and to reduce redundancy and waste by better understanding how the new activities fit into the broader context of activities by other actors and institutional conditions.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2017.08.010.

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