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

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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.

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 Brugge 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

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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 m^2). Macro-catchment systems are characterized by having runoff water collected from a catchment area greater than 1000 m^2. Two commonly used macro-catchment systems in the region are *marabs*[1] and *hafirs*[2] (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 Caniëls, 2011) and minimally on Latin America (exceptions include Marques et al., 2010; Mejía-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 (Szogs 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., 2010; 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 subsystem 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.